Assessing Organic Production Efficiency: A Stochastic Distance Function Approach

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Abstract:
A stochastic distance function frontier was estimated using data from a national survey of organic farmers to evaluate the effect of farm-specific attributes on efficiency. Farm-specific and regional variables that shift efficiency were incorporated into the multioutput distance function, including organic farming experience, use of soil-improving inputs, and farmer involvement in research. Participation in research projects reduces the level of on-farm technical inefficiency with mean technical efficiency of participating farmers 25 percent higher than nonparticipating farmers. The results suggest that differences in productivity across organic farmers are closely linked to input use and observable management decisions.

Key words: distance function, organic farming, stochastic frontier, farmer participatory research, soil-improving inputs

Acknowledgments: This paper was initiated while the authors were visiting faculty at the University of Minnesota. Dr. Park received support from the Sloan Foundation and The Food Industry Center. Dr. Lohr received support from the School of Agriculture Endowed Chair in Agricultural Systems and the Minnesota Institute for Sustainable Agriculture. Research for this paper was also supported by Cooperative Agreement 43-3AEK-9-80002 with the USDA-ERS. The cooperation of the Organic Farming Research Foundation is gratefully acknowledged.

Selected Paper prepared for presentation at the Western Agricultural Economics Association Annual Meeting, Honolulu, Hawaii, June 30-July 2, 2004

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Introduction

Productivity of organic farmers has been the subject of much debate, as it goes to the heart of the issue of whether incentives and technical support for organic sector expansion are needed and even whether widespread organic agriculture would be capable of producing sufficient food (Avery and Avery). Opponents of organic agriculture have argued that this system necessarily results in lower productivity than conventional agriculture, resulting in more land needed for biodiversity being converted to production agriculture (Avery and Avery). Self-sufficiency in input use has been identified by one critic as a cause of lower yields in organic farming (Bruulsema). However, without knowledge of the factors affecting productivity, the premise of these claims - that organic agriculture is necessarily lower yielding - cannot be verified, and improvements in organic efficiency cannot be proposed.

Interest in organic production efficiency has focused on comparisons with nonorganic agriculture. Most evaluations of organic agriculture productivity have found lower yields, measured as output per areal unit, compared with nonorganic farms (Offermann and Nieberg; Anderson). Such comparisons fail to address the causes of differences in farm efficiency within the organic sector, which must be the focus if yield improvements are to be made. Although labor, farm size, crop mix, and soil quality have been identified as factors in organic farm productivity (Hanson; Offermann and Nieberg; Anderson), there has been no formal analysis to determine the sources of inefficiency that can result in lower yields for organic farming. We develop a framework to assess the efficiency of organic producers and use it to identify key production constraints on organic farming systems.

The pace of conversion from conventional to organic agricultural production in the United States is accelerating. Between 1997 and 2001, total certified acreage increased 74% from 1.3 million to 2.3 million acres, compared with a 44% increase from 935,000 to 1.3 million acres between 1992 and 1997 (Greene and Kremen). During the same periods, the number of organic farmers also increased, but the percentage change was almost constant at 40% between 1992 and 1997 and 38% between 1997 and 2001. Average organic farm size increased from 260 acres in 1992 to 268 acres in 1997 to 337 acres in 2001. Existing literature suggests that as organic farms increase in size, they become more efficiently run in that larger farms are able to streamline their enterprises to minimize production costs and numbers of different practices required per unit of output (Caswell *et al.*).

National survey data from the Organic Farming Research Foundation (OFRF) in 1997 and subsequent analyses suggested three additional factors that seem to differentiate efficient organic or sustainable farms - more hired labor use, greater self-sufficiency in soil management inputs, and participation in on-farm research (Walz; Hansen; Jaenicke and Drinkwater; Kroma and Butler Flora). Using a stochastic distance function frontier, we quantified the effect of farm-specific attributes on organic farm efficiency using data from the OFRF survey.

The West and Northeast regions historically have made greater spending and institutional commitments to organic research and education, and continue to offer greater support for organic farmers. These regions are home to the nation's oldest organic organizations, California Certified Organic Farmers, Oregon Tilth, and the Northeast Organic Farmers' Association, and instituted the first state laws regulating organic production. Linking each observation to the appropriate Sustainable Agriculture Research and Education Program (SARE) region, we also test the effects of institutional support and regulatory environments that differ by region.

