MEASURING THE EFFICIENCY AND PRODUCTIVITY OF AGRICULTURAL COOPERATIVES

by

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AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the
requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Agricultural Economics
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Manhattan, Kansas

2016

Abstract

This dissertation focuses on measuring the efficiency and productivity for agricultural cooperatives in the United States using the data envelopment analysis (DEA) approach. Economic measures such as cost efficiency, economies of scale, and economies of scope are measured by estimating a cost frontier in a multiproduct framework. Productivity growth is measured using the biennial Malmquist index approach.

The cost frontier is the basis for calculating cost efficiency, economies of scale, and economies of scope as the cost frontier estimation in a multiproduct approach describes how cost changes as output changes. The estimates of economies of scale and scope have important implications for agricultural cooperatives because most of the cooperatives sell more than one product. Understanding the impact of changing output levels or mixes on the cost structure is helpful to improve the performance of cooperatives. Further, scope economies estimate the percentage of cost savings through product diversification in a multiproduct firm. The trade-off between cost efficiency and multiproduct scale economies allows the estimation of whether a higher percentage of cost can be eliminated by becoming cost efficient or changing the scale of operations. The economic measures are estimated using a single cost frontier (multi-year frontier) and annual cost frontiers.

Multiproduct economies of scale and economies of scope exist indicating that increasing scale and product diversification can reduce cost for agricultural cooperatives. The mean values of product-specific economies of scale for all outputs are close to one indicating that cooperatives are operating close to constant returns to scale. The comparison between cost efficiency and scale economies suggests that smaller cooperatives can save a higher percentage of cost by increasing the scale of operations rather than just becoming cost efficient. Because larger incentives exist for small cooperatives to increase scale, mergers will likely continue until economies of scale are exhausted in the industry.

Annual estimates show that agricultural cooperatives have become less cost efficient over time, but economies of scale and economies of scope remain consistent across years. Many agricultural cooperatives face economies of scale indicating that variable returns to scale as opposed to constant returns to scale is the appropriate technology for modeling agricultural farm marketing and supply cooperatives.

Further, the Kolmogorov-Smirnov (KS) test and two sample t-test are used to examine whether economic measures estimated from a single frontier and annual frontiers are statistically different. The KS test and t-test indicate that economic measures obtained from the single frontier are statistically different from those measures calculated from annual frontiers. This indicates that the cost frontier has shifted over time.

Productivity growth of agricultural cooperatives is estimated using the biennial Malmquist productivity index (BMI) under variable returns to scale over the period 2005 to 2014. The BMI avoids numerical infeasibilities under variable returns to scale compared to traditional methods. The BMI is decomposed into efficiency change and technical change to evaluate the sources of productivity growth. Overall, agricultural cooperatives gained 34% cumulative productivity growth during the decade allocated by -2% and 37% cumulative technical efficiency change and technical change over the study period. Technical change was the major source of productivity growth rather than efficiency change. Cooperatives can achieve higher productivity by increasing managerial efficiency and investing in technology.

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Dedication

To my mother: Bishnu Devi, my father: Kapil Mani, my brothers: Arjun, Ishori, and Laxman, my wife: Barsha, and our children: Ryan and Aarvi.

Chapter 1

Introduction

Agricultural cooperatives in the United States have gone through significant market fluctuations since 2005 due to variable commodity prices, increased competition, international market conditions, consolidations, mergers, and acquisitions. The number of agricultural cooperatives decreased by 27 percent from 2005 to 2014; however, gross sales more than doubled. The gross business volume for agricultural cooperatives was $118 billion in 2005 and $246 billion in 2014 (U.S. Department of Agriculture, 2016). Further, market share is more concentrated in a few large agricultural cooperatives. The top 10 largest agricultural cooperatives accounted for 43 percent of agricultural cooperatives gross business volume and 38 percent of total assets in 2014 (U.S. Department of Agriculture, 2016). Figure 1.1 displays the number of agricultural cooperatives by the types of cooperatives. The number of agricultural cooperatives decreased from 2,895 in 2005 to 2,106 in 2014. Figure 1.2 illustrates the gross business volume of agricultural cooperatives (U.S. Department of Agriculture, 2016). The number of agricultural cooperatives had a downward trend, whereas the total business volume had an increasing trend from 2005 to 2014.

During the same time period, cooperatives formed joint ventures and strategic alliances with other cooperatives and/or with investor-owned firms that changed the structure of cooperatives (Reynolds, 2012). The structural change in agricultural cooperatives may allow them to operate more efficiently and productively. Otherwise, they may be forced to leave the industry if they are not competitive with investor-owned firms (Schroeder, 1992).[1] In addition, free trade and other macroeconomic policies have increased international market access into the U.S. agricultural industry that provided greater and cheaper access to imported capital goods (Deb and Ray, 2014).

An agricultural cooperative is an important institution as it provides benefits to not only producers, but also its employees and rural communities. Agricultural cooperatives are the major employers in many rural towns in the United States. More than 130,000 people have jobs with agricultural cooperatives and about 80,000 people work in the grain marketing and farm supply sectors (U.S. Department of Agriculture, 2016).

The study of the efficiency and productivity for agricultural cooperatives is important to the U.S. rural economy in a dynamic market as the future structure of agricultural cooperatives depends on the current relative cost and efficiency of individual cooperatives in the industry (Ariyaratne et al., 2000). In addition, the study of efficiency and productivity may help identify the sources of differences in the performance of firms (Fried, Lovell, and Schmidt, 2008). As indicated by Lewis (2005), macro performance depends on micro performance and the growth of national gross domestic product (GDP) depends on the performance of different economic sectors including the agricultural sector. Further, productivity growth leads to improving financial performance, which is one of the indicators of success for firms (Miller, 1984).

The estimation of efficiency and productivity of cooperatives helps to quantify performance differences consistent with economic theory (Fried, Lovell, and Schmidt, 2008). The estimation of economies of scale and scope is more important in a rapidly changing market because understanding changes reduces uncertainty for individual firms, minimizes stress for consumers, and helps firms allocate resources efficiently (Hallam, 1991).

The cost frontier is the basis for calculating economic measures such as efficiency, economies of scale and scope, and productivity. Two approaches have been used to

[1] Reasons for the existence of cooperatives includes assuring products and services in local regions where the market does not provide service, creating pro-competitive effects in imperfectly competitive markets, and providing opportunities for farmers to share risks, etc. (Cobia, 1989).

estimate these economic measures. One employs the parametric approach (stochastic frontier and non-frontier methods) to estimate the cost frontier. Previous studies that use the parametric approach to estimate economies of scale or scope include Schroeder (1992); Ray (1999); and Paul et al. (2004). Featherstone and Moss (1994) argue that parametric frontiers may violate the necessary conditions that are required for the existence of indirect cost functions. If the estimates of parametric methods are not consistent with the underlying theoretical conditions of the cost function, then the reliability of economic analyses for policy recommendations would be suspect, potentially weakening the value of empirical research (Tomek, 1993).

The purpose of this study is to examine efficiency and productivity of agricultural cooperatives in the United States using a nonparametric approach. One of the major advantages of the nonparametric approach is that it does not impose a specific functional form so that it is less prone to misspecification error (Färe et al., 1985). The first objective is to estimate cost efficiency, economies of scale, and economies scope in a multiproduct framework using input quantity, input price, and output quantity data. Economies of scale show the percentage of cost saving from adjusting the size of operations for agricultural cooperatives. This information may explain the decreasing number of agricultural cooperatives through mergers and/or acquisitions in the industry. Economies of scope show the potential for cost reduction by producing multiple outputs in a firm rather than producing them separately. Further, cost efficiency shows the potential for overall cost reduction by changing input bundles. Further, efficiency and productivity estimates provide a control mechanism for management to track the economic performance of production units (Fried, Lovell, and Schmidt, 2008).

Existing literature on the study of productivity change using data envelopment analysis (DEA) usually assumes constant returns to scale (CRS) and decomposes the Malmquist index into technical change and efficiency change (Ariyaratne, Featherstone, and Langemeier, 2006; Candemir et al., 2011). However, the decomposition of the traditional Malmquist index into technical change and efficiency change may be misleading under CRS (Ray and Desli, 1997). Under variable returns to scale (VRS) the Malmquist index may result in numerical infeasibilities (Pastor, Asmild, and Lovell, 2011; Umetsu, Lekprichakul, and Chakravorty, 2003). Moreover, Funk (2015) shows that technical change estimates were biased when the Malmquist index was estimated under CRS for farms in the United States.

The second objective of this study is to estimate productivity growth of agricultural cooperatives, which is one of the performance measures of firms that shows how the production frontier is shifting over time. Productivity growth is measured using the biennial Malmquist approach developed by Pastor, Asmild, and Lovell (2011) that avoids numerical infeasibilities under variable returns to scale and does not impose a specific functional form for the production function. The biennial Malmquist index is decomposed into efficiency change and technical change to examine the sources of productivity change. The improvements in technical efficiency and technical change are components of reaching higher economic performance of firms and thus achieving higher efficiency (Coelli and Rao, 2001). The DEA estimation methods for study of efficiency and productivity provides information on how to improve the economic performance of agricultural cooperatives.

This dissertation is organized as follows. Chapter 2 estimates economic measures such as cost efficiency, economies of scale and scope applying a nonparametric approach for agricultural cooperatives in the United States. The economic measures are also reported from a single multi-year frontier and annual frontiers. The annual frontier method allows information whether economies of scale and scope remain relatively stable if the cost frontier changes over time. In addition, the economic measures are reported based on the size of cooperatives. This provides a greater amount of detail on potential cost reductions by either becoming more cost efficient or adjusting the size of the operation.

Chapter 3 estimates productivity growth of agricultural cooperatives under variable returns to scale using the biennial Malmquist approach. The biennial Malmquist index is decomposed into efficiency change and technical change to provide an understanding of productivity growth. Chapter 4 presents conclusions, implications, and suggestions for future research related to efficiency and productivity.

The information included in this dissertation will be useful to researchers, cooperative boards of directors, as well as managers of those agricultural cooperatives as it provides information for quantifying the cost advantages of agricultural cooperatives. Cooperatives need to be efficient and productive to compete in the industry and achieve higher productivity.

Figures

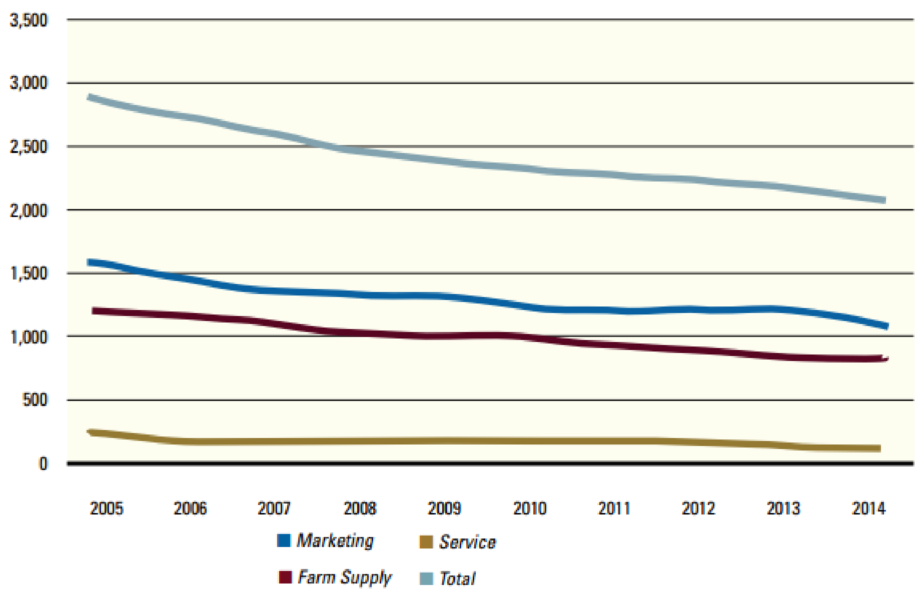

Figure 1.1: Number of agricultural cooperatives from 2005 to 2014

Source: U.S. Department of Agriculture (2016)

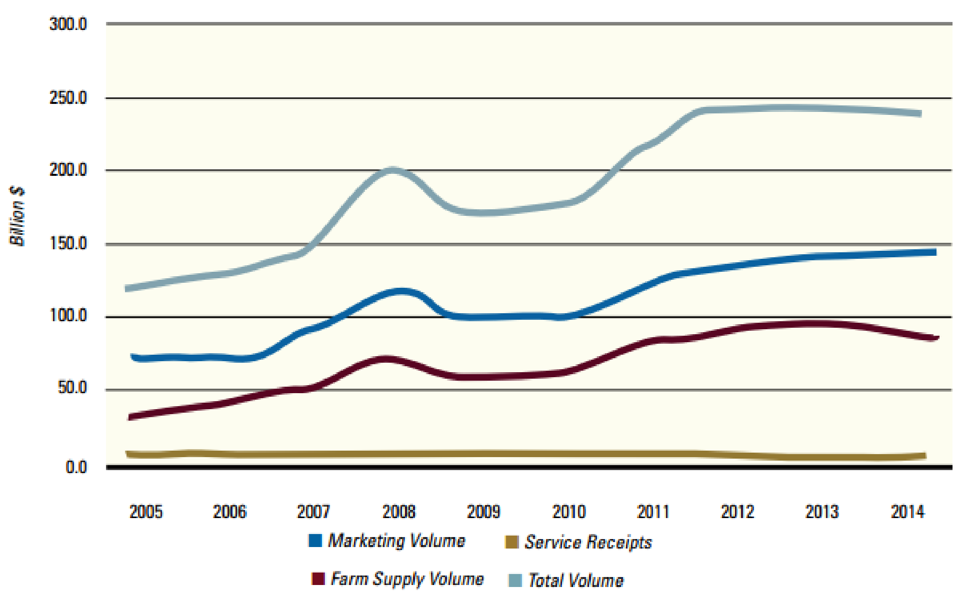

Figure 1.2: Gross business volume of agricultural cooperatives from 2005 to 2014

Source: U.S. Department of Agriculture (2016)

Chapter 2

A Nonparametric Approach to Estimate Multiproduct and Product-specific Scale and Scope Economies for Agricultural Cooperatives

2.1 Introduction

Cost reduction through scale economies and scope economies is the basis of the theory of the firm. Measuring scale economies and scope economies allows to quantify the potential gain by adjusting size or from product diversification in a multiproduct firm. Understanding the potential cost saving areas is important to improve the economic performance of firms and it is more important to agricultural cooperatives where resource expansion is more expensive as many cooperatives have limited access to equity capital (Dunn et al., 2002).

The structure of agricultural cooperatives has changed (Ariyaratne, Briggeman, and Mickelsen, 2014; Reynolds, 2012) and the change may be associated with the potential gain through scale economies. The number of agricultural cooperatives decreased by almost 30 percent from 2005 to 2014; however, gross sales more than doubled and market share is more concentrated with a few large cooperatives (U.S. Department of Agriculture, 2016). The decreasing number of agricultural cooperatives and increasing total assets (gross sales) may imply that scale inefficient cooperatives went out of business or these cooperatives merged with or were acquired by other cooperatives due to potential cost reduction through scale economies.

The estimation of a cost frontier allows economic measures such as efficiency, economies of scale and scope to be computed. Existing literature uses two methods to estimate these economic measures. One applies the parametric method (stochastic frontier and non-frontier methods) to estimate the cost frontier. Previous studies that use the parametric approach to estimate economies of scale or scope include Schroeder (1992); Ray (1999); and Paul et al. (2004). Featherstone and Moss (1994) indicate that parametric frontiers may violate the necessary curvature conditions that are required for the existence of indirect cost functions.

Schroeder (1992) uses a translog cost function to estimate scale and scope economies of agricultural supply and marketing cooperatives. The results show that product-specific scale economies exist for some products like grain, petroleum, feed etc. However, the translog cost form is problematic for estimating scale economies because of the multiplicative nature of outputs which impose extreme diseconomies of scale on data sets (Berger, Hunter, and Timme, 1993). The translog cost form also uses two-sided error systems that violate the economic theory of the cost frontier. In addition, relative price variability is required for the estimation of dual cost functions to accurately recover the underlying production technology. If there is low relative price variation, scale and scope measures calculated from parametric methods may be fragile due to the inability to recover the underlying production technology (Lusk et al., 2002).

A second line of research estimates the cost frontier using the data envelopment analysis (DEA) approach developed by Farrell (1957) and operationalized by Banker, Charnes, and Cooper (1984) and Färe et al. (1985). The advantages of the DEA method are that it uses a one-sided error system without any distributional assumptions and it does not impose functional restrictions on technology. It can model multiple inputs and multiple outputs. In addition, Parman et al. (2016) show the ability of the DEA approach in estimating multiproduct and product-specific economies of scale and scope.

Ariyaratne et al. (2000) estimate X-efficiency and scale efficiency of Great Plains grain marketing and farm supply cooperatives using the DEA method. The results indicate that large cooperatives are fairly scale efficient, indicating a relatively flat cost frontier. Scale efficiency explains whether the per-unit cost is increasing, constant or decreasing, but it does not show the magnitude of potential cost savings by changing the size of the operation (Paul et al., 2004). Further, scale efficiency does not explain why a firm produces more than one output. The concept of multiproduct economies of scope and scale is helpful in understanding a firm's decision to produce multiple outputs (Coelli et al., 2005). In addition, the aggregate estimation of the cost function does not provide information about the impact of output-mix and output level on total cost. Thus, the multiproduct cost approach is useful to understand how cost changes over a variety of outputs (Baumol, Panzar, and Willig, 1982). Economies of scale and economies of scope are estimated using the DEA method as it provides robust results in a multiproduct framework (Parman et al., 2016).

The purpose of this study is to evaluate economies of scale and scope of agricultural cooperatives in the United States using a nonparametric approach. The objective of this research is to estimate cost efficiency, multiproduct economies of scale, product-specific economies of scale, and economies of scope using the DEA approach for agricultural cooperatives. The use of a multiproduct framework in estimating economies of scale and scope has important implications for cooperatives because most of agricultural cooperatives sell more than one product and not all cooperatives have the same output mix. Understanding the contribution of each product on the cost of cooperatives is helpful to adjust the scale of that product or products.

Moreover, a multiproduct framework allows to examine cost-output relationships rather than in a single product framework. The multiproduct framework provides a greater amount of information to managers and a board of directors about the effects of output mixes and output levels on cost (Akridge and Hertel, 1986). Understanding the impact of changing output levels or mixes on cost structure is helpful in improving the economic performance of these cooperatives. Scope economies show the percentage of cost savings through product diversification in multiproduct operations. The comparison between cost efficiency and multiproduct scale economies show whether becoming cost efficient reduces more cost than changing the size of operations.

The second objective is to estimate cost efficiency, multiproduct economies of scale, product-specific economies of scale, and economies of scope annually. The annual frontier allows the cost frontier to shift, which provides information on how cost structure changes over time due to the improvements in technology, macroeconomic shocks, weather variation, etc. The shift in the cost frontier shows whether scale economies and scope economies remain consistent when the cost frontier shifts over time.

This study is organized as follows. Section two discusses the literature on scale and scope economies. Section three and four present the theoretical framework for the research methods and data description, respectively. Section five reports empirical results. Section six provides implications of the study followed by summary and conclusions in the final section.

2.2 Related Literature

Past research that used the parametric approach to estimate economic measures of scale and scope include Akridge and Hertel (1986); Featherstone and Moss (1994); Heshmati and Kumbhakar (1997); Kim (1986); Murray and White (1983); Schroeder (1992); and Thraen, Hahn, and Roof (1987). Akridge and Hertel (1986) use the translog cost function to analyze multiproduct cost relationships for Indiana and Illinois retail fertilizer plants from 1975 to 1982 and find that the plants could reduce average cost by increasing their size and through product diversification. Schroeder (1992) estimates scale and scope economies for grain marketing and farm supply cooperatives from 1979 to 1988 using the translog cost specification. The results indicate that these cooperatives experienced economies of scale. To be specific, the multiproduct scale economies estimate indicate that agricultural supply and marketing cooperatives can save 59% cost by increasing scale of the operation. Economies of scope for each product and different combinations (e.g. grain, fertilizers, grain, chemicals) are higher than 0.30. Moreover, product-specific economies of scale exist for grain, petroleum, feed, and other sales as they have product-specific scale economies greater than 1.5, indicating they are on the region of increasing returns to scale. Product-specific scale economies were not present for chemicals.

Akridge and Hertel (1992) use a multiproduct variable cost function to compare the efficiency of Midwestern cooperative and investor-orientated (IOFs) grain and farm supply firms (74 cooperatives and 46 IOFs) in 1980. They find that cooperatives are no less efficient than investor-orientated firms. Furthermore, results suggest that investor-orientated firms are slightly more efficient in their plant and equipment use, while cooperatives use other inputs more efficiently. However, the regression result show that both cooperatives and investor-orientated firms over-invest in fixed inputs.

Yoo, Buccola, and Gopinath (2013) examine pricing and scale efficiency of rice processing cooperatives in Korea using a translog cost function from 2002 to 2008. The estimated net revenue product elasticities for small and medium-sized rice processing cooperatives are 1.050 and 1.024, respectively indicating the potential for exploiting scale economies by increasing size. Small and medium-sized cooperatives are scale inefficient, while only large rice cooperatives are scale efficient (elasticity is close to 1).

The translog cost can give biased results in estimating scale and scope economies because of the multiplicative nature of outputs that imposes extreme diseconomies of scale on data sets (Berger, Hunter, and Timme, 1993). Moreover, McAllister and McManus (1993) show that the translog cost functional form including risk as a cost factor provides a poor approximation when employed for different bank sizes.

The estimation of economies of scale in a multiproduct setting defined by Baumol, Panzar, and Willig (1982) is different than scale efficiency (Paul et al., 2004). This research uses a multiproduct approach following the work of Baumol, Panzar, and Willig (1982) and it complements previous studies by estimating a minimum cost frontier in a multiproduct framework for agricultural cooperatives using the DEA method. The results help identify the percentage of average cost savings through scope economies and scale economies that would be helpful to improve the performance of agricultural cooperatives in a rapidly changing rural economy in the United States.

2.3 Research Methods

2.3.1 Data Envelopment Analysis

Shephard (1953) suggested a mathematical programming approach to construct a piece-wise linear surface and Farrell (1957) provided the basis for the nonparametric approach. The Farrell (1957) approach did not get much attention until the work of Charnes, Cooper, and Rhodes (1978) who used data envelopment analysis (DEA) with an input orientated approach under constant returns to scale (CRS). Banker, Charnes, and Cooper (1984) proposed models for DEA with variable returns to scale. The DEA method is a linear programming approach that uses input quantities and output quantities to construct a piece-wise linear surface over the data points. The piece-wise frontier surface is constructed using the optimal solution obtained from the linear programing problem for each firm or decision making unit.[1]

Traditional economic theory assumes that firms are either cost minimizers or profit maximizers. However, frontier analysis assumes that some firms operate above the cost minimizing or below the profit maximizing levels (Coelli et al., 2005). In the DEA approach, a firm's efficiency is compared with the efficiency of frontier firms (the "best" practice firms) from the sample. This method can be applied to both input- and output-orientations. The two orientations yield the same technical efficiency scores under the CRS technology, but may give different results for technical efficiency under variable returns to scale (VRS) (Coelli and Rao, 2005; Coelli et al., 2005; Farrell, 1957). Some of the important assumptions for DEA are inputs and outputs are non-negative, less is preferred for inputs, more is preferred for outputs, and the measurement unit of inputs and outputs can be different.

DEA can model multiple input and multiple output firms. It helps to identify inefficiencies in each input and output providing information to improve a firm's performance. DEA does not assume any specific functional form on technology and is less

[1]Decision making units are used in data envelopment analysis literature. However, this dissertation uses the term "firm" for simplicity.

prone to misspecification error. Further, DEA is a good alternative for parametric methods when a researcher is unsure about the functional form or data generation process (Färe et al., 1985; Parman et al., 2016). Parman et al. (2016) show the ability of the DEA approach for estimating multiproduct and product-specific economies of scale. However, the DEA approach is not without limitations as it does not account for measurement error; in that it assumes that any deviation from the frontier estimation is due to inefficiency (Coelli et al., 2005). Measurement error and noise may affect the DEA results because DEA is an extreme point approach and the results are affected by outliers if those outliers are on the frontier. Efficiency scores obtained from DEA are relative scores to the best firms in the sample. Hypothesis tests are often not completed with DEA (Charnes, Cooper, and Rhodes, 1978; Färe, Grosskopf, and Lovell, 1985),coelli2005intro though Simar and Wilson (1998) provide methods to construct confidence intervals.

2.3.2 Cost Measures

The objective of cooperatives is assumed to be cost minimization (Featherstone and Rahman, 1996). Featherstone and Rahman (1996) find that the cooperatives' optimization objective is more consistent with cost minimization than profit maximization. The cost frontier is the minimum cost curve to produce a vector of outputs (y) with given a vector of inputs (x). The minimum cost obtained from the DEA method is used to estimate multiproduct and product-specific economies of scale and economies of scope for agricultural cooperatives following Parman et al. (2016). The following linear programming problem is solved to estimate the cost frontier.

$$\min C_j = \sum_j {w_j}' x_j^*$$
subject to
$$\sum_{j=1}^{k} \lambda x \leq x_j^*$$
$$\sum_{j=1}^{k} \lambda y - y_j \geq 0 \tag{2.1}$$
$$\sum_{j=1}^{k} \lambda = 1$$
$$\lambda_j \geq 0$$

where C_j is the minimum cost of producing output y for jth cooperative, k is the number of cooperatives, x is the vector of inputs, y is the vector of outputs, and λ is an intensity vector (i.e. the weight of an individual cooperative). The sum of the intensity vector is one under variable returns to scale (VRS). Model 2.1 can estimate the minimum cost of producing output y under the CRS technology when the intensity constraint ($\sum_{j=1}^{K} \lambda = 1$) is removed from the model.

The minimum cost obtained from the VRS model is used to compute cost efficiency (CE), that is a ratio of the total minimum cost (C_j) to the observed total cost (TC_j) of firm j for producing a given output bundle. Mathematically,

$$CE_j = \frac{C_j}{TC_j}. \tag{2.2}$$

The cost efficiency score lies between zero and one and a cost efficiency score of one indicates that the firm is on the cost frontier or is cost efficient (i.e. minimum total cost is equals to actual total cost). A cost efficiency score of less than one indicates the firm is above the cost frontier. The relative distance of a cooperative to the cost frontier shows how efficient a cooperative is compared to the frontier cooperatives.

Figure 2.1 shows the minimum cost frontier and by definition of the cost frontier no firm can produce below the frontier and firms above the cost frontier are not cost efficient. Firms above the cost frontier can reduce cost by changing input bundles to move to the cost frontier. For example, firms P and Q are not cost efficient as they are away from the cost frontier, but firms R, S, and T are on the minimum cost frontier. The vertical distance between firms (P and Q) and the cost frontier shows the potential for cost reduction by adjusting input to produce the same level of output.

In a multiproduct approach, economies of scale exist when increasing all outputs proportionally leads to a decline of the average cost of production. Multiproduct scale economies (MPSE) are defined following Baumol, Panzar, and Willig (1982).

$$MPSE = \frac{C(Y)}{Y\nabla C(Y)} = \frac{C(Y)}{\sum_i MC_i Y_i} \tag{2.3}$$

where $C(Y)$ is the cost of producing all outputs, MC_i is the marginal cost with respect to the ith output, which is determined by the shadow price from the cost minimization problem (equation 2.1), Y_i is the ith output and Y is an output vector containing all Y_i outputs. If the MPSE is greater than one, multiproduct economies of scale exist (i.e. a firm is at the region of increasing returns to scale), which means firms can reduce average cost by increasing the size of all outputs proportionally keeping the mix of outputs constant. Similarly, if the MPSE is less than (equals) one, firms are at the region of decreasing (constant) returns to scale.

In a multiproduct approach, product-specific economies and economies of scope are two sources of economies of scale. Product-specific economies of scale exist if the per-unit cost of producing output decreases as the output increases. Note that product-specific economies of scale are similar to economies of scale for the single output case. Incremental costs (IC) and marginal costs are required to estimate product-specific economies of scale. Incremental cost for the ith output is calculated by subtracting the cost of all outputs except the ith output $C(Y_{N-i})$ from the total cost of producing all outputs ($C(Y)$). Formally, the incremental cost is defined as:

$$IC_i = C(Y) - C(Y_{N-i}) \tag{2.4}$$

where $Y_{N-i} = (Y_1, \ldots, Y_{i-1}, 0, Y_{i+1}, \ldots, Y_N)$. Product-specific economies of scale (PSE) are defined as the ratio of the average incremental cost (AIC) of producing the ith output to the marginal cost (MC) of producing the ith output. Mathematically,

$$PSE = \left(\frac{IC_i/Y_i}{\partial C/\partial Y_i} \right) = \frac{AIC_i}{MC_i}. \tag{2.5}$$

Product-specific economies (diseconomies) of scale exist if the PSE is greater (less) than one and if the PSE is equal to one, it indicates that the product is at CRS. Another important economic measure is economies of scope (EOS_i) that shows the potential for cost savings from the joint production of two or more outputs rather than producing them separately. Economies of scope exist if it is cheaper to produce in a multiproduct firm than producing the same level of outputs in separate firms. Economies of scope exist if the following inequality holds.

$$C(Y_i) + C(Y_{N-i}) > C(Y) \tag{2.6}$$

where $C(Y_i)$ and $C(Y_{N-i})$ are the cost of producing i and $N - i$ outputs separate firms, while $C(Y)$ represents the total cost of producing all outputs in a multiproduct firm. A scale free measure of economies of scope can be defined as

$$EOS(Y_i) = \frac{C(Y_i) + C(Y_{N-i}) - C(Y)}{C(Y)}. \tag{2.7}$$

If $EOS(Y_i)$ is greater than zero, then economies of scope exist. This estimates the potential for cost reduction through product diversification.

For the calculation of product-specific scale economies in a four output case, total cost and cost of producing the other three outputs jointly needs to be estimated. To estimate the cost of the other three outputs in a multiproduct framework using a nonparametric approach, in general either one of the output constraints is forced to zero or one of the constraints is dropped during optimization. This study drops a constraint to estimate the cost of i and $N - i$ groups.

The DEA approach allows for the output from the dropped constraints to be non-zero. This may overestimate the cost of that output ($C(Y_i)$). The cost of producing Y_1 is $C(Y_1)$, which assumes that Y_1 is the only output being produced. However, dropping a constraint with DEA allows some portion of Y_2, Y_3, and Y_4 to be produced in a four output case. This estimation process overestimates the cost of $C(Y_1)$. Parman et al. (2016) use the portion of Y_i times the cost of Y_i only to remove the additional cost of a dropped output constraint in the two output case. However, this method needs to be adapted for the more than two output case due to different combinations of dropped output constraints.

