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Productivity growth, Technical Efficiency and Technical Change on Minnesota farms

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Abstract

Changes and trends in farm productivity have been of intense interest to many involved with agriculture. This study used data envelopment analysis (DEA) to estimate the output-oriented Malmquist total factor productivity (TFP) index from panel data for 1993-2006 for farms in Southern Minnesota. Bootstrap methods were used to estimate confidence intervals for the productivity, efficiency change and technical change indices. The model included three inputs (labor, land and immediate expenditures) and six outputs (corn, soybean, milk, hog, beef, and nonfarm income). Productivity growth was found to be positive during the period, with an average annual productivity growth of 6.6 percent. However, TFP growth has been slowing down in recent years and indeed negative in 2000/01, 2002/03 and 2005/06.

In the second stage of the analysis, the significance of various factors that might affect farm performance was estimated. Farm size (as measured by the log of farm income) was correlated with higher productivity which may help explain the increase in farm size in Minnesota farms in recent years. Government subsidies were found to have a negative impact on farm performance supporting the argument that agricultural subsidies may create disincentives for farmers to improve their productivity and efficiency. A higher nonfarm income ratio was positively related with higher productivity growth. A higher proportion of hired labor has a negative effect implying family labor is more crucial than hired labor in improving productivity.

JEL classification: Q12, C14

Keywords: total factor productivity, farms, Malmquist index, data envelopment analysis, DEA, bootstrap, government subsidies

1. Introduction

Changes and trends in farm productivity have been of intense interest to many involved with agriculture. This interest has been due to many reasons: productivity growth as a driver of structural change in production; the need for increasing levels of food, fiber, and fuel due to an expanding population; a fixed or declining land resource base; changing inputs and methods of production; changes and potential changes in domestic policies and international trading rules; and so on.

Productivity growth in agriculture has been a subject of intensive research. Many previous studies of productivity have been at the country level (e.g., Fuglie et al. 2007; Trueblood and Coggins 2004, Fulginiti and Perin 1998, and others). In the U.S., Grilliches and Jorgenson (1967), Jorgenson et al. (1987), Antle and Capalbo (1988), Ball and Norton (2002), Fuglie et al. (2007) are some of numerous studies measuring the US agricultural productivity. In particular, a report by USDA (Fuglie et al. 2007) estimated US agricultural total factor productivity growth during the period 1948-2004 and reported a growth of 1.8 percent annually throughout the whole period, 1.4 percent during 1989-1999 and 2.8 percent during 1999-2004.

There are several methods of productivity measurement such as growth accounting and index number methods. However, these approaches suffer from several limitations. First, they assume all production units to be fully efficient. Second, they need the price information which may be not always available. The Malmquist index developed by Fare, Grosskopf, Lindren and Ross (1989), based on data envelopment analysis (DEA) has an important practical advantage over these approaches since it does not require price data. Moreover, the Malmquist index can be decomposed into technical change and efficiency change, therefore providing information about the relative impacts of these factors. Yet, one important disadvantage of the method is the inability to allow for random error, therefore making the method unable to provide statistical inference. However, recent advances in methodology have developed models that allow researchers to derive statistical properties of DEA estimates. Particularly for the Malmquist index, Simar and Wilson (1999) define a model that applies the bootstrap method to provide confidence intervals for the Malmquist productivity index, efficiency change and technical change index.

In agriculture, the Malmquist productivity index has been applied to cross-country comparisons of total factor productivity (TFP, Thirtle, Hadley and Townsend 1995, Fare et al. 1994, Fulginiti and Perrin 1998, Coelli and Rao 2005). There are also studies using farm level data (e.g., Thirtle, Piesse and Turk 1996, Zhengfei and Lansink 2006). However, most previous studies deal only with deterministic estimates. The exception is Balcombe et al. (2008), who estimate bootstrapped Malmquist indices for a sample of Polish farms. Their study is among the first attempts that apply bootstrap method to provide statistical properties for Malmquist productivity, efficiency and technical change indices in agriculture.

In this current study, we estimate the output-oriented Malmquist total factor productivity index based on a panel data for 1993-2006 for farms in Southern Minnesota. In addition to the point estimates, we apply the bootstrap method as in Simar and Wilson (1999) to provide statistical testing for our estimates. In the second stage, we consider the factors that might affect farm performance. We are particularly interested in the relationship of farm size and government subsidies to farm efficiency and productivity.

This study contributes to the literature in several ways. First, it is one of the first empirical applications that use a bootstrap to provide statistical inference for the Malmquist method. In addition, to Balcombe et al. (2008), other previous studies, all in different settings not in agriculture, include González and Miles (2002) for Spanish public services, Tortosa-Austina et al. (2008) for Spanish saving banks, and Hoff (2006) for Danish seiners. Second, we contribute to the empirical studies on the relationship between farm performance and farm size, farm financial conditions and agricultural subsidies. The relationship between agricultural subsidies and farm performance has been paid little attention in the literature even though subsidies are considered very important for farm survival in many developed countries where farms receive significant support from their government.

The paper is structured as follows. The next section is the literature review on farm productivity and factors affecting it. Section 3 describes the Malmquist productivity index and its decomposition. Section 4 describes the data. The finding of farm productivity and efficiency is presented in Section 5. Section 6 provides the discussion of factors affecting farm performance.

2. Literature review on farm productivity

In developed countries, most studies of factors affecting farm productivity and efficiency often attempt to understand variations in farm performance by differences in the farm production and financial structure as well as agency factors such as human capital level (Gorton & Davidova 2004.) In this approach, the neoclassical framework is often presumed and the individual farm is considered as the unit of analysis. In the contrast, studies on developing and transition countries are often more influenced by institutional economics. In this line of studies, factors considered as influencing on farm performance are more diverse. In addition to farm characteristics, the external environment and institutional factors (e.g., formal and informal rules and laws) are considered important. Thirtle, Piesse and Turk (1996) studied the productivity of private and social farms in Slovenia and found that TFP growth was faster for private farms. Umetsu, Lekprichakul and Chakravorty (2003) considered efficiency and technical change in the Philippine Rice factors and argued that regions with higher investments in irrigation, increased adoption of tractors, and higher population growth rates also exhibit higher technical change.

In this paper, we examine some factors commonly identified by both approaches as the "core" factors that may explain variations in farm efficiency which are farm size and farm financial conditions. Moreover, we are particularly interested in how government subsidies in agriculture could affect farm performance.

Farm size and farm productivity

Among the factors that receive much attention in the literature is the relationship between farm size and efficiency. In developed countries, there has been a consistent increase in farm size in the last decades. In view of this pattern, many authors hypothesize that larger farms benefited from higher efficiency and higher technical change than smaller farms. However, some authors, particularly in studies on developing countries, suggest the presence of an "inverse hypothesis" that smaller farms are more productive because they make use of the land more intensively (Johnson and Ruttan 1994, Binswanger and Elgin 1998, Barrett 1998).

One aspect of the debate over U.S. federal agricultural policy (i.e., the farm bill as it is commonly called) was that federal commodity programs provide disproportionately larger subsidies to larger farms which give these larger farms an economic advantage over smaller farms. These larger payments, as the argument goes, allow the larger farms to pay higher land rents than their smaller neighbors due to improved efficiencies because of being larger and better cash flows because of larger government payments. Thus, the argument continues, larger farms are able to increase in size while smaller farms cannot grow and may even cease to exist. Depending on one's point of view, the government subsidies either exacerbate the efficiencies associated with size or take away the efficiency advantages that smaller farms possess.