The results from the distance function approach suggest that investing in farmer-participatory research will improve efficiency in the organic agriculture sector. Kroma and Butler Flora documented that locality-specific production systems that emphasize stabilizing ecological processes, such as organic agriculture, benefit from local knowledge obtained in systematic ways through on-farm research and disseminated farmer-to-farmer.

Modeling Efficiency in Organic Production

Färe and Primont demonstrated that the output distance function is a natural generalization of the production function for multiple outputs. The technology is represented by the set of all outputs **y** which can be produced given the input vector **x** and the external technical or market regulatory factors **r** facing the firm. The feasible output set is given by P(**x**, **r**). The output distance function defines the maximum output that can be produced given the inputs:

$$D_O(x, y, r) = \min\left[\, \mu : (y/\mu) \in P(x, r)\right] \tag{1}$$

where D_O (**x**, **y**, **r**) ≤ 1 and y $\leq \mu$. If observed output is on the boundary of the production set and is efficient, the distance function is equal to 1. For farmers whose output is not efficient, and lies below the frontier, the distance function is less than 1. The difference between μ and 1 is how far the organic operation falls short of "best practice" production.

The output distance function for a given farm is written as

$$1 = D_O(x_i, y_i, r_i)\, h(\epsilon_i) \tag{2}$$

where the two component error term $h(\epsilon_i) = \exp(v_i - u_i)$. In stochastic frontier analysis firms are constrained to produce at or below the deterministic production frontier, a condition recognized by inclusion of a composite error term consisting of two random variables. The first element in the composite error, ν_i, is a symmetric noise term reflecting uncertainty in the production function and can take on both positive and negative values. The second error term, u_i, accounts for random shocks uncontrolled by the producer, including inefficiency in firm operations and environmental conditions that reduce output, and assumes only negative values.

Kumbhakar and Lovell summarized the properties of the output distance function, which we recognized in developing an empirical model for estimating the output distance function for organic farmers. Empirical application of the output distance function requires a flexible functional form. Building on extensive work in duality theory for cost and profit functions, Morrison Paul *et al.* proposed a translog distance function for m outputs, k inputs and b exogenous factors.

We adopted the translog form, and follow Cornwell, Schmidt, and Sickles in using a fixed-effects approach for firm-varying inefficiency composed of $u_i = \sum_g \lambda_g f_{gi}$. Producer-specific variables and regional factors that affect the efficiency of cropping systems are identified by f_{gi} with the estimated parameters λ_g so that:

$$0 = \ln D_O(x_i, y_i, r_i) + \nu_i - u_i \quad . \tag{3}$$

Technical efficiency (TE) measures are from the estimated distance function are derived from the method outlined by Atkinson and Primont. The one-sided error term which represents technical efficiency must be non-negative and the procedure ensures that $0 < TE_i \leq 1$.

Morrison Paul *et al.* implemented the translog model under the distance function's regularity conditions and the restrictions implied by homogeneity of degree one in the distance function. They capitalized on the homogeneity restriction and normalized by one output, y_1, to obtain the modified translog output distance function:

$$y_{1i} = \alpha_0 + \sum_m \alpha_m \ln y^*_{mi} + \frac{1}{2}\sum_m \sum_n \beta_{mn} \ln y^*_{mi} \ln y^*_{ni} + \sum_m \sum_b \gamma_{mb} \ln y^*_{mi} r_b + \sum_k \alpha_k \ln x_{ki}$$

$$+ \sum_k \sum_b \gamma_{kb} \ln x_{ki} r_b + \frac{1}{2}\sum_k \sum_l \beta_{kl} \ln x_{ki} \ln x_{li} + \sum_k \sum_m \beta_{km} \ln x_{ki} \ln y^*_{mi} \qquad \textbf{(4)}$$

$$+ \sum_b \alpha_b r_{bi} + v_i - u_i \qquad .$$

The distance function is normalized by the first output so that $y^*_1 = 1$ and $y^*_m = y_m/y_1$. The summations signs for the m outputs in the transformed distance function apply to the —1 outputs not used in the normalization.