Before estimating product-specific economies of scale, incremental cost is adjusted by:

$$\text{Adjusted } IC_i = \frac{IC_i}{1 - \frac{Y_{i,Res,Drop}}{Y_{i,Actual,Drop}}} \tag{2.8}$$

where IC_i is incremental cost for ith output, $Y_{i,Res,Drop}$ is the residual output of the dropped constraints and $Y_{i,Actual,Drop}$ is the actual quantity for ith dropped products.[2] For example, in a four product case ($Y_i = Y_1, Y_2, Y_3, Y_4$), incremental cost for Y_1 is the difference between total cost and the cost of other three products ($C(0, Y_2, Y_3, Y_4)$). To estimate $C(0, Y_2, Y_3, Y_4)$, the Y_1 constraint was dropped during cost optimization. However, some portion of the dropped output (Y_1) may be produced, which overestimates $C(0, Y_2, Y_3, Y_4)$. It means the incremental cost of Y_1 ($IC(Y_1)$) is underestimated, which would result in a lower product-specific scale economies. Thus, to calculate product-specific economies of scale, the adjusted incremental cost is used. Similarly, the incremental cost of other outputs can be adjusted using the above method.

To calculate scope economies in a multiproduct framework, the cost associated with individual output and group outputs are needed. To compute the cost of individual output, all output constraints except the output constraint of interest are deleted. This estimates the minimum cost associated with that output. Economies of scope are estimated dividing the cost of all four outputs into two groups. To estimate $C(0, Y_2, Y_3, Y_4)$ scope economies, the cost of an output separately and the cost of three outputs jointly are adjusted. Since the incremental cost adjustment allows the average incremental cost for each output to be

[2] Residual output is defined as the quantity being produced for a dropped output constraint for the cost optimization problem only for i or $N - i$ groups. There would be no residual output for a total cost minimization problem because no output constraint is being dropped out.

obtained, the quantity of individual residual of the dropped output constraint is multiplied by the respective average incremental cost and subtracted it from the cost of the individual output alone to obtain the adjusted cost of that output. Mathematically,

$$\text{Adjusted } C_i = C_i - \sum_{\substack{j=1 \\ j \neq i}}^{4} AIC_j * Y_{j,Res,Drop} \tag{2.9}$$

where C_i is the cost of ith individual output produced separately, AIC_j is the average incremental cost for jth product, and $Y_{j,Res,Drop}$ is the residual quantity of jth dropped constraints.

A similar method is used to adjust the cost of three outputs produced jointly where one output constraint is dropped during optimization. To obtain the adjusted (actual) cost of producing three outputs jointly, subtract the residual quantity of dropped output constraint times the respective average incremental cost from the cost of three outputs. When adjusted incremental cost and marginal cost for each product are estimated, product-specific economies of scale can be calculated. In the same way when the cost of the individual output provided separately and cost of other three outputs jointly are adjusted, scope economies can be calculated.

The Kolmogorov-Smirnov test is used to examine whether the empirical distribution of economic measures (cost efficiency, multiproduct scale economies, product-specific scale economies, and scope economies) from annual frontiers and a single (multi-year) frontier are drawn from the same population. In addition, a two-sample t-test is used to evaluate the equality of means for economic measures estimated from a single frontier and annual frontiers (NIST/SEMATECH, 2016).

2.4 Data Description

The empirical analysis uses financial data from CoBank, a part of the Farm Credit System. CoBank loans to farmer cooperatives and agricultural businesses across the United States. The majority of agricultural cooperatives are located in Midwestern and a few agricultural cooperatives are located on the eastern, and western regions. The data include annual financial records with complete balance sheet and service statement from audited financial statements of grain marketing and farm supply (agricultural) cooperatives. For empirical analysis, only cooperatives with a Standardized Industrial Code (SIC) of 5153, 5190, and 5191 that represent agricultural cooperatives are included. Labor, capital, and variable (other) expense are the three inputs used for the analysis. The outputs are grain sales, farm input supply sales, service income (operating income), and other product sales. It is important to note that the agricultural cooperatives may market all outputs together, a subset of outputs or any one of them.

Since CoBank reports inputs and outputs in dollar values, they are transformed to respective quantities (indexes). Nominal input expenses and output revenues are converted to 2014 constant dollar values using the implicit gross domestic product (GDP) price deflator. Annual producer price indexes for inputs and outputs including the GDP price deflator are obtained from U.S. Department of Labor (2016).

2.4.1 Input Data

Labor expense includes wage expense and fringe benefit expense. Average hourly earnings for the manufacturing sector (U.S. Department of Labor, 2016) are used to convert labor expenses to labor quantity (index). Total assets are used as the quantity of capital and the U.S. real interest rate (World Bank, 2016) is used as the cost of capital. Capital expenses are calculated as the product of real interest rate to total assets. The third input is variable (other) expense that includes utility expense, advertising expense, telephone expense, collection expense, lease expense, and rent expense. The variable quantity is constructed by dividing variable expense by general producer price index (U.S. Department of Labor, 2016). Ariyaratne, Briggeman, and Mickelsen (2014) defined capital expense as the sum of annual depreciation, rent and leases, and total assets times bank prime loan rate. Since depreciation is not an economic cost including depreciation as capital expense may overestimate the capital expense and result in higher cost for cooperatives.

Table 2.1 reports the summary statistics of input expense for the study period. All input expenses are reported in million dollars. Labor and other expenses account for more than 80% for overall input expenses. The average labor, capital, and variable input expenses are $3,498,000; $742,000 and $3,041,000, respectively.

Figure 2.2 displays the arithmetic means of input expenses from 2005 to 2014. Labor and other (variable input) expenses have an upward trend in the sample period, but capital has an increasing trend from 2005 to 2007 and a decreasing trend between 2008 to 2011 and remain relatively stable after 2012. The highest use of capital was in 2008 over the study period.

2.4.2 Output Data

The four output variables are grain sales (aggregation of sales commodities and grain), farm input supply sales (aggregated form of feed, fertilizer, chemicals, petroleum, etc.), service income (aggregated form of storage revenue, handling revenue, and other revenue) and other product sales. Since these outputs are expressed in dollars, they are transformed to output quantities (indexes). The producer price index (PPI) for grains, PPI by commodity for crude materials for further processing and PPI by commodity for finished goods and general producer price index (U.S. Department of Labor, 2016) are used to convert grain sales, farm input supply sales, other product sales, and service income into output quantities (indexes), respectively.

The bottom part of Table 2.1 reports the summary statistics of output sales over the study period. The total sale for all products are reported in million dollars. The contribution of grain is highest whereas the contribution of service income is smallest of the total revenue of agricultural cooperatives, on average.

Figure 2.3 plots annual averages for all outputs in the sample periods. The service and other product sales are relatively stable. The revenue obtained from farm input sales showed an increasing trend except in 2009 and 2010. The revenue from grain displays significant fluctuations from 2005 to 2014. It shows an upward trend between two periods:

2006 to 2008 and 2010 to 2012. The sale of grain decreased in 2009 and 2010 and again after 2013. The period after 2013 is associated with high crop production in the United States.

The fluctuations of input expenses and marketing revenues for agricultural cooperatives are associated with fluctuations in income in the farm sectors. Recent USDA projections show that total farm assets and equity growth slowed during 2014. Farm income decreased as crop prices decreased due to high levels of crop production in 2013 and 2014. The highest grain sales occurred in 2012 and started to decrease in the following year.

Agricultural cooperatives with less than \$10,000 in annual labor and capital expenses were dropped from the analysis. Similarly, if a cooperative had annual sales of zero for all outputs, they are dropped from the analysis. Based on the criteria, 170 observations were dropped from the empirical analysis. In addition, if a ratio of total income to total expense is greater than three times the standard deviation of the ratio, those observations were deleted (44 observations). The total number of observations used for single cost frontier and annual cost frontiers is 3511 from 2005 to 2014. Since unbalanced panel data is used for the empirical analysis, the number of cooperatives differs by year. For instance, the number of cooperatives was 279 in 2005 and 452 in 2014 (Tables 2.2 to 2.5). The output quantities are graphed in Figure 2.4 illustrating that output quantities followed a similar trend like output sales with large fluctuations on the grain quantity index.

2.5 Empirical Results

This section reports empirical results for cost efficiency, economies of scale and scope (economic measures) from a single frontier and annual frontiers. Furthermore, the results for all economic measures obtained from both frontiers are also reported based on the size of agricultural cooperatives.

Agricultural (grain marketing and farm supply) cooperatives are classified into five groups (sizes) based on the value of total assets to examine how the economic measures vary with the size of cooperatives. The five sizes are: cooperatives with less than \$15 million (m) in assets, cooperatives with greater than \$15m to less than \$30m in assets, cooperatives greater than \$30m and less than \$60m in assets, cooperatives with greater than \$60m and less than \$100m in assets, and cooperatives with greater than \$100m in assets.

For estimating single and annual cost frontiers, 3511 observations are used for the empirical analysis from 2005 to 2014. On average, a cost efficiency score from a single frontier is lower than the cost efficiency score from annual frontiers (Tables 2.6 and 2.7). Approximately 77% (38%) cooperatives have a cost efficiency score less than 0.50, 18% (42%) cooperatives have a cost efficiency score greater than 0.50 and less than 0.8, 4% (13%) cooperatives have a cost efficiency score greater than 0.80 and less than 1.0, and 1% (7%) cooperatives have a cost efficiency score equals 1.0 from a single frontier (annual frontiers).

The cooperatives with a cost efficiency score equals 1.0 occur on the minimum cost ("best-practice") frontier. These cooperatives have non-unique marginal costs so they are not used for the calculation of multiproduct scale economies and product specific scale economies. In addition, economic measures are only calculated if they produced at least two outputs

The number of observations for economic measures between annual frontiers and a single frontier are different because there are ten frontiers in the first analysis and one frontier in the second analysis. The different frontier estimation gives the different numbers of non-unique marginal costs that affect the calculation of multiproduct scale economies and product-specific scale economies.

In addition, the number of observations for product-specific scale economies from both frontiers are different among products as not all cooperatives market all four products. If a cooperative only sells a single product, product-specific economies of scale are estimated for only that product. For example, to calculate grain-specific scale economies, cooperatives are dropped if the quantity of grain is zero or the marginal cost is non-unique and a similar approach is used for other products as well.

Tables 2.6 and 2.7 report overall summary statistics of cost efficiency, economies of scale and scope from a single frontier and annual frontiers, respectively. From the single frontier, the average cost efficiency score is 0.39, which indicates that cooperatives could save 61% of cost, whereas from the annual frontiers, the average cost efficiency score is 0.59, indicating that cooperatives could save 41% of cost on average by changing input bundles to achieve the same level of output.

The number of cooperatives on the annual cost frontier are - 2005: 24, 2006: 24, 2007: 25, 2008: 18, 2009: 22, 2010: 20, 2011: 23, 2012: 26, 2013: 22, 2014: 29. For the annual cost frontiers, more than 50% of cost efficient cooperatives repeatedly appeared on the cost frontier. In general, relativity large cooperatives consistently formed the cost frontier if they were on the cost frontier in 2005 and these cooperatives were relatively cost efficient over time even if they did not occur on the cost frontier in other years.

The number of cooperatives on the single cost frontier is 34. The majority of cooperatives (27 cooperatives) that formed the single cost frontier came from 2011 to 2014. More than 55% of agricultural cooperatives that appeared on the single cost frontier had greater than $60 million in assets.

Since a unbalanced panel was used, new cooperatives that were added primarily after 2010 into the CoBank dataset achieved the cost efficiency score of 1. The new added cooperatives in the dataset that formed the cost frontier are large cooperatives. This may affect the cost efficiency of small cooperatives and could provide evidence for the decreasing cost efficiency trend in the agricultural cooperative industry over time.

Tables 2.6 and 2.7 report multiproduct and product-specific scale and scope economies. The mean value of multiproduct scale economies (MPSE) is 1.20 and 1.27 from the single and annual frontiers suggesting that cooperatives can reduce average cost by 20% and 27%, respectively by increasing production uniformly across outputs. However, there is a difference between mean and median values of MPSE indicating MPSEs have an asymmetric distribution.

Product-specific scale economies are summarized in Tables 2.6 and 2.7. The product-specific scale economies for all products are less than 1 for both frontier methods. For instance, the mean value of grain-specific scale economies is 0.92 (0.83) from the single frontier (annual frontier) indicating that cooperatives benefit by reducing the scale of grain quantity. On average, the mean value of scope economies are greater than 0 (e.g. 0.14 from the single frontier and 0.13 from the annual frontier for grain versus (vs) farm, service, and other products) from both frontiers, which implies that economies of scope exist. The single frontier and annual frontier results suggest that product diversification could result in more than 10% of cost savings for agricultural cooperatives. The conclusion of this study for multiproduct scale economies and scope economies are consistent with Schroeder (1992), who find that multiproduct scale and scope economies exist for agricultural supply and marketing cooperatives. However, this study finds that all outputs are close to constant returns to scale, which contradicts with the findings of Schroeder (1992), who find that most of the outputs were under increasing returns to scale (the mean value of product-specific scale economies lies between 1.25 and 2.99).

2.5.1 Cost Efficiency

Previous literature shows that smaller firms are less cost efficient than larger firms. Cost efficiency is reported based on the size of cooperatives (Ariyaratne et al., 2000; Parman et al., 2016; Wu and Prato, 2006). Since cost efficiency is the product of technical efficiency and allocative efficiency, cooperatives can reduce cost either by increasing technical efficiency or allocative efficiency or both.

The descriptive statistics of cost efficiency by the size of agricultural cooperatives from single and annual frontiers are summarized in Table 2.9. Cost efficiency, particularly for small cooperatives are low as they could reduce cost by more than 50%. One reason for a low cost efficiency score could be that agricultural cooperatives have limited access to capital and they are less involved in research and development as it is capital intensive and financially risky (Dunn et al., 2002). Limited access to equity capital may restrict cooperatives from achieving the potential for overall cost reduction.

The cost efficiency results show that smaller cooperatives are less cost efficient than larger cooperatives for both frontier methods (Table 2.9). This indicates that, on average, larger sized cooperatives are closer to the cost frontier ("best-practice" frontier) than smaller sized cooperatives. However, the Kolmogorov-Smirnov test and two-sample t-test show that the economic measures between single and annual frontiers are significantly different indicating the cost frontier shifts across years (Table 2.19). Thus, the discussions of the results are focused on the annual estimates by the size of agricultural cooperatives.

Cooperatives with less than $15 million (m) in assets have the mean cost efficiency score between 0.44 and 0.73 from 2005 to 2014 while the mean cost efficiency score ranges from 0.75 to 0.99 for the cooperatives with assets size greater than $100m over the same period. In other words, larger cooperatives are more cost efficient than smaller cooperatives. The result is consistent with Ariyaratne et al. (2000), who find that large agricultural cooperatives are more X-efficient than smaller ones over the period 1988 to 1992. The numerical value of cost efficiency decreases over time while the cost efficiency score increases with the increasing size of cooperatives. In general, the agricultural cooperative industry is becoming less X-efficient over time.

The multiproduct scale economies and cost efficiency measures show the trade-off for the cooperatives to reduce cost either by increasing size or becoming cost efficient. For example, cooperatives within the category of less than $15m in assets could reduce total cost by 30% in 2005 and 56% in 2014 (Table 2.20) by becoming cost efficient, whereas the same-sized of cooperatives could reduce average cost by 13% in 2005 and 173% in 2014, respectively by increasing the size of operations (Table 2.25). This is a clear indication that cooperatives will experience more mergers and/or acquisitions in the future and the process of increasing the size of cooperatives continue until economies of scale are exhausted in the agricultural cooperative industry.

The Kolmogorov-Smirnov test (KS test) is performed in Stata 14 to examine the difference between the distributions of economic measures (cost efficiency, multiproduct economies of scale, product-specific economies of scale, and economies of scope) obtained from a single frontier and annual frontiers. The results reject the null hypothesis of empirical distribution drawn from the same population, indicating that these economic measures estimated from single frontier and annual frontiers are significantly different at

1% level of significance (Table 2.19). In other words, the results provide strong evidence that empirical distribution are not drawn from the same population. The results indicate a shift in the cost frontier across years.

Furthermore, a two sample t-test is used to examine if the means of two cumulative distributions from a single frontier and annual frontiers are equal. The null hypothesis for the t-test is two means are equal (NIST/SEMATECH, 2016). The null hypothesis for all economic measures except scope: grain vs farm, service, and other are rejected at 1% level of significance indicating that the mean values are statistically different (Table 2.19).

2.5.2 Multiproduct Economies of Scale

Table 2.8 depicts multiproduct scale economies (MPSE) from annual frontiers across years. The mean MPSE value of cooperatives for all years is greater than 1, which indicates that cooperatives are operating under increasing returns to scale and they can reduce average cost by increasing the scale of their operations. Cooperatives could save 6% in average cost in 2005 whereas they could reduce cost by 80% in 2014 by increasing the size of the operation, on average.

Multiproduct scale economies are reported based on the size of cooperatives. The mean multiproduct scale economies for cooperatives less than $15 million in assets are greater than 1.0 for all years. The mean MPSE values range between 1.13 in 2005 and 2.73 in 2014. This indicates that small cooperatives have strong incentives to increase the scale of the operation (Table 2.25). However, scale economies are exhausted with the increasing size of cooperatives (Tables 2.26 to 2.29).

When cost efficiency and multiproduct scale economies are compared across years, the potential cost reduction either by becoming cost efficient or increasing the scale of operations changes. When cooperatives are moving closer to an efficient frontier, there is a smaller percentage of potential gain by increasing scale even for small cooperatives. For example, cooperatives less than $15 million in assets have a cost efficiency value of 0.70 in 2005 while a mean value of multiproduct scale economies is 1.13 indicating that becoming cost efficient could save higher percentage of cost (30%) rather than increasing scale. However, there is a variation of cost savings through scale economies over time.

Figure 2.9 displays annual average of cost efficiency and multiproduct scale economies estimated from annual cost frontiers over the study period 2005 to 2014. The cost efficiency score has a decreasing trend and reached the lowest in 2011 and remain relatively stable after 2012. The annual average of cost efficiency between 2005 to 2010 is higher than 60% and for the period 2011 to 2014 an average cost efficiency score is approximately 50%. Multiproduct scale economies has an upward trend except in two years: 2012 and 2013. The annual average of MPSE has the highest value in 2014, indicating the higher potential for cost reduction by increasing the scale of operations.

2.5.3 Product-specific Economies of Scale

A numerical value of product-specific scale economies greater than 1.0 indicates that cooperatives can reduce cost by increasing that output and if a product-specific scale economies measure is less than 1.0, it implies the potential cost savings by reducing that product. Since the contribution of each output to the total revenue of a cooperative is different, product-specific scale economies provide additional information for adjusting the size of each product to improve the performance of cooperatives.

The annual average of product-specific scale economies (PSE) from 2005 to 2014 are summarized in Table 2.8. The mean PSE values of four outputs across years are close to 1, suggesting these cooperatives are close to constant returns to scale. The PSE values are relatively consistent across years.

The summary statistics of product-specific scale economies for all products are reported based on the size of cooperatives. The mean value of product-specific scale economies for smaller cooperatives is less than larger cooperatives, though all the PSE estimates are less than or equal to 1. Product-specific scale economies are generally increasing over time for all products. For example, the mean PSE is 0.74 in 2005 and 0.97 in 2014 for cooperatives less than $15 million in assets and a similar pattern is shown for other products and other sizes of cooperatives (Tables 2.30 to 2.49).

Figure 2.10 plots annual average for product-specific scale economies for all four outputs. The PSE for farm input is relatively stable over the sample period, while the rest of the PSEs have high fluctuations. Overall, all products are moving towards constant returns to scale (optimal scale) over time.

2.5.4 Economies of Scope

Economies of scope represent the cost saving through product diversification. If significant cost reduction is possible through scope economies, then diversified firms are more profitable than specialized firms (Clark, 1988). Economies of scope were estimated dividing four products (grain, farm input, service income, and other outputs) into two groups with different combinations of products that give four economies of scope measures. The first economies of scope is between grain and the other three output categories are taken as a group. The second economies of scope measure is between farm input and the other three products, the third economies of scope measure is between service and the other three products, and the fourth economies of scope measure is between other products and rest of the other three products.

The annual economies of scope for all output combinations are greater than 0 indicating that cooperatives could reduce cost through product diversification. Economies of scope remain relatively consistent across years (Table 2.8).

Tables 2.50 to 2.69 report scope economies by the size of cooperatives from annual frontiers. For all economies of scope categories, cooperatives less than $30m in assets have the average scope economies score greater than 0 across years except 2009 for the farm input versus the other three products group, which suggests that cooperatives can save cost by joint production rather than producing them separately. However, larger cooperatives with greater than $30m in assets have slightly negative mean scope economies. The results suggest that economies of scope are exhausted for large cooperatives.

Figure 2.11 plots the annual average of scope economies for all combinations. The annual percentage gain from product diversification ranges from 5% to 30%. The potential benefit for cost reduction through scope economies increases significantly in 2014 compared with other years.

Overall, the mean values of multiproduct and product-specific scale and scope economies are higher for smaller cooperatives than those measures of larger cooperatives. Small cooperative less than $15m in assets can save more cost by increasing the size rather than becoming more cost efficient. For example, the mean cost efficiency score for the category of less than $15 million in assets is 0.44 (Table 2.20), whereas the mean MPSE score is 2.73 in 2014 (Table 2.25), indicating that these cooperatives can reduce cost by 56% becoming cost efficient, while they could reduce average cost by more than 100% by increasing the size of the operation, on average. However, the benefits tend to be exhausted with the increased size of cooperatives.

2.6 Implications

The Kolmogorov-Smirnov test (KS test) is used to examine the distributions of economic measures obtained from a single frontier and annual frontiers. The KS test shows that these economic measures estimated from single frontier and annual frontiers are significantly different at 1% level of significance (Table 2.19). It indicates a shift in the cost frontier.

A cost efficiency score is lower from a single frontier than annual frontiers. The shift in the cost frontier may imply that the single frontier may provide biased results for scale and scope economies.

The trade-off between cost efficiency and multiproduct scale economies for small sized cooperatives indicate that the cooperatives with less than $15 million in assets could save higher percentage of cost by increasing the scale of operations rather than by becoming more cost efficient.

For the cooperatives greater than $30 million in assets, the implication is that cooperatives can save the higher percentage of cost by becoming cost efficient rather than increasing size. The cooperatives with greater than $30 million in assets may need to change input bundles or mixes to be more cost efficient that would save a higher percentage of total cost.

The average product-specific scale economies for smaller cooperatives are lower than larger cooperatives across years. Economies of scope are greater than 0 for cooperatives less than $30 million in assets, while scope economies tend to be exhausted with the increased size of cooperatives. The magnitude of scope economies for smaller cooperatives are higher than larger cooperatives, indicating product diversification is more important to smaller cooperatives than larger cooperatives. Small cooperatives need to diversify their businesses to reduce cost.

2.7 Summary and Conclusions

Agricultural cooperatives market a variety of outputs such as grain and farm inputs, which creates problems for inter-firm comparison among agricultural cooperatives. Further, managers of cooperatives lack an adequate framework for analyzing the impact of changes of product mixes (levels) on cost structure in multiproduct operations (Akridge and Hertel, 1986). This study provides a framework for inter-cooperative performance comparison and the effects of changes on product mixes and/or product levels on cost structure for an individual cooperatives decision.

Since each product is not equally profitable for a cooperative, understanding the contribution of each product on the cost of cooperatives is helpful as it provides information whether to increase or decrease the production of that product. Moreover, a multiproduct framework allows for the examination of cost-output relationships, which is not possible in a single product framework. This framework also is useful to managers for price and promotional decisions as well as it provides the information about the contribution of each output on the cost of a firm (Akridge and Hertel, 1986).

The nonparametric approach estimates a cost frontier without imposing a functional form. Thus, the estimates are less prone to misspecification error (Färe et al., 1985). The nonparametric approach allows the estimation of scale and scope measures using cross-sectional data. Furthermore, the DEA method helps in understanding the impact of technological change on scale economies due to its ability to estimate a cost frontier using a single year's of data (Parman et al., 2016). The annual cost frontier estimation is useful in understanding how cost changes over time.

The results indicate that the cooperative industry became less cost efficient and the potential for cost reduction by expanding the operation has increased over time. Each product are operating close to constant returns to scale and product diversification could reduce cost for cooperatives relative to current costs.

Moreover, the results by the size of cooperatives indicate that small cooperatives with less than $15 million in assets have an economies of scale greater than 1, which suggests that small cooperatives have large incentives to expand their size, whereas cooperatives having more than $15 million in assets may need to reduce the size of operations. For instance, the multiproduct scale economies is 0.74 for cooperatives with more than $100 million in assets, indicating that these cooperatives could benefit by decreasing the size of their operations. Therefore, the understanding of cost structure is useful to make a proper decision based on their specific issues.

The results for cost efficiency indicate that smaller cooperatives are less cost efficient than larger cooperatives, while higher scale economies are present for smaller cooperatives. The average score of multiproduct scale economies for small cooperatives with less than $15 million in assets is 2.73 in 2014, indicating that small cooperatives have a large incentive to expand the size of the operation. The multiproduct scale economies are mainly obtained through product diversification for smaller cooperatives though at larger sizes (greater than $30 million in assets) scale and scope economies are exhausted.

Similarly, an average score for product-specific scale economies is close to (less than) 1, which implies that individual products are close to constant returns to scale (on the region of diseconomies of scale). The magnitude of product-specific scale economies is lower for smaller cooperatives than larger ones, though they are less than 1.

Overall, cost efficiency is lower for smaller cooperatives than larger cooperatives, whereas product-specific scale economies, multiproduct scale economies, and scope economies are higher for smaller cooperatives than larger cooperatives. The trade-off in the magnitude of cost efficiency and multiproduct scale economies' scores indicates that smaller cooperatives can benefit more by increasing the size of the operation. Since smaller cooperatives can reduce a higher percentage of cost by increasing the scale of operations rather than becoming cost efficient, it is likely that mergers of agricultural cooperatives will continue as smaller cooperatives attempt to benefit from economies of scale.

Tables

Table 2.1: Summary statistics of input expense and output revenue for agricultural cooperatives from 2005 to 2014

Variables ($ million)	N	Mean	Median	Std. Dev.
		Input Expense		
Labor expense	3511	3.498	1.618	5.205
Capital expense	3511	0.742	0.317	1.211
Other expense	3511	3.041	1.334	4.752
		Output Revenue		
Grain sales	3511	51.357	14.606	104.651
Farm-input sales	3511	25.070	10.196	42.671
Service income	3511	2.591	1.098	4.410
Other sales	3511	8.930	1.771	36.131

Note: Std. Dev. stands for standard deviation.

Table 2.2: Annual summary statistics of input quantity indexes for agricultural cooperatives from 2005 to 2008

	Labor	Capital	Others		Labor	Capital	Others
2005	N = 279			2006	N= 276		
Mean	2.17	18.57	1.62	Mean	2.19	20.19	1.70
Median	1.25	9.85	0.90	Median	1.28	10.60	0.94
Std. Dev.	2.55	23.80	2.22	Std. Dev.	2.57	26.71	2.27
2007	N = 274			2008	N = 272		
Mean	2.35	27.22	1.88	Mean	2.66	39.48	2.44
Median	1.32	12.24	0.99	Median	1.49	16.36	1.21
Std. Dev.	2.92	39.78	2.64	Std. Dev.	3.42	68.15	3.60

Note: All input quantities are in millions.

Table 2.3: Annual summary statistics of input quantity indexes for agricultural cooperatives from 2009 to 2014

	Labor	Capital	Others		Labor	Capital	Others
2009	N = 271			2010	N = 270		
Mean	3.00	28.12	2.50	Mean	3.25	32.42	2.78
Median	1.56	13.73	1.23	Median	1.65	15.16	1.34
Std. Dev.	4.07	40.56	3.98	Std. Dev.	4.43	45.94	4.27
2011	N = 493			2012	N = 468		
Mean	3.66	43.21	3.19	Mean	3.93	40.52	3.47
Median	1.51	16.25	1.30	Median	1.58	15.54	1.44
Std. Dev.	5.59	68.14	4.94	Std. Dev.	5.97	61.22	5.40
2013	N = 456			2014	N = 452		
Mean	4.07	37.04	3.49	Mean	4.22	37.11	3.69
Median	1.63	15.11	1.38	Median	1.68	15.47	1.48
Std. Dev.	6.21	52.65	5.36	Std. Dev.	6.48	53.16	5.74

Note: All input quantities are in millions.

Table 2.4: Annual summary statistics of output quantity indexes for agricultural cooperatives from 2005 to 2008

	Grain	Farm	Service	Others		Grain	Farm	Service	Others
2005	N = 279				2006	N = 276			
Mean	11.96	11.22	1.48	3.26	Mean	14.49	11.79	1.54	3.71
Median	5.46	5.84	0.84	1.15	Median	6.70	6.26	0.82	1.22
Std. Dev.	19.88	16.20	2.26	7.84	Std. Dev.	23.89	16.40	2.29	10.23
2007	N = 274				2008	N = 272			
Mean	28.87	14.73	1.58	4.39	Mean	64.23	24.50	2.01	5.72
Median	12.25	7.22	0.83	1.30	Median	24.83	11.90	0.93	1.53
Std. Dev.	50.25	21.87	2.43	12.72	Std. Dev.	116.05	39.24	3.24	16.31

Note: All output quantities are in millions.

Table 2.5: Annual summary statistics of output quantity indexes for agricultural cooperatives from 2009 to 2014

	Grain	Farm	Service	Others		Grain	Farm	Service	Others
2009	N = 271				2010	N = 270			
Mean	46.45	16.63	2.54	5.46	Mean	44.90	17.95	2.84	5.44
Median	15.57	7.26	1.22	1.60	Median	17.14	8.34	1.35	1.69
Std. Dev.	88.31	26.14	4.39	15.39	Std. Dev.	77.69	28.06	4.77	13.76
2011	N = 493				2012	N = 468			
Mean	89.03	26.29	2.37	9.76	Mean	101.74	30.79	2.79	11.65
Median	23.71	9.87	0.85	1.69	Median	24.02	10.91	0.99	1.89
Std. Dev.	173.33	42.59	3.89	38.93	Std. Dev.	212.73	52.04	4.72	46.81
2013	N = 456				2014	N = 452			
Mean	89.53	31.12	2.80	13.10	Mean	54.98	30.20	3.21	12.35
Median	19.94	10.66	0.98	1.92	Median	11.34	10.87	1.13	1.97
Std. Dev.	180.76	53.16	4.76	49.95	Std. Dev.	104.36	51.26	5.44	48.75

Note: All output quantities are in millions.