Financial conditions and performance

Previous research has studied the relationship between firm-level financial condition and productivity. One area is the role of financial slack and debt level. The free-cash-flow theory of Jensen (1986) argues that if a firm has too much free cash flow and little debt, the managers would behave irresponsibly and engage in inefficient investments.

Therefore, a higher debt level is helpful in disciplining firm management. Nasr et al. (1998) and Giannakas et al. (2001) find support for the cash flow theory to farms in the US and Canada. In their cases, a higher level of farm's indebtedness is found to have a positive effect on farm efficiency. In addition, higher farm indebtedness might reflect the results of credit screening. Because risk-averse lenders screen farmers for credit based on some factors such as profitability, liquidity, management capability etc., they may, in effect, be choosing farms with higher technical efficiency and productivity. Therefore, better farm performance can be found associated with higher debt level. The recent study by Zhengfei and Lansink (2006) finds a positive effect of debt on productivity growth in Dutch agriculture.

On the other hand, some authors argue that higher indebtedness implies less efficiency. One rationale is from the agency theory by Jensen and Meckling (1976) which states that since higher-indebted borrowers are more risky to bankers, they have to bear higher costs in obtaining funds. Due to the increasing costs, these farmers would be less technically efficient and productive. Some empirical studies such as Morrison Paul et al. (2000), Hadley et al. (2001), Sotnikov (1998), and Weersink et al. (1990) found this inverse relationship between efficiency and financial indebtedness.

Subsidies and farm performance

Farm subsidies are very important in the agricultural sector in developed countries. In the US, it is estimated that the US government spends from $10 to $30 billion on farm subsidies each year, of which about $5 billion are spent on direct payments each year (Edwards 2007). The role of agricultural subsidies affecting agricultural performance is not a clear-cut issue. Some supporters of farm subsidies argue that agricultural subsidies can reduce the risk from the fluctuating nature of agricultural production and markets. Price support and countercyclical payments, supporters say, help smooth farmers' income and reduce production and market risks, therefore allowing farmers to increase their productivity due to greater income stability allowing them to invest in new technology.

On the other hand, some claim that agricultural subsidies are unhealthy for farm productivity and efficiency. Bergström (1998) argues that subsidies have negative effects on a firm's technical efficiency because they decrease incentives to reorganize activities and improve efficiency. Other foes argue that farm subsidies drive overproduction, over borrowing and overuse of farm land. The case of New Zealand agriculture could serve as a good example for the critics of farm subsidies. In 1984, New Zealand ended its farm subsidy program. Edwards (2007) argued that New Zealand farmers coped well with the changes and that farm productivity and output increased in the following years.

Several previous studies on the relationship between subsidies and farm performance seem to support the "negative effect" hypothesis. Rezitis et al. (2003) report that subsidies had a negative effect on Greek farms' technical efficiency. Giannakas et al. (2001) find negative impact of subsidies on farms' technical efficiency in Saskatchewan, Canada, in the period 1987-1995. Makki et al. (1999) point out that on the whole, commodity programs probably have a small, mostly negative, impact on farm productivity in US agriculture during the period 1930-1990. In contrast, Huffman and Evenson (1993) and Makki and Tweeten (1993) find a positive relationships between government programs and agricultural productivity.

In this context, a study on the impacts of agricultural subsidies on farm performance in the U.S. can be very illuminating. A recent report from USDA (2006) highlights the role of USDA agricultural research on farm productivity but does not address the potential role of direct subsidies on farm productivity. This current study is an attempt to investigate the impacts of farm subsidies on Minnesotan farms by including the level of subsidies as one explanatory variable.

3. Malmquist Productivity Index

The output distance function is defined on the output set P(x) as:

$$d(x, y) = \min\{d : (y/d) \in P(x)\}$$

The output distance function $d(x, y)$ will take a value larger than zero and less than or equal to 1 if the output vector *y* is an element of the feasible production set. If y is located on the boundary of the feasible production set, the output distance function will take a value of unity.

The output-oriented Malmquist TFP index measures the TFP change between two periods by calculating the distance functions of each data point to the relevant technology. Following Färe et al. (1994), the Malmquist (output-oriented) TFP change index between period s (the base period) and period t under constant return to scale (VRS) is defined as

$$m_o(y_s, x_s, y_t, x_t) = \left[\frac{d_t^s(y_t, x_t)}{d_s^s(y_s, x_s)} \times \frac{d_t^t(y_t, x_t)}{d_s^t(y_s, x_s)}\right]^{1/2} \tag{1}$$

in which $d_t^s, d_s^s, d_t^t, d_s^t$ are distance functions under CRS and *y, x* are the output and input vector.

The TFP change index in (1) is actually the geometric mean of two TFP change measure: the first is relative to period *s*, and the second is relative to period *t*. In all, a Malmquist index greater than unity indicates a TFP increase from s to t, while a Malmquist index less than unity indicates a TFP decrease.

Equation (1) can be arranged to show that the TFP change index is equivalent to the product of a technical efficiency change index and an index of technical change:

$$M_s^t(y_s, x_s, y_t, x_t) = \frac{d_t^t(y_t, x_t)}{d_s^s(y_s, x_s)}\left[\frac{d_t^s(y_t, x_t)}{d_t^t(y_t, x_t)} \times \frac{d_s^s(y_s, x_s)}{d_s^t(y_s, x_s)}\right]^{1/2} \tag{2}$$

$$Efficiency\ change\text{: } E_s^t = \frac{d_t^t(y_t, x_t)}{d_s^s(y_s, x_s)} \tag{3}$$

$$\text{and } Technical\ change\text{: } T_s^t = \left[\frac{d_t^s(y_t, x_t)}{d_t^t(y_t, x_t)} \times \frac{d_s^s(y_s, x_s)}{d_s^t(y_s, x_s)} \right]^{1/2} \tag{4}$$

Furthermore, the efficiency change in (3) can be further decomposed into pure efficiency change (or efficiency change under VRS) and scale efficiency change.

$$Pure\ efficiency\ change\text{: } PE_s^t = \frac{d_{t-VRS}^t(y_t, x_t)}{d_{s-VRS}^s(y_s, x_s)}$$

$$\text{and a } scale\ efficiency\ change \text{ component} = SE_s^t = \frac{d_t^t(y_t, x_t)/d_{t-VRS}^t(y_t, x_t)}{d_s^t(y_s, x_s)/d_{s-VRS}^t(y_s, x_s)} \tag{5}$$

where d_{VRS} denotes a distance function under variable return to scale (VRS) assumption.

The distance function $\hat{d}_s^t(y_s, x_s)$ is estimated by the following linear programming problems under constant return to scale (CRS).

$$[\hat{d}_s^t(y_s, x_s)]^{-1} = \max_{q,l} \hat{q} \text{ such that} \tag{6}$$

$$\begin{aligned} -qy_{is} + Y_t l &\geq 0, \\ x_{is} - X_t l &\geq 0, \\ l &\geq 0, \end{aligned}$$

Replacing (6) with appropriate time period notations, we would calculate

$$\hat{d}_s^s(y_s, x_s), \hat{d}_t^s(y_t, x_t), \hat{d}_t^t(y_t, x_t).$$

The corresponding distance functions under VRS are obtained by adding the convex constraint $I1'l = 1$ into (6).