Restrictions imposed by homogeneity and symmetry in cross effects are:

$$\sum_m \alpha_m = 1, \quad \sum_n \beta_{mn} = 0, \quad \sum_b \gamma_{mb} = 0 \qquad (m = 1, \ldots, M),$$

$$\sum_m \beta_{km} = 0 \qquad (k = 1, \ldots, K), \qquad \textbf{(5)}$$

$$\beta_{mn} = \beta_{nm} \qquad \forall\ m, n, \quad m \neq n,$$

$$\beta_{kl} = \beta_{lk} \qquad \forall\ k, l, \quad k \neq l\ .$$

The left side of equation 4 was respecified as ln y_{1i}, reversing the signs of the coefficients in the typical distance function. Elasticities with respect to the output variables should be negative, consistent with tradeoffs along the production possibility frontier. Marginal product relationships for inputs take on positive signs in the respecified model.

Input and output substitution patterns are evaluated in the elasticities of y_1 or D_O with respect to the arguments of the distance function. The returns to the kth input measured as its impact on output are:

$$\varepsilon_{y1,\,k} = \frac{\partial \ln y_1}{\partial \ln x_k} = \alpha_k + \sum_b \gamma_{kb} r_b + \sum_l \beta_{kl} \ln x_{li} + \sum_m \beta_{km} \ln y^*_{mi} \,. \tag{6}$$

Elasticities representing tradeoffs between the produced outputs along the production possibility frontier are:

$$\varepsilon_{D_O,\,m} = \frac{\partial \ln D_O}{\partial \ln y_m} = \alpha_m + \sum_m \beta_{mn} \ln y_{ni} + \sum_b \gamma_{mb} r_{bi} + \sum_k \beta_{km} \ln x_{ki} \,. \tag{7}$$

The successful application of this model to measuring efficiency of organic farmers relies on capturing the unique aspects of these operations. Production characteristics of organic farms are just beginning to be catalogued and compared with conventional farms. As an initial effort in quantifying efficiency, we used measures of factors identified by practitioners and researchers as having special significance for organic productivity. Besides the direct relationship between inputs, **x**, and outputs, **y**, expressed by the production frontier, features of the farms and regions, **r**, included in the model and captured in the error term, $u_{i,}$ indirectly affect the ability of the farmer to make the most efficient use of those inputs. The fixed effects stochastic distance function model identifies significant constraints to productivity that would otherwise be attributed to farmer inefficiency.

Data and Model Formulation

Representativeness of the Data

Efficiency analysis using distance functions requires sufficient data to represent the industry production frontier, so that deviation from the efficient level may be calculated for each producer. To obtain this scale, national survey data representative of all organic farmers is desirable. The 1997 OFRF survey was sent to all U.S. certified organic farmers, based on grower lists maintained by organic certification organizations. The stated purpose was to "...provide the most comprehensive picture currently available about the state of organic farming in the United States, *from the organic farmer's perspective*" (Walz, p. 1).

The data on production practices, demographic characteristics, and farm attributes represent all crops grown organically, and all regions in which organic production is conducted. Of 49 states with organic producers in 1997, 44 states were represented in the OFRF data (Walz). The five states missing from the survey response set represented only 0.18% of the total certified organic cropland in 1997. Lohr and Park (2003) documented the representativeness of the OFRF data with respect to all U.S. farm data, showing that farm structure and income class distributions are nearly the same across the two groups.

The OFRF data were deemed sufficiently representative of the organic industry to use in estimating the distance function. Of the 1,192 surveys returned to the OFRF (26% response rate), sufficient detail was provided in 993 responses to test the model. The data were obtained by special agreement with the OFRF as part of a project to assess the U.S. organic sector.

Appropriateness of the Model

Organic farmers of necessity operate diverse enterprises, partly to offset risk and partly to exploit natural cycles for pest and nutrient management (Kroma and Butler Flora). The OFRF survey asked farmers to list acreage allocated to specific crops. We grouped these data into three categories - field crops (including grains, beans, oilseeds, and the like), vegetable crops (vegetables, herbs, flowers, ornamentals), and fruit crops (fruits, nuts, and tree crops). These correspond to the outputs y_1, y_2, and y_3 in equation 4. More than 41% of farmers in the 1997 survey allocated production across a portfolio of at least two of the crop categories.

Table 1 shows the descriptions and summary statistics for variables appearing in the distance function, as well as the question number from the OFRF survey results that corresponds to each variable. Diversification was observed within, as well as across, the three crop categories. Field crops (FLDCRP) were the predominant crop category, with 48% of farmers allocating an average of 106 acres across an average of two specific field crops. Vegetable crops (VEGCRP) were grown by more than 30% of the farmers with an average of 19 acres planted to an average of four different crops in this category. Fruit crops (FRTCRP) were produced by 22% of the farmers on an average of 16 acres, planted with an average of two different crops.