Table 2.6: Overall summary statistics of estimated economic measures from a single frontier for agricultural cooperatives

Single Frontier				
	N	Mean	Median	Std. Dev.
Cost efficiency	3511	0.39	0.34	0.19
Multiproduct scale economies	3358	1.20	0.94	0.66
Grain-specific scale economies	2223	0.92	1.00	0.14
Farm input-specific scale economies	2783	0.93	1.00	0.14
Service-specific scale economies	2970	0.87	0.90	0.13
Other product-specific scale economies	2877	0.97	1.00	0.07
Scope: grain vs (farm, service & others)	2223	0.14	0.09	0.19
Scope: farm vs (grain, service & others)	2783	0.15	0.12	0.24
Scope: service vs (grain, farm & others)	2970	0.13	0.09	0.22
Scope: others vs (grain, farm & service)	2877	0.19	0.14	0.19

Table 2.7: Overall summary statistics of estimated economic measures from annual frontiers for agricultural cooperatives

Annual Frontiers				
	N	Mean	Median	Std. Dev.
Cost efficiency	3511	0.59	0.57	0.22
Multiproduct scale economies	3137	1.27	0.94	1.29
Grain-specific scale economies	1993	0.83	0.91	0.20
Farm input-specific scale economies	2592	0.86	0.93	0.18
Service-specific scale economies	2703	0.84	0.89	0.17
Other product-specific scale economies	2527	0.94	1.00	0.12
Scope: grain vs (farm, service & others)	1993	0.13	0.10	0.20
Scope: farm vs (grain, service & others)	2592	0.17	0.12	0.24
Scope: service vs (grain, farm & others)	2703	0.18	0.14	0.23
Scope: others vs (grain, farm & service)	2527	0.16	0.08	0.23

Table 2.8: Annual average of economic measures for agricultural cooperatives from 2005 to 2014

Measures/Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Cost efficiency	0.73	0.71	0.74	0.64	0.66	0.63	0.50	0.52	0.53	0.50
Multiproduct scale economies	1.06	1.12	1.11	1.24	1.23	1.26	1.61	1.02	1.02	1.80
Grain-specific scale economies	0.72	0.75	0.82	0.77	0.84	0.72	0.87	0.84	0.94	0.93
Farm input-specific scale economies	0.81	0.83	0.82	0.83	0.79	0.83	0.86	0.90	0.89	0.91
Service-specific scale economies	0.78	0.79	0.83	0.74	0.85	0.80	0.90	0.88	0.91	0.83
Other product-specific scale economies	0.93	0.96	0.85	0.96	0.96	0.93	0.91	0.95	0.97	0.94
Scope: grain vs (farm, service & others)	0.09	0.13	0.09	0.19	0.10	0.22	0.16	0.10	0.05	0.22
Scope: farm vs (grain, service & others)	0.16	0.16	0.13	0.16	0.12	0.16	0.23	0.10	0.09	0.30
Scope: service vs (grain, farm & others)	0.22	0.23	0.16	0.26	0.20	0.26	0.14	0.11	0.07	0.23
Scope: others vs (grain, farm & service)	0.11	0.11	0.13	0.17	0.11	0.19	0.24	0.10	0.09	0.30

Table 2.9: Cost efficiency by the size of cooperatives from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1838	0.35	0.31	0.16
15 M- 30 M	661	0.36	0.33	0.15
30 M- 60 M	459	0.40	0.37	0.18
60 M- 100 M	254	0.46	0.46	0.18
Greater than 100 M	299	0.63	0.61	0.21
		Annual Frontiers		
Less than 15 M	1838	0.55	0.53	0.21
15 M- 30 M	661	0.56	0.54	0.20
30 M- 60 M	459	0.61	0.61	0.21
60 M- 100 M	254	0.67	0.64	0.20
Greater than 100 M	299	0.80	0.85	0.20

Table 2.10: Multiproduct scale economies by the size of cooperatives from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1740	1.52	1.36	0.77
15 M- 30 M	639	0.95	0.92	0.16
30 M- 60 M	449	0.83	0.90	0.14
60 M- 100 M	250	0.73	0.71	0.12
Greater than 100 M	280	0.71	0.73	0.12
		Annual Frontiers		
Less than 15 M	1656	1.64	1.09	1.68
15 M- 30 M	617	0.95	0.92	0.23
30 M- 60 M	418	0.84	0.88	0.14
60 M- 100 M	226	0.76	0.75	0.13
Greater than 100 M	220	0.74	0.75	0.13

Table 2.11: Grain-specific scale economies by the size of cooperatives from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	961	0.95	1.00	0.12
15 M- 30 M	505	0.95	1.00	0.10
30 M- 60 M	358	0.95	1.00	0.09
60 M- 100 M	194	0.84	0.88	0.16
Greater than 100 M	205	0.76	0.78	0.18
		Annual Frontiers		
Less than 15 M	801	0.85	0.96	0.20
15 M- 30 M	486	0.86	0.92	0.17
30 M- 60 M	326	0.84	0.91	0.18
60 M- 100 M	192	0.77	0.83	0.21
Greater than 100 M	188	0.72	0.77	0.23

Table 2.12: Farm input-specific scale economies by the size of cooperatives from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1480	0.98	1.00	0.07
15 M- 30 M	500	0.94	1.00	0.10
30 M- 60 M	354	0.87	0.95	0.17
60 M- 100 M	212	0.85	0.89	0.15
Greater than 100 M	237	0.77	0.83	0.23
		Annual Frontiers		
Less than 15 M	1395	0.89	0.99	0.17
15 M- 30 M	494	0.89	0.93	0.14
30 M- 60 M	336	0.82	0.89	0.20
60 M- 100 M	189	0.76	0.77	0.17
Greater than 100 M	178	0.68	0.71	0.24

Table 2.13: Service-specific scale economies by the size of cooperatives from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1449	0.91	0.96	0.12
15 M- 30 M	597	0.87	0.88	0.10
30 M- 60 M	414	0.85	0.89	0.13
60 M- 100 M	242	0.80	0.80	0.13
Greater than 100 M	268	0.74	0.74	0.16
		Annual Frontiers		
Less than 15 M	1379	0.87	0.95	0.16
15 M- 30 M	568	0.83	0.85	0.15
30 M- 60 M	371	0.81	0.85	0.17
60 M- 100 M	205	0.80	0.84	0.17
Greater than 100 M	180	0.79	0.83	0.19

Table 2.14: Other product-specific scale economies by the size of cooperatives from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1528	0.98	1.00	0.06
15 M- 30 M	543	0.97	1.00	0.07
30 M- 60 M	387	0.96	1.00	0.07
60 M- 100 M	216	0.97	1.00	0.08
Greater than 100 M	203	0.93	1.00	0.14
		Annual Frontiers		
Less than 15 M	1357	0.94	1.00	0.12
15 M- 30 M	480	0.93	1.00	0.12
30 M- 60 M	340	0.96	1.00	0.09
60 M- 100 M	190	0.95	1.00	0.11
Greater than 100 M	160	0.91	1.00	0.14

Table 2.15: Economies of scope: grain vs farm input, service, and other products from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	961	0.29	0.26	0.17
15 M- 30 M	505	0.10	0.07	0.10
30 M- 60 M	358	0.01	0.01	0.06
60 M- 100 M	194	-0.03	-0.02	0.06
Greater than 100 M	205	-0.07	-0.07	0.09
		Annual Frontiers		
Less than 15 M	801	0.24	0.20	0.21
15 M- 30 M	486	0.12	0.09	0.14
30 M- 60 M	326	0.04	0.04	0.10
60 M- 100 M	192	0.01	0.00	0.15
Greater than 100 M	188	-0.01	-0.04	0.18

Table 2.16: Economies of scope: farm input vs grain, service, and other products from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1480	0.32	0.29	0.18
15 M- 30 M	500	0.07	0.06	0.10
30 M- 60 M	354	-0.05	-0.02	0.11
60 M- 100 M	212	-0.15	-0.15	0.10
Greater than 100 M	237	-0.10	-0.10	0.10
		Annual Frontiers		
Less than 15 M	1395	0.28	0.20	0.24
15 M- 30 M	494	0.09	0.07	0.13
30 M- 60 M	336	0.02	0.02	0.12
60 M- 100 M	189	-0.05	-0.04	0.14
Greater than 100 M	178	-0.02	-0.04	0.15

Table 2.17: Economies of scope: service vs grain, farm input, and other products from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1449	0.29	0.27	0.18
15 M- 30 M	597	0.05	0.03	0.12
30 M- 60 M	414	-0.06	-0.04	0.11
60 M- 100 M	242	-0.11	-0.11	0.12
Greater than 100 M	268	-0.01	-0.01	0.13
		Annual Frontiers		
Less than 15 M	1379	0.28	0.23	0.23
15 M- 30 M	568	0.11	0.09	0.14
30 M- 60 M	371	0.05	0.04	0.16
60 M- 100 M	205	0.01	-0.01	0.20
Greater than 100 M	180	0.03	0.03	0.18

Table 2.18: Economies of scope: other products vs grain, farm input, and service from a single frontier and annual frontiers

Assets ($ million)	N	Mean	Median	Std. Dev.
		Single Frontier		
Less than 15 M	1528	0.31	0.27	0.18
15 M- 30 M	543	0.09	0.08	0.08
30 M- 60 M	387	0.04	0.03	0.06
60 M- 100 M	216	0.00	0.00	0.05
Greater than 100 M	203	0.01	0.01	0.09
		Annual Frontiers		
Less than 15 M	1357	0.27	0.17	0.25
15 M- 30 M	480	0.08	0.04	0.12
30 M- 60 M	340	0.03	0.01	0.08
60 M- 100 M	190	0.00	0.00	0.07
Greater than 100 M	160	0.01	0.00	0.09

Table 2.19: The Kolmogorov-Smirnov test and T-test comparing economic measures from a single frontier and annual frontiers

	KS-test		T-test	
	Test-statistic	P-value	Test-statistic	P-value
Cost efficiency	0.415	0.000	-41.645	0.000
Multiproduct scale economies	0.183	0.000	-2.986	0.003
Grain-specific scale economies	0.263	0.000	17.508	0.000
Farm input-specific scale economies	0.283	0.000	17.291	0.000
Service-specific scale economies	0.101	0.000	6.635	0.000
Other product-specific scale economies	0.153	0.000	12.238	0.000
Scope: grain vs (farm, service & others)	0.054	0.002	-1.261	0.207
Scope: farm vs (grain, service & others)	0.084	0.000	-3.988	0.000
Scope: service vs (grain, farm & others)	0.139	0.000	-7.877	0.000
Scope: others vs (grain, farm & service)	0.145	0.000	3.702	0.000

Table 2.20: Annual cost efficiency for agricultural cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	187	0.70	0.68	0.15
2006	174	0.69	0.66	0.16
2007	155	0.73	0.73	0.17
2008	127	0.60	0.56	0.19
2009	146	0.61	0.56	0.18
2010	133	0.61	0.56	0.20
2011	234	0.43	0.38	0.21
2012	232	0.44	0.40	0.18
2013	228	0.47	0.44	0.17
2014	222	0.44	0.41	0.20

Table 2.21: Annual cost efficiency for agricultural cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	42	0.73	0.75	0.15
2006	51	0.68	0.68	0.15
2007	52	0.70	0.70	0.14
2008	63	0.64	0.62	0.16
2009	57	0.64	0.65	0.15
2010	59	0.57	0.54	0.17
2011	86	0.45	0.38	0.19
2012	82	0.51	0.46	0.19
2013	82	0.52	0.48	0.18
2014	87	0.43	0.40	0.18

Table 2.22: Annual cost efficiency for agricultural cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	32	0.78	0.77	0.15
2006	30	0.74	0.72	0.16
2007	34	0.80	0.79	0.15
2008	35	0.67	0.68	0.16
2009	35	0.72	0.70	0.14
2010	36	0.63	0.61	0.16
2011	73	0.50	0.45	0.19
2012	62	0.53	0.51	0.19
2013	61	0.55	0.52	0.19
2014	61	0.52	0.47	0.26

Table 2.23: Annual cost efficiency for agricultural cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	14	0.91	0.97	0.13
2006	15	0.86	0.87	0.15
2007	17	0.77	0.76	0.18
2008	20	0.67	0.66	0.18
2009	17	0.79	0.81	0.21
2010	24	0.70	0.71	0.21
2011	39	0.58	0.58	0.19
2012	38	0.62	0.61	0.19
2013	36	0.57	0.56	0.16
2014	34	0.62	0.61	0.17

Table 2.24: Annual cost efficiency for agricultural cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	4	0.92	0.94	0.09
2006	6	0.99	1.00	0.03
2007	16	0.87	0.95	0.17
2008	27	0.76	0.76	0.20
2009	16	0.87	0.92	0.16
2010	18	0.84	0.94	0.20
2011	61	0.75	0.79	0.20
2012	54	0.82	0.87	0.20
2013	49	0.78	0.80	0.20
2014	48	0.79	0.87	0.22

Table 2.25: Annual multiproduct scale economies for agricultural cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	172	1.13	0.98	0.70
2006	158	1.24	1.02	0.98
2007	137	1.27	0.94	1.30
2008	116	1.63	1.06	1.83
2009	130	1.54	0.93	1.71
2010	122	1.63	1.02	2.13
2011	197	2.52	1.52	2.56
2012	214	1.22	1.17	0.25
2013	208	1.20	1.15	0.27
2014	202	2.73	2.22	2.25

Table 2.26: Annual multiproduct scale economies for agricultural cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	41	0.92	0.93	0.07
2006	50	0.93	0.96	0.09
2007	50	0.92	0.96	0.09
2008	59	0.90	0.92	0.08
2009	53	0.89	0.90	0.09
2010	56	0.97	0.91	0.20
2011	79	1.01	1.02	0.37
2012	73	0.93	0.92	0.15
2013	75	0.95	0.93	0.11
2014	81	1.03	0.89	0.43

Table 2.27: Annual multiproduct scale economies for agricultural cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	28	0.87	0.93	0.12
2006	27	0.86	0.85	0.11
2007	28	0.93	0.94	0.07
2008	34	0.89	0.93	0.08
2009	34	0.88	0.91	0.07
2010	35	0.82	0.85	0.13
2011	66	0.80	0.90	0.22
2012	56	0.83	0.86	0.14
2013	56	0.84	0.87	0.11
2014	54	0.79	0.83	0.17

Table 2.28: Annual multiproduct scale economies for agricultural cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	6	0.85	0.86	0.08
2006	7	0.82	0.86	0.06
2007	17	0.84	0.88	0.11
2008	18	0.88	0.89	0.08
2009	13	0.86	0.90	0.14
2010	20	0.77	0.75	0.11
2011	36	0.69	0.66	0.14
2012	37	0.68	0.66	0.14
2013	36	0.79	0.81	0.09
2014	32	0.70	0.71	0.07

Table 2.29: Annual multiproduct scale economies for agricultural cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	3	0.74	0.73	0.04
2006	4	0.84	0.84	0.04
2007	10	0.83	0.84	0.06
2008	20	0.85	0.88	0.09
2009	11	0.76	0.83	0.15
2010	10	0.78	0.79	0.06
2011	52	0.71	0.73	0.12
2012	40	0.74	0.76	0.11
2013	41	0.71	0.74	0.16
2014	33	0.69	0.70	0.12

Table 2.30: Annual grain-specific scale economies for agricultural cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	89	0.74	0.90	0.29
2006	96	0.73	0.76	0.23
2007	82	0.87	0.90	0.15
2008	56	0.80	0.85	0.19
2009	62	0.89	0.96	0.16
2010	57	0.78	0.81	0.24
2011	89	0.84	0.91	0.17
2012	97	0.91	1.00	0.14
2013	92	0.99	1.00	0.03
2014	81	0.97	0.99	0.05

Table 2.31: Annual grain-specific scale economies for agricultural cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	36	0.72	0.75	0.20
2006	43	0.76	0.74	0.19
2007	42	0.83	0.88	0.16
2008	46	0.79	0.83	0.17
2009	44	0.84	0.89	0.18
2010	44	0.76	0.75	0.17
2011	58	0.94	0.99	0.10
2012	55	0.85	0.85	0.12
2013	56	0.97	0.99	0.05
2014	62	0.97	1.00	0.07

Table 2.32: Annual grain-specific scale economies for agricultural cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	23	0.71	0.64	0.16
2006	19	0.79	0.85	0.21
2007	23	0.80	0.87	0.21
2008	27	0.75	0.75	0.19
2009	26	0.80	0.84	0.13
2010	28	0.62	0.65	0.25
2011	53	0.96	1.00	0.08
2012	44	0.88	0.91	0.14
2013	44	0.91	0.94	0.11
2014	39	0.92	0.99	0.12

Table 2.33: Annual grain-specific scale economies for agricultural cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	4	0.62	0.65	0.12
2006	7	0.70	0.75	0.26
2007	16	0.61	0.61	0.19
2008	16	0.77	0.81	0.24
2009	8	0.64	0.56	0.24
2010	16	0.69	0.74	0.22
2011	33	0.83	0.87	0.16
2012	30	0.72	0.77	0.22
2013	29	0.91	0.94	0.09
2014	29	0.85	0.95	0.20

Table 2.34: Annual grain-specific scale economies for agricultural cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	2	0.39	0.39	0.08
2006	4	0.80	0.82	0.19
2007	10	0.65	0.62	0.18
2008	20	0.67	0.64	0.23
2009	7	0.66	0.83	0.33
2010	9	0.46	0.43	0.30
2011	48	0.77	0.79	0.18
2012	35	0.68	0.75	0.23
2013	30	0.80	0.90	0.21
2014	27	0.79	0.76	0.18

Table 2.35: Annual farm-specific scale economies for agricultural cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	145	0.79	0.82	0.19
2006	132	0.84	0.83	0.12
2007	112	0.80	0.84	0.17
2008	92	0.89	0.93	0.14
2009	101	0.70	0.78	0.27
2010	100	0.80	0.86	0.20
2011	179	0.95	1.00	0.13
2012	191	0.99	1.00	0.02
2013	173	0.96	1.00	0.09
2014	170	0.99	1.00	0.05

Table 2.36: Annual farm-specific scale economies for agricultural cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	35	0.87	0.87	0.10
2006	41	0.84	0.82	0.10
2007	41	0.88	0.92	0.11
2008	46	0.81	0.85	0.15
2009	40	0.92	0.93	0.06
2010	46	0.90	0.95	0.13
2011	70	0.84	0.96	0.22
2012	57	0.94	0.99	0.09
2013	57	0.90	0.93	0.12
2014	61	0.97	1.00	0.09

Table 2.37: Annual farm-specific scale economies for agricultural cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	23	0.84	0.90	0.18
2006	23	0.80	0.79	0.15
2007	21	0.79	0.83	0.16
2008	27	0.79	0.89	0.26
2009	32	0.94	0.98	0.09
2010	31	0.81	0.86	0.20
2011	52	0.76	0.78	0.24
2012	46	0.82	0.86	0.16
2013	39	0.86	0.91	0.13
2014	42	0.81	0.95	0.24

Table 2.38: Annual farm-specific scale economies for agricultural cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	6	0.84	0.89	0.17
2006	5	0.67	0.70	0.09
2007	12	0.79	0.79	0.12
2008	14	0.74	0.83	0.26
2009	10	0.83	0.83	0.15
2010	19	0.84	0.93	0.17
2011	32	0.76	0.77	0.18
2012	30	0.67	0.68	0.19
2013	30	0.80	0.81	0.11
2014	27	0.75	0.74	0.17

Table 2.39: Annual farm-specific scale economies for agricultural cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	2	0.57	0.57	0.07
2006	4	0.74	0.75	0.13
2007	6	0.79	0.77	0.08
2008	13	0.68	0.77	0.31
2009	10	0.78	0.81	0.19
2010	10	0.88	0.89	0.10
2011	36	0.69	0.68	0.20
2012	34	0.65	0.65	0.22
2013	36	0.62	0.64	0.28
2014	31	0.68	0.73	0.23

Table 2.40: Annual service-specific scale economies for agricultural cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	155	0.81	0.83	0.17
2006	139	0.79	0.82	0.17
2007	119	0.88	0.90	0.11
2008	101	0.77	0.79	0.22
2009	114	0.86	0.94	0.17
2010	107	0.82	0.90	0.21
2011	151	0.93	0.99	0.09
2012	167	0.91	0.98	0.13
2013	165	0.97	1.00	0.06
2014	161	0.89	1.00	0.18

Table 2.41: Annual service-specific scale economies for agricultural cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	34	0.71	0.70	0.12
2006	47	0.77	0.77	0.15
2007	46	0.80	0.81	0.13
2008	55	0.76	0.76	0.15
2009	50	0.87	0.92	0.16
2010	49	0.81	0.88	0.19
2011	69	0.90	0.95	0.12
2012	70	0.87	0.92	0.13
2013	71	0.92	0.96	0.10
2014	77	0.78	0.78	0.14

Table 2.42: Annual service-specific scale economies for agricultural cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	21	0.75	0.74	0.13
2006	22	0.77	0.76	0.17
2007	22	0.72	0.75	0.13
2008	31	0.73	0.72	0.16
2009	28	0.82	0.88	0.20
2010	28	0.74	0.93	0.31
2011	61	0.88	0.91	0.11
2012	54	0.87	0.90	0.13
2013	52	0.86	0.92	0.14
2014	52	0.74	0.76	0.13

Table 2.43: Annual service-specific scale economies for agricultural cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	6	0.59	0.59	0.11
2006	7	0.82	0.80	0.11
2007	14	0.76	0.72	0.25
2008	16	0.70	0.65	0.17
2009	9	0.87	0.94	0.18
2010	17	0.72	0.75	0.28
2011	33	0.87	0.93	0.12
2012	35	0.80	0.84	0.16
2013	32	0.84	0.86	0.12
2014	32	0.81	0.85	0.13

Table 2.44: Annual service-specific scale economies for agricultural cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	2	0.67	0.67	0.21
2006	4	0.80	0.79	0.07
2007	8	0.63	0.61	0.16
2008	14	0.59	0.59	0.19
2009	9	0.74	0.75	0.16
2010	5	0.70	0.76	0.25
2011	42	0.85	0.86	0.14
2012	33	0.86	0.90	0.16
2013	36	0.77	0.81	0.21
2014	31	0.81	0.84	0.14

Table 2.45: Annual other product-specific scale economies for agricultural cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	128	0.92	1.00	0.15
2006	121	0.95	1.00	0.09
2007	100	0.86	0.92	0.17
2008	87	0.97	1.00	0.09
2009	107	0.96	1.00	0.10
2010	94	0.93	1.00	0.11
2011	184	0.89	1.00	0.17
2012	186	0.98	1.00	0.07
2013	178	0.98	1.00	0.06
2014	172	0.94	1.00	0.13

Table 2.46: Annual other product-specific scale economies for agricultural cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	33	0.96	1.00	0.09
2006	39	0.97	1.00	0.08
2007	31	0.77	0.82	0.22
2008	39	0.94	1.00	0.13
2009	43	0.98	1.00	0.05
2010	45	0.93	0.96	0.08
2011	69	0.89	0.98	0.15
2012	58	0.95	1.00	0.09
2013	59	0.95	1.00	0.07
2014	64	0.96	1.00	0.11

Table 2.47: Annual other product-specific scale economies for agricultural cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	21	0.94	1.00	0.11
2006	23	0.96	1.00	0.10
2007	18	0.83	0.90	0.20
2008	28	0.95	1.00	0.10
2009	31	0.98	1.00	0.05
2010	33	0.94	1.00	0.09
2011	57	0.96	1.00	0.08
2012	47	0.97	1.00	0.07
2013	41	0.98	1.00	0.06
2014	41	0.97	1.00	0.08

Table 2.48: Annual other product-specific scale economies for agricultural cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	5	1.00	1.00	0.00
2006	2	0.92	0.92	0.08
2007	10	0.96	1.00	0.08
2008	14	0.96	1.00	0.09
2009	11	0.92	0.98	0.17
2010	17	0.93	1.00	0.17
2011	33	0.99	1.00	0.04
2012	33	0.90	1.00	0.14
2013	34	0.98	1.00	0.04
2014	28	0.91	0.92	0.09

Table 2.49: Annual other product-specific scale economies for agricultural cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	3	0.89	0.85	0.09
2006	3	0.99	1.00	0.02
2007	3	0.81	0.75	0.17
2008	15	0.97	1.00	0.07
2009	6	0.87	1.00	0.31
2010	8	0.96	1.00	0.06
2011	42	0.96	1.00	0.09
2012	29	0.82	0.88	0.17
2013	25	0.93	1.00	0.12
2014	29	0.89	0.96	0.12

Table 2.50: Annual economies of scope: grain vs farm, service, and other for cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	89	0.10	0.08	0.13
2006	96	0.18	0.13	0.18
2007	82	0.07	0.01	0.20
2008	56	0.28	0.24	0.15
2009	62	0.15	0.11	0.16
2010	57	0.36	0.31	0.20
2011	89	0.42	0.37	0.19
2012	97	0.24	0.22	0.13
2013	92	0.19	0.14	0.15
2014	81	0.47	0.46	0.18

Table 2.51: Annual economies of scope: grain vs farm, service, and other for cooperatives greater than $15 million less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	36	0.06	0.03	0.11
2006	43	0.05	0.04	0.06
2007	42	0.03	0.01	0.06
2008	46	0.16	0.15	0.08
2009	44	0.03	0.01	0.12
2010	44	0.19	0.15	0.15
2011	58	0.23	0.21	0.15
2012	55	0.10	0.06	0.11
2013	56	0.04	0.04	0.09
2014	62	0.23	0.17	0.16

Table 2.52: Annual economies of scope: grain vs farm, service, and other for cooperatives greater than $30 million less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	23	0.08	0.07	0.07
2006	19	0.04	0.00	0.11
2007	23	0.07	0.05	0.07
2008	27	0.10	0.11	0.06
2009	26	0.02	0.00	0.07
2010	28	0.10	0.10	0.12
2011	53	0.04	0.06	0.12
2012	44	0.00	-0.02	0.06
2013	44	-0.04	-0.04	0.05
2014	39	0.10	0.10	0.08

Table 2.53: Annual economies of scope: grain vs farm, service, and other for cooperatives greater than $60 million less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	4	0.11	0.11	0.02
2006	7	0.13	0.08	0.15
2007	16	0.25	0.25	0.21
2008	16	0.11	0.09	0.12
2009	8	0.13	0.14	0.12
2010	16	0.03	0.04	0.14
2011	33	-0.09	-0.09	0.11
2012	30	-0.04	-0.04	0.08
2013	29	-0.06	-0.06	0.11
2014	29	-0.01	-0.02	0.08

Table 2.54: Annual economies of scope: grain vs farm, service, and other for cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	2	0.14	0.14	0.01
2006	4	0.04	0.04	0.04
2007	10	0.22	0.20	0.12
2008	20	0.22	0.17	0.15
2009	7	0.20	0.17	0.10
2010	9	0.15	0.14	0.24
2011	48	-0.09	-0.10	0.15
2012	35	-0.04	-0.05	0.12
2013	30	-0.11	-0.13	0.15
2014	27	-0.10	-0.07	0.10

Table 2.55: Annual economies of scope: farm vs grain, service, and other for cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	145	0.19	0.15	0.16
2006	132	0.19	0.17	0.11
2007	112	0.13	0.10	0.15
2008	92	0.22	0.19	0.14
2009	101	0.21	0.18	0.27
2010	100	0.31	0.25	0.27
2011	179	0.52	0.51	0.26
2012	191	0.19	0.16	0.11
2013	173	0.17	0.14	0.10
2014	170	0.57	0.59	0.20

Table 2.56: Annual economies of scope: farm vs grain, service, and other for cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	35	0.10	0.08	0.06
2006	41	0.15	0.15	0.08
2007	41	0.08	0.07	0.07
2008	46	0.08	0.07	0.08
2009	40	-0.02	-0.03	0.07
2010	46	0.07	0.03	0.14
2011	70	0.12	0.12	0.21
2012	57	0.03	0.03	0.06
2013	57	0.06	0.06	0.06
2014	61	0.19	0.13	0.16

Table 2.57: Annual economies of scope: farm vs grain, service, and other for cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	23	0.05	0.06	0.03
2006	23	0.11	0.09	0.07
2007	21	0.16	0.20	0.10
2008	27	0.14	0.12	0.10
2009	32	0.02	0.00	0.06
2010	31	0.00	0.02	0.08
2011	52	-0.10	-0.09	0.17
2012	46	-0.02	-0.01	0.06
2013	39	-0.01	-0.01	0.05
2014	42	0.01	0.03	0.13

Table 2.58: Annual economies of scope: farm vs grain, service, and other for cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	6	0.07	0.07	0.05
2006	5	0.06	0.06	0.03
2007	12	0.16	0.17	0.08
2008	14	0.14	0.17	0.10
2009	10	0.06	0.03	0.09
2010	19	-0.05	-0.03	0.08
2011	32	-0.20	-0.23	0.11
2012	30	-0.08	-0.08	0.07
2013	30	-0.03	-0.02	0.06
2014	27	-0.17	-0.17	0.10

Table 2.59: Annual economies of scope: farm vs grain, service, and other for cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	2	0.18	0.18	0.05
2006	4	0.03	0.03	0.05
2007	6	0.22	0.24	0.07
2008	13	0.15	0.17	0.11
2009	10	0.09	0.04	0.10
2010	10	-0.04	-0.06	0.14
2011	36	-0.11	-0.13	0.13
2012	34	0.02	-0.01	0.12
2013	36	-0.01	-0.01	0.10
2014	31	-0.13	-0.13	0.14

Table 2.60: Annual economies of scope: service vs grain, farm, and other for cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	155	0.24	0.21	0.17
2006	139	0.27	0.23	0.18
2007	119	0.16	0.08	0.21
2008	101	0.32	0.26	0.21
2009	114	0.31	0.26	0.30
2010	107	0.34	0.30	0.26
2011	151	0.37	0.35	0.21
2012	167	0.21	0.19	0.12
2013	165	0.16	0.12	0.12
2014	161	0.48	0.51	0.24

Table 2.61: Annual economies of scope: service vs grain, farm, and other for cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	34	0.18	0.17	0.06
2006	47	0.15	0.14	0.10
2007	46	0.11	0.10	0.09
2008	55	0.18	0.18	0.09
2009	50	0.04	-0.01	0.16
2010	49	0.14	0.07	0.17
2011	69	0.09	0.08	0.17
2012	70	0.08	0.05	0.10
2013	71	0.03	0.02	0.07
2014	77	0.13	0.09	0.19

Table 2.62: Annual economies of scope: service vs grain, farm, and other for cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	21	0.17	0.17	0.04
2006	22	0.14	0.13	0.08
2007	22	0.18	0.19	0.09
2008	31	0.19	0.18	0.10
2009	28	0.05	0.02	0.10
2010	28	0.20	0.19	0.22
2011	61	-0.06	-0.01	0.17
2012	54	0.00	0.01	0.08
2013	52	-0.02	-0.03	0.07
2014	52	0.00	0.01	0.12

Table 2.63: Annual economies of scope: service vs grain, farm, and other for cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	6	0.21	0.21	0.06
2006	7	0.20	0.17	0.11
2007	14	0.29	0.29	0.12
2008	16	0.26	0.22	0.12
2009	9	0.12	0.13	0.11
2010	17	0.17	0.16	0.16
2011	33	-0.17	-0.22	0.15
2012	35	-0.01	-0.02	0.14
2013	32	-0.08	-0.08	0.10
2014	32	-0.12	-0.14	0.12

Table 2.64: Annual economies of scope: service vs grain, farm, and other for cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	2	0.23	0.23	0.09
2006	4	0.12	0.12	0.03
2007	8	0.19	0.18	0.10
2008	14	0.31	0.30	0.13
2009	9	0.14	0.13	0.07
2010	5	0.15	0.08	0.24
2011	42	-0.06	-0.04	0.18
2012	33	0.03	0.04	0.15
2013	36	0.04	0.05	0.12
2014	31	-0.09	-0.10	0.10

Table 2.65: Annual economies of scope: other vs grain, farm, and service for cooperatives less than $15 million in assets

Year	N	Mean	Median	Std. Dev.
2005	128	0.15	0.08	0.19
2006	121	0.15	0.08	0.19
2007	100	0.16	0.08	0.23
2008	87	0.28	0.20	0.23
2009	107	0.21	0.12	0.31
2010	94	0.32	0.29	0.22
2011	184	0.46	0.47	0.26
2012	186	0.17	0.15	0.11
2013	178	0.16	0.12	0.12
2014	172	0.51	0.56	0.24

Table 2.66: Annual economies of scope: other vs grain, farm, and service for cooperatives greater than $15 million and less than $30 million in assets