A measure of productivity in the simplest case with one input X and one output Y is illustrated in Figure 1 (Ahern et al. 1998). Points B, C, and D are on the production curves, while point A is below the curve, or technically inefficient. The distance from point A to point B reflects the inefficiency, because at point B, more output can be produced with the same amount of input as point A. The distance between point B and D reflects the change in productivity due to technical change. The curve Y_1 indicates a production technology with decreasing returns to scale, because at C, more of X is needed to produce each unit of Y than at B.

Bootstrapping the Malmquist Productivity Index

Simar and Wilson (2000) propose a bootstrap method to estimate confidence intervals for DEA efficiency scores. Simar and Wilson (1999) method to estimate confidence intervals for Malmquist indices, based on efficiency scores. They argue that the deterministic DEA scores as well as the Malmquist index are only estimates of the underlying true frontiers. Therefore, the estimates obtained involved uncertainty due to sampling variation. The aim of the bootstrap is to estimate the population distribution, thus enabling the researchers to test hypotheses regarding the true parameter value.

Bootstrapping is based on the idea that by resampling the data with replacement, we can mimic the data-generating process characterizing the true data generation. The following algorithm describes the procedure for bootstrapping Malmquist indices.

i. Calculate the Malmquist index by applying the DEA method for each farm among N farms, obtaining a set of $\{ \hat{d}_o^t(y_t, x_t), \hat{d}_o^s(y_s, x_s), \hat{d}_o^t(y_s, x_s), \hat{d}_o^s(y_t, x_t) \}$ with s, t as time periods and the DEA estimates $\hat{q}_1, .. \hat{q}_n$. From these estimates of the distance functions, we calculate Malmquist indices including the Malmquist TFP change and its components: $\hat{M}_s^t, \hat{E}_s^t, \hat{T}_s^t, \hat{P}E_s^t, \hat{S}E_s^t$.

ii. Let $b_1^*,....b_n^*$ be a simple bootstrap sample from $\hat{q}_1,..\hat{q}_n$. Draw bootstrap estimates from the original sample of scores $\{\hat{q}_1,..\hat{q}_n\}$ using a bivariate smoothed representation of the probability density F.

iii. For i=1, …, n, create a pseudo data set (x_i^*, y_i^*) where $x_i^* = x_i$ and $y_i^* = (\hat{q}_i / q_i^*)$ y_i with x_i , y_i the original input and output vectors of the i*th* farm, respectively.

iv. Solve the linear programming in (6) with the pseudo-data (x_i^*, y_i^*), we obtain the distance function estimates: $\tilde{d}_o^t(y_t, x_t), \tilde{d}_o^s(y_s, x_s), \tilde{d}_o^t(y_s, x_s), \tilde{d}_o^s(y_t, x_t)$. Use these distance functions to construct Malmquist indices $\tilde{M}_s^t, \tilde{E}_s^t, \tilde{T}_s^t, \tilde{P}E_s^t, \tilde{S}E_s^t$.

v. Repeat step (ii) to (iv) for B times to yield B set of bootstrap estimates: $\{\tilde{M}_s^t(b), \tilde{E}_s^t(b), \tilde{T}_s^t(b), \tilde{P}E_s^t(b), \tilde{S}E_s^t(b)\}_{b=1}^B$. In our empirical work, we set B=2000 to ensure the low variability of the bootstrap confidence intervals. The number of bootstrap iterations should be more than 1000 if we are interested in confidence interval estimation. A smaller number of iterations would be enough if we only needed estimates for bias and standard deviation (see Efron and Tibshirani 1993).

vi. Construct the confidence intervals for the Malmquist indices. Since we do not know the distribution of $(\tilde{M}_s^t - M_s^t)$, we use the bootstrap values to finds a_a, b_a such that Prob $(-b_a \leq \tilde{M}_s^t - \hat{M}_s^t \leq -a_a) = 1 - a$. This involves sorting the value of $(\hat{q}_i^* - \hat{q}_i)$ for b =1, …, B in increasing order and deleting $((a / 2) \times 100$ percent of the elements at either end of this sorted array and setting $-\hat{a}_a$ and $-\hat{b}_a$ at the two endpoints, with $\hat{a}_a \leq \hat{b}_a$.

Thus, the bootstrap estimate of the (1-α) confidence interval for the Malmquist index is given by $\hat{M}_s^t - \hat{a}_a \leq M_s^t \leq \hat{M}_s^t - \hat{b}_a$.

4. Data

For this analysis, we used data from the Southeastern and Southwestern Minnesota Farm Business Associations collected by the Department of Applied Economics at the University of Minnesota. The complete data contains financial and farm characteristic records from 341 farms, which had been members of either Association in at least two consecutive years from 1993 through 2006, and had records of sufficient quality to be included. The number of records per year averaged 191 and ranged from a high of 228 in 1999/2000 to a minimum of 125 in 2004/2005. Membership in the Associations is not stable; farms have differing frequencies of years in the data. There are 38 farms with only two years of consecutive data and 54 farms with 14 years of data. Eighty-four percent of the observations were from the 200 farms (59% of the total) with at least 7 consecutive years of data. The farms were also classified on the basis of size and type. Farms were classified as large or small depending on whether their annual gross farm sales were larger or smaller than $250,000. Farms were classified as crop, livestock or diversified farms depending on whether 70% of their annual gross farm sales were from crop sales, livestock sales, or from a diverse set of products.

The model includes three inputs: labor, land and immediate expenditure (Table 1). Data for nonlabor inputs come directly from the data base. Labor is measured by total working hours of the farm households including non-farm labor. Land input is the total crop and pasture land used in production. Immediate expenditures include all the expenses for livestock, crop and operating purposes, measured in dollar value.

Since we did not have direct information on the hours of nonfarm family labor (i.e., working hours not on the farm), we estimated these hours from the available data on total nonfarm wages and salary. A proxy for nonfarm wages was taken from the average nonfarm wages of the counties where the farms reside. The nonfarm wages based on the weighted average wages of nonfarm sectors, specifically construction, manufacturing, and service wages from 2000 to 2006 (NAICS Industries list) and of mining, construction, manufacturing, transportation, finance, services, public administration, and trade wages from 1993-1999 (SIC Industries list). After calculating the nonfarm wages at the county level, we estimated each farm's nonfarm labor hours as that farm's total nonfarm wages and salary divided by the appropriate county's nonfarm wage rate.

The model includes six outputs: two crops (corn and soybean), three livestock products (milk, hog, and beef), and nonfarm income. Corn and soybean were the most important crop outputs in Minnesota; they were produced on more than 90% of the farms in the data. Hog, milk and beef are the main livestock products, accounting for 90% of total livestock production value on these farms.

Annual output price data were taken from National Agricultural Statistics Service, assuming all farms in the region faced the same prices for their outputs in a given year. Physical crop production for a specific crop on an individual farm in a specific year was calculated by dividing that farm's gross production value by that year's price of that crop.

Physical livestock production for a specific livestock enterprise on an individual farm in a specific year was calculated by dividing the total livestock value by the price of livestock.