Observed farm diversification within and across the three crop categories supports the use of the multiple output distance function specified in equation 1. The outputs were normalized on the field crop category so that y_1 = FLDCRP in equation 4. To apply the fixed effects approach, we included both firm-specific and regional input variables in the translog model.

Input Variables

The farm input variables comprising the vector **x** were labor, organic acreage, and a proxy for organic farming experience. The output return to the labor input is a typical measure of productivity, but on organic farms, there is a critical management component to labor. Labor on organic farms consists of production tasks, monitoring, information-seeking, and management decision making. Organic farmers heavily rely on ecological processes for nutrient management, pest control, and yield enhancement. The ability of a farmer to collect and interpret localized information and use it in management decisions is an important determinant of success, and information sharing can be critical to this process (Kroma and Butler Flora). To account for this, we defined labor (LABOR) as the number of managers involved in major farm planning decisions plus the number of full-time and part-time employees on the farm operation. The average farm employed 13 workers, including four full-time and five part-time paid employees. About 56% of farmers hired no full-time workers and 39% employed no part-time workers.

Scale effects could hold for individual crop categories as well as for overall efficiency. An average of 157 acres, described by the variable ORGACRE, was farmed organically in the sample, with the largest farm at 6,250 acres. Increasing farm size was most closely related to field crop production, with a correlation coefficient of 0.73, followed by vegetable production with a correlation coefficient of 0.61and fruit crops at 0.40.

Farm-Specific and Regional Efficiency Determinants

Farm-specific and regional variables included in f_{gi} may shift efficiency below the frontier by their indirect influence on how inputs are used. Several factors that have been identified as significant influences on productivity are not inputs, but can alter input use. These include length of organic farming experience, building soil organic matter, and experimenting with new practices or systems. The latter tasks require investment in management activities, particularly planning beyond the current crop year. Organic farmers must file a multi-year farm plan that details a program for improving soil organic matter and resource conservation. Effective experimentation requires information sharing, which takes management effort to identify sources, collect and interpret information, and implement trials. By explicitly recognizing these factors as possible constraints to efficient production, the nature of management inefficiencies can be unraveled.

Lohr and Park (2002) showed that length of experience with organic systems positively affects the number of management practices implemented on a farm. Farmers with greater experience were hypothesized to be better able to manage a wide range of practices and to be more open to using new strategies. Extending this analysis, we attempted to measure quality of experience by using a dichotomous variable, ORIGALL, for those who initiated their farming careers as organic farmers and farmed exclusively certified acreage. Farmers who meet this definition have allocated continuous time and resources to learning about the full complement of organic practices available and designing an optimal organic system, compared with those operating parallel systems that include both organic and nonorganic acreage. More than 75% of OFRF respondents had committed their whole farm to organic production and 58% of respondents had farmed continuously as organic farmers (Walz). In the sample, 48% of farmers met both criteria.

Successful implementation of alternative cropping systems is intimately linked to soil quality improvements (Jaenicke and Drinkwater). The relationship between production efficiency and soil quality enhancement is well known (Kuyvenhoven, Ruben, and Roseboom) and is so well accepted that international environmental indicators include several measures related to soil protection and soil nutrient balance (OECD, 2001). A common complaint from organic farmers responding to the OFRF survey was that organic inputs for building soil organic matter and otherwise improving soil quality may be difficult or costly to obtain from outlets that are close to the farm (Walz).

Respondents to the OFRF survey identified the sources of their soil management inputs (see Walz, Question 5.9, p. 83). The inputs included animal manures for compost, green waste for compost, finished compost, mineral soil amendments, and biological soil fertilizers. We calculated a count index of self-sufficiency in organic soil materials, defined as producing the input entirely on farm, for each organic producer. This index formed the soil improvement error variable, SOILIMP.

The mean number of inputs produced entirely on farm was 1.12. About 45% of the farmers were self-sufficient in at least two of the soil materials, with more than 40% producing all of their green waste for compost or finished compost on farm. There is a strong correlation between ORIGALL and SOILIMP. Original organic farmers were more likely to produce their own organic soil amendments, with 63% of this group being self-sufficient in at least two inputs, compared with 38% for farmers who converted to organic production. The correlation between SOILIMP and ACRES was low, indicating that farm size is not a constraint to self-sufficiency in soil improving inputs. The labor measure revealed a slight negative correlation with the soil improvement measure of -0.09.