Year	N	Mean	Median	Std. Dev.
2005	33	0.04	0.01	0.07
2006	39	0.05	0.03	0.07
2007	31	0.07	0.01	0.11
2008	39	0.10	0.09	0.10
2009	43	0.00	-0.03	0.09
2010	45	0.11	0.09	0.10
2011	69	0.12	0.10	0.15
2012	58	0.04	0.03	0.05
2013	59	0.03	0.02	0.05
2014	64	0.15	0.11	0.16

Table 2.67: Annual economies of scope: other vs grain, farm, and service for cooperatives greater than $30 million and less than $60 million in assets

Year	N	Mean	Median	Std. Dev.
2005	21	0.02	0.00	0.09
2006	23	0.04	0.01	0.10
2007	18	0.09	0.03	0.13
2008	28	0.07	0.05	0.08
2009	31	0.00	-0.01	0.04
2010	33	0.05	0.02	0.07
2011	57	0.01	0.00	0.09
2012	47	0.01	0.01	0.04
2013	41	0.00	0.00	0.03
2014	41	0.04	0.02	0.08

Table 2.68: Annual economies of scope: other vs grain, farm, and service for cooperatives greater than $60 million and less than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	5	0.00	0.01	0.01
2006	2	0.00	0.00	0.00
2007	10	0.03	0.02	0.03
2008	14	0.02	0.03	0.04
2009	11	0.05	-0.01	0.21
2010	17	0.00	0.00	0.03
2011	33	-0.03	-0.03	0.05
2012	33	0.01	0.01	0.09
2013	34	-0.01	-0.01	0.02
2014	28	0.00	0.00	0.02

Table 2.69: Annual economies of scope: other vs grain, farm, and service for cooperatives greater than $100 million in assets

Year	N	Mean	Median	Std. Dev.
2005	3	-0.02	-0.01	0.02
2006	3	0.00	-0.01	0.01
2007	3	0.01	0.00	0.02
2008	15	0.02	0.02	0.02
2009	6	0.00	0.00	0.01
2010	8	-0.01	0.00	0.03
2011	42	0.00	-0.01	0.11
2012	29	0.03	0.01	0.12
2013	25	0.01	0.00	0.10
2014	29	0.02	0.01	0.07

Figures

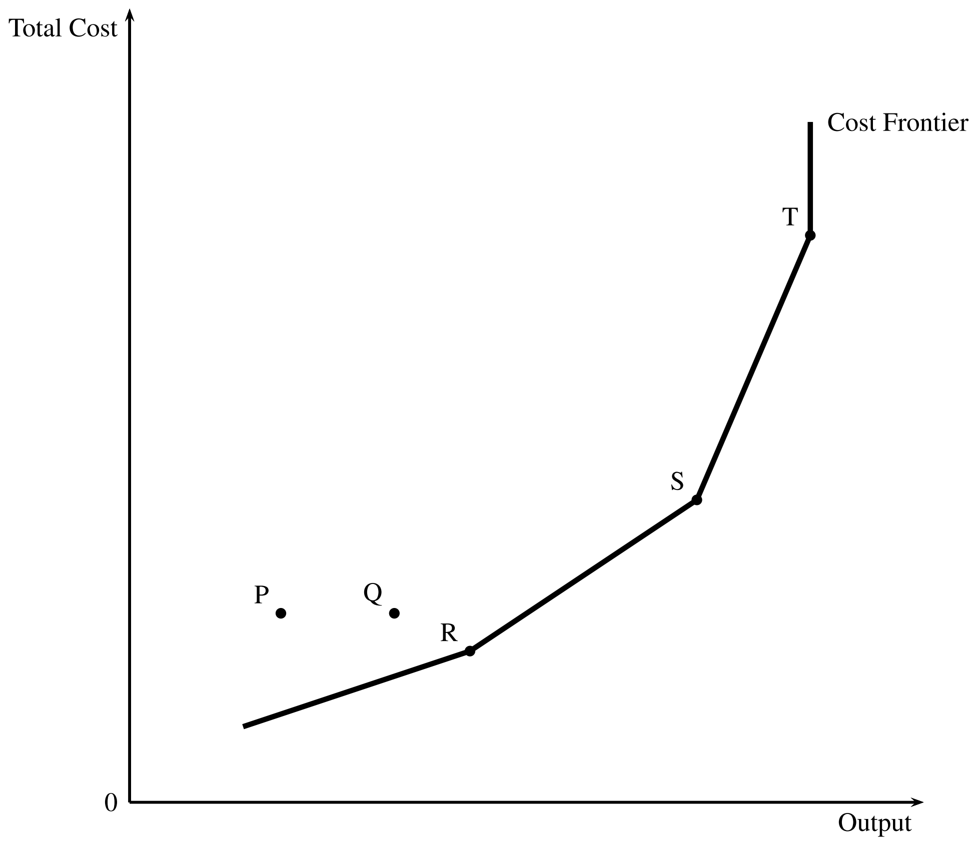

Figure 2.1: Actual total cost and minimum total cost frontier

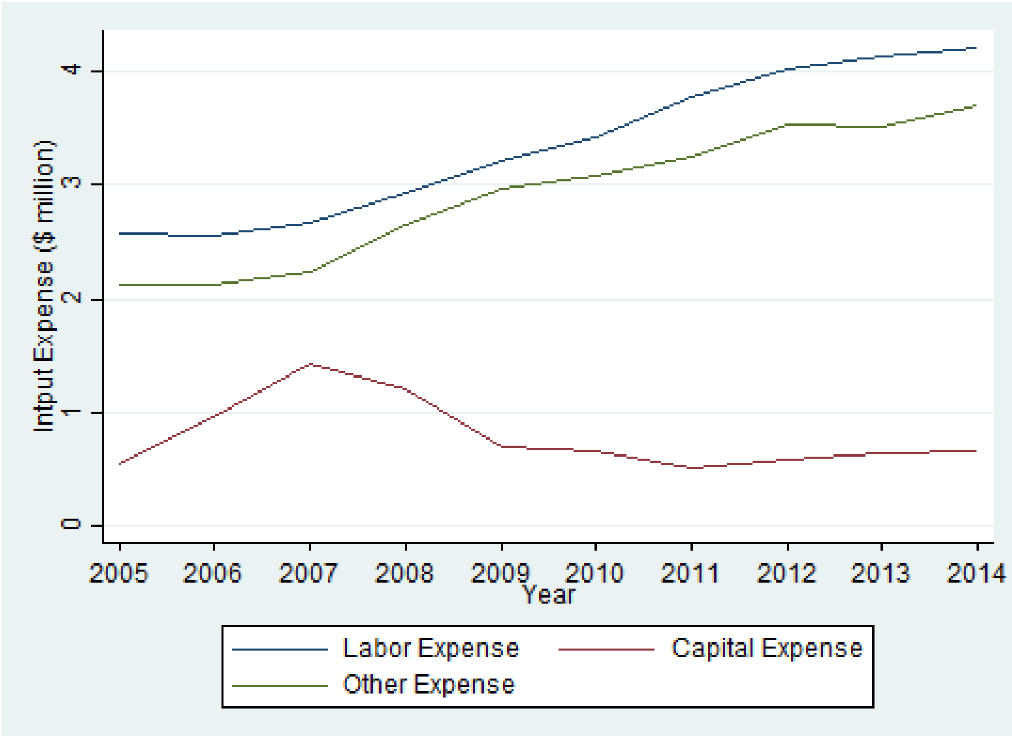

Figure 2.2: Average annual input expense for agricultural cooperatives

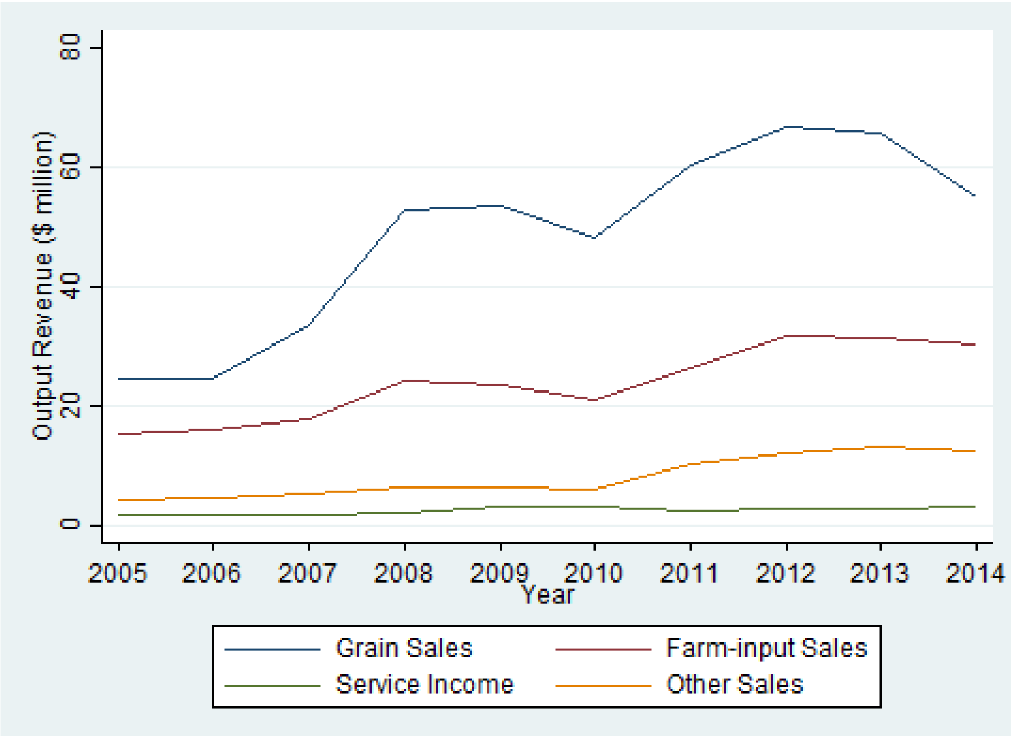

Figure 2.3: Average annual output revenue for agricultural cooperatives

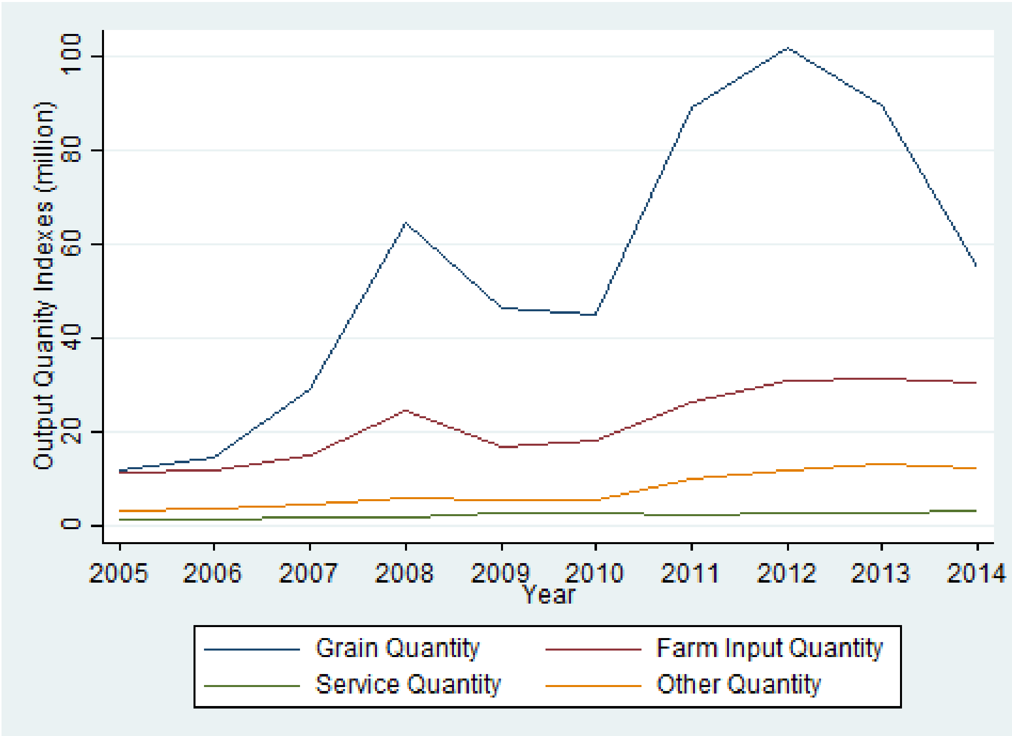

Figure 2.4: Annual average output quantity (index) for agricultural cooperatives

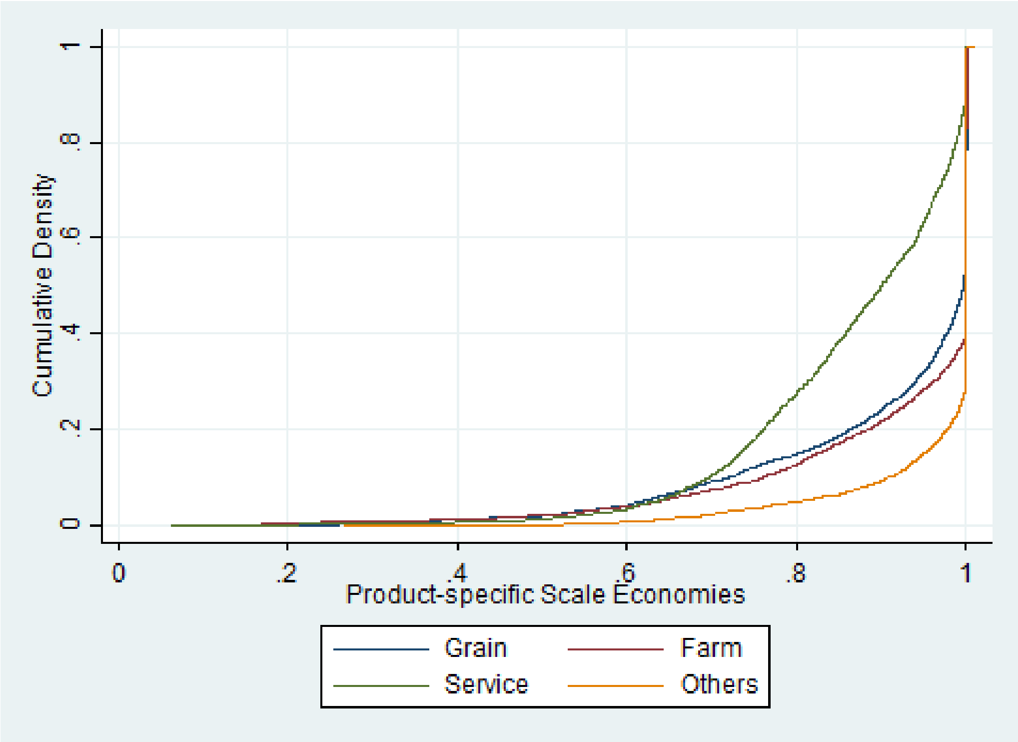

Figure 2.5: Cumulative density of product-specific scale economies from a single frontier

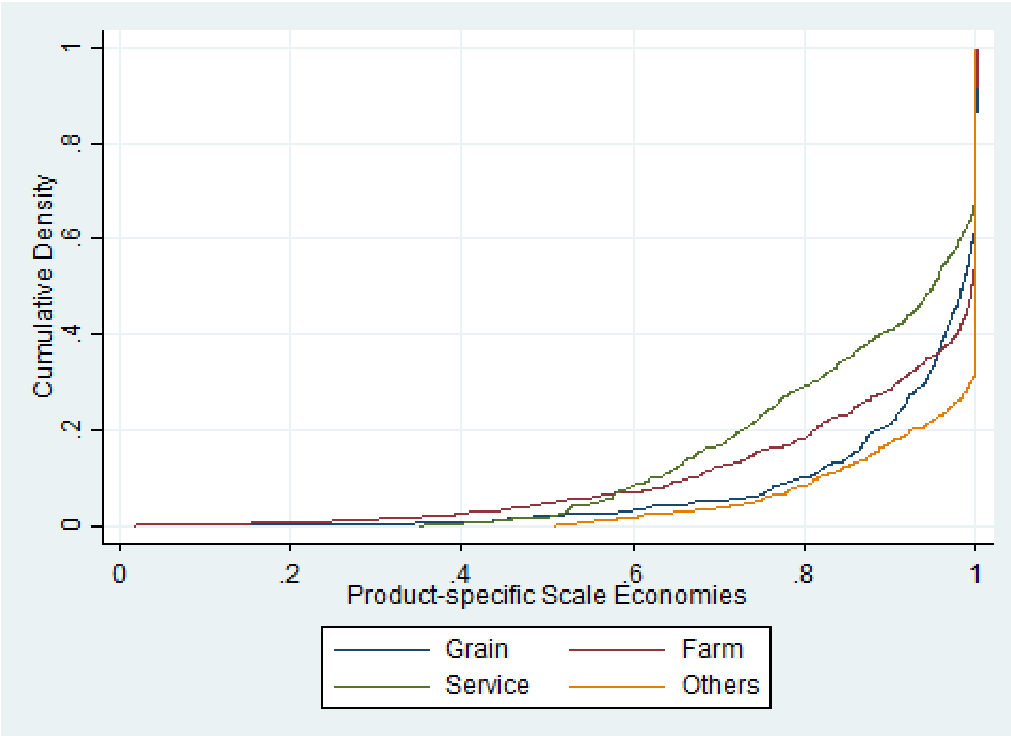

Figure 2.6: Cumulative density of product-specific scale economies from annual frontiers

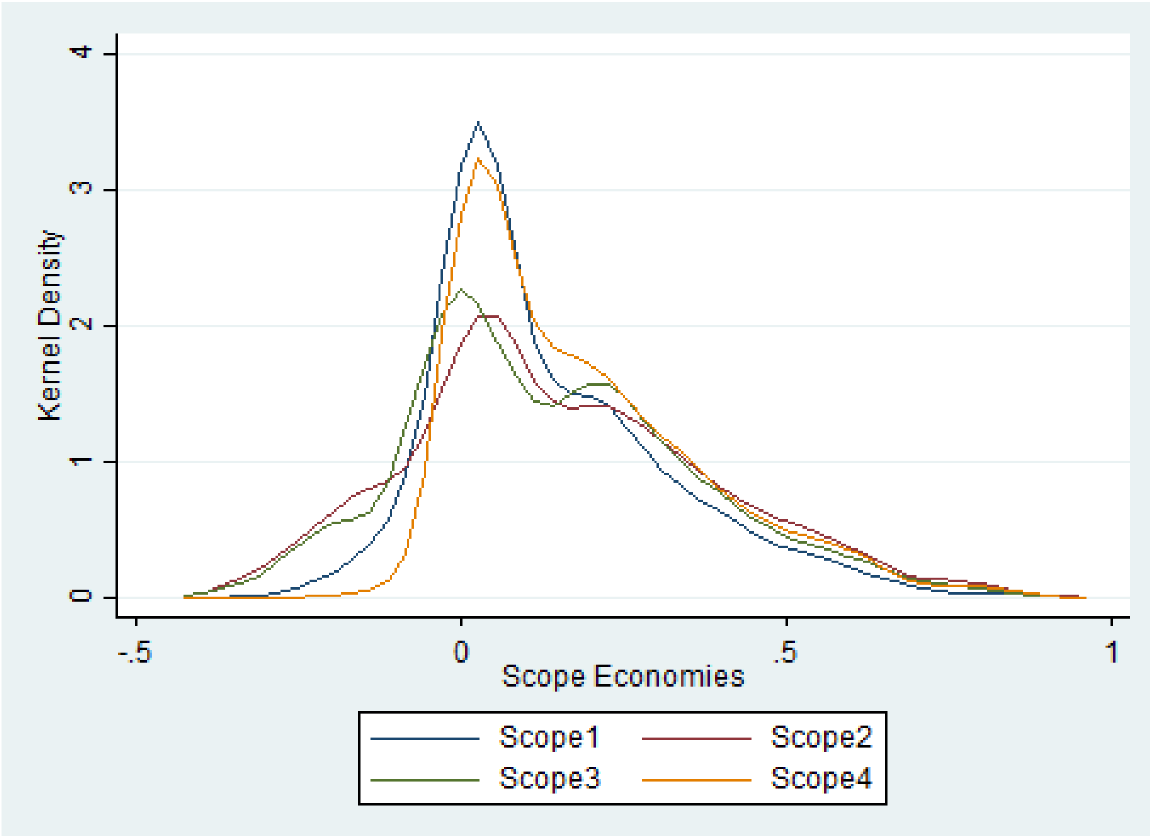

Figure 2.7: Kernel density of scope economies from a single frontier

Note: Scope1: grain separately vs farm, service and others jointly; Scope2: farm input separately vs grain, service and others jointly; Scope3: service separately vs grain, farm, and others jointly and Scope4: other separately vs grain, farm, and service jointly.

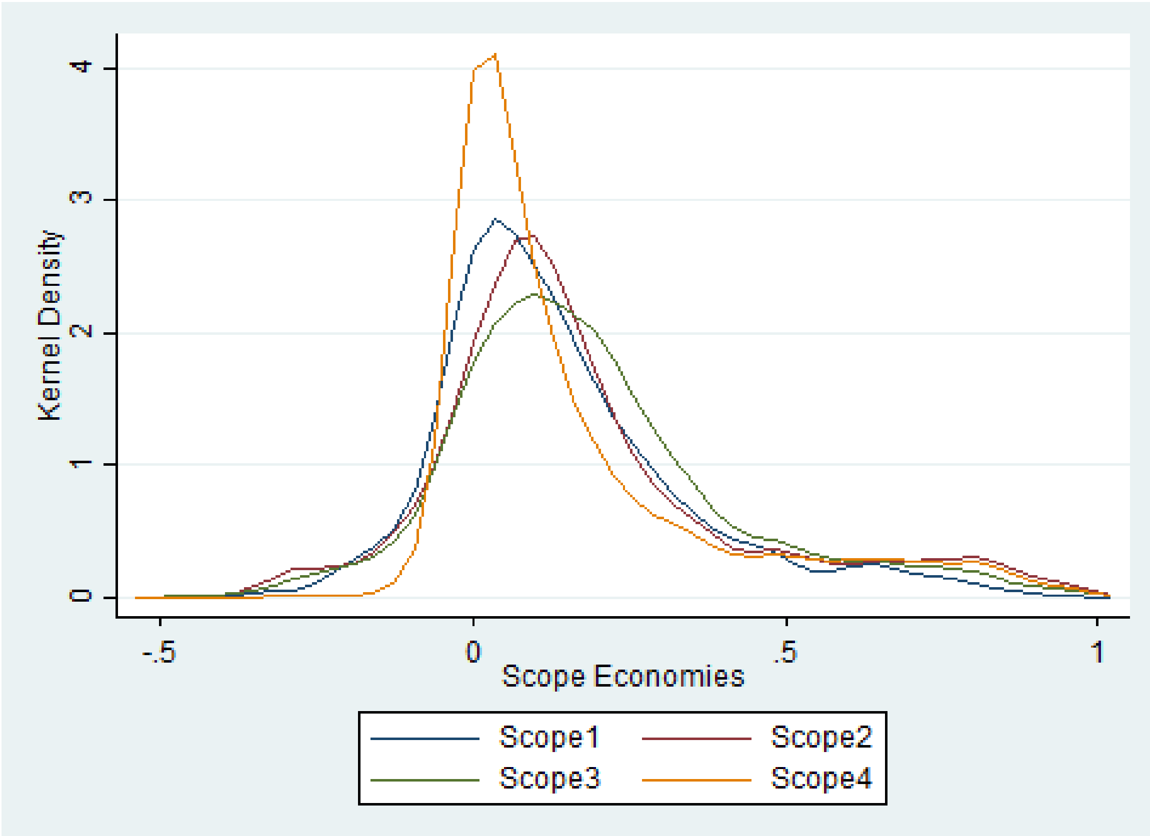

Figure 2.8: Kernel density of scope economies from annual frontiers

Note: Scope1: grain separately vs farm, service and others jointly; Scope2: farm input separately vs grain, service and others jointly; Scope3: service separately vs grain, farm, and others jointly and Scope4: other separately vs grain, farm, and service jointly.

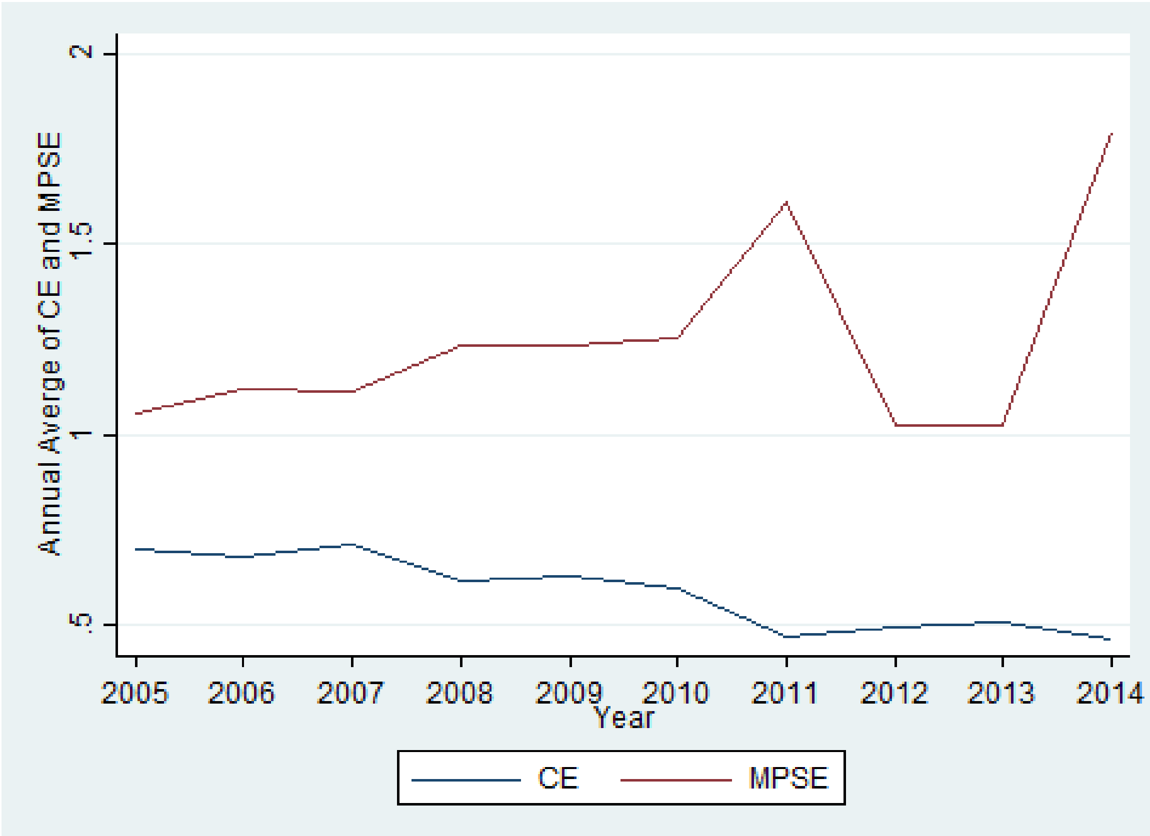

Figure 2.9: Annual average of cost efficiency (CE) and multiproduct scale economies (MPSE) for agricultural cooperatives

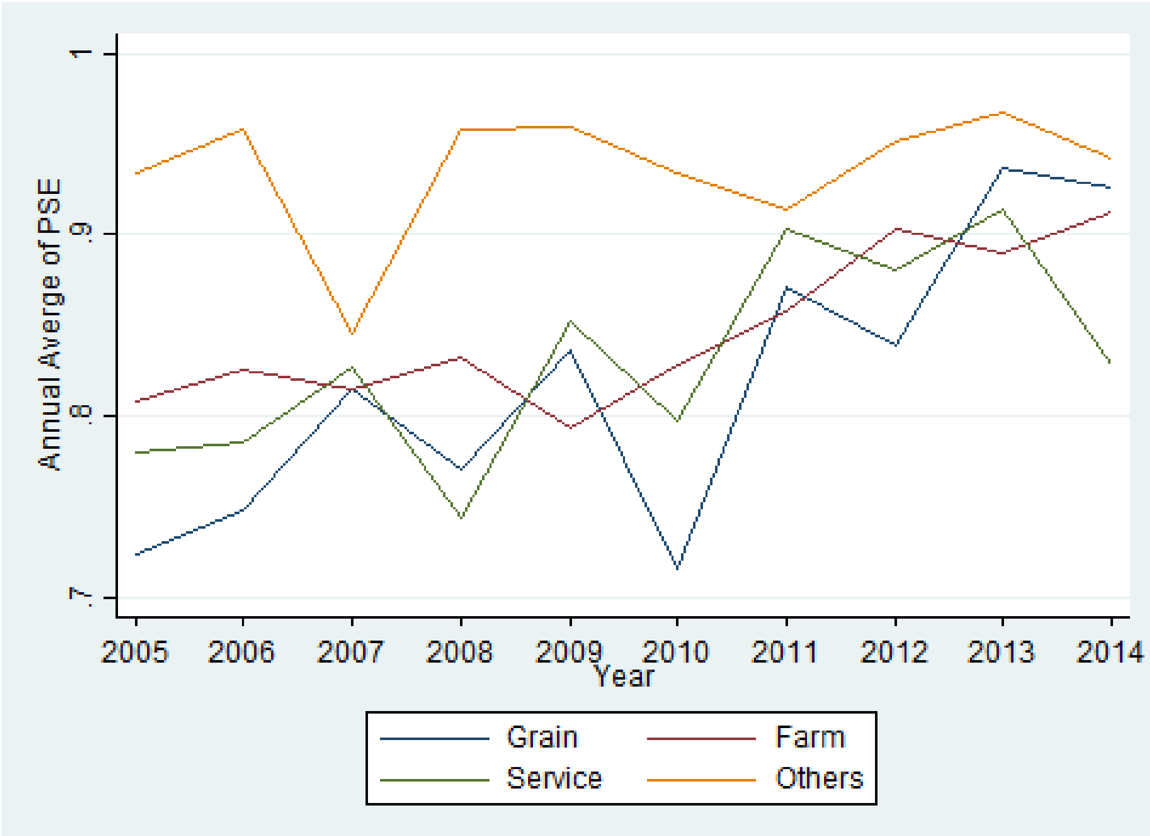

Figure 2.10: Annual average of product-specific scale economies (PSE) for agricultural cooperatives

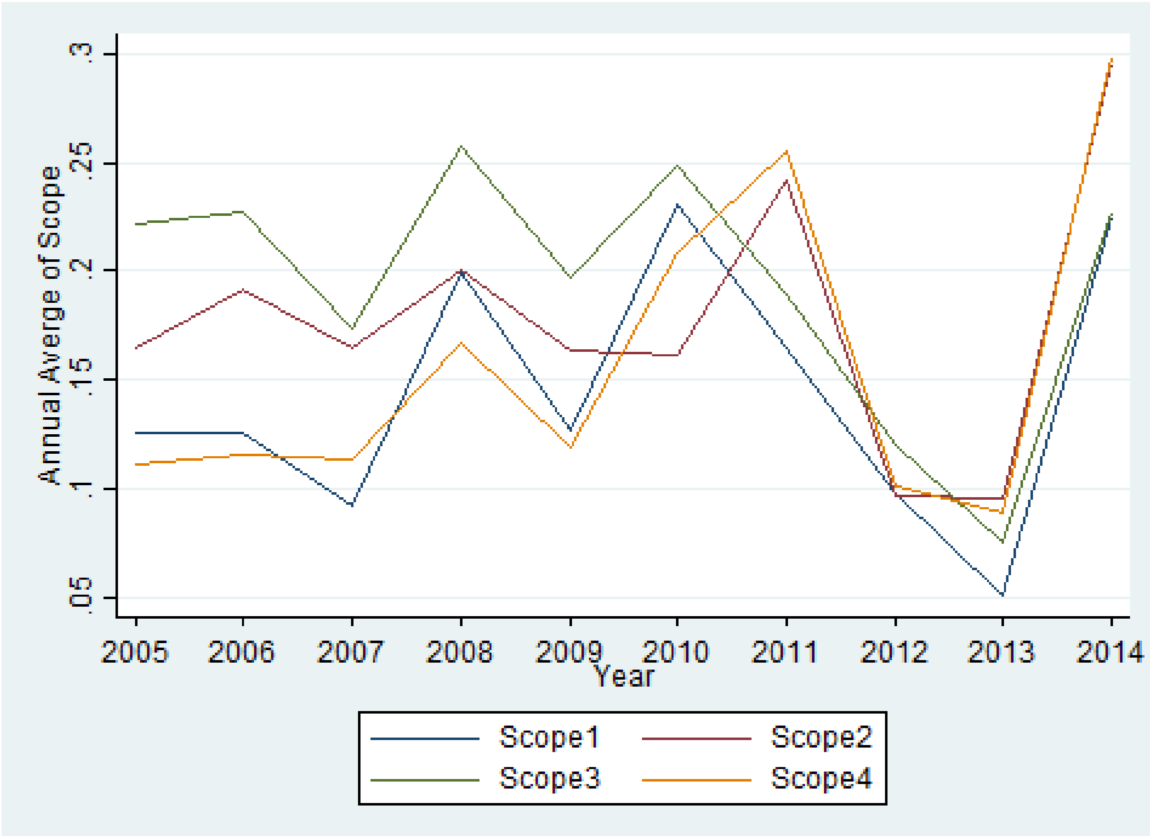

Figure 2.11: Annual average of scope economies for agricultural cooperatives

Note: Scope1: grain separately vs farm, service and others jointly; Scope2: farm input separately vs grain, service and others jointly; Scope3: service separately vs grain, farm, and others jointly and Scope4: other separately vs grain, farm, and service jointly.