The variables used in the second stage to determine factors explaining differences in farm productivity include financial condition, farm characteristics, labor characteristics, land tenure, the relative importance of different outputs and government subsidies. Financial condition and farm characteristics were measured by farm income, debt-asset ratio, current ratio and land-labor ratio. Labor characteristics were measured by the main operator's years farming and the hired labor ratio. Land tenure was measured by the tenancy ratio. The relative importance of different outputs was measured by the nonfarm income ratio and the Herfindahl index. The Herfindahl index measures the degree of output concentration and is defined as $\sum_{i=1}^{n} s_i^2$ in which s_i is the share or ratio of each farm's output of the i^{th} output to the total of that farm's six outputs in this study. Government subsidies are calculated as the ratio of income received from the government to gross farm income. Several variables (capital to labor ratio, years of farming and current ratio) are scaled down by 100 for presentation purposes.

5. Results

Using the data and methods described above, TFP was estimated to range from a low of 0.91 in 2003 to a high of 1.28 in 1998 (Table 2). The geometric mean of TFP was 1.07 with an annual growth rate of 6.6%. Explanations for this productivity growth come from the decomposition of the Malmquist productivity index. The annual growth rate of technical efficiency change was estimated to be 3.6% under the VRS assumption and 3.2% under CRS. Technical change was at the rate of 3.3%. Scale efficiency change was at 0.5%. Thus, over this period, change in technical efficiency played a slightly larger role in TFP growth than change in technology. Scale efficiency improved but not much. Because the data was not a balanced panel data, these results reflect the change in farm performance of the whole sample and do not indicate the productivity, efficiency and technical change of an average farm.

TFP growth rates are highest during the period 1993-1998 (Figure 2). During the period 1998-2004, TFP growth rates are still positive but lower than the previous period, with the exception of the years 2000/01, 2002/03, and 2005/06 when TFP growth rates were negative. It appears that TFP growths are due to the growth in both efficiency change and technical change. While the efficiency change rates are mostly positive and steady, the technical change rates are more fluctuating, resulting in the fluctuation of TFP growth. At the same time, scale efficiency is almost unchanged.

Bootstrapping was used to estimate the confidence intervals for the Malmquist productivity and its decompositions. While the average Malmquist index is 1.07, the lower bound is 0.95 and the upper bound is 1.17, implying that at 95% confidence level, the Malmquist index should be within these bounds. Our results of confidence intervals are 0.22, on average, much lower than the estimates in Balcombe et al. (2008) for Poland agriculture, which are 0.48 on average. The confidence intervals are much larger for efficiency change and technical change than for Malmquist index. The confidence intervals are, on average, 0.44 for efficiency change and 0.37 for technical change.

One major advantage of bootstrapping Malmquist index is that it provides a statistical test of the estimates. Without bootstrapping, we cannot test if the Malmquist TFP growth is increasing, decreasing or unchanged. Thanks to bootstrapping, we could test if the Malmquist TFP index is greater than 1, less than 1 or equal to 1. This is an important contribution of the bootstrap, since as Simar and Wilson (1999) states “it is not enough to know whether the Malmquist productivity index indicates increases or decreases in productivity, but whether the indicated changes are significant in a statistical sense.” Our bootstrap method allows examination of the “null hypothesis” of insignificant productivity growth. If the 95% confidence interval for TFP of one farm includes the unity, then that farm’s TFP is not statistically different from unity at the 5% significant level, i.e., it is not possible to conclude that changes occurred in its productivity.

Figure 3 shows the percentages of farms with positive, unity and negative TFP at 95% confidence interval. The years with highest percentage of farms with positive TFP growth are 1996/1997 and 1997/1998 when over 60% of farms have positive TFP growth. In contrast, the years with highest percentage of farms with negative TFP are 2000/2001 and 2002/2003, when about half of the farms have negative TFP growth. Throughout the period from 1993 to 1999, the number of farms with positive TFP growth is larger than the number of those with negative TFP growth. But from 1999 to 2006, there is not a clear pattern for TFP growth among farms: In the years 1999/2000, 2000/01, 2002/03 and 2004/05, there are more farms which suffered productivity decline than farms with productivity increase. But in the years 2001/02, 2003/04 and 2005/06, there are more farms with positive TFP growth than those with negative TFP growth.

Results of the farms classified by farm size and by output specification are reported in Tables 3 and 4, respectively. Table 3 indicates that large farms have higher TFP growth than small farms. The average Malmquist TFP growth rate of large farms is

7.6% annually, compared with 5.8% of small farms. Large farms have higher efficiency change than small farms (4.8% and 2%, respectively) but have lower technical change than small farms (2.9% and 4.3%, respectively). The scale efficiency changes are positive at 0.9% for large farms, but negative at -0.04% for small farms. Table 4 shows that livestock farms have higher TFP growth rates (7.5%) than crop (6.5%) and diversified farms (6.4%). Livestock farms also have higher technical change rates (4.4%) than crop farms (3.3%) and diversified farms (2.9%). Yet, the crop and diversified farms have higher efficiency change rates (both have 3.8%) than livestock farms (2.6%).

Figure 4 shows the percentages of farms with positive, unity and negative TFP at 95% confidence interval, categorized by farm size. It indicates that the TFP growth pattern is similar for large and small farms, as the period 1996-1998 is the best period, while the years 2000/01 and 2002/03 are the worst period for the productivity growth of both large and small farms. However, the curve in Figure 4 for large farms is more fluctuating than the curve for small farms, implying more variability in TFP growth for large farms than for small farms.

Figure 5 indicates the percentages of farms with positive, unity and negative TFP at 95% confidence interval, categorized by farm type. Some differences are worthwhile to note. In 1995/96, there more crop farms with positive TFP growth than those with negative TFP growth, but there are more livestock and diversified farms with negative TFP growth than those with positive TFP growth. In 2005/06, most of the livestock farms have positive TFP growth, but a majority of crop farms have negative TFP growth. There are also more fluctuation in TFP growth among livestock and diversified farms than among crop farms.

Do farm size and subsidies matter for farm productivity?

In the second stage of our analysis, we use two models to determine factors explaining differences in farm productivity. The first model is normal OLS regression. The second model incorporated weights obtained from the bootstrap results from stage 1. Based on the width of the confidence intervals, we use a weight in the regression, which is equal to the reciprocal of the confidence interval widths. The idea of using the width is to "punish" the farms with possible imprecise DEA estimates as those with larger confidence interval widths.

In the weighted model, the effect of the Herfindahl index and tenancy ratio on productivity is negative and significant while they are insignificant in the OLS model. The weighted model is preferred to the OLS model since the weighted model utilizes the information obtained from the confidence intervals. The weighted model also has higher R-squared values than the OLS model, thus seems explain the relationship better than the OLS model.

Several variables are significant ($p \leq 0.05$) in both models: log of farm income, hired labor ratio, the nonfarm income ratio and the subsidy ratio. The positive sign on the log of farm income indicates that larger farms have higher productivity than smaller farms. A higher nonfarm income ratio is also positively related with higher productivity growth. The hired labor ratio effect has a negative effect implying family labor is more crucial than hired labor for higher productivity. The subsidy ratio had a negative influence on productivity.

On the other hand, farm financial conditions, as reflected by the current ratio and the debt to asset ratio do not have significant ($p \geq 0.05$) impact on farm productivity.