Kalirajan and Shand suggested that a main constraint in achieving technical efficiency in agricultural production is the lack of information about best practice techniques. With limited information farmers benefit from gradual "learning by doing" in adopting new production and management methods, highlighting the value of on-farm research projects. Information accessibility and reliability are of particular importance in the adoption of management strategies for organic systems. As Padel and Lampkin pointed out, direct costs of information and experience gathering constitute major barriers to organic conversion.

On-farm research is related to the producer's entrepreneurial and management expertise, consistent with labor theories of the research process. Lazear's model of the incentives for initiating basic research demonstrated that more productive individuals tend to initiate and become involved in research projects. In measuring agricultural productivity of sustainable agricultural systems, Jaenicke and Drinkwater also documented an important role for both experimental on-farm learning and "tinkering" as farmers adjust production techniques.

Experimentation with new practices and systems is consistent with organic farmers' entrepreneurial goals (Duram), and is necessary to adapt technologies to the local agroecology (Krome and Butler Flora). The 1997 OFRF survey revealed that 87% of respondents had conducted their own on-farm experiments. Observation of and experimentation on their own farms and information gathered from books, other farmers, and researchers were reported by more than 70% of respondents to be very important elements in shaping their personal knowledge base. Links among farmers, researchers, and extensionists were formalized by the USDA's producer grants program under the Sustainable Agriculture Research and Education

Program, which promotes farmer participatory research, and by the Organic Farming Research Foundation's grants program, which encourages university-farm collaborations.

The OFRF survey queried farmers about their contribution of seven different resources required for collaborative experimental or research efforts. The seven resources were providing land, financial support, labor, or materials and publishing and distributing research results. We measured the farmer's research involvement by counting the number of resources the farmer provided in collaborative research and including this variable (RESCOMT) in f_g.

The distribution of organic farmers who participate in on-farm research is distinctly bimodal, as 75% of farmers remain uninvolved and contribute no resources. The second highest category of farmers (12%) showed the maximum commitment to collaborative research by providing all seven resources listed. The percentage of farmers providing research inputs in each category is fairly uniform, ranging from a maximum of 20% of farmers who commit land to a minimum of 16% who assist in published and distributing research results. Organic producers with the largest acreage are the dominant group among the farmers showing the most commitment to collaborative research. Farmers with over 100 acres commit an average of 1.52 resources compared with the an average of 1.20 resources from producers with less than 20 acres.

Producer involvement in on-farm research projects may be motivated by significant production problems that are emerging in the farm operation. If true, the research commitment variable would be correlated with farmers who face higher production constraints, observed as higher inefficiency components for these farmers. We tested the effect of the research commitment variable on organic efficiency using the econometric model.

Regional variation exists in climate, organic cropping history, crop production practices, and regulatory environments which we accounted for with a set of regional fixed effects in $\mathbf{r}_b$. Variations in resources allocated to the extension service are also apparent at the regional level, with the result that sustainable agriculture practices advocated by extension have been unevenly adopted (Comer *et al.*).

To assess institutional support and information availability for organic production and marketing systems, we used the four USDA Sustainable Agriculture Research and Education (SARE) regions (see http://www.sare.org/htdocs/sare/about.html for a listing of states in each region). These regions reflect the U.S. government's demarcation for sustainable agriculture extension-research support. We created a dichotomous variable for each region, equal to one if the respondent's farm was in that region, and zero otherwise. In our sample, 35% of farmers were in the SARE 1 region (WEST), 28% in the SARE 2 region (NORCENT), 9% in the SARE 3 region (SOUTH), and 28% in the SARE 4 region (NOREAST).

Significant regional variation is evident in the proportion of original organic farmers who commit their complete farm operation to organic methods (ORIGALL). Over half of the farmers meet this criterion in the West, South, and Northeastern regions, with the South showing the highest percentage at 62%. Only 32% of organic producers from the North Central region are described as original, all organic farmers. Regional patterns also emerge in the index of on-farm production of organic soil amendments (SOILIMP) as farms in the Western region use an average of 0.883 amendments produced on-farm, compared with an average of 1.20 for the other regions.