Chapter 3

Examining the Productivity Growth of Agricultural Cooperatives

3.1 Introduction

Productivity growth occurs when less input is used to produce the same level of output or more output is produced using the same level of input. Productivity growth occurs due to increasingly efficient operations or technical change or a combination of both. The improvements in technology shift the production frontier upwards or the cost frontier downwards. Multiproduct productivity measures can be used to estimate productivity growth of firms that reflect a change in outputs that cannot be accounted for by a change in the joint inputs. This measure demonstrates the impact of new technology, economies of scale and management on productivity (Ariyaratne, Featherstone, and Langemeier, 2006).

In a competitive business environment, inefficient firms shut down and the average efficiency level increases in the industry. Firms become more efficient in the use of resources such as labor, capital through better utilization of production, increasing managerial efficiency and better capacity utilization due to improved technology (Deb and Ray, 2014).

An agricultural cooperative is an important institutional form supporting farmers in the United States. Cooperatives have gone through significant market fluctuations since 2005 due to the high volatility of commodity prices, increased competition, consolidations, mergers, and acquisitions. The number of agricultural cooperatives decreased by almost 30 percent from 2005 to 2014; however, gross sales more than doubled and market share is more concentrated. For example, the top 10 largest agricultural cooperatives accounted for 43 percent of cooperatives' gross business volume and 38 percent of total assets in 2014 (U.S. Department of Agriculture, 2016). In a dynamic market, efficient and productive operations are critical factors for survival in the industry. Moreover, the existence of agricultural cooperatives has strong implications for the U.S. rural agricultural economy as these cooperatives provide inputs to farmers and provide processing and marketing services and other logistical supports to move products to markets and negotiate sales (Cobia, 1989).

Previous estimates of productivity growth using the Malmquist index in a data envelopment analysis framework assumes constant returns to scale (CRS) and decomposes the Malmquist index into technical change and efficiency change (Ariyaratne, Featherstone, and Langemeier, 2006; Umetsu, Lekprichakul, and Chakravorty, 2003; Yamamoto, Kondo, and Sasaki, 2006). The decomposition of the Malmquist index into technical change and efficiency change may be misleading under CRS (Ray and Desli, 1997) and technical change is biased if the true technology is VRS (Funk, 2015).

The results from Chapter 2 show many agricultural cooperatives face economies of scale that are different than one, indicating that variable returns to scale (VRS) is the appropriate technology for the estimation and decomposition of productivity growth. The Malmquist index presents numerical infeasibilities for estimating cross period efficiency scores under VRS, but the biennial Malmquist index introduced by Pastor, Asmild, and Lovell (2011) provides the same decomposition as the Malmquist index and avoids a numerical infeasibility problem.

The purpose of this research is to measure productivity growth of agricultural cooperatives. The objective is to estimate the productivity growth of agricultural cooperatives using the biennial Malmquist productivity index (BMI) assuming variable returns to scale. A data envelopment analysis (DEA) approach is used to measure the BMI. This study also decomposes the BMI into efficiency change and technical change to examine the sources of productivity growth. One of main advantages of the biennial Malmquist index is that it does not impose any specific functional form on the production function. The traditional parametric approach for analyzing technical change may be sensitive to the functional form (Diamond, McFadden, and Rodriguez, 1978).

The biennial Malmquist index developed by Pastor, Asmild, and Lovell (2011) allows for technical regress, and does not need to re-calculate when a new time period is added to the data set. Productivity change between two periods using the MI has substantially changed when a third time period is added to the dataset while the BMI gives consistent results (Pastor, Asmild, and Lovell, 2011).

The rest of the study is organized as follows. Section two reviews relevant literature on productivity growth. Section three and four present the theoretical framework for the BMI and decomposition of the BMI into technical change and efficiency change in explaining productivity and data description, respectively. The fifth section reports empirical results. The last section concludes.

3.2 Productivity Growth

Productivity growth is one of the measures of firms' performance and how the frontier is shifting over time. The Malmquist index is useful in examining productivity growth of firms (Färe et al., 1994). The Malmquist index has been widely used to estimate the total factor productivity growth of banks, credit unions, farms, and agricultural cooperatives (Ariyaratne, Featherstone, and Langemeier, 2006; Coelli and Rao, 2005; Quintana-Ashwell and Featherstone, 2014; Sufian, 2011; Worthington, 1999). One of the main findings of these studies is that firms experience productivity growth mainly due to the improvements in technology.

Yamamoto, Kondo, and Sasaki (2006) estimate total factor productivity of agricultural cooperatives in the dairy-farming region of Hokkaido in Japan from 1982 to 1991 using a nonparametric Malmquist index approach under constant returns to scale. Their results suggest that productivity growth was mainly driven by technical progress at an annual rate of 1.7% rather than progress in technical efficiency that was at an annual rate of 0.2%, on average.

Bonfiglio (2006) examines efficiency and productivity of Italian agrifood (fruit and vegetables, oil cooperatives etc.) cooperatives over the period 2000–2002 using data envelopment analysis under constant returns to scale. The Malmquist index is decomposed into technical change and efficiency change. The results exhibit that productivity improved by approximately 2% due to the progress in managerial efficiency and technical change.

In contrast to general beliefs that technical change is the prime source of productivity, a few studies find that technical efficiency change is the main source of productivity growth. Kondo et al. (2008) use a nonparametric approach to measure total productivity of agricultural cooperatives in Japan using a panel data set over the period 1982–1991 and decompose the Malmquist index into technical change and efficiency change under constant returns to scale. The results show that productivity growth is mainly driven by technical efficiency progress rather than technological progress. Likewise, Candemir et al. (2011) use a nonparametric approach under CRS to estimate production efficiencies and total factor productivity of Hazelnut agricultural sales cooperatives in Turkey over the period of 2004 to 2008 and find that these cooperatives experienced 1.3% improvements in technical efficiency, while a deterioration in technical change and productivity of 3% and 1.7%, respectively.

Previous literature using the Malmquist index mainly estimate productivity growth under constant returns to scale. Technical change often is the major source of productivity (Ariyaratne, Featherstone, and Langemeier, 2006; Bonfiglio, 2006). However, the decomposition of the Malmquist index into technical change and efficiency change may be misleading under CRS because scale efficiency does not exist if the global technology is CRS (Ray and Desli, 1997). Further, Grifell-Tatjé and Lovell (1995) argue that "in the presence of non-constant returns to scale, the Malmquist productivity index does not accurately measure productivity change. The bias is systematic, and depends on the magnitude of scale economies (p. 169)." Ray and Desli (1997) provide a modified decomposition of the Malmquist index under VRS as a benchmark. In that decomposition, constant returns to scale technology and variable returns to technology are used to estimate scale efficiency change. However, the nonparametric Malmquist index may result in a linear programming (numerical) infeasibility problem under VRS for computing cross period efficiency scores (Pastor, Asmild, and Lovell, 2011; Umetsu, Lekprichakul, and Chakravorty, 2003). Grifell-Tatjé and Lovell (1995) state that "a new productivity index is required one which scales the Malmquist productivity index by a term which accounts for returns to scale. The additional term should be comprised of distance functions so as to preserve the advantages that the Malmquist index enjoys over the Törnqvist and Fisher Ideal indexes, both of which require price information and impose possibly unwarranted behavioral assumptions (p. 174)."

The biennial Malmquist index developed by Pastor, Asmild, and Lovell (2011) avoids numerical infeasibilities and gives the similar decomposition as the Malmquist index developed by Färe et al. (1994). The biennial Malmquist index has been recently used to measure the productivity growth of wine industry, manufacturing industry, and farms (Deb and Ray, 2014; Funk, 2015; Vidal et al., 2013). Vidal et al. (2013) estimate the productivity growth of the Spanish wine sector over the period 2008 to 2010 using the biennial Malmquist index and the results show a small productivity decline over the study period. Their results under VRS and CRS are similar for scale efficiency (i.e. scale efficiency is close to one) indicating that size does not matter. Deb and Ray (2014) use the Malmquist index and biennial Malmquist index under CRS to estimate productivity growth of Indian manufacturing sector after the economic reforms of 1991. Productivity increases for all sectors at the country level except for cotton textile and chemical products after the reform. The selected industries experienced productivity gain at the national and state levels and in most cases technical progress was the main source of productivity growth. However, the textile product industry gained productivity growth even though there was technical regress. Improvements in technical efficiency and scale efficiency led to productivity growth. Funk (2015) uses the Malmquist index and biennial Malmquist index to compare the productivity growth of biotechnology adopted and non-adopted farmers in the United States. The results show a difference between the Malmquist index under CRS and the biennial Malmquist index under VRS methods, which implies that technical change is biased if it is selected under constant returns to scale instead of variable returns to scale.

3.3 Research Methods and Data

This research uses a balanced panel obtained from CoBank to calculate productivity growth of agricultural cooperatives. The balanced panel includes 171 agricultural cooperatives between 2005 and 2014. The descriptions for constructing input and output quantity indexes are given in Chapter 2.

The productivity growth of agricultural cooperatives is estimated using the biennial Malmquist index under VRS as many agricultural cooperatives face economies of scale different than one (not operating under CRS) as found in Chapter 2. The Malmquist index allows the decomposition of catching-up to the frontier (efficiency change) from shifts of the frontier (technical change).

The Malmquist index was proposed by Caves, Christensen, and Diewert (1982) as the ratio of the period t and the period $t+1$ output-orientated Shephard distance functions relative to a certain reference technology. Distance functions represent the functional relationship of output and input technologies and are equivalent to technical efficiency defined by Farrell (1957). This measure of technical efficiency shows "how far" a firm is from the frontier of technology. If a firm lies on the frontier, then the firm is technically efficient. The efficiency of other firms are compared to the efficiency of the frontier firms. Further, the Malmquist index can model multiple-output and multiple-input firms when panel data are available (Coelli et al., 2005).

Productivity growth occurs due to operations becoming closer to the technology frontier and/or the technology frontier shifting. Technical change shifts the production frontier to a higher level with a given set of inputs while efficiency change measures how close a firm is moving to the frontier firms. Improvement in the Malmquist productivity index may occur even when firms are operating inefficiently (Coelli et al., 2005).

The assumption of constant returns to scale is widely discussed in literature. The CRS assumption is appropriate when all firms are operating at an optimal scale, but due to government regulation, imperfect markets, and financial constraints, a firm may operate at sub-optimal scale. In such situations, the CRS DEA model should be adjusted to account for VRS (Banker, Charnes, and Cooper, 1984; Coelli et al., 2005).

3.3.1 Malmquist Productivity Index

Existing literature employs stochastic frontier analysis (SFA) and data envelopment analysis (DEA) for measuring the total factor productivity of firms. This research applies the DEA method as it does not impose any specific functional form on technology and is less prone to misspecification error. The flexibility in the production function is an advantage whenever the true functional form is unknown (Lovell, 1993). The DEA method was developed by Charnes, Cooper, and Rhodes (1978) who used DEA with an input orientated approach under constant returns to scale (CRS) and further generalized by Banker, Charnes, and Cooper (1984) for variable returns. The DEA method is a linear programming approach that uses observed input and output quantities to construct a piece-wise linear frontier over the data points. The piece-wise frontier is constructed using the optimal solution obtained from the linear programing problem for each firm or decision making unit. The following assumptions are the basis for constructing a production frontier (output-orientation) from observed input and output bundles (Ray, 2004).

1. The production technology (P) is a set of feasible input and output vectors: $P = [(x, y)|\ x$ can produce $y]$ i.e. all input and output bundles are feasible where $x = (x_1, \ldots, x_n)$ and $y = (y_1, \cdots, y_m)$;
2. The production set is assumed to be nonempty, closed, and convex;
3. Inputs and outputs are freely disposable.

The following steps are used to compute the Malmquist index with output orientation. First, define Shephard distance functions that represent multiple output and multiple input technology with respect to two time periods. Assume there are n inputs: $x = (x_1, \ldots, x_n)$, m outputs: $y = (y_1, \cdots, y_m)$, j cooperatives ($j = 1, 2, \ldots, k$), and t time periods ($t = 1, 2, \ldots, T$). The Malmquist index can be defined with the t period reference technology and the $t+1$ period reference technology. The Malmquist index with the t period reference technology following Caves, Christensen, and Diewert (1982) is:

$$M_o^t(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_o^t(y^{t+1}, x^{t+1})}{D_o^t(y^t, x^t)}\right] \tag{3.1}$$

where $D_o^t(y^t, x^t)$ and $D_o^t(y^{t+1}, x^{t+1})$ are the distance functions with respect to the period t and adjacent time period $t+1$ for the reference technology t. Similarly, the Malmquist index with $t+1$ reference technology is:

$$M_o^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_o^{t+1}(y^{t+1}, x^{t+1})}{D_o^{t+1}(y^t, x^t)}\right] \tag{3.2}$$

where $D_o^{t+1}(y^t, x^t)$ and $D_o^{t+1}(y^{t+1}, x^{t+1})$ are the distance functions with respect to the period t and adjacent time period $t+1$ to the benchmark technology $t+1$.

Färe et al. (1994) suggest the geometric mean of the Malmquist index for periods t and $t+1$ period to avoid choosing an arbitrary time period for estimating the productivity index. The geometric mean of the Malmquist index can be written as:

$$M_o(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_o^t(y^{t+1}, x^{t+1})}{D_o^t(y^t, x^t)} \frac{D_o^{t+1}(y^{t+1}, x^{t+1})}{D_o^{t+1}(y^t, x^t)}\right]^{0.5} \tag{3.3}$$

where the notations have the similar meaning as equations 3.1 and 3.2.

Equation (3.3) can be rewritten as similar to Fare et al. (1994):

$$M_o(.) = \frac{D_o^{t+1}(y^{t+1}, x^{t+1})}{D_o^t(y^t, x^t)} \left[\frac{D_o^t(y^{t+1}, x^{t+1})}{D_o^{t+1}(y^{t+1}, x^{t+1})} \frac{D_o^t(y^t, x^t)}{D_o^{t+1}(y^t, x^t)}\right]^{0.5} \tag{3.4}$$

where the ratios outside the brackets and inside the brackets in equation (3.4) represent efficiency change and technical change, respectively. Efficiency change indicates how successful a firm is in catching-up to the best production frontier (i.e. the change in how far observed output is from the maximum potential output). Technical change indicates the portion of productivity change accounted for by a change in the frontier. Equation (3.4) shows the impact of technical change between two periods indicating the shifts of the frontier. A numerical value of the Malmquist index greater (less) than one indicates progress (regress) in productivity and a numerical value of Malmquist index equal to one indicates no change in productivity growth.

3.3.2 Biennial Malmquist Productivity Index

The "internal inconsistencies" of the Malmquist index as stated by Ray and Desli (1997) and the problem of numerical infeasibility under variable returns to scale for estimating cross period efficiency scores motivated a new productivity index, the biennial Malmquist index (Pastor, Asmild, and Lovell, 2011). Pastor, Asmild, and Lovell (2011) state that "being forced to tell that story on the basis of a feasible subset of the data, not because of inadequacies in the data but due to a shortcoming of the analytical technique, diminishes the credibility of the story (p. 14)." The reason for using the biennial Malmquist index is that it avoids linear programming infeasibilities under any returns to scale measure and provides results closer to the adjacent Malmquist index than the global Malmquist index (Pastor, Asmild, and Lovell, 2011; Vidal et al., 2013). In additional, the BMI allows for technical regress, unlike other nonparametric Malmquist index methods developed based on Färe et al. (1994) and does not need to recompute when a new time period is added to the data. Pastor, Asmild, and Lovell (2011) indicate that productivity change between two periods using the traditional Malmquist index has substantially changed when a third time period is added to the data set while the biennial Malmquist index gives consistent results with this problem.

The biennial Malmquist index is developed based on the analysis of Färe et al. (1994) to measure productivity growth and decompose the BMI into efficiency change and technical change avoiding the numerical infeasibilities under VRS. The Malmquist index under CRS and the biennial frontier under VRS are shown in figures (3.2) and (3.3), respectively. Figure (3.3) depicts the biennial production frontier developed by Deb and Ray (2014) and a measure of output-orientated technical efficiency for a single input and single output firm with respect to periods t (point A) and $t+1$ (point B). The rays through origin OP_0 and OP_1 are the CRS frontiers for the period t and the period $t+1$. The CRS biennial frontier coincides with that of the $t+1$ period. The VRS frontier for periods t and $t+1$ are $K_0L_0M_0$ and $K_1L_1M_1$ while the biennial production frontier under VRS is denoted by the dotted line $K_1L_1DFM_0$. Output-orientated technical efficiency ($TE_c^B(y^t, x^t)$) under the CRS biennial frontier with the t reference technology is

$$TE_c^B(y^t, x^t) = AX^t/QX^t.$$

Output-orientated technical efficiency for the biennial CRS frontier with the $t+1$ reference technology is

$$TE_c^B(y^{t+1}, x^{t+1}) = BX^{t+1}/RX^{t+1}.$$

Similarly, output-orientated technical efficiency for the biennial VRS frontier with the t and $t+1$ technologies are

$$TE_v^B(y^t, x^t) = AX^t/DX^t \text{ and } \qquad TE_v^B(y^{t+1}, x^{t+1}) = BX^{t+1}/FX^{t+1}$$

where the subscripts c and v represent constant returns to scale and variable returns to scale, respectively.

The biennial Malmquist index ($M^B(y^{t+1}, x^{t+1}, y^t, x^t)$) uses a ratio of technical efficiency from the t and $t+1$ periods with the CRS and VRS frontiers are:

$$M_c^B(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{BX^{t+1}/RX^{t+1}}{AX^t/QX^t}$$

and

$$M_v^B(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{BX^{t+1}/FX^{t+1}}{AX^t/DX^t}$$

.

For the traditional Malmquist index, cross period technical efficiency needs to be calculated. The cross period technical efficiency is calculated by comparing observed output in period t with respect to the maximum potential output obtainable from the input set of $t+1$ period. For example, to compute technical efficiency with the reference technology t for input and output with the $t+1$ period (point L_1) under VRS (Figure 3.3), this point lies outside the boundary of the VRS frontier indicating that the traditional Malmquist index presents numerical infeasibilities while the biennial frontier envelops all the points under VRS and the output distance function for point L_1 is well defined (Deb and Ray, 2014; Pastor, Asmild, and Lovell, 2011).

The biennial Malmquist index is calculated as the ratio of distance functions for the periods t and $t+1$ following Pastor, Asmild, and Lovell (2011).

$$M_o^B(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{D_o^B(y^{t+1}, x^{t+1})}{D_o^B(y^t, x^t)} \tag{3.5}$$

where $M_o^B(.)$ and $D_o^B(.)$ are the biennial Malmquist index and the biennial output distance function based on the biennial reference technology (T_v^B), respectively. The base t period biennial technology is defined as the convex hull of period t technology and period $t+1$ technology: $T_v^{B,t} =$ convex (T_v^t, T_v^{t+1}). The subscript v denotes for variable returns to scale. Similarly, the base $t+1$ period biennial technology can be defined with respect to variable returns to scale. One overlapping biennial technology would occur for two time periods, one for each adjacent time periods t and $t+1$. Since the BMI uses a single ratio of distance functions from two reference periods that consist of observations from both periods, there is no need to calculate the geometric mean when defining the BMI (Pastor, Asmild, and Lovell, 2011).

The BMI is decomposed into two components: efficiency change and technical change. Pastor, Asmild, and Lovell (2011) define efficiency change under VRS similar to the Malmquist index method under VRS defined by Färe et al. (1994).

$$EC_v^B = \left[\frac{D_v^{t+1}(y^{t+1}, x^{t+1})}{D_v^t(y^t, x^t)}\right] = EC_v \tag{3.6}$$

where EC_v^B and EC_v are efficiency change with respect to the biennial frontier and single frontier, respectively. Similarly, technical change (TC_v^B) under the BMI is defined as:

$$TC_v^B = \frac{M_v^B}{EC_v^B} = \left[\frac{D_v^B(y^{t+1}, x^{t+1})}{D_v^B(y^t, x^t)} \frac{D_v^t(y^t, x^t)}{D_v^{t+1}(y^{t+1}, x^{t+1})} \right]. \quad (3.7)$$

The technical change component is the percentage of productivity change not accounted for by efficiency change (Färe et al., 1994). Equation (3.7) shows the impact of technical change between two periods in a biennial period setting, which results in the shift of the frontier.

The biennial frontier may contain data from periods t and $t+1$. The inputs x^t and x^{t+1} for all firms could potentially give optimal input combination and the outputs y^t and y^{t+1} could potentially give optimal output combination for all firms for the biennial period. Thus, the intensity vectors for two periods must be considered jointly (i.e. $\sum_{j=1}^{k}[\lambda_j^t + \lambda_j^{t+1}] = 1$) in the linear programming model (Funk, 2015; Pastor, Asmild, and Lovell, 2011).

The linear programming problem to estimate period t output-orientated distance function ($D_{v,s}^B(y^t, x^t)$) of firm s with respect to a biennial frontier technology is given below.

$$[D_{v,s}^B(y^t, x^t]^{-1} = \max \theta_{v,s}^B$$

subject to

$$\sum_{j=1}^{k}[\lambda_j^t x_j^t + \lambda_j^{t+1} x_j^{t+1}] \leq x_s^t$$

$$\sum_{j=1}^{k}[\lambda_j^t y_j^t + \lambda_j^{t+1} y_j^{t+1}] \geq \theta_{v,s}^B y_s^t \quad (3.8)$$

$$\sum_{j=1}^{k}[\lambda_j^t + \lambda_j^{t+1}] = 1$$

$$\lambda_j^t \geq 0 \text{ and } \lambda_j^{t+1} \geq 0$$

where j is the number of cooperatives, x is the vector of inputs, y is the vector of outputs, and λ^t is an intensity vector (i.e. the weight of an individual cooperative) for the period t and λ^{t+1} is an intensity vector for the period $t+1$. The sum of the intensity vectors is one under variable returns to scale. Equation (3.8) estimates output-orientated technical efficiency with respect to a biennial CRS frontier when the intensity constraint ($\sum_{j=1}^{k}[\lambda_j^t + \lambda_j^{t+1}] = 1$) is dropped from the model. An important point to note is that estimating technical efficiency with respect to a biennial frontier, the weights of the intensity factor for all firms must sum to one should be imposed in the linear programming problem. This calculates the distance function that represents the level of inefficiency for the sample firms to reach the VRS frontier regardless of the observed period in the biennial period of the efficient firms. Otherwise, it may give a greater potential for numerical infeasibilities similar to the traditional adjacent Malmquist index (Funk, 2015; Pastor, Asmild, and Lovell, 2011).

Similarly, the linear programming problem to estimate the period $t+1$ output-orientated distance function ($D_{v,s}^{B}(y^{t+1}, x^{t+1})$) of firm s with respect to a biennial frontier technology is:

$$[D_{v,s}^{B}(y^{t+1}, x^{t+1}]^{-1} = \max\ \theta_{v,s}^{B}$$

subject to

$$\sum_{j=1}^{k}[\lambda_j^t x_j^t + \lambda_j^{t+1} x_j^{t+1}] \leq x_s^{t+1}$$

$$\sum_{j=1}^{k}[\lambda_j^t y_j^t + \lambda_j^{t+1} y_j^{t+1}] \geq \theta_{v,s}^{B} y_s^{t+1} \tag{3.9}$$

$$\sum_{j=1}^{k}[\lambda_j^t + \lambda_j^{t+1}] = 1$$

$$\lambda_j^t \geq 0 \text{ and } \lambda_j^{t+1} \geq 0$$

where notations in equation (3.9) have the similar meaning as equation (3.8). The biennial efficient frontier is the same for equations (3.8) and (3.9) while considering each firm for the same periods t and $t+1$ within the sample.

The denominator ($D_v^t(y^t, x^t)$) and numerator ($D_v^{t+1}(y^{t+1}, x^{t+1})$) of technical efficiency change (equation 3.6) is estimated using a single production frontier. The standard linear programming problem to estimate the t period output-orientated distance function of a firm s under VRS is:

$$[D^t_{v,s}(y^t, x^t]^{-1} = \max\ \theta_{v,s}$$

subject to

$$\sum_{j=1}^{k} \lambda_j x^t_j \leq x^t_s$$

$$\sum_{j=1}^{k} \lambda_j y^t_j \geq \theta_{v,s} y^t_s \tag{3.10}$$

$$\sum_{j=1}^{k} \lambda_j = 1, \text{ for all } \lambda_j \geq 0$$

where j is the number of cooperatives, x is the vector of inputs, y is the vector of outputs, and λ is an intensity vector (i.e. the weight of an individual cooperative) with the t reference technology. The sum of the intensity vector is one under variable returns to scale. Equation (3.10) estimates output-orientated technical efficiency with the t reference technology under a CRS frontier when the intensity constraint ($\sum_{j=1}^{k} \lambda_j = 1$) is dropped from the model.

Similarly, the output-orientated distance function with the $t + 1$ reference technology under VRS for a firm s can be estimated using a standard nonparametric method.

$$[D_{v,s}^{t+1}(y^{t+1}, x^{t+1}]^{-1} = \max\ \theta_{v,s}$$

subject to

$$\sum_{j=1}^{k} \lambda_j x_j^{t+1} \leq x_s^{t+1} \tag{3.11}$$

$$\sum_{j=1}^{k} \lambda_j y_j^{t+1} \geq \theta_{v,s} y_s^{t+1}$$

$$\sum_{j=1}^{k} \lambda_j = 1,\ \text{for all } \lambda_j \geq 0$$

where j is the number of cooperatives, x is the vector of inputs, y is the vector of outputs, and λ is an intensity vector (i.e. the weight of an individual cooperative). The sum of the intensity vector is one under variable returns to scale. Equation 3.11 estimates output-orientated technical efficiency with the $t + 1$ reference technology under CRS when the intensity constraint ($\sum_{j=1}^{k} \lambda_j = 1$) is removed from the model.

3.4 Empirical Results

Productivity growth measures the performance of firms over the periods of time. The biennial Malmquist index under variable returns to scale is used to measure the performance for a sample of agricultural cooperatives in the United States. The data envelopment analysis approach is used to measure the biennial Malmquist index for a balanced panel of 171 agricultural cooperatives over the period 2005 to 2014.[1] Finally, the BMI is decomposed into technical change and efficiency change to examine the sources of productivity growth.

The productivity growth, efficiency change, and technical change for agricultural

[1]The traditional Malmquist index was also calculated, but it presents numerical infeasibilities for cross period technical efficiency scores. Thus, the results from the Malmquist index are not reported.

cooperatives are also examined based on the size of cooperatives. Cooperatives are classified into four groups (sizes) based on the dollar value of total assets. The four sizes are: cooperatives with less than $10 million (m) in assets, cooperatives with greater than $10m to less than $20m in assets, cooperatives greater than $20m and less than $50m in assets, and cooperatives with greater than $50m in assets.

3.4.1 Biennial Malmquist Index Results

A numerical score of the biennial Malmquist index less than 1 shows productivity regress indicating that the second year observed data are further from the estimated biennial frontier than the first year of observed data. If a measure of the BMI is equals 1, there is no productivity change whereas if the BMI is greater than 1, it indicates productivity gain.

Table 3.1 reports summary statistics of the biennial Malmquist index from 2005 to 2014. Agricultural cooperatives gain productivity on average in 6 periods while productivity regresses in 3 periods. For instance, the productivity gain between 2005 and 2006 is 5%. The highest productivity gain is 22% from 2007 to 2008. In that period, 82% of the total cooperatives gain productivity while 11% and 27% of the total cooperatives had no change or productivity regress, respectively. The sample of agricultural cooperatives experienced cumulative productivity growth of 34%, on average as the magnitude of progress was higher than the regress in productivity and the improvements in technology is the prime source of productivity growth. The results are consistent with past studies for cooperatives (Ariyaratne, Featherstone, and Langemeier, 2006; Bonfiglio, 2006; Yamamoto, Kondo, and Sasaki, 2006). Ariyaratne, Featherstone, and Langemeier (2006) find that productivity change and technical change were 6.1% and 11.2% from 1990 to 1992, respectively with some variation from 1996 to 1998. The distribution of productivity growth follows close to symmetric distribution as the mean and median values are close to each other over the study period.

There is a productivity regress of 11% from 2008 to 2009 and a productivity decrease after 2012. The period 2008–2009 is associated with high farm input prices in the United States. Agricultural cooperatives bought farm inputs at high prices to sell to farmers in anticipation of higher farm input prices. Higher cost inventories decreased cash balances. The farm input prices plummeted in the next period, which significantly reduced the total revenue of these cooperatives (Henderson and Fitzgerald, 2008). Another reason could be associated with the 2008 financial market crash. The financial market crash affected the overall economy and the impact could have spilled-over to the agricultural sector as well. Similarly, productivity regress after 2012 is associated with drought years in the United States.

The productivity growth by the size of cooperatives follows the similar trend as the trend of overall productivity. In other words, productivity is fairly consistent across sizes over time indicating that if cooperatives are relatively productive in a period t, the productivity of the cooperatives relatively stable in the $t+1$ period (Tables 3.4 to 3.7).