Similar results were found with different farm sizes and farm types (Tables 6 and 7). Farm size had a positive and significant effect on the productivity of large and small farms (except in the OLS model for large farms) and of crop and diversified farms--but not of livestock farms. The nonfarm income ratio effect was positive in all cases, except normal OLS of diversified farms. The hired labor and tenancy ratios had significant negative impacts on crop farms (except for tenancy in the OLS model), but neither ratio had a significant impact on large and small farms or on livestock and diversified farms. The effects of subsidies are negative for all types of farms except in the normal OLS model for diversified farms.

6. Conclusions

In this paper, we have analyzed and estimated productivity growth for a panel data set of Minnesota farms during the period 1993-2006. Our results indicate that productivity growth is significant during the period, with an average productivity growth of 6.6 percent. However, TFP growth has been slowing down in recent years. Throughout the period, productivity growth has been positive except in 2000/01, 2002/03 and 2005/06. Both technical change and improvements in technical efficiency contributed almost equally to productivity growth during the period.

Using the bootstrap technique, we constructed the confidence intervals for Malmquist point estimates to test statistically the significance of these estimates. Our results indicate that average productivity growth is positive and significant in 1993/94, 1996/97, 1997/98, 2001/02 and negative significantly in 2000/01 and 2002/03. In the other years, the average productivity growth is not significantly different from zero.

Among the factors that can influence productivity growth in this group of farms, farm size has a positive impact on productivity for all farms and types (except livestock farms). This might explain the increase in farm size in Minnesota farms in recent years. The positive impact of nonfarm income on TFP is another reason for the continued and sizeable contribution of nonfarm sources of farm household income. Government agricultural subsidies are found to have a negative impact on farm productivity. This may call for a re-examination of the claim that government support increases farm efficiency and productivity. In contrast, our results support the argument that agricultural subsidies may create disincentives for farmers to improve their productivity and efficiency.

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Table 1. Summary statistics of variables.

Variable	Mean	Std. Dev.
INPUTS		
Land (acres)	715.9	509.6
Labor (hours)	4,862.5	3,554.1
Immediate expenditures[a]	182.1	234.7
OUTPUTS		
Corn income[a]	76.1	92.6
Soybean income[a]	67.0	64.7
Milk income[a]	52.1	184.2
Hog income[a]	60.3	223.8
Beef income[a]	45.8	191.3
Net nonfarm income[a]	22.0	28.9
PRICES		
Corn price ($/bu)	2.17	0.46
Soybean price ($/bu)	5.64	1
Milk price ($/cwt)	13.7	1.3
Hog price ($/cwt)	43.3	7.0
Beef price ($/cwt)	63.7	7.1
ENVIRONMENTAL VARIABLES		
Gross farm income[a]	369.4	386.5
Debt asset ratio	0.50	0.23
Years of farming	24.4	11.1
Nonfarm ratio	0.09	0.13
Tenancy ratio (rented land/total land)	0.60	0.33
Hired labor ratio (to total farm labor)	0.13	0.23
Land/labor ratio (acre/hours)	0.25	0.18
Capital/labor ratio	6.24	7.95
Herfindahl index	0.56	0.18
Current ratio	4.7	9.7
Subsidy ratio	0.09	0.07

[a] Thousand dollars

Table 2. Malmquist TFP index and its decompositions, 1994-2006.

	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**Average**	**Annual Growth (%)**
Malmquist index	1.15	1.09	1.06	1.13	1.28	1.07	1.06	0.93	1.17	0.91	1.03	1.06	0.97	1.07	6.57
Malmquist upper	1.26	1.20	1.14	1.21	1.38	1.16	1.14	1.00	1.28	0.98	1.11	1.15	1.06	1.16	
Malmquist lower	1.00	0.98	0.94	1.03	1.18	0.96	0.95	0.83	1.01	0.80	0.94	0.92	0.86	0.95	
Efficiency change	1.03	1.05	1.06	1.12	0.99	0.97	1.05	1.06	1.00	1.07	1.05	1.06	0.97	1.04	3.62
Efficiency change upper	1.20	1.25	1.27	1.31	1.14	1.11	1.24	1.24	1.17	1.30	1.25	1.27	1.13	1.22	
Efficiency change lower	0.72	0.80	0.84	0.92	0.79	0.69	0.82	0.82	0.70	0.83	0.78	0.80	0.63	0.78	
Technical change	1.12	1.05	0.99	1.02	1.30	1.10	1.01	0.89	1.18	0.86	0.98	0.98	1.03	1.03	3.27
Technical change upper	1.31	1.22	1.14	1.13	1.47	1.31	1.16	1.01	1.40	0.97	1.15	1.14	1.24	1.20	
Technical change lower	0.93	0.83	0.80	0.83	1.11	0.97	0.80	0.72	0.96	0.63	0.77	0.75	0.85	0.83	
Pure efficiency change	1.04	1.07	1.01	1.08	1.00	0.99	1.02	1.05	0.99	1.08	1.07	1.05	0.98	1.03	3.16
Pure efficiency change upper	1.25	1.30	1.20	1.29	1.19	1.15	1.22	1.26	1.19	1.34	1.29	1.28	1.18	1.24	
Pure efficiency change lower	0.61	0.79	0.71	0.82	0.78	0.65	0.73	0.76	0.62	0.79	0.74	0.72	0.54	0.71	
Scale efficiency change	0.99	0.98	1.05	1.04	0.99	0.98	1.03	1.01	1.01	1.00	0.98	1.01	0.99	1.01	0.53
Scale efficiency change upper	1.10	1.09	1.21	1.14	1.07	1.08	1.17	1.11	1.13	1.10	1.09	1.13	1.11	1.12	
Scale efficiency change lower	0.86	0.81	0.90	0.90	0.85	0.85	0.90	0.87	0.88	0.85	0.85	0.86	0.85	0.86	

Table 3. Malmquist TFP index and its decompositions, categorized by farm size.

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average	Annual Growth (%)
Large farms (1433 observations)															
MI	1.21	1.15	1.10	1.13	1.31	1.08	1.04	0.92	1.18	0.90	1.06	1.02	0.97	1.08	7.59
EC	1.05	1.12	1.06	1.11	1.00	0.99	1.04	1.07	1.01	1.04	1.10	1.06	0.98	1.05	4.77
TC	1.15	1.03	1.03	1.03	1.30	1.09	1.00	0.87	1.18	0.87	0.96	0.96	0.99	1.03	2.89
PEC	1.03	1.14	1.01	1.08	1.02	1.00	1.03	1.05	1.00	1.03	1.11	1.04	0.97	1.04	3.86
SEC	1.01	0.98	1.05	1.03	0.98	0.99	1.01	1.02	1.01	1.01	0.99	1.02	1.01	1.01	0.79
Small farms (1039 observations)															
MI	1.11	1.04	1.00	1.12	1.25	1.06	1.09	0.95	1.15	0.93	0.96	1.15	0.99	1.06	5.84
EC	1.01	0.98	1.07	1.13	0.98	0.95	1.07	1.05	0.98	1.13	0.95	1.06	0.94	1.02	2.01
TC	1.10	1.07	0.95	1.00	1.30	1.12	1.03	0.91	1.19	0.84	1.00	1.03	1.10	1.04	4.31
PEC	1.05	1.00	1.01	1.09	0.98	0.98	1.00	1.05	0.97	1.17	0.97	1.05	0.99	1.02	2.23
SEC	0.97	0.98	1.06	1.05	1.01	0.97	1.07	1.00	1.01	0.98	0.97	1.00	0.94	1.00	-0.04

Note: MI = Malmquist index, EC = efficiency change, TC = technical change, PEC = pure efficiency change, and SEC = scale efficiency change

Table 4. Malmquist TFP index and its decompositions, categorized by farm type.