Estimation Results

Coefficient estimates and asymptotic standard errors for the multi-output fixed effects distance function are presented in Table 2. The measures of output mix in the Farell efficiency framework are considered to be exogenous (Grosskopf *et al.*). Empirical models of the distance function have been estimated with exogenous right-hand side output and input mixes that are uncorrelated with the firm effects and with the stochastic error (Park *et al.*, Morrison Paul *et al.*, Cuesta and Orea).

As the focus of this research is on efficiency, we do not interpret the estimated coefficients for the individual and interaction effects, except to note that the restrictions consistent with a Cobb-Douglas functional form were rejected. Among the fixed effects (α_b) and inefficiency determinants (λ_g), only RESCOMT was significant, with the expected negative sign.

Table 3 shows the mean technical efficiency of the sample of organic farmers, overall and by fixed effects components. The estimated mean technical efficiency was 0.75 across the complete set of 993 organic producers. By comparison, Oude Lansink, Pietola, and Bäckman documented a technical efficiency of 0.95 under variable returns to scale for Finnish organic farmers. We explored the effects o f the farm-level variables (RESCOMT, ORIGALL, and SOILIMP) on efficiency in more detail on Table 3.

The efficiency estimates for all firms were grouped and averaged according to the conditions of interest. The research commitment (RESCOMMT) variable was -0.048, negative and statistically significant, indicating that participation in collaborative research projects reduces the level of technical inefficiency, a result that aligns with Lazear's model. Producers who participated in on-farm research had a mean technical efficiency of 0.87, while farmers who did not participate had efficiency of only 0.70.

We tested whether commitment to on-farm research was correlated with more significant production problems using data from the OFRF survey. We constructed an index of the severity of five production constraints facing organic producers, including difficulties in achieving production levels, finding appropriate inputs, costs of organic inputs, distance or transporting of organic inputs, and the effectiveness of organic inputs. Farmers rated the severity of the problem from "not a constraint" (severity = 1) to a "serious constraint" (severity = 5). The index had a mean of 13 on a scale ranging from 5 to 25. The correlation between the production constraints index and the research commitment variable was very small (below 5%), suggesting that research was not undertaken in response to more severe production problems, but is probably related to managerial "tinkering."

We estimated separate models to determine whether the efficiency-enhancing effects of research involvement were due to the type of research partner, including other farmers, university colleagues, or private companies or research organizations. None of these factors affected the efficiency measure, suggesting that efficiency gains are not linked to specific collaborative partnerships but are due to the on-farm research effort itself.

Farming experience may be qualitatively different between those who began farming and converted to organic systems and those who always farmed organically. We hypothesized that original organic farmers would be more efficient that converted organic farmers. Table 3 shows that the converse is true. Original organic farmers' mean efficiency was 0.73 compared with

0.77 for converted farmers. Although ORIGALL was not significant in the regression equation, the positive sign suggests that this condition results in lower technical efficiency.

A critical issue faced by organic farmers is to build and maintain organic matter through effective soil management. Use of on-farm sources for inputs is perceived as improving the sustainability of organic farms (Rigby *et al.*). Farmers who were self-sufficient in at least one of the soil improving inputs averaged an efficiency of 0.74, compared with 0.77 for those not self-sufficient. The coefficient on the SOILIMP was positive, suggesting lower technical efficiency, but was not statistically significant.

The strong correlation between ORIGALL and SOILIMP noted previously could have masked the individual effects of the two variables. Converted organic farmers and those purchasing all soil-improving inputs off-farm had mean efficiencies close to the overall efficiency for the entire sample. Original organic farmers and those self-sufficient in at least one input exhibited efficiencies somewhat below this mean. Within the organic farming sector, these differences may become significant as more conventional farmers convert to organic systems and compete with original organic farmers.

Summary measures of output and input elasticities calculated in equations 6 and 7 are presented in Table 4. For the full sample, elasticities for outputs (-0.351 for vegetables and -0.396 for fruits) have the correct negative signs while the input elasticities (0.118 for labor and 0.287 for acreage) have positive values as expected. For a one percent increase in vegetable or fruit acreage, the producer must reduce other crop acreage by 0.35 and 0.40 percent. For a one percent increase in labor and organic acreage, field crop acreage increases by 0.12 and 0.29 percent. Labor has less effect on output than does acreage. The effect of research commitment on both input and output elasticities was negative, but was stronger for the output elasticity. Greater research effort reduces acreage farmed, possibly because time and resources allocated to research cannot be allocated to farming.