The biennial Malmquist index is decomposed into efficiency change and technical change. The decomposition of productivity growth allows for the examination of the sources of productivity change (Färe et al., 1994; Pastor, Asmild, and Lovell, 2011).

3.4.2 Efficiency Change

Efficiency change for the biennial Malmquist index is similar to efficiency change under the traditional Malmquist index. Efficiency change is calculated using the single frontier not the biennial frontier method. A numerical value of the catch-up component (efficiency change) greater (less) than 1 indicates a progress (regress) in efficiency change whereas a efficiency change score of 1 indicates no change in technical efficiency.

Table 3.2 shows the efficiency change estimates under variable returns to scale. There are 5 periods where the mean of efficiency change is slightly greater than 1 indicating progress while 3 periods have mean scores less than 1 indicating regress. The period 2005-2006 has no change in technical efficiency, on average.

Efficiency change is fairly consistent across size indicating that if agricultural cooperatives are relatively efficient in a period t, they are relatively efficient in the next period $(t+1)$ as well (Tables 3.8 to 3.11). Efficiency change varies across years, but remain relatively stable by the size cooperatives.

3.4.3 Technical Change

A numerical value of technical change greater (less) than 1 indicates technical progress (regress) and the value of technical change equals 1 indicates no technical change. The technical change from 2005 to 2014 is summarized in Table 3.3. The results indicate that four periods show technical regress whereas 5 periods show technical progress over the study period. For the period 2005–2006, there was technical regress for 24 cooperatives, no technical change for 18 cooperatives, and technical progress for 129 cooperatives. On average, there was 5% technical progress for the 2005–2006 period. For the period 2008–2009, there was a technical regress of 9%. This period (2008–2009) is associated with the financial stress of agricultural cooperatives due to high fluctuations in farm input prices (Henderson and Fitzgerald, 2008).

Similarly, there was a technical regress of 2% and 8% for the periods 2012–2013 and 2013–2014, respectively. Since the magnitude of technical progress is higher than the magnitude of technical regress, agricultural cooperatives experienced a cumulative technological progress of 37%, on average over the study period.

The results for technical change by the size of cooperatives show that technical change is fairly consistent across size over time (Tables 3.12 to 3.15). However, technical change varies across years.

Overall, agricultural cooperatives experienced cumulative productivity growth of 34% between 2005 and 2014 whereas cumulative efficiency change and cumulative technical change were -2% and 37%, respectively for the same period. Technical progress was the major source of improvement in productivity growth of agricultural cooperatives. The findings of this study are consistent with past studies that have found that productivity was mainly driven by technological progress (Ariyaratne, Featherstone, and Langemeier, 2006; Bonfiglio, 2006; Yamamoto, Kondo, and Sasaki, 2006) but contradicts with the findings of Candemir et al. (2011) who found that the Hazelnut agricultural sales cooperatives in Turkey experienced deterioration in technical change and productivity growth of 3% and 1.7% from 2004 to 2008, respectively. Since the improvements in technology is the major source of productivity growth, agricultural cooperatives can achieve high productivity growth by investing in technology.

3.5 Summary and Conclusions

This study measured productivity growth of agricultural cooperatives in the United States using balanced panel data between 2005 to 2014 applying the nonparametric biennial Malmquist index (BMI) introduced by Pastor, Asmild, and Lovell (2011). Agricultural cooperatives face economies of scale different than one as discussed in Chapter 2, productivity growth is estimated under variable returns to scale and decomposed into efficiency change and technical change.

This study identified the periods of productivity regress during the period of 2008 financial market crash and at the end of the study periods with increased agricultural production in the United States. This indicates that changes in macroeconomic situations may affect productivity growth of agricultural cooperatives besides the fluctuations in farm incomes and farm assets. Of the 171 agricultural cooperatives, 66 experienced productivity growth, 14 faced no change in productivity, and 91 faced productivity decrease in the 2012–2013 period and the distribution of efficiency change and technical change is similar as the distribution of productivity. For instance, 114 cooperatives faced technical regress or a downward shift in the production frontier, while 14 faced no change in technology and 43 experienced progress in technical change or an upward shift in the production frontier in the 2012–2013 period. The period 2013–2014 follows a similar distribution like the distribution of the period 2012-2013 for productivity growth, technical efficiency change, and technical change.

Agricultural cooperatives gained 34% cumulative productivity growth between 2005 and 2014 whereas a 2% decrease in efficiency change and a 37% progress in technical change for the same period, on average. Technical progress was the major source of improvement in the productivity growth of agricultural cooperatives. Since the productivity growth of agricultural cooperatives is mainly achieved due to improvements in technology, the results suggest that investment in and/or adoption of new technology and increasing managerial efficiency lead to higher productivity growth.

Tables

Table 3.1: The biennial Malmquist index (BMI) under VRS for agricultural cooperatives

				Distribution of Cooperatives		
Periods	Mean	Median	Std. Dev.	BMI < 1	BMI = 1	BMI > 1
2005–2006	1.05	1.04	0.12	47	18	106
2006–2007	1.08	1.06	0.14	32	26	113
2007–2008	1.22	1.16	0.28	19	11	141
2008–2009	0.89	0.89	0.25	122	14	35
2009–2010	1.01	1.00	0.13	75	18	78
2010–2011	1.20	1.18	0.23	20	14	137
2011–2012	1.07	1.07	0.13	42	12	117
2012–2013	0.98	0.99	0.12	91	14	66
2013–2014	0.92	0.93	0.12	124	22	25
Cumulative BMI	1.34	1.30	0.37	23	0	148

N = 171

Table 3.2: Efficiency change (EC) under VRS for agricultural cooperatives

				Distribution of Cooperatives		
Periods	Mean	Median	Std. Dev.	EC < 1	EC = 1	EC > 1
2005–2006	1.00	1.00	0.13	74	36	61
2006–2007	1.02	1.00	0.12	59	36	76
2007–2008	0.98	0.99	0.17	90	33	48
2008–2009	0.98	0.96	0.22	93	25	53
2009–2010	1.06	1.02	0.13	48	33	90
2010–2011	1.02	1.00	0.15	66	33	72
2011–2012	0.98	0.99	0.12	92	29	50
2012–2013	1.01	1.00	0.12	68	31	72
2013–2014	1.01	1.00	0.13	74	36	61
Cumulative EC	0.98	1.00	0.18	94	13	64

N = 171

Table 3.3: Technical change (TC) under VRS for agricultural cooperatives

				Distribution of Cooperatives		
Periods	Mean	Median	Std. Dev.	TC < 1	TC = 1	TC > 1
2005–2006	1.05	1.05	0.08	24	18	129
2006–2007	1.06	1.05	0.08	19	27	125
2007–2008	1.24	1.23	0.18	6	11	154
2008–2009	0.91	0.91	0.15	119	15	37
2009–2010	0.96	0.95	0.08	117	18	36
2010–2011	1.19	1.19	0.19	12	17	142
2011–2012	1.10	1.09	0.08	14	12	145
2012–2013	0.98	0.97	0.06	114	14	43
2013–2014	0.92	0.95	0.10	118	22	31
Cumulative TC	1.37	1.36	0.29	14	0	157

N = 171

Table 3.4: Productivity by the size of agricultural cooperatives less than $10 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	98	1.05	1.04	0.12
2006–2007	91	1.07	1.05	0.15
2007–2008	80	1.19	1.13	0.32
2008–2009	69	0.81	0.77	0.22
2009–2010	77	1.02	1.00	0.13
2010–2011	73	1.19	1.18	0.22
2011–2012	60	1.03	1.01	0.11
2012–2013	58	0.98	0.99	0.12
2013–2014	65	0.92	0.93	0.12

Table 3.5: Productivity by the size of cooperatives greater than $10 million and less than $20 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	36	1.06	1.05	0.13
2006–2007	38	1.10	1.08	0.11
2007–2008	37	1.28	1.24	0.24
2008–2009	40	0.96	0.90	0.34
2009–2010	38	1.01	1.00	0.14
2010–2011	33	1.25	1.22	0.28
2011–2012	39	1.08	1.05	0.16
2012–2013	40	0.95	0.95	0.12
2013–2014	38	0.93	0.94	0.12

Table 3.6: Productivity by the size of cooperatives greater than $20 million and less than $50 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	25	1.06	1.07	0.08
2006–2007	28	1.11	1.11	0.15
2007–2008	34	1.18	1.16	0.18
2008–2009	29	0.92	0.90	0.18
2009–2010	32	0.97	0.96	0.12
2010–2011	33	1.20	1.19	0.17
2011–2012	34	1.11	1.08	0.15
2012–2013	38	0.98	0.98	0.13
2013–2014	33	0.92	0.91	0.11

Table 3.7: Productivity by the size of cooperatives greater than $50 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	12	1.01	1.00	0.07
2006–2007	14	1.03	1.00	0.07
2007–2008	20	1.27	1.20	0.27
2008–2009	33	0.95	0.99	0.15
2009–2010	24	1.01	1.00	0.11
2010–2011	32	1.19	1.11	0.26
2011–2012	38	1.10	1.09	0.12
2012–2013	35	1.03	1.01	0.12
2013–2014	35	0.93	0.94	0.12

Table 3.8: Efficiency change by the size of cooperatives less than $10 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	98	1.01	1.00	0.15
2006–2007	91	1.00	1.00	0.12
2007–2008	80	1.00	0.99	0.21
2008–2009	69	0.91	0.90	0.19
2009–2010	77	1.07	1.03	0.13
2010–2011	73	1.04	1.01	0.14
2011–2012	60	0.96	0.98	0.10
2012–2013	58	1.01	1.00	0.11
2013–2014	65	0.99	1.00	0.13

Table 3.9: Efficiency change by the size of cooperatives greater than $10 million and less than $20 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	36	0.99	1.00	0.11
2006–2007	38	1.04	1.01	0.11
2007–2008	37	1.01	1.00	0.16
2008–2009	40	1.03	0.95	0.29
2009–2010	38	1.07	1.03	0.15
2010–2011	33	1.01	1.00	0.17
2011–2012	39	0.98	0.97	0.14
2012–2013	40	0.99	1.01	0.13
2013–2014	38	1.01	0.98	0.14

Table 3.10: Efficiency change by the size of cooperatives greater than $20 million and less than $50 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	25	1.00	1.00	0.08
2006–2007	28	1.05	1.03	0.13
2007–2008	34	0.94	0.95	0.10
2008–2009	29	1.02	1.00	0.20
2009–2010	32	1.03	1.00	0.13
2010–2011	33	0.96	1.00	0.12
2011–2012	34	1.00	0.98	0.13
2012–2013	38	1.00	1.00	0.12
2013–2014	33	1.03	1.00	0.12

Table 3.11: Efficiency change by the size of cooperatives greater than $50 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	12	0.97	1.00	0.05
2006–2007	14	0.99	1.00	0.06
2007–2008	20	0.97	1.00	0.12
2008–2009	33	1.03	1.00	0.15
2009–2010	24	1.05	1.01	0.09
2010–2011	32	1.02	1.00	0.14
2011–2012	38	1.00	1.00	0.10
2012–2013	35	1.04	1.00	0.11
2013–2014	35	1.02	1.00	0.10

Table 3.12: Technical change by the size of cooperatives less than $10 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	98	1.05	1.05	0.09
2006–2007	91	1.07	1.05	0.08
2007–2008	80	1.19	1.18	0.17
2008–2009	69	0.90	0.86	0.17
2009–2010	77	0.96	0.96	0.10
2010–2011	73	1.15	1.13	0.17
2011–2012	60	1.08	1.08	0.08
2012–2013	58	0.98	0.96	0.06
2013–2014	65	0.93	0.96	0.09

Table 3.13: Technical change by the size of cooperatives greater than $10 million and less than $20 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	36	1.07	1.06	0.07
2006–2007	38	1.06	1.06	0.06
2007–2008	37	1.27	1.29	0.15
2008–2009	40	0.93	0.96	0.12
2009–2010	38	0.95	0.95	0.07
2010–2011	33	1.24	1.22	0.22
2011–2012	39	1.10	1.09	0.09
2012–2013	40	0.96	0.96	0.04
2013–2014	38	0.93	0.97	0.13

Table 3.14: Technical change by the size of cooperatives greater than $20 million and less than $50 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	25	1.07	1.03	0.09
2006–2007	28	1.06	1.04	0.10
2007–2008	34	1.26	1.30	0.17
2008–2009	29	0.91	0.88	0.14
2009–2010	32	0.94	0.94	0.06
2010–2011	33	1.25	1.25	0.16
2011–2012	34	1.11	1.10	0.06
2012–2013	38	0.98	0.98	0.06
2013–2014	33	0.90	0.89	0.09

Table 3.15: Technical change by the size of cooperatives greater than $50 million in assets

Periods	N	Mean	Median	Std. Dev.
2005–2006	12	1.04	1.00	0.10
2006–2007	14	1.04	1.03	0.05
2007–2008	20	1.32	1.28	0.25
2008–2009	33	0.93	0.95	0.13
2009–2010	24	0.96	0.97	0.08
2010–2011	32	1.16	1.10	0.20
2011–2012	38	1.10	1.09	0.07
2012–2013	35	0.99	1.00	0.05
2013–2014	35	0.91	0.93	0.09

Figures

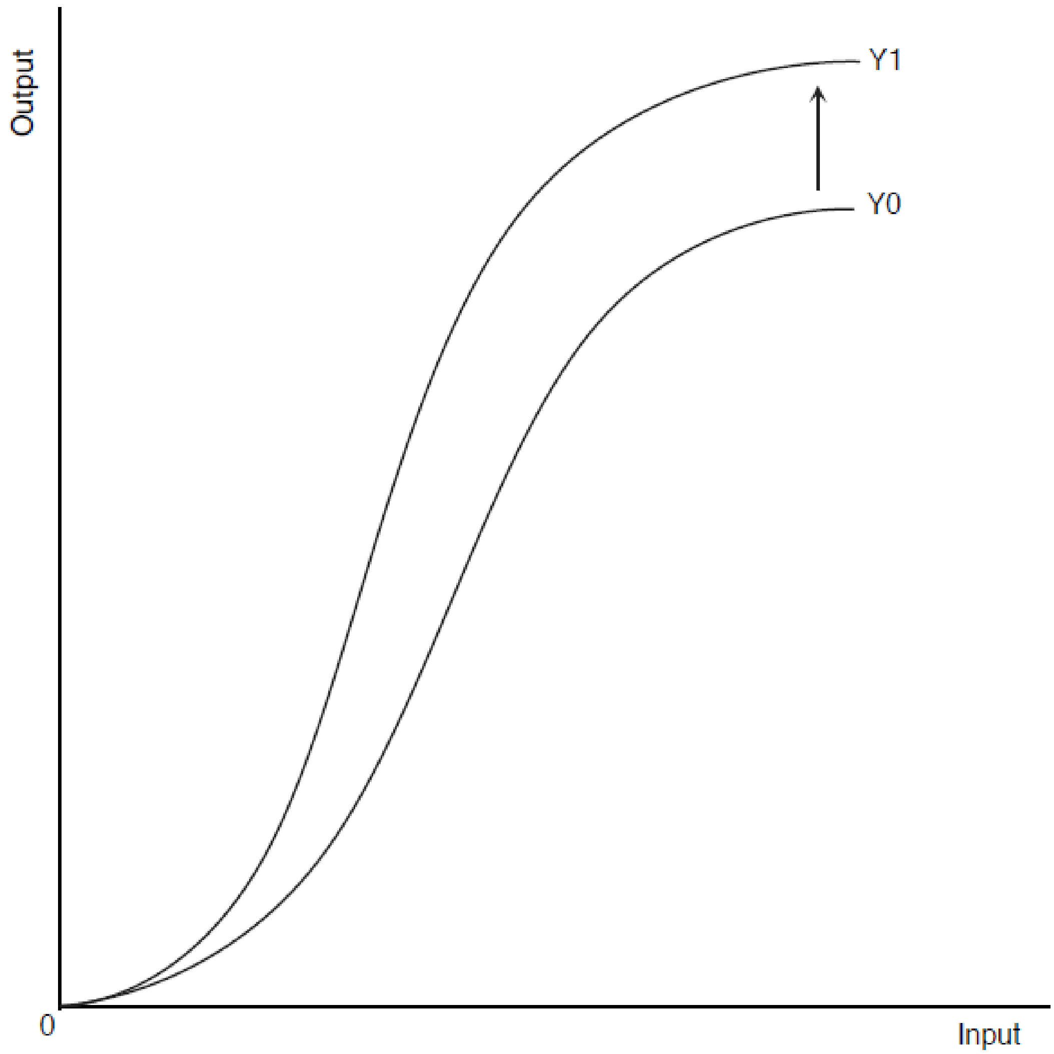

Figure 3.1: Change in production function due to technology improvements

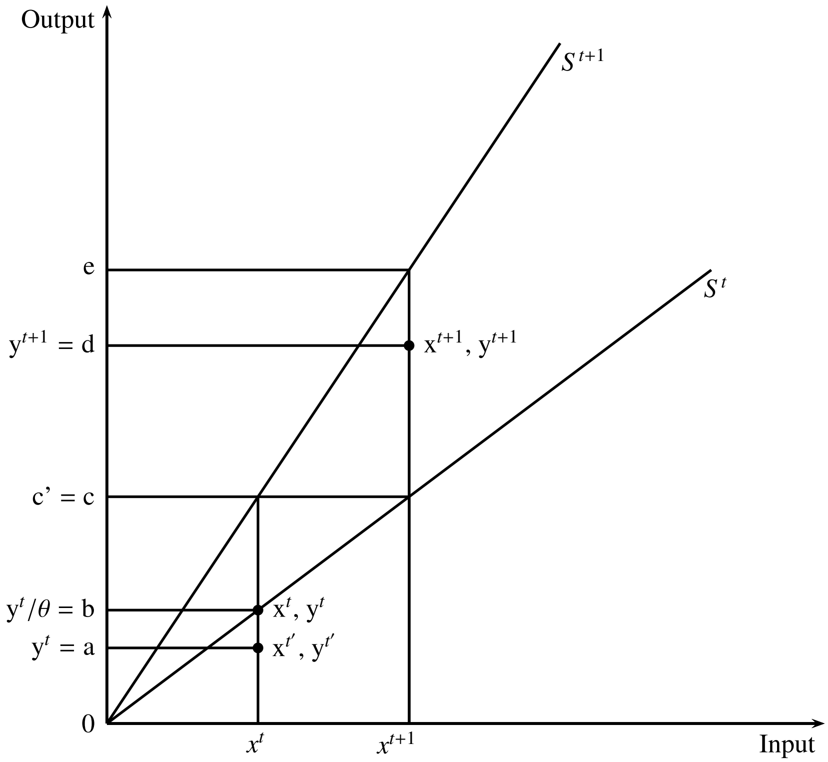

Figure 3.2: Output orientated distance functions and the Malmquist index

Source: Lall, Featherstone, and Norman (2002)

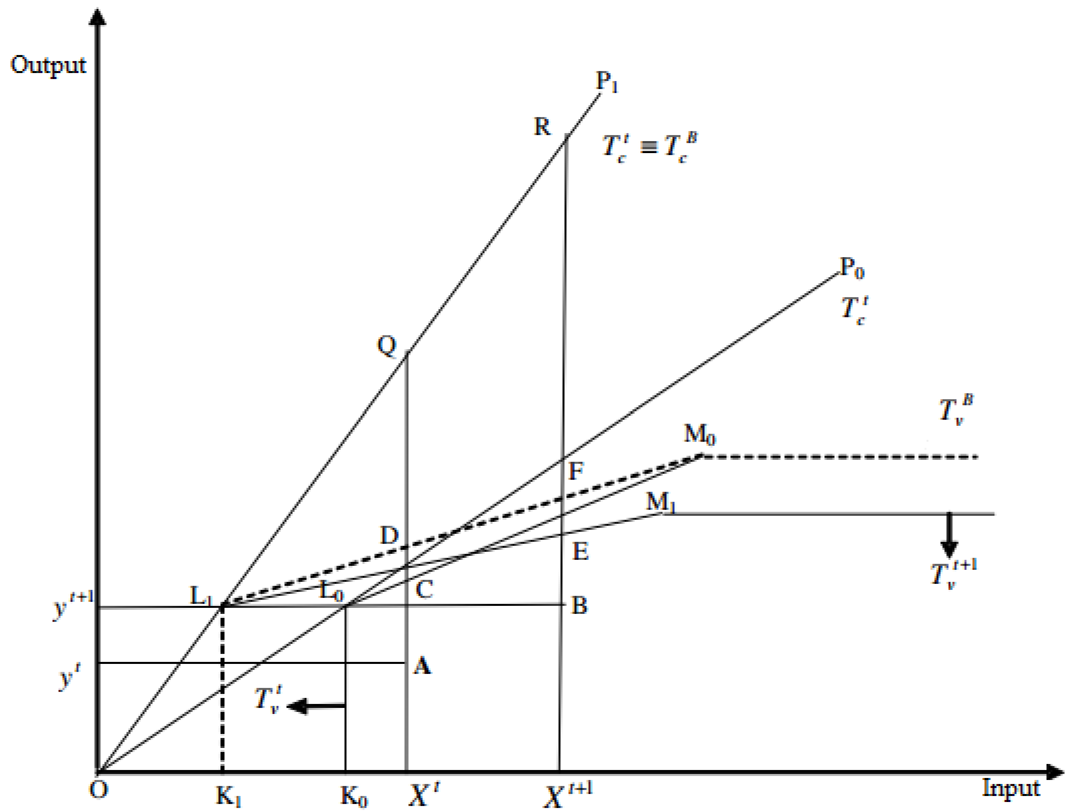

Figure 3.3: Output orientated distance functions and the biennial Malmquist index

Source: Deb and Ray (2014)

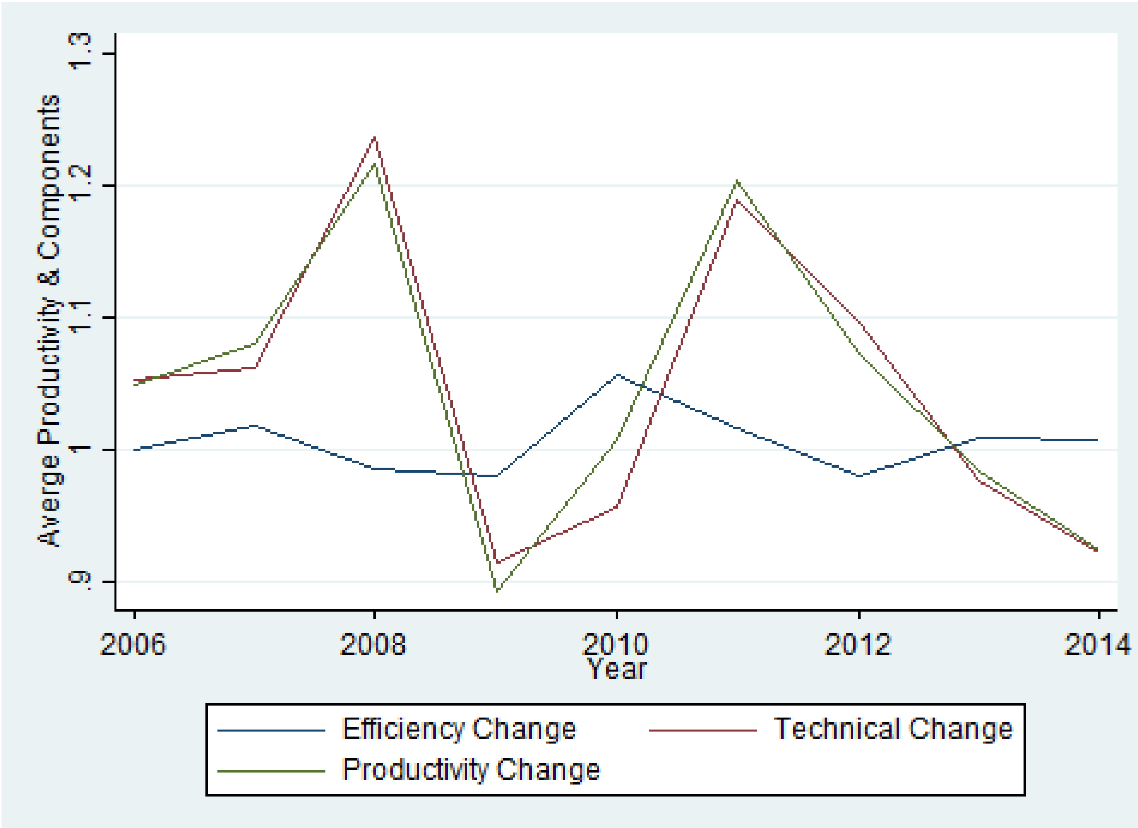

Figure 3.4: The average values of efficiency change, technical change, and productivity change

Chapter 4

Conclusions

4.1 Summary

The purpose of this dissertation was to measure the efficiency and productivity of agricultural cooperatives in the United States. The estimation of minimum cost frontier is the basis for computing economic measures such as cost efficiency, economies of scale, and economies of scope, while measuring the biennial Malmquist index allows to decompose productivity growth into efficiency change and technical change. Cost efficiency shows the potential for total cost reduction by adjusting input mixes or input bundles. Economies of scale and scope show the percentage of cost savings by changing the scale of operations and by producing multiple outputs in a firm rather than producing them separately, respectively. And productivity growth shows the economic performance of agricultural cooperatives over time.

The data envelopment analysis approach was used to estimate a single cost frontier and annual cost frontiers using panel data from 2005 to 2014 for agricultural cooperatives. The annual cost frontier allows to examine whether economies of scale and economies of scope remain relatively consistent when the cost frontier shifts due to the improvements in technology and/or random weather shock (Parman et al., 2016) and it is useful to examine how cost changes over time.

Agricultural cooperatives sell a variety of outputs such as grain and farm inputs, which creates problems for inter-firm comparison among agricultural cooperatives. Further, managers of cooperatives lack an adequate framework for analyzing the impact of changes of product mix (level) on cost structure in a multiproduct operation (Akridge and Hertel, 1986). This study provides a framework for inter-cooperative performance comparison and the impact of changes on product mix and/or product level on cost structure for an individual cooperatives decision.

The cost efficiency results suggest that agricultural cooperatives can reduce total cost from 37% to 65% based on the single frontier, while the percentage of total cost savings ranges from 20% to 45% based on the annual frontiers. The mean value of cost efficiency decreased across years indicating that these cooperatives became less cost efficient. Further, the KS test and t-test indicated that economic measures between a single frontier and annual frontiers were statistically different, suggesting the cost frontier shifts over time, but scale economies and scope economies remained fairly consistent over time. Thus, economic measures estimated from annual frontiers are statistically different than those measures obtained from the single multi-year frontier indicating technical change. Multiproduct scale economies indicated that these cooperatives faced economies of scale different than one, suggesting that variable returns to scale is the appropriate technology for modeling agricultural cooperatives.

When the cooperatives become more cost efficient, the benefits obtained from multiproduct scale economies and scope economies are relatively low, but when they become less cost efficient the importance of scale and scope economies increases, particularly for small-sized cooperatives. For instance, the mean cost efficiency score for cooperatives less than $15 million in assets is 0.70 in 2005 while multiproduct scale and scope economies were 1.13 and 0.10, respectively, but in 2014 cost efficiency, multiproduct scale economies, and scope economies were 0.44, 2.73, and 0.47, respectively indicating that smaller cooperatives are becoming less cost efficient over time. It suggests that smaller cooperatives can save a higher percentage of average cost by increasing the scale of the operation rather than by becoming more cost efficient. However, scale economies tend to be exhausted for cooperatives greater than $15 million in assets. The multiproduct scale economies are mainly obtained through product diversification for smaller cooperatives. Further, when the size of cooperatives increases, particularly for cooperatives with greater than $30 million in assets, scope economies tend to be exhausted.

Overall, cost efficiency is lower for smaller cooperatives than larger cooperatives, whereas product-specific scale economies, multiproduct scale economies, and scope economies are higher for small cooperatives than large cooperatives. The trade-off on the magnitude of cost efficiency and multiproduct scale economies scores indicates that smaller cooperatives can benefit more by increasing the size of operations, though there is a variation on the percentage of gain across years. Since smaller cooperatives can reduce a higher percentage of average cost by increasing the scale of the operation rather than becoming cost efficient, it is likely that mergers of agricultural cooperatives continue until economies of scale are exhausted in the agricultural cooperative industry.

Productivity growth is one of the measures of performance of agricultural cooperatives showing how they are doing across years. The nonparametric biennial Malmquist index (BMI) is used to estimate productivity growth of agricultural cooperatives under variable returns to scale and decomposed the BMI into efficiency change and technical change. The decomposition of BMI allows to evaluate the sources of productivity change.

Agricultural cooperatives gained 34% cumulative productivity growth between 2005 and 2014, whereas -2% and 37% cumulative efficiency change and technical progress for the same period, on average. The productivity growth of cooperatives was mainly achieved due to the improvements in technology indicated that investment in and/or adoption of a new technology is likely to contribute to a higher productivity growth.

This study identified the periods of productivity regress at the middle (during the period of 2008 financial market crash) and the end of the study periods. This suggests that changes in macroeconomic situations may affect productivity growth of agricultural cooperatives besides the fluctuations in farm incomes and farm assets.

Productivity growth increases by increasing the number of agricultural cooperatives producing near the production frontier and/or operating at an optimal scale. Induced innovation theory suggests that input and output prices determine technical change and a new technology can substitute relatively abundant (cheap) factors of production for relatively scare (expensive) factors of production in the economy (Hayami and Ruttan, 1971; Ruttan, 1977). Since input and output prices are exogenous for agricultural cooperatives, these cooperatives may adjust input bundles or output portfolio to gain a higher percentage of efficiency and productivity. In other words, a manager's decision to allocate resources and the use of technology would give signals to innovate technology. This may imply that the improvements in technology is determined by the collective actions of cooperatives (producers).

4.2 Implications

Several implications for cooperatives can be drawn from the study. The Kolmogorov-Smirnov test shows that economic measures between a single frontier and annual frontiers are statistically different indicating that the cost frontier shifts over time. This implies that an analysis with the single frontier is less informative and could be biased as it ignores the shift of the cost frontier over time. The agricultural cooperative industry became less cost efficient over time. The results indicate that small cooperatives can save a higher percentage of cost by increasing the scale of operations rather than becoming more cost efficient. Further, scale economies and scope economies are fairly consistent over time.

This dissertation examined whether cooperatives were operating under variable returns to scale or constant returns to scale. Agricultural cooperatives faced economies of scale different than one indicating that variable returns to scale is an appropriate technology.

Another implication of this dissertation is related to productivity growth of cooperatives. The productivity growth for cooperatives is mainly obtained due to the improvements in technology rather than technical efficiency change, they could gain higher productivity by investing in a new technology. In addition, this study identifies the periods of productivity regress at the middle (during the period of 2008 financial market crash) and the end of the study periods. These periods are associated with the high fluctuations in farm production, farm income, and input prices in the United States, which suggests that changes in farm situations may affect productivity growth of agricultural cooperatives. Managers and boards of directors may make an appropriate strategy to mitigate the adverse impact of farm income fluctuations on efficiency and productivity growth.

4.3 Future Research

This dissertation focused on estimating the efficiency and productivity of agricultural cooperatives using a nonparametric approach that uses series of linear segments to construct a minimum cost frontier. The marginal cost for efficient cooperatives are non-unique and they were dropped for our empirical analysis. An analysis of non-unique marginal costs would worth future research.