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average	Annual Growth (%)
Crop farms (1323 observations)															
MI	1.13	1.15	1.15	1.13	1.26	1.07	1.05	0.91	1.13	0.93	1.08	0.99	0.92	1.06	6.49
EC	1.00	1.04	1.10	1.13	0.97	0.96	1.06	1.06	1.01	1.09	1.05	1.07	0.97	1.04	3.83
TC	1.12	1.11	1.06	1.01	1.30	1.12	1.00	0.87	1.13	0.86	1.03	0.92	0.97	1.03	3.29
PEC	1.03	1.08	1.01	1.06	0.99	0.98	1.02	1.05	1.00	1.09	1.07	1.06	0.99	1.03	3.33
SEC	0.99	0.95	1.08	1.06	0.99	0.97	1.05	1.01	1.01	1.01	0.98	1.01	0.98	1.01	0.64
Livestock farms (635 observations)															
MI	1.15	1.03	0.97	1.16	1.36	1.05	1.05	0.95	1.28	0.88	0.90	1.25	1.05	1.07	7.45
EC	1.03	1.02	1.03	1.11	1.05	0.97	0.99	1.08	0.96	1.04	1.02	1.07	0.97	1.03	2.58
TC	1.11	1.01	0.93	1.06	1.28	1.09	1.06	0.88	1.33	0.86	0.87	1.10	1.10	1.04	4.41
PEC	1.06	1.01	1.02	1.09	1.06	0.98	0.99	1.08	0.96	1.07	1.04	1.04	0.97	1.03	2.68
SEC	0.98	1.01	1.02	1.02	1.00	0.99	1.00	1.00	1.01	0.98	0.98	1.02	1.00	1.00	0.01
Diversified farms (514 observations)															
MI	1.19	1.08	1.00	1.09	1.27	1.09	1.09	0.99	1.17	0.85	1.00	1.01	1.04	1.06	6.35
EC	1.05	1.08	1.05	1.12	0.95	1.02	1.10	1.04	1.00	1.04	1.09	1.01	0.96	1.04	3.78
TC	1.15	1.00	0.96	0.99	1.34	1.07	0.98	0.95	1.19	0.82	0.92	1.01	1.10	1.03	2.89
PEC	1.04	1.09	0.99	1.11	0.97	1.03	1.06	1.03	0.99	1.05	1.09	0.99	0.96	1.03	2.85
SEC	1.01	0.99	1.05	1.01	0.99	0.99	1.04	1.01	1.01	0.99	1.01	1.01	1.00	1.01	0.83

Note: MI = Malmquist index, EC = efficiency change, TC = technical change, PEC = pure efficiency change, and SEC = scale efficiency change

Table 5. Explanatory factors of TFP for all farms.

	Normal OLS		Weighted OLS	
	Coeff	t-stat	Coeff	t-stat
Log of farm income	0.06	4.03	0.07	5.80
Herfindahl index	-0.06	-1.40	-0.07	-2.28
Current ratio	0.10	1.22	-0.02	-0.30
Debt/Asset ratio	-0.04	-1.00	-0.02	-0.49
Capital to labor	0.12	0.98	-0.14	-1.40
Land/labor ratio	0.11	2.00	0.07	1.59
Years of farming	0.05	0.66	-0.05	-0.90
Nonfarm ratio	0.48	6.40	0.28	4.56
Tenancy ratio	0.04	1.38	-0.04	-2.33
Hired labor ratio	-0.09	-2.20	-0.06	-2.16
Subsidy rate	-0.81	-5.29	-0.64	-5.81
1995	-0.11	-3.04	-0.07	-2.71
1996	-0.17	-4.71	-0.13	-5.10
1997	-0.09	-2.56	0.03	1.19
1998	0.11	3.01	0.19	6.95
1999	-0.08	-2.25	0.02	0.56
2000	-0.09	-2.47	-0.04	-1.45
2001	-0.24	-6.41	-0.13	-4.91
2002	-0.10	-2.65	0.00	0.00
2003	-0.32	-8.50	-0.21	-7.44
2004	-0.19	-4.65	-0.08	-2.66
2005	-0.16	-3.86	-0.06	-2.07
2006	-0.26	-6.23	-0.17	-5.42
Constant	0.85	8.90	0.77	10.93
F-stat	12.05		18.38	
R-squared	0.11		0.15	

Note: Shaded areas mean significant at 5%.

Table 6. Explanatory factors of TFP by farm size.

	Large				Small			
	Normal OLS		**Weighted OLS**		**Normal OLS**		**Weighted OLS**	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Log of farm income	0.04	1.62	0.04	2.58	0.10	2.42	0.11	3.65
Herfindahl index	0.00	-0.02	-0.04	-1.09	-0.09	-1.17	-0.10	-1.89
Current ratio	0.09	0.92	0.09	1.08	0.13	1.00	-0.11	-1.05
Debt/Asset ratio	0.06	1.23	0.01	0.22	-0.22	-3.21	-0.01	-0.25
Capital to labor	0.00	0.02	-0.10	-0.92	0.93	2.56	-0.40	-1.38
Land/labor ratio	0.16	2.37	0.10	1.79	0.06	0.63	0.01	0.17
Years of farming	0.09	0.90	-0.08	-1.04	-0.05	-0.43	-0.04	-0.48
Nonfarm ratio	0.75	4.48	0.35	2.52	0.53	4.95	0.36	4.23
Tenancy ratio	0.06	1.73	-0.02	-0.82	0.02	0.50	-0.08	-2.59
Hired labor ratio	-0.07	-1.65	-0.05	-1.73	-0.05	-0.43	-0.05	-0.64
Subsidy rate	-0.84	-3.82	-0.67	-4.20	-0.82	-3.68	-0.69	-4.30
1995	-0.10	-2.05	-0.04	-0.99	-0.13	-2.42	-0.10	-2.75
1996	-0.17	-3.55	-0.12	-3.35	-0.19	-3.56	-0.15	-4.00
1997	-0.13	-2.71	0.02	0.54	-0.07	-1.19	0.04	0.91
1998	0.08	1.81	0.19	5.16	0.11	2.05	0.17	4.27
1999	-0.13	-2.71	-0.01	-0.24	-0.04	-0.71	0.05	1.33
2000	-0.16	-3.36	-0.06	-1.56	-0.01	-0.19	-0.01	-0.19
2001	-0.29	-5.97	-0.15	-4.11	-0.18	-3.02	-0.10	-2.32
2002	-0.11	-2.21	0.03	0.66	-0.12	-2.06	-0.04	-0.91
2003	-0.37	-7.67	-0.21	-5.70	-0.27	-4.11	-0.20	-4.33
2004	-0.21	-4.12	-0.06	-1.55	-0.19	-2.70	-0.10	-2.26
2005	-0.19	-3.69	-0.06	-1.58	-0.16	-1.90	-0.06	-1.03
2006	-0.30	-5.86	-0.15	-3.77	-0.23	-3.06	-0.22	-4.05
Constant	0.92	6.51	0.88	8.24	0.78	3.66	0.61	3.87
F-stat	9.66		12.43		4.65		7.05	
R-squared	0.14		0.17		0.10		0.15	

Note: Shaded areas mean significant at 5%.