We tested for differences in input use and output tradeoffs between high and low performers. High performers were defined as farms with technical efficiency scores above the 90th percentile (TE of at least 0.937). Low performers were defined as farms with technical efficiency scores below the 10th percentile (TE below 0.659). Across these groups, the results were statistically different. High performers had a lower rate of substitution of vegetable acreage for grains than low performers (-0.347 vs. -0.381), and a higher rate of substitution of fruit acreage (-0.394 vs. -0.364). High performers exhibited a higher input elasticity for labor than low performers (0.121 vs. 0.100), and a lower input elasticity for acreage (0.280 vs. 0.292). These results suggest that the most efficient organic farmers shift into vegetable, rather than fruit production, and that they are more flexible in their labor use than lower performers.

Implications of the Results

This research does not directly address the claims that organic agriculture is less efficient than conventional agriculture. Rather, we assumed that regardless of current efficiency levels, changes in input use and fixed effects can improve productivity. Identifying the significant factors in organic efficiency provides guidance on how to close the gap between organic and conventional production yields.

Our results showed that there are differences in productivity across organic farmers and that may be significantly affected by input use and farm effects. The most striking result was that farmer research commitment dramatically increases production efficiency to 0.87 from an overall level of 0.75. This result could be related to the intensely local nature of organic farming systems as it relates to field agroecology and microclimates. The on-farm research itself contributes to a farmer's ability to respond to these conditions. As well, collaboration encourages the discussion and exchange of ideas to counter production constraints. Programs encouraging farmer-participatory research are extremely important in promoting organic efficiency improvement.

The results with respect to self-sufficiency in soil improving inputs and organic farming history were less definitive. Converted organic farmers and those not self-sufficient in any soil improving inputs were more efficient than original organic farmers and self-sufficient farmers. If markets for organic foods continue to grow, more acreage will be converted to organic production by conventional farmers. Those with conventional farming experience and those relying on purchased inputs will have an advantage over original organic farmers and those attempting to produce their soil inputs on-farm. The implication is that farmers need to be conversant in general production methods before attempting to farm organically. This argues for devoting more effort to teach and mentor original organic farmers in production methods and for expanding availability and reducing costs of off-farm soil inputs to improve efficiency.

Within the organic sector, there are high performers and low performers. In the sample, the 90th percentile exhibited technical efficiency above 0.90, and the 10th percentile averaged 0.67. The tradeoffs between fruit and vegetables, and grains among high performers suggests more efficient producers are less likely to substitute fruit production. High performers also exhibit more manipulation of labor than of acreage to increase productivity. As the industry becomes more efficient, fruit production could decline relative to grain and vegetable production, and labor markets will experience greater demand.

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Table 1. Variable Descriptions and Summary Statistics (N = 993 farms)

Variable	Description	Mean	Standard Deviation	Survey Question[a]
FLDCRP	Field crop production, acres	105.69	271.39	3.3
VEGCRP	Vegetable production, acres	18.89	216.40	3.1
FRTCRP	Fruit and nut production, acres	16.48	161.07	3.2
LABOR	Managers and employees, number	13.50	41.90	8.4, 8.5
ORGACRE	Total acreage farmed organically	157.28	451.54	8.6A
ORIGALL	Farmer originally an organic producer, still farms only organic acres, 1 if yes	0.48	0.50	6.1, 8.1
SOILIMP	Soil improving inputs produced entirely on-farm, number from 0 to 5	1.12	1.08	5.9
	Share of farms producing the input			
	Animal manures for compost	0.26	0.44	
	Green waste for compost	0.42	0.49	
	Finished compost	0.42	0.49	
	Mineral soil amendments	0.01	0.07	
	Biological/blended fertilizers	0.01	0.10	
RESCOMT	Resources provided by farmer for research efforts, number from 0 to 7	1.29	2.51	1.5B
	Share of farms providing the resource			
	Provided land	0.21	0.41	
	Helped define problem for study	0.20	0.40	
	Provided financial support	0.17	0.37	
	Provided materials and/or equipment	0.20	0.40	
	Provided staff and/or labor	0.19	0.39	
	Helped publish research results	0.16	0.37	
	Distributed results	0.16	0.36	
WEST	Farm is in SARE Region 1, 1 if yes	0.36	0.48	8.12

NORCENT	Farm is in SARE Region 2, 1 if yes	0.33	0.47	8.12
SOUTH	Farm is in SARE Region 3, 1 if yes	0.07	0.26	8.12
NOREAST	Farm is in SARE Region 4, 1 if yes	0.24	0.42	8.12

[a] The question number in Walz corresponding to each variable.