Moreover, estimating the impact of mergers on profit efficiency and cost efficiency for agricultural cooperatives would worth future research. Previous literature on banking shows that profit efficiency increased from mergers (Akhavein, Berger, and Humphrey, 1997) and the results for cost efficiency and profit efficiency are different because the effects of changes in outputs that occur after the merger are not accounted for in cost efficiency changes (Berger and Humphrey, 1997). Some studies find the significant benefit of merger on the revenue or output side, but they did not find the benefit of mergers when firms are examined from the cost or input side. These approaches can be applied to examine the impact of merger on cost efficiency as the number of agricultural cooperatives are decreasing in industry through mergers and/or acquisitions. The analysis of efficiency and productivity of this dissertation can be extended to include risk factors such as crop production as a non-discretionary variable in the linear programming problem and compare the results with and without risk factors.

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Appendices

Appendix A

Economic Measures using Balanced Panel Data

This section provides the results when the sample is restricted to a balanced panel that have 171 cooperatives from 2005 to 2014. However, results are reported only for 2014 as we reached the similar conclusion using unbalanced and balanced panel data. The overall summary statistics of cost efficiency, economies of scale, and economies of scope are summarized in Table A.1. The average cost efficiency score is 0.70, which indicates that cooperatives could save 30% of cost on average by changing input bundles to achieve the same level of output. Of 171 cooperatives in 2014, 23 cooperatives have a cost efficiency score of 1.0, which indicates that these cooperatives are on the minimum cost ("best-practice") frontier.

Table A.1 reports multiproduct and product-specific scale economies, and scope economies. The mean value of multiproduct scale economies (MPSE) is 1.22, which suggests that cooperatives can reduce average cost by 22% by increasing production uniformly across outputs. However, MPSEs have an asymmetric distribution as there is a large difference between mean and median values of the MPSE. Multiproduct scale economies for agricultural cooperatives are mainly obtained from scope economies or product diversification. Table A.1 also reports descriptive statistics of product-specific scale economies. On average, the product-specific scale economies for all products are less than 1. For instance, the mean value of grain-specific scale economies is 0.77, indicating that cooperatives benefit by reducing the scale of grain quantity. On average, the mean value of scope economies are greater than 0, which implies that economies of scope exist. In other words, product diversification could result in cost savings for cooperatives.

The results for cost efficiency and multiproduct scale economies are compared based on the size of cooperatives. The cost efficiency results show that smaller cooperatives are less cost efficient than larger cooperatives (Table A.2). This indicates that, on average, larger cooperatives are closer to the cost frontier than smaller cooperatives. The multiproduct scale economies and cost efficiency scores show the trade-off for the cooperatives to reduce cost either by increasing the size or becoming cost efficient. For example, cooperatives within the category of less than $15m in assets, they could reduce cost by 37% becoming cost efficient, whereas they could reduce average cost by 56% by increasing the size of their operations.

Similarly, product-specific scale economies for all outputs are close to 1, indicating that these products are either close to constant returns to scale or on the region of diseconomies of scale. Further, the agricultural cooperatives gain scale economies mainly through product diversification. The percentage gain becoming cost efficient or increasing the scale of operations from the full sample (unbalanced panel) and restricted sample (balanced panel) is slightly different as the nonparametric approach is a relative performance measure. However, we exactly reach the same conclusions that small agricultural cooperatives can save the higher percentage of cost by increasing the scale of operations rather than becoming cost efficient and scale economies are mainly achieved through product diversification.

Table A.1: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2014

	N	Mean	Median	Std. Dev.
Cost efficiency	171	0.70	0.67	0.18
Multiproduct scale economies	139	1.22	0.91	0.88
Grain-specific scale economies	87	0.77	0.81	0.21
Farm input-specific scale economies	118	0.82	0.85	0.16
Service-specific scale economies	109	0.81	0.87	0.20
Other product-specific scale economies	96	0.92	1.00	0.15
Scope: grain vs (farm, service & others)	87	0.15	0.08	0.25
Scope: farm vs (grain, service & others)	118	0.20	0.11	0.24
Scope: service vs (grain, farm & others)	109	0.15	0.11	0.21
Scope: others vs (grain, farm & service)	96	0.22	0.14	0.24

Table A.2: Cost efficiency and multiproduct scale economies by the size of agricultural cooperatives, 2014

Assets ($ million)	N	Mean	Median	Std. Dev.
Cost efficiency				
Less than 15 M	83	0.63	0.61	0.17
15 M- 30 M	39	0.70	0.69	0.16
30 M- 60 M	21	0.73	0.68	0.18
60 M- 100 M	14	0.83	0.79	0.14
Greater than 100 M	14	0.91	0.99	0.14
Multiproduct scale economies				
Less than 15 M	68	1.56	1.04	1.15
15 M- 30 M	36	0.92	0.87	0.25
30 M- 60 M	18	0.91	0.93	0.04
60 M- 100 M	10	0.85	0.91	0.11
Greater than 100 M	7	0.89	0.92	0.06

Table A.3: Grain and farm input-specific scale economies for agricultural cooperatives, 2014

Assets ($ million)	N	Mean	Median	Std. Dev.
Grain-specific scale economies				
Less than 15 M	34	0.71	0.63	0.24
15 M- 30 M	26	0.79	0.86	0.20
30 M- 60 M	12	0.83	0.86	0.11
60 M- 100 M	8	0.81	0.85	0.18
Greater than 100 M	7	0.79	0.82	0.17
Farm input-specific scale economies				
Less than 15 M	59	0.80	0.85	0.20
15 M- 30 M	28	0.82	0.83	0.12
30 M- 60 M	15	0.86	0.86	0.08
60 M- 100 M	9	0.83	0.76	0.12
Greater than 100 M	7	0.86	0.85	0.08

Table A.4: Service and other product-specific scale economies for agricultural cooperatives, 2014

Assets ($ million)	N	Mean	Median	Std. Dev.
Service-specific scale economies				
Less than 15 M	51	0.86	0.92	0.16
15 M- 30 M	31	0.78	0.83	0.21
30 M- 60 M	13	0.70	0.68	0.28
60 M- 100 M	9	0.70	0.72	0.21
Greater than 100 M	5	0.92	0.95	0.09
Other product-specific scale economies				
Less than 15 M	53	0.94	1.00	0.14
15 M- 30 M	23	0.96	1.00	0.09
30 M- 60 M	12	0.85	0.94	0.18
60 M- 100 M	5	0.88	1.00	0.26
Greater than 100 M	3	0.81	0.79	0.18

Table A.5: Economies of scope: grain vs farm input, service, and other products and farm input vs grain, service, and other products, 2014

Assets ($ million)	N	Mean	Median	Std. Dev.
Scope: grain vs the other three products				
Less than 15 M	34	0.31	0.27	0.29
15 M- 30 M	26	0.04	0.01	0.18
30 M- 60 M	12	0.05	0.04	0.06
60 M- 100 M	8	0.08	0.06	0.08
Greater than 100 M	7	0.01	0.01	0.10
Scope: farm input vs the other three products				
Less than 15 M	59	0.35	0.32	0.25
15 M- 30 M	28	0.06	0.02	0.14
30 M- 60 M	15	0.02	0.03	0.06
60 M- 100 M	9	0.06	0.10	0.07
Greater than 100 M	7	0.04	0.06	0.05

Table A.6: Economies of scope: service vs grain, farm input, and other products and other products vs grain, farm input and service, 2014

Assets ($ million)	N	Mean	Median	Std. Dev.
Scope: service vs the rest of three products				
Less than 15 M	51	0.28	0.29	0.21
15 M- 30 M	31	0.03	0.04	0.14
30 M- 60 M	13	0.05	0.06	0.06
60 M- 100 M	9	0.08	0.09	0.11
Greater than 100 M	5	-0.05	-0.04	0.03
Scope: other product vs the rest of three products				
Less than 15 M	53	0.35	0.29	0.23
15 M- 30 M	23	0.08	0.07	0.14
30 M- 60 M	12	0.02	0.02	0.06
60 M- 100 M	5	0.03	0.03	0.01
Greater than 100 M	3	0.01	0.01	0.02

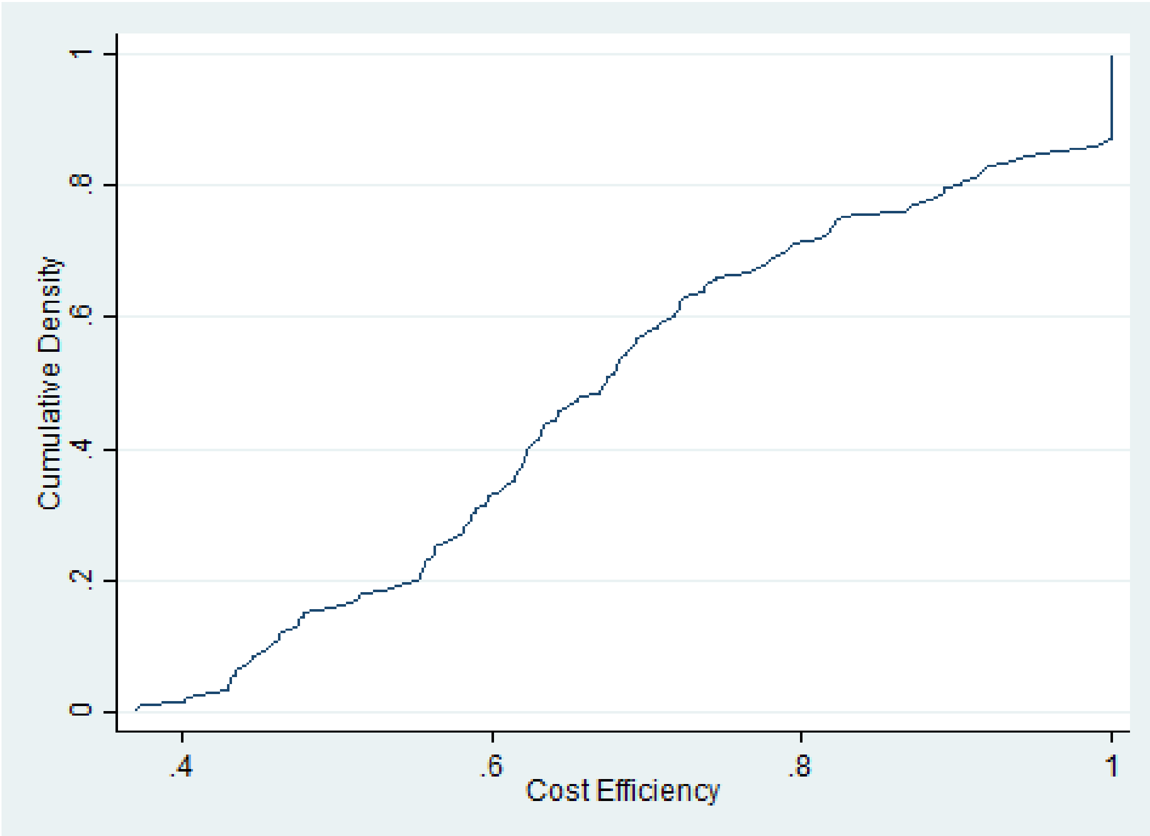

Figure A.1: Cumulative density of cost efficiency for agricultural cooperatives, 2014

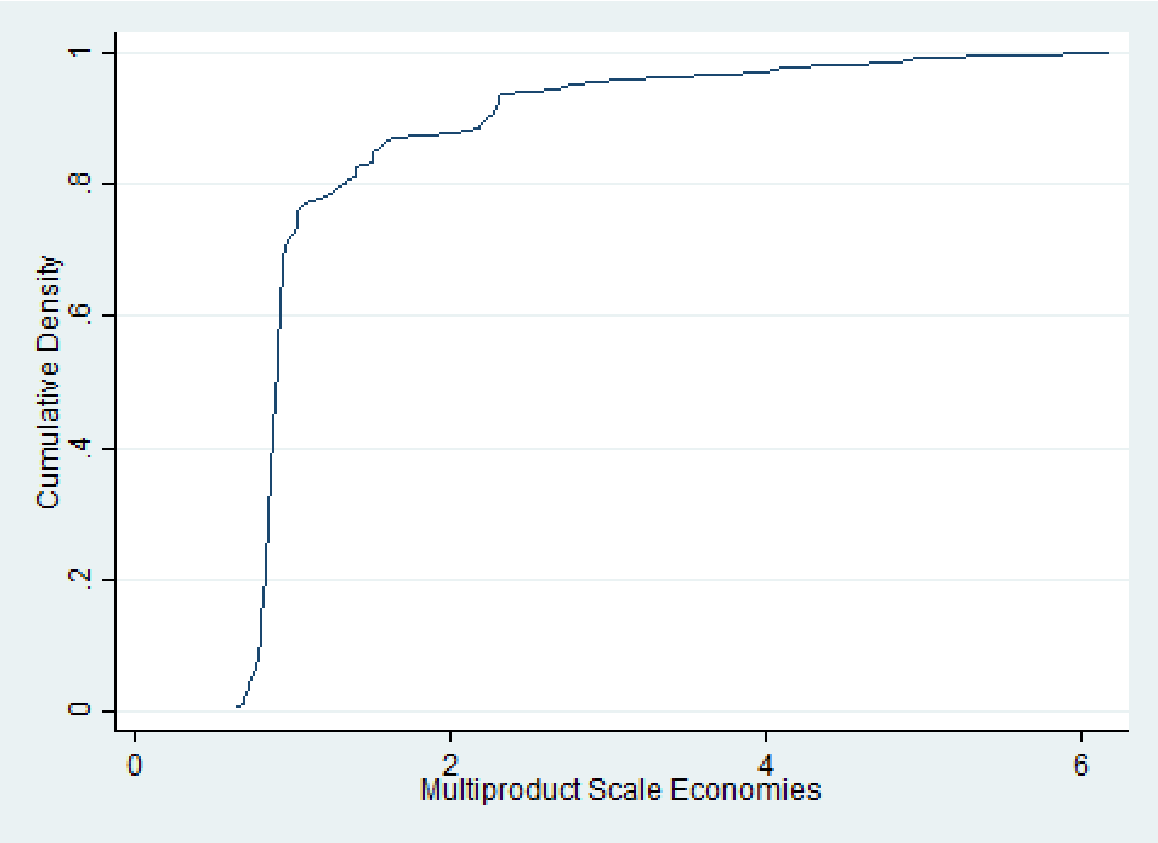

Figure A.2: Cumulative density of multiproduct scale economies for agricultural cooperatives, 2014

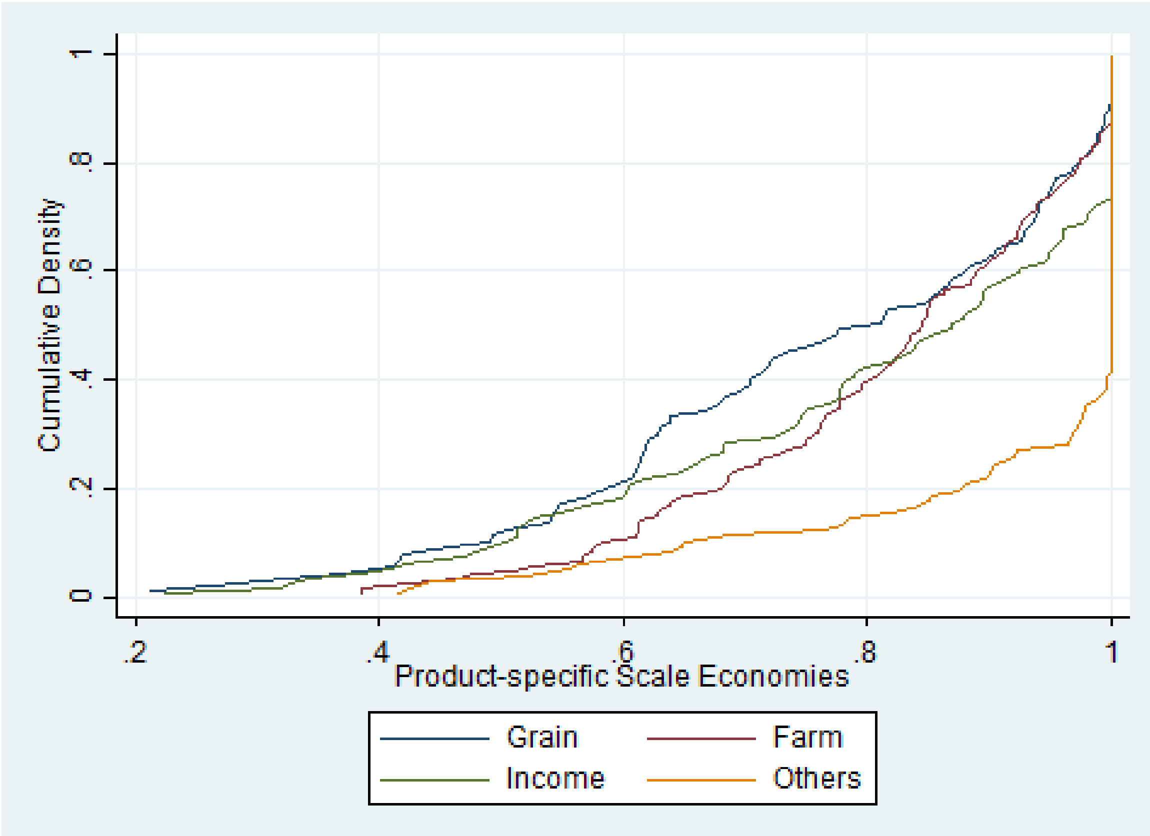

Figure A.3: Cumulative density of product-specific scale economies (PSE) for agricultural cooperatives, 2014

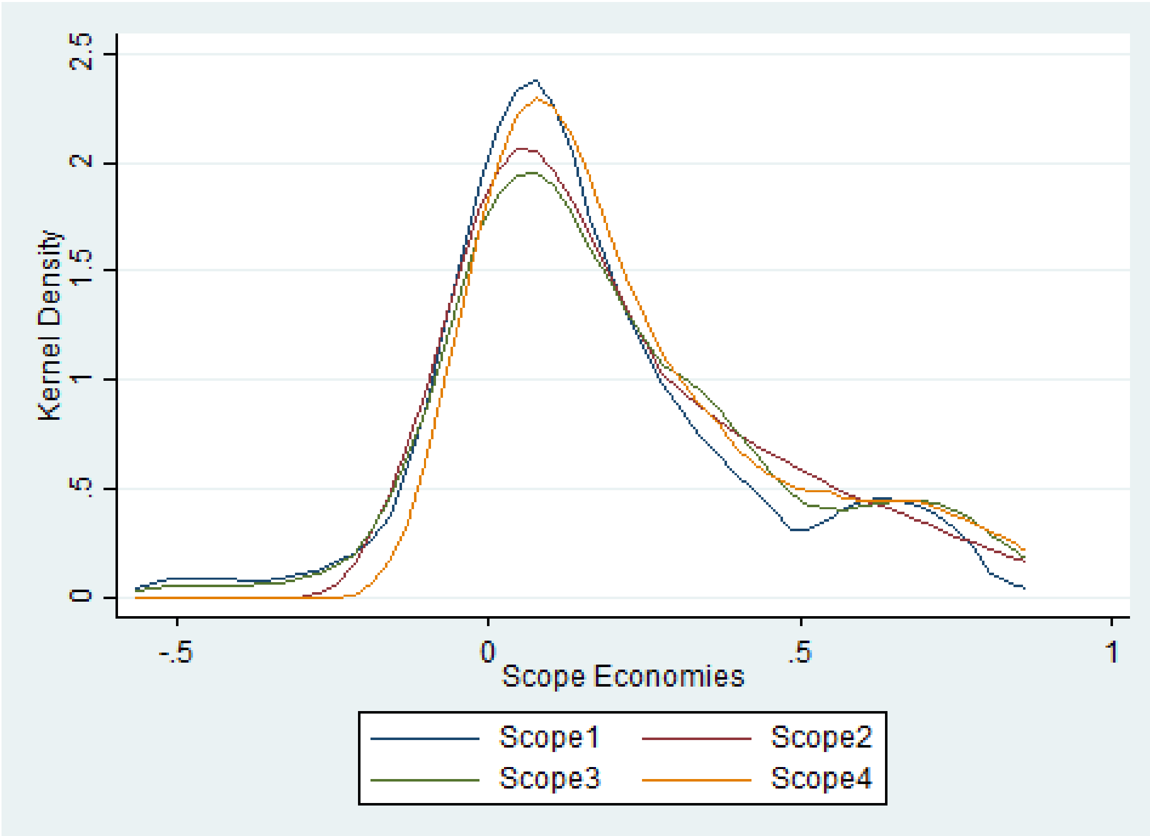

Figure A.4: Kernel density of scope economies for agricultural cooperatives, 2014

Note: Scope1: grain separately vs farm, service and others jointly; Scope2: farm input separately vs grain, service and others jointly; Scope3: service separately vs grain, farm, and others jointly and Scope4: other separately vs grain, farm, and service jointly.

Appendix B

Summary Statistics of Economic Measures by Year

Appendix B provides summary statistics for cost efficiency, multiproduct and product-specific scale economies, and scope economies estimated from both frontiers between 2005 and 2014.

Table B.1: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2005

	N	Mean	Median	Std. Dev.
Cost efficiency	279	0.73	0.72	0.16
Multiproduct scale economies	250	1.06	0.96	0.59
Grain-specific scale economies	154	0.72	0.76	0.25
Farm input-specific scale economies	211	0.81	0.85	0.18
Service-specific scale economies	218	0.78	0.79	0.16
Other product-specific scale economies	190	0.93	1.00	0.13
Scope: grain vs (farm, service & others)	154	0.09	0.07	0.12
Scope: farm vs (grain, service & others)	211	0.16	0.12	0.14
Scope: service vs (grain, farm & others)	218	0.22	0.19	0.15
Scope: others vs (grain, farm & service)	190	0.11	0.05	0.17

Table B.2: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2006

	N	Mean	Median	Std. Dev.
Cost efficiency	276	0.71	0.68	0.17
Multiproduct scale economies	246	1.12	0.98	0.81
Grain-specific scale economies	169	0.75	0.76	0.22
Farm input-specific scale economies	205	0.83	0.83	0.12
Service-specific scale economies	219	0.79	0.80	0.16
Other product-specific scale economies	188	0.96	1.00	0.09
Scope: grain vs (farm, service & others)	169	0.13	0.08	0.16
Scope: farm vs (grain, service & others)	205	0.16	0.15	0.11
Scope: service vs (grain, farm & others)	219	0.23	0.19	0.17
Scope: others vs (grain, farm & service)	188	0.11	0.05	0.17

Table B.3: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2007

	N	Mean	Median	Std. Dev.
Cost efficiency	274	0.74	0.73	0.17
Multiproduct scale economies	242	1.11	0.94	1.00
Grain-specific scale economies	173	0.82	0.87	0.19
Farm input-specific scale economies	192	0.82	0.85	0.15
Service-specific scale economies	209	0.83	0.85	0.15
Other product-specific scale economies	162	0.85	0.91	0.18
Scope: grain vs (farm, service & others)	173	0.09	0.02	0.17
Scope: farm vs (grain, service & others)	192	0.13	0.10	0.13
Scope: service vs (grain, farm & others)	209	0.16	0.11	0.17
Scope: others vs (grain, farm & service)	162	0.13	0.04	0.20

Table B.4: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2008

	N	Mean	Median	Std. Dev.
Cost efficiency	272	0.64	0.62	0.19
Multiproduct scale economies	247	1.24	0.94	1.31
Grain-specific scale economies	165	0.77	0.79	0.20
Farm input-specific scale economies	192	0.83	0.90	0.19
Service-specific scale economies	217	0.74	0.75	0.19
Other product-specific scale economies	183	0.96	1.00	0.10
Scope: grain vs (farm, service & others)	165	0.19	0.17	0.14
Scope: farm vs (grain, service & others)	192	0.16	0.14	0.13
Scope: service vs (grain, farm & others)	217	0.26	0.22	0.18
Scope: others vs (grain, farm & service)	183	0.17	0.10	0.20

Table B.5: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2009

	N	Mean	Median	Std. Dev.
Cost efficiency	271	0.66	0.64	0.19
Multiproduct scale economies	241	1.23	0.91	1.30
Grain-specific scale economies	147	0.84	0.90	0.19
Farm input-specific scale economies	193	0.79	0.89	0.23
Service-specific scale economies	210	0.85	0.91	0.17
Other product-specific scale economies	198	0.96	1.00	0.10
Scope: grain vs (farm, service & others)	147	0.10	0.06	0.14
Scope: farm vs (grain, service & others)	193	0.12	0.02	0.22
Scope: service vs (grain, farm & others)	210	0.20	0.12	0.27
Scope: others vs (grain, farm & service)	198	0.11	-0.01	0.26

Table B.6: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2010

	N	Mean	Median	Std. Dev.
Cost efficiency	270	0.63	0.58	0.20
Multiproduct scale economies	243	1.26	0.92	1.55
Grain-specific scale economies	154	0.72	0.75	0.24
Farm input-specific scale economies	206	0.83	0.89	0.18
Service-specific scale economies	206	0.80	0.89	0.23
Other product-specific scale economies	197	0.93	0.99	0.11
Scope: grain vs (farm, service & others)	154	0.22	0.18	0.20
Scope: farm vs (grain, service & others)	206	0.16	0.07	0.25
Scope: service vs (grain, farm & others)	206	0.26	0.21	0.24
Scope: others vs (grain, farm & service)	197	0.19	0.11	0.21

Table B.7: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2011

	N	Mean	Median	Std. Dev.
Cost efficiency	493	0.50	0.44	0.23
Multiproduct scale economies	430	1.61	1.03	1.93
Grain-specific scale economies	281	0.87	0.94	0.16
Farm input-specific scale economies	369	0.86	1.00	0.20
Service-specific scale economies	356	0.90	0.95	0.11
Other product-specific scale economies	385	0.91	1.00	0.15
Scope: grain vs (farm, service & others)	281	0.16	0.13	0.26
Scope: farm vs (grain, service & others)	369	0.23	0.20	0.37
Scope: service vs (grain, farm & others)	356	0.14	0.11	0.28
Scope: others vs (grain, farm & service)	385	0.24	0.14	0.29

Table B.8: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2012

	N	Mean	Median	Std. Dev.
Cost efficiency	468	0.52	0.46	0.22
Multiproduct scale economies	420	1.02	0.95	0.29
Grain-specific scale economies	261	0.84	0.90	0.18
Farm input-specific scale economies	358	0.90	1.00	0.17
Service-specific scale economies	359	0.88	0.92	0.14
Other product-specific scale economies	353	0.95	1.00	0.10
Scope: grain vs (farm, service & others)	261	0.10	0.07	0.16
Scope: farm vs (grain, service & others)	358	0.10	0.09	0.14
Scope: service vs (grain, farm & others)	359	0.11	0.09	0.15
Scope: others vs (grain, farm & service)	353	0.10	0.06	0.12

Table B.9: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2013

	N	Mean	Median	Std. Dev.
Cost efficiency	456	0.53	0.49	0.20
Multiproduct scale economies	416	1.02	1.01	0.28
Grain-specific scale economies	251	0.94	0.98	0.11
Farm input-specific scale economies	335	0.89	0.97	0.17
Service-specific scale economies	356	0.91	0.97	0.13
Other product-specific scale economies	337	0.97	1.00	0.07
Scope: grain vs (farm, service & others)	251	0.05	0.04	0.17
Scope: farm vs (grain, service & others)	335	0.09	0.09	0.12
Scope: service vs (grain, farm & others)	356	0.07	0.06	0.13
Scope: others vs (grain, farm & service)	337	0.09	0.06	0.12

Table B.10: Overall summary statistics of estimated economic measures for agricultural cooperatives, 2014

	N	Mean	Median	Std. Dev.
Cost efficiency	452	0.50	0.45	0.23
Multiproduct scale economies	402	1.80	0.90	1.86
Grain-specific scale economies	238	0.93	0.99	0.13
Farm input-specific scale economies	331	0.91	1.00	0.17
Service-specific scale economies	353	0.83	0.86	0.17
Other product-specific scale economies	334	0.94	1.00	0.12
Scope: grain vs (farm, service & others)	238	0.22	0.16	0.25
Scope: farm vs (grain, service & others)	331	0.30	0.28	0.34
Scope: service vs (grain, farm & others)	353	0.23	0.15	0.31
Scope: others vs (grain, farm & service)	334	0.30	0.20	0.29

Figures

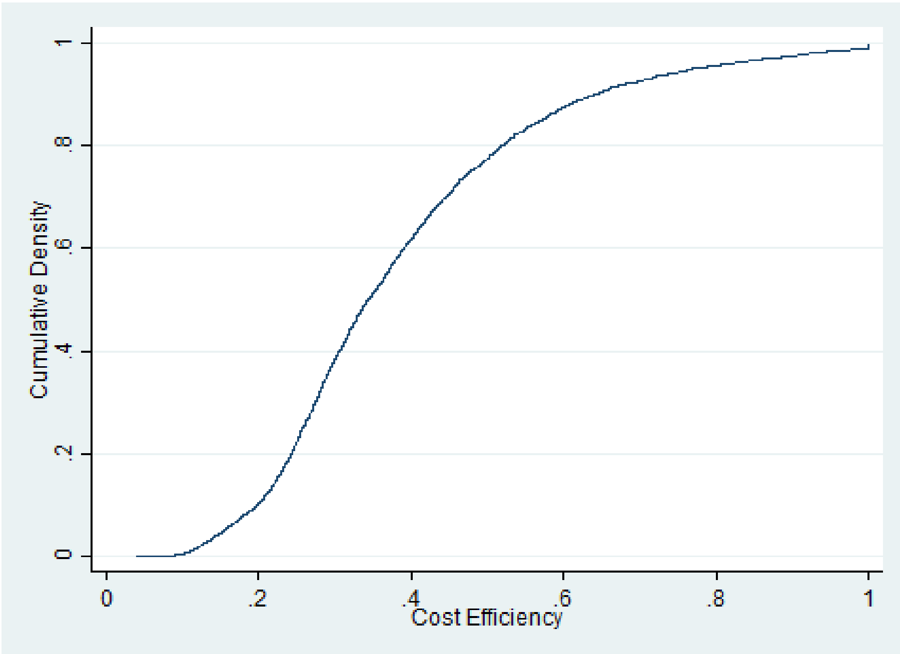

Figure B.1: Cumulative distribution of cost efficiency from a single frontier for agricultural cooperatives

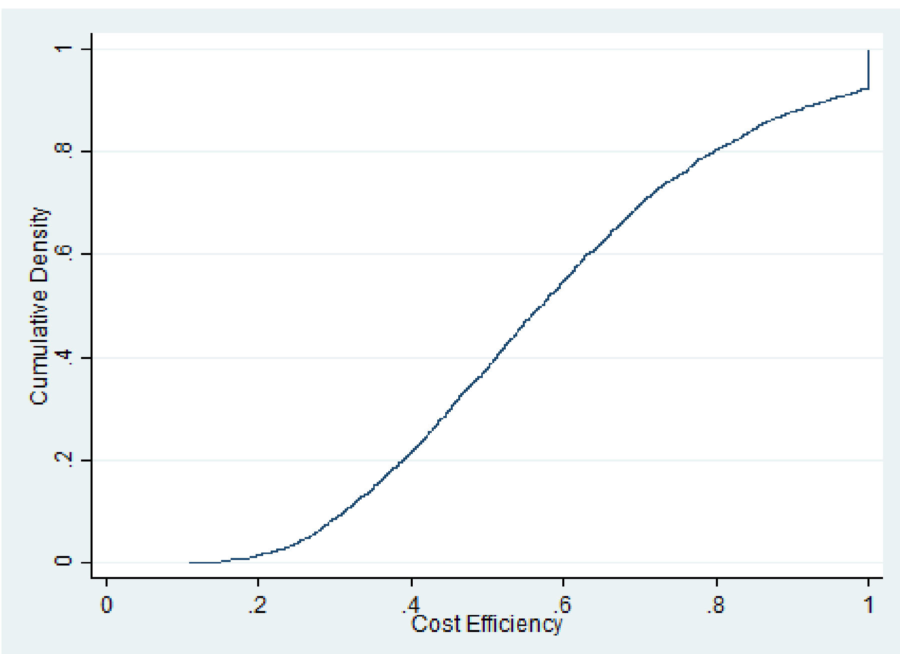

Figure B.2: Cumulative distribution of cost efficiency from annual frontiers for agricultural cooperatives