Table 7. Explanatory factors of TFP by farm type.

	Crop farms				Livestock farms				Diversified farms			
	Normal OLS		Weighted OLS		Normal OLS		Weighted OLS		Normal OLS		Weighted OLS	
	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat	Coeff.	t-stat
Log of farm income	0.12	4.59	0.10	4.89	-0.01	-0.50	0.03	1.44	0.08	2.41	0.08	3.17
Herfindahl index	0.03	0.33	-0.11	-1.76	-0.02	-0.24	0.02	0.28	-0.12	-0.61	-0.10	-0.68
Current ratio	0.14	1.16	-0.03	-0.24	0.04	0.25	0.08	0.67	0.10	0.75	-0.11	-1.00
Debt/Asset ratio	-0.05	-0.83	-0.06	-1.29	-0.15	-2.13	-0.01	-0.19	0.18	2.21	0.10	1.61
Capital to labor	0.01	0.09	-0.15	-1.14	0.70	2.65	0.02	0.10	-0.61	-1.45	-0.26	-0.82
Land/labor ratio	0.03	0.39	0.06	0.96	0.26	1.23	0.19	1.14	0.12	0.62	-0.08	-0.56
Years of farming	0.04	0.36	-0.11	-1.31	0.05	0.38	0.04	0.38	-0.09	-0.61	-0.07	-0.60
Nonfarm ratio	0.57	5.52	0.31	3.64	0.51	3.06	0.32	2.52	0.34	1.95	0.37	2.56
Tenancy ratio	-0.01	-0.14	-0.06	-2.12	0.09	1.95	-0.02	-0.70	-0.01	-0.10	-0.01	-0.35
Hired labor ratio	-0.17	-2.51	-0.13	-2.61	0.06	0.86	0.01	0.18	-0.07	-1.01	-0.07	-1.37
Subsidy rate	-0.97	-4.62	-0.68	-4.34	-0.89	-2.34	-0.59	-2.24	-0.71	-1.79	-0.71	-2.30
1995	-0.03	-0.54	0.01	0.22	-0.17	-3.15	-0.08	-2.13	-0.15	-2.56	-0.17	-3.60
1996	-0.08	-1.34	0.05	1.14	-0.25	-4.48	-0.26	-6.70	-0.22	-3.61	-0.24	-5.03
1997	-0.09	-1.51	0.12	2.61	-0.05	-0.89	0.05	1.12	-0.13	-2.07	-0.09	-1.90
1998	0.10	1.63	0.29	6.43	0.17	3.00	0.13	3.06	0.08	1.18	0.12	2.26
1999	-0.05	-0.8	0.11	2.40	-0.12	-2.08	0.00	-0.02	-0.09	-1.23	-0.08	-1.50
2000	-0.06	-1.02	0.09	2.06	-0.12	-2.15	-0.12	-3.12	-0.08	-1.06	-0.15	-2.66
2001	-0.20	-3.37	-0.02	-0.40	-0.24	-3.84	-0.17	-3.83	-0.28	-3.75	-0.26	-4.62
2002	-0.13	-2.11	0.06	1.32	-0.03	-0.54	0.05	0.99	-0.02	-0.26	-0.01	-0.22
2003	-0.31	-5.07	-0.10	-2.17	-0.32	-4.41	-0.24	-5.17	-0.34	-4.51	-0.34	-5.76
2004	-0.13	-2	0.06	1.25	-0.28	-4.14	-0.17	-3.76	-0.25	-2.86	-0.22	-3.32
2005	-0.14	-2.11	0.03	0.51	-0.14	-1.77	-0.06	-1.16	-0.18	-2.12	-0.15	-2.28
2006	-0.31	-4.71	-0.12	-2.53	-0.16	-1.96	-0.07	-1.13	-0.14	-1.81	-0.17	-2.57
Constant	0.56	3.41	0.60	4.87	1.23	7.21	0.88	7.68	0.77	3.64	0.76	4.64
F-stat	6.95		10.10		5.27		7.40		3.28		5.98	
R-squared	0.11		0.14		0.18		0.24		0.14		0.23	

Note: Shaded areas mean significant at 5%.

Figure 1. Productivity change and efficiency change.