Table 2. Distance Function Parameter Estimates for Organic Producers (N = 993 farms)

Parameter	Variable	Estimate	T-ratio[a]
Vector α_0 - Intercept			
	Intercept	-0.148	-1.425
Vector α_m - Outputs			
	VEGCRP	-0.446*	-17.932
	FRTCRP	-0.300*	-13.071
Vector α_k - Inputs			
	LABOR	-0.008	-0.129
	ORGACRE	0.332*	8.493
Vector α_b - Fixed Effects			
	ORIGALL	0.049	1.292
	SOILIMP	0.016	0.985
	RESCOMT	-0.048*	-2.594
	WEST	-0.030	-0.631
	SOUTH	-0.053	-0.744
	NOREAST	0.024	0.494
Vector β_{mn} - Output-Output Interactions			
	VEGFRT	-0.029*	-4.503
	VEGSQ	0.007	1.759
	FRTSQ	0.025*	7.131
Vector β_{km} - Input-Output Interactions			
	LABXVEG	-0.013	-1.441
	LABXFRT	-0.030*	-3.514

	ACRXVEG	0.024*	4.134
	ACRXFRT	0.003	0.376
	RCOMXVEG	0.005	1.273
	RCOMXFRT	-0.006	-1.728
Vector β_{kl} - Input-Input Interactions			
	LABXACR	-0.036*	-2.430
	LABXRCOM	0.014	1.762
	ACRXRCOM	0.006	1.195
	LABORSQ	0.044*	2.928
	ACRESQ	0.008	1.069
Vector λ_g - Inefficiency determinants			
	ORIGALL	0.049	1.500
	SOILIMP	0.016	1.033
	RESCOMT	-0.048*	-7.485
	WEST	-0.046	-1.287
	SOUTH	-0.062	-1.049
	NOREAST	0.011	0.269

[a] Asterisk indicates asymptotic t-values with significance at $\alpha = 0.05$ level.

Table 3. Technical Efficiency of Organic Producers, Overall and by Fixed Effects

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Overall Efficiency	993	0.748	0.083	0.653	1.000
By Research Involvement					
Positive Involvement	242	0.871	0.078	0.680	1.000
No Involvement	751	0.709	0.028	0.653	0.769
By Farming Experience					
Original Organic Farmer	473	0.729	0.077	0.653	0.954
Converted to Organic Farming	520	0.766	0.085	0.677	1.000
By Soil Input Self-Sufficiency					
Self-Sufficient in at Least One	606	0.737	0.080	0.653	0.987
Not Self-Sufficient	387	0.766	0.084	0.682	1.000

Table 4. Output and Input Elasticity Estimates for Organic Producers[a]

Output	Observations	Vegetables	Fruit	On-Farm Research
Overall:				
$\epsilon_{Do, m}$	993	-0.351	-0.396	-0.253
		(0.095)	(0.104)	(0.063)
High Performers:				
$\epsilon_{Do, m}$	87	-0.347	-0.394	-0.259
		(0.106)	(0.094)	(0.066)
Low Performers:				
$\epsilon_{Do, m}$	164	-0.381	-0.364	-0.257
		(0.101)	(0.128)	(0.068)

Input	Observations	Labor	Acreage	On-Farm Research
Overall:				
$\epsilon_{y1, k}$	993	0.118	0.287	-0.004
		(0.105)	(0.607)	(0.022)
High Performers:				
$\epsilon_{y1, k}$	87	0.121	0.280	-0.004
		(0.099)	(0.061)	(0.021)
Low Performers:				
$\epsilon_{y1, k}$	164	0.100	0.292	-0.006
		(0.121)	(0.062)	(0.026)

[a] Asymptotic standard error in parentheses with 0.05 significance level. High performers are farms with technical efficiency scores above the 90th percentile at least 0.937). Low performers have technical efficiency scores below the 10th percentile (below 0.659).

[b] Across category comparison (different variables) is statistically different at the 0.05 significance level.

[c] Within category comparison (high vs. low performers) is statistically different at the 0.05 significance level.