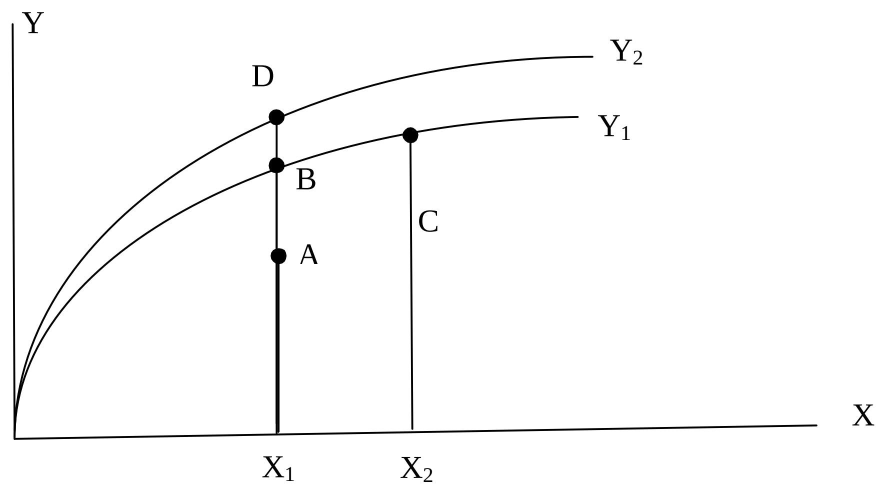

Figure 2. Efficiency and productivity change in Minnesota farms, 1993-2006

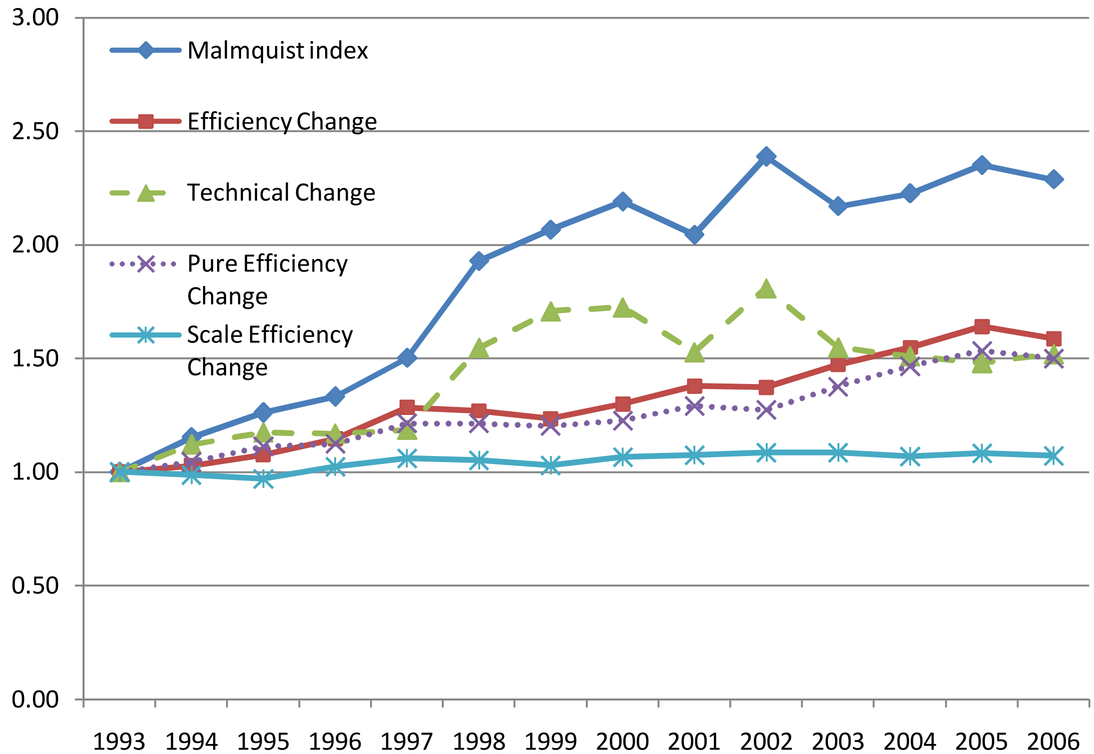

Figure 3. Farms with different growth rates, all farms 1993-2006

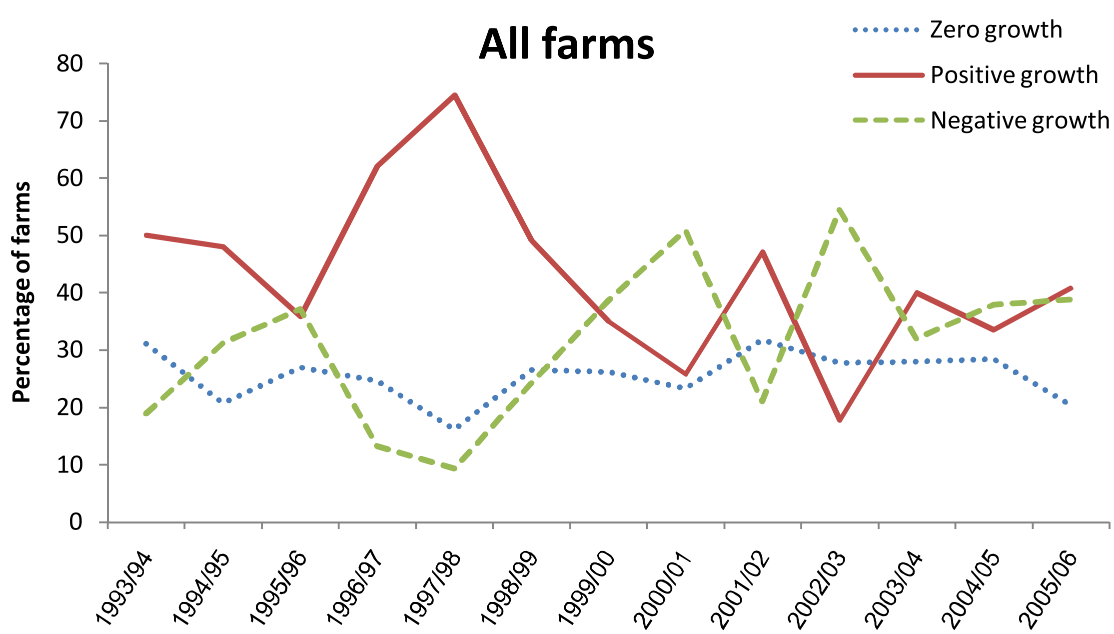

Figure 4. Farms with different growth rates, by farm size, 1993-2006

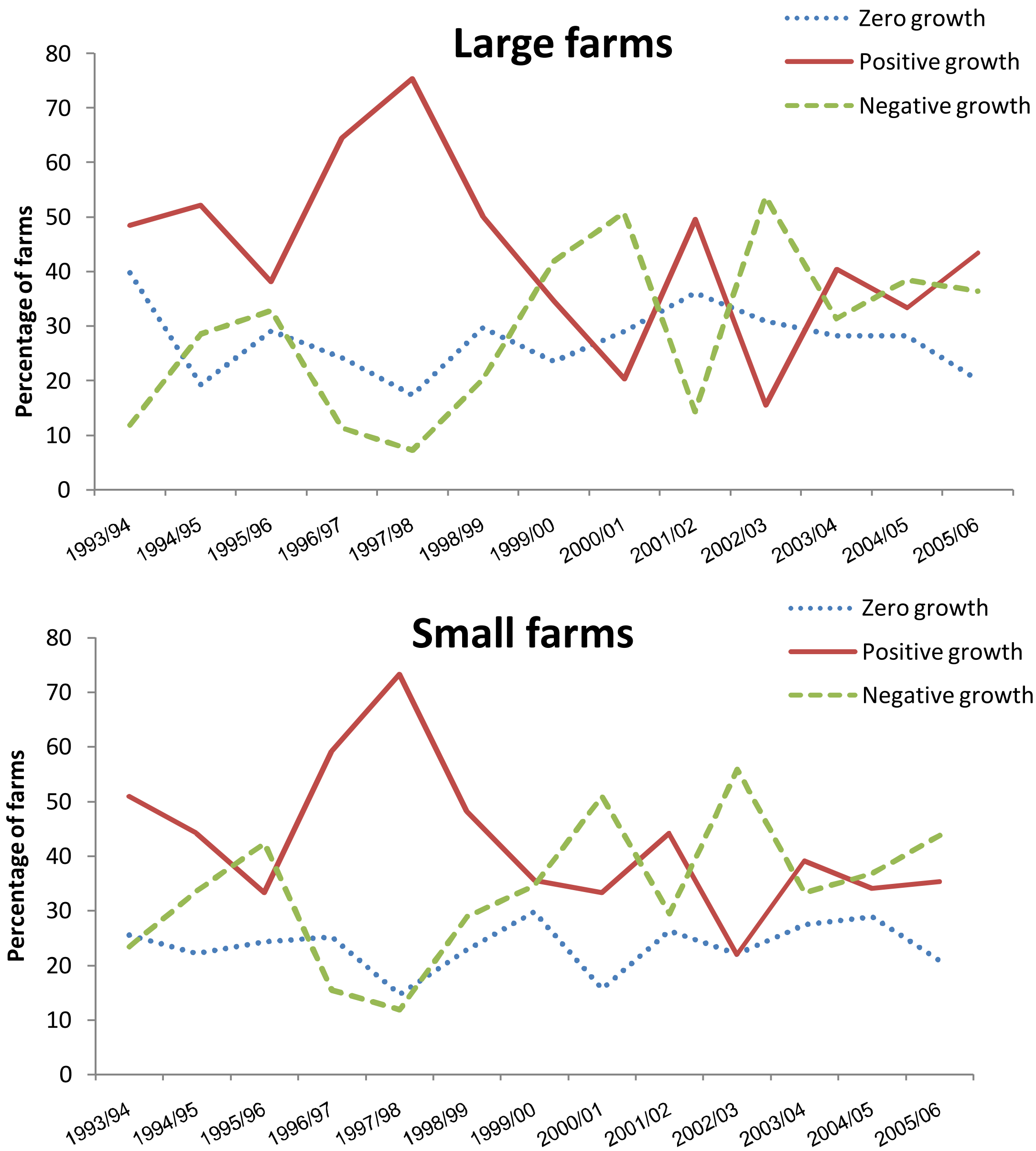

Figure 5. Farms with different growth rates, by farm type, 1993- 2006