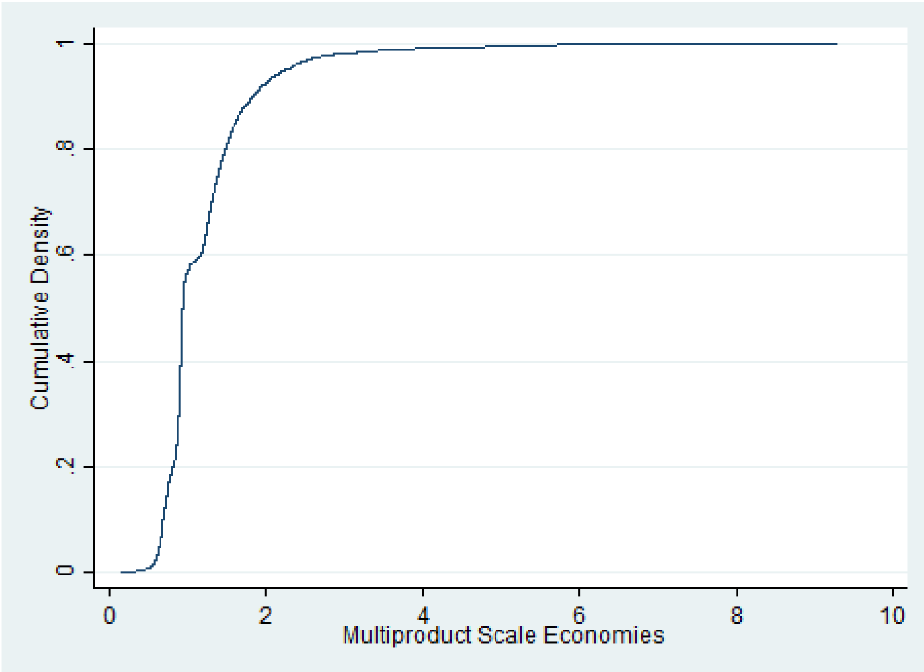

Figure B.3: Cumulative distribution of multiproduct scale economies from a single frontier for agricultural cooperatives

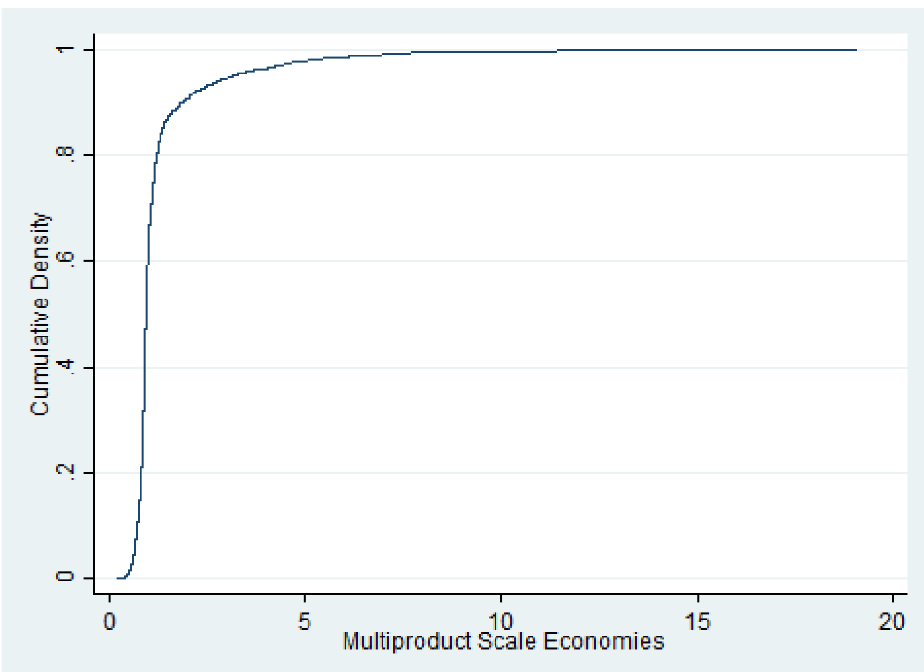

Figure B.4: Cumulative distribution of multiproduct scale economies from annual frontiers for agricultural cooperatives

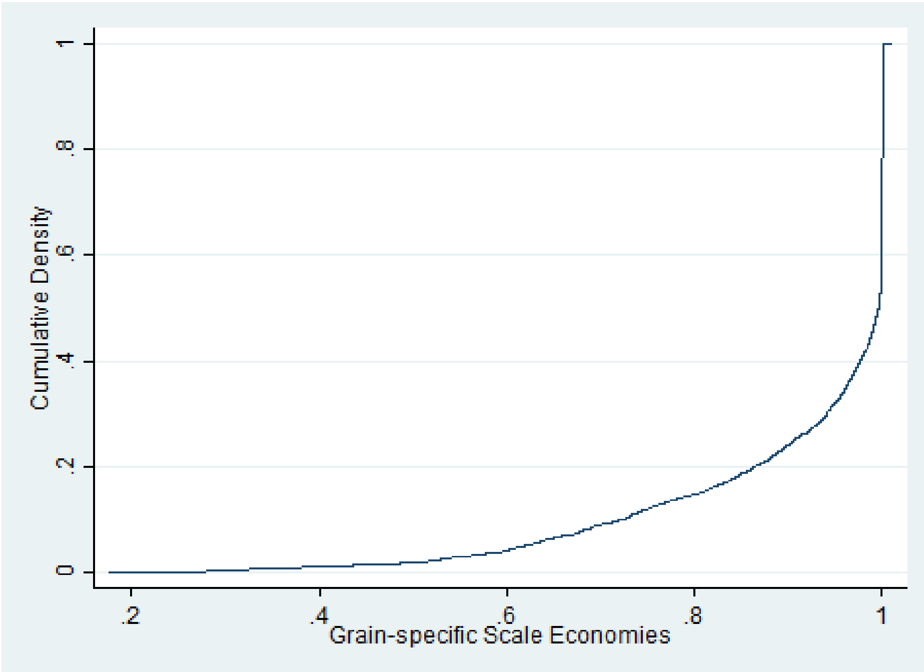

Figure B.5: Cumulative distribution of grain-specific scale economies from a single frontier for agricultural cooperatives

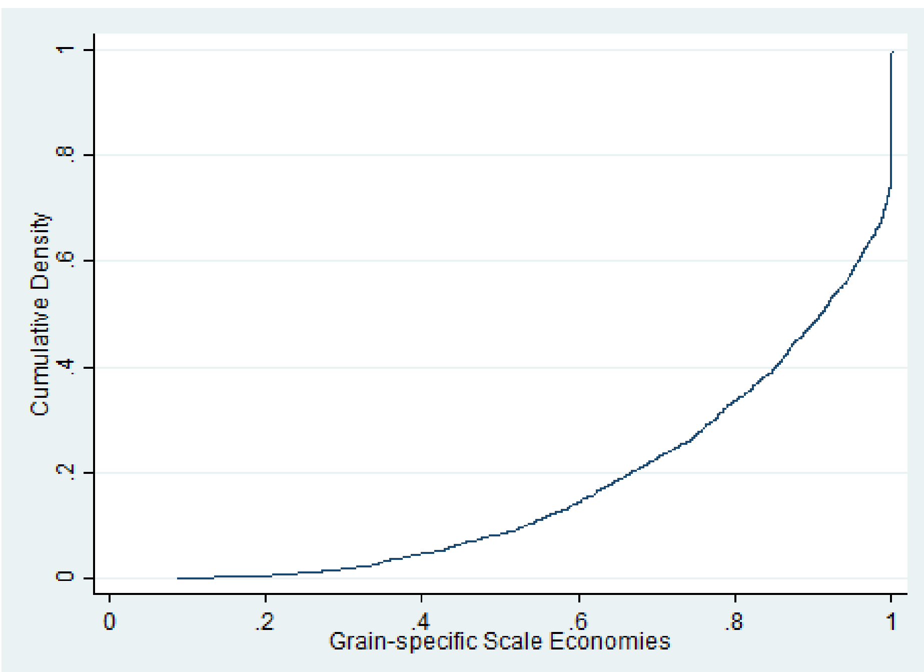

Figure B.6: Cumulative distribution of grain-specific scale economies from annual frontiers for agricultural cooperatives

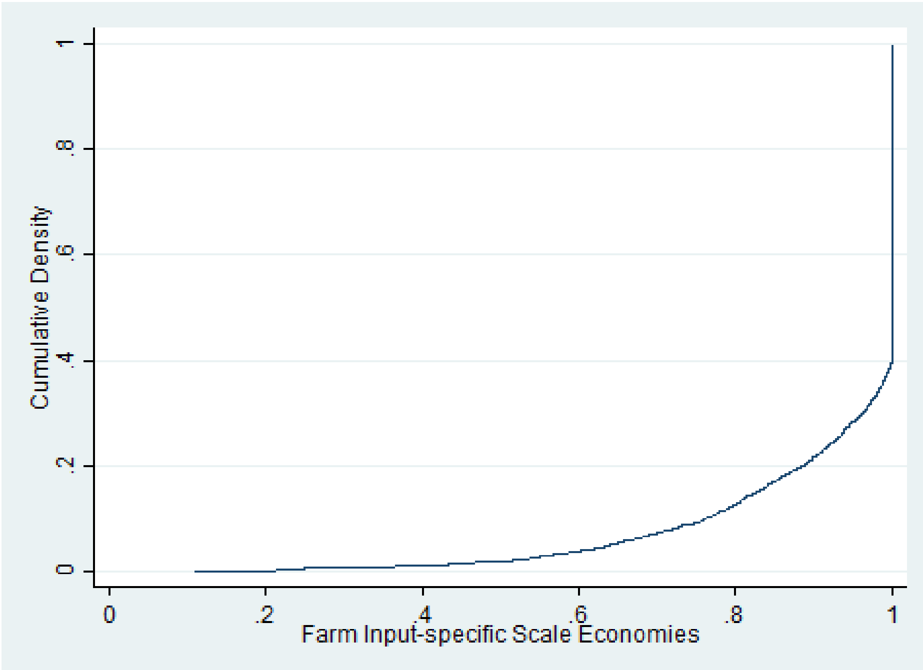

Figure B.7: Cumulative distribution of farm input-specific scale economies from a single frontier for agricultural cooperatives

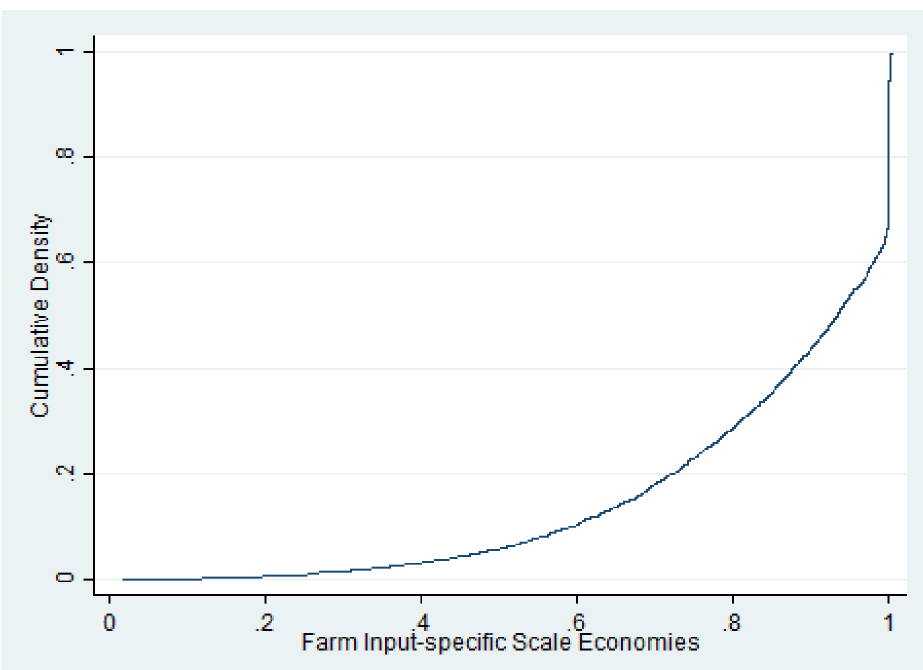

Figure B.8: Cumulative distribution of farm input-specific scale economies from annual frontiers for agricultural cooperatives

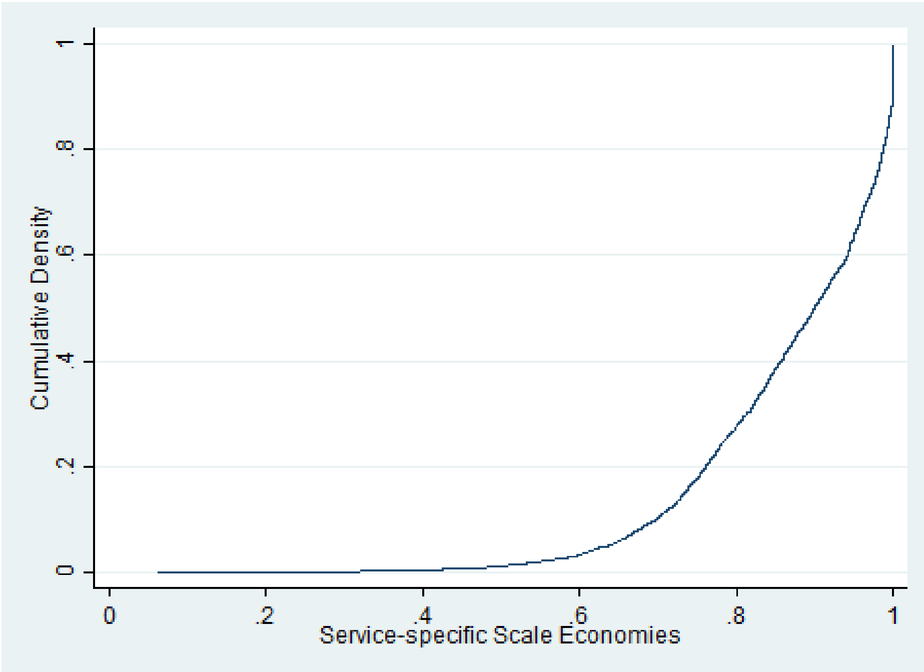

Figure B.9: Cumulative distribution of service-specific scale economies from a single frontier for agricultural cooperatives

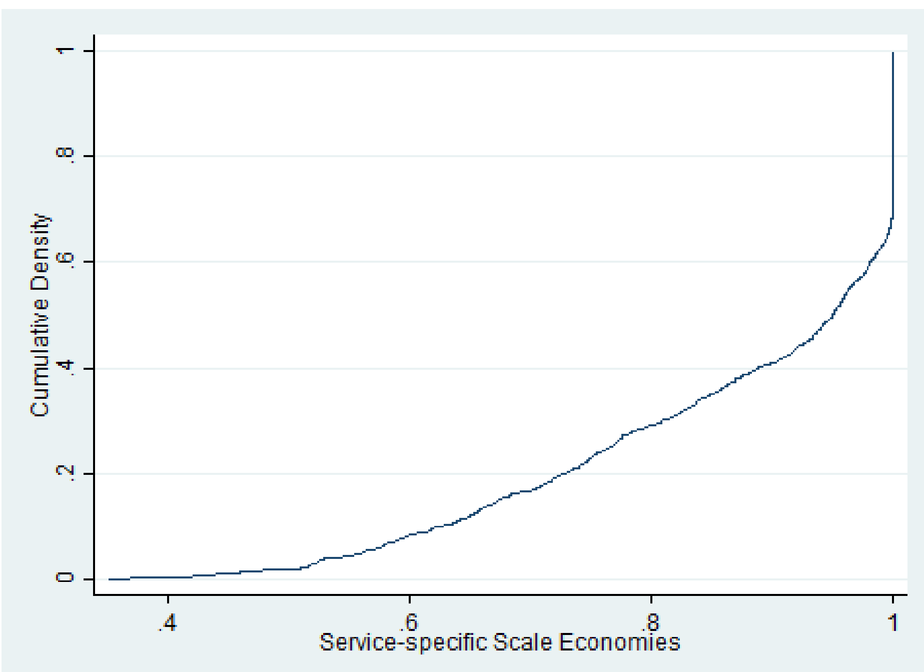

Figure B.10: Cumulative distribution of service-specific scale economies from annual frontiers for agricultural cooperatives

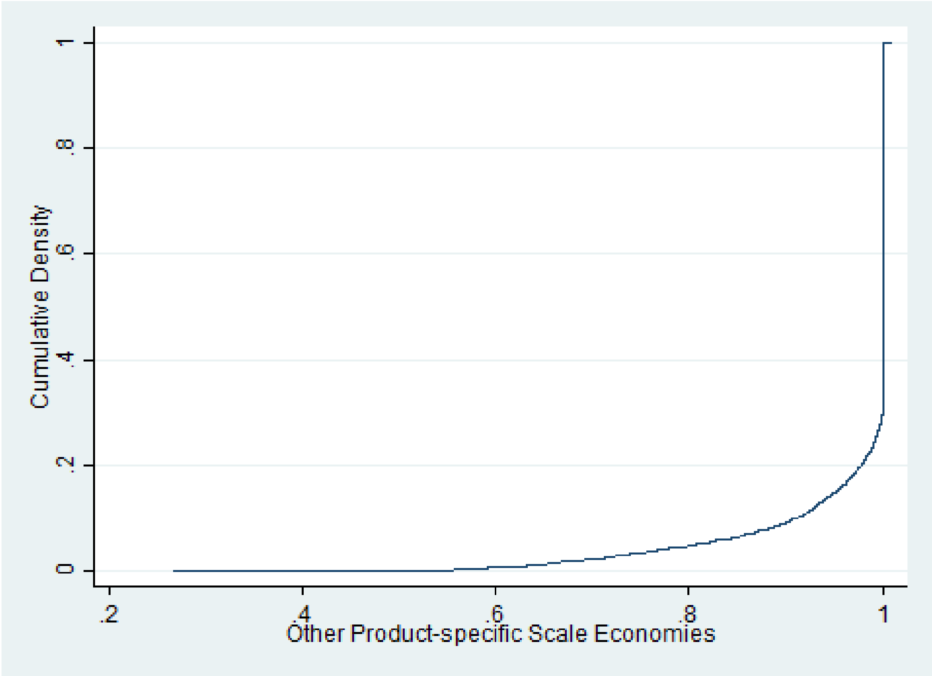

Figure B.11: Cumulative distribution of other product-specific scale economies from a single frontier for agricultural cooperatives

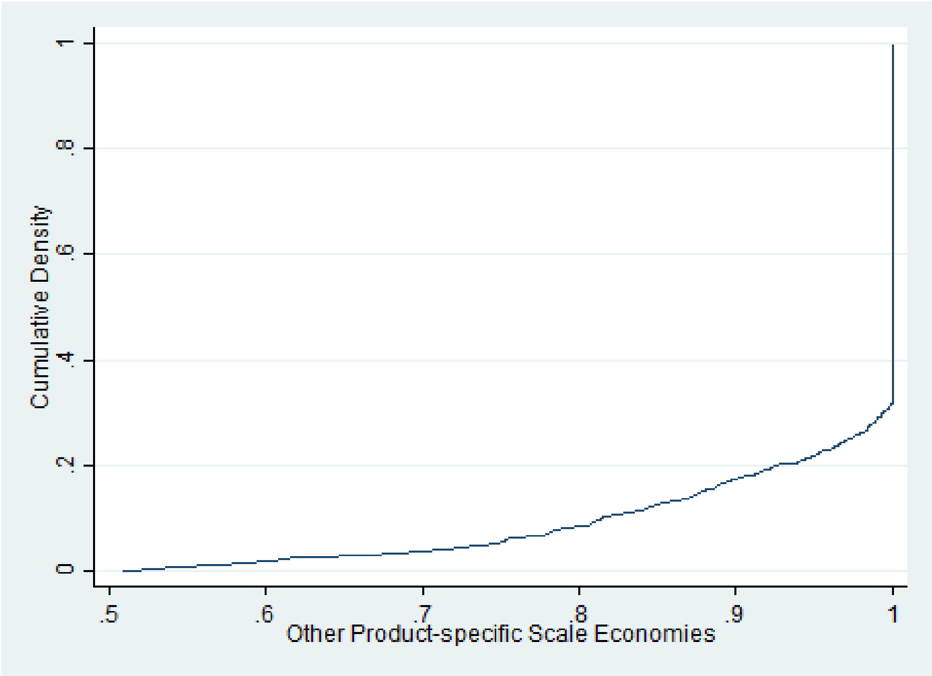

Figure B.12: Cumulative distribution of other product-specific scale economies from annual frontiers for agricultural cooperatives

Appendix C

Distributions of Productivity Growth, Efficiency Change, and Technical Change

This section plots the distributions of productivity growth, efficiency change, and technical change. These graphs depict the changes in productivity growth, technical efficiency, and technology from 2005 to 2014.

Figures (C.1) to (C.9) depict that more than 60% cooperatives gain productivity except the three periods 2008–2009, 2012–2013, and 2013–2014. During these three periods, more than 50% cooperatives show productivity regress. The cumulative density graphs (Figures C.1 to C.9) exhibit that productivity growth and technical change are moving more closely than efficiency change over the study period and the majority of cooperatives have productivity growth greater than 1.0. This demonstrates that improvements in technology is the main source of productivity. Similarly, Figures C.10 to C.12 illustrate how productivity growth is changing over time.

The cumulative density graphs for efficiency change show changes in technical efficiency for a sample of agricultural cooperatives. More than 50% of cooperatives have a technical efficiency change less than 1 for the three periods: 2007–2008, 2008–2009, and 2011–2012 indicating that the cooperatives did not catch-up to the best practice frontier (Figures C.13 to C.15).

The cumulative distribution graphs for technical change indicate that the four periods 2008–2009, 2009–2010, 2012–2013, and 2013–2014 exhibit technical regress; more than 60% of cooperatives are found to have a technical regress (Figures C.16 to C.18).

Figures

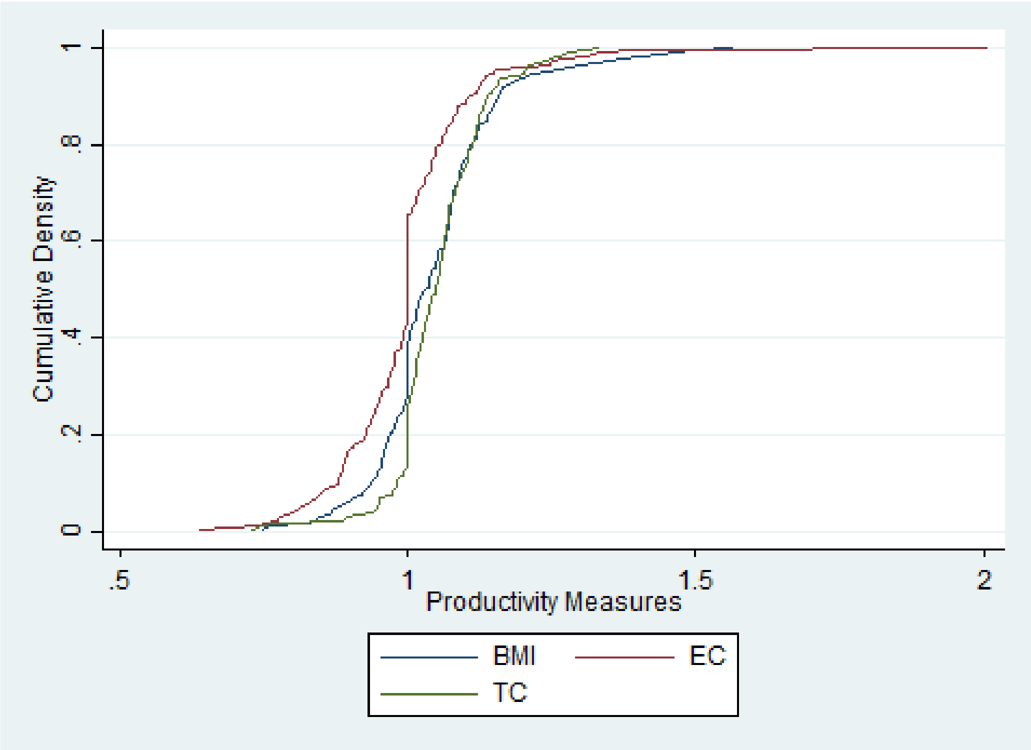

Figure C.1: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2005-2006

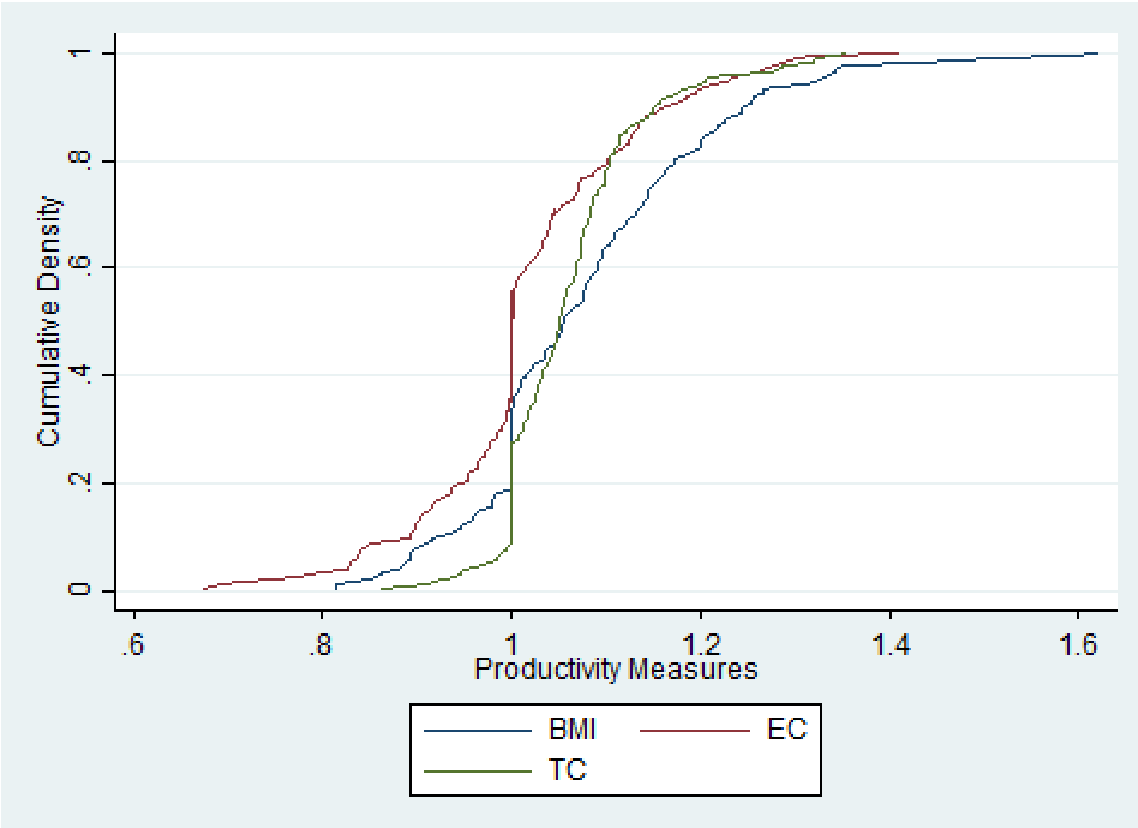

Figure C.2: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2006-2007

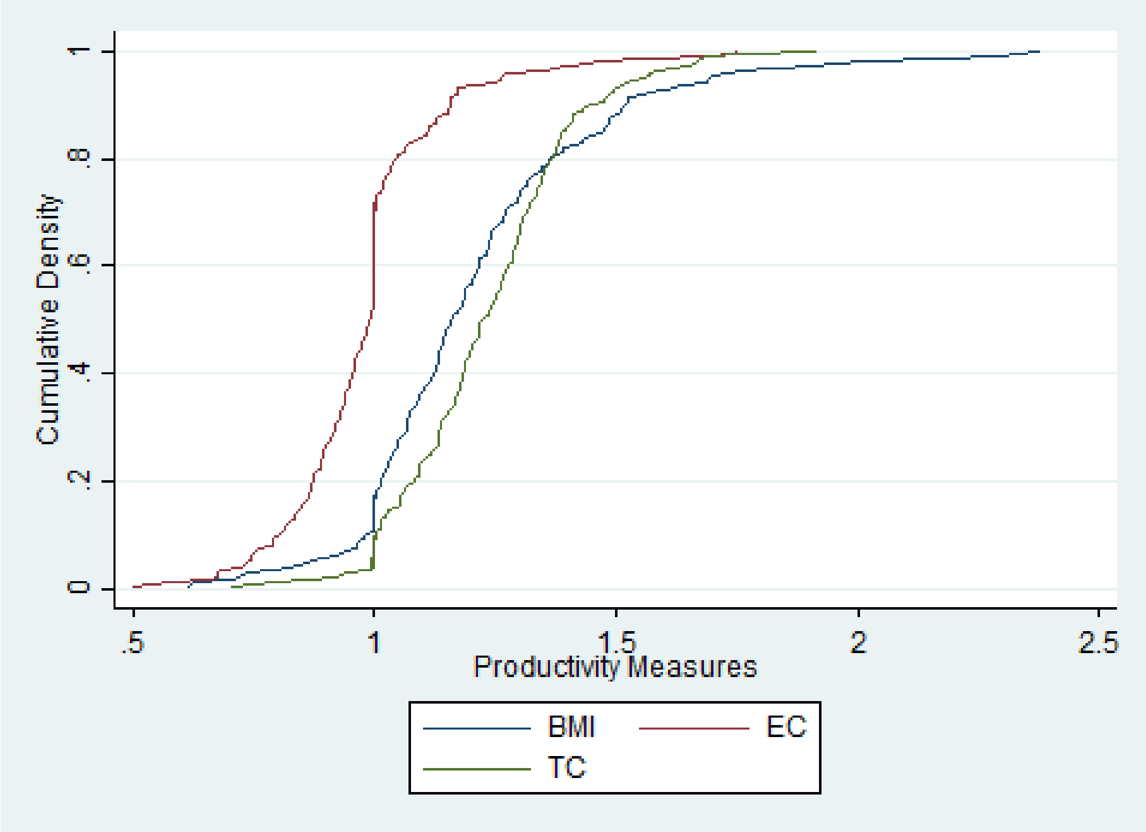

Figure C.3: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2007-2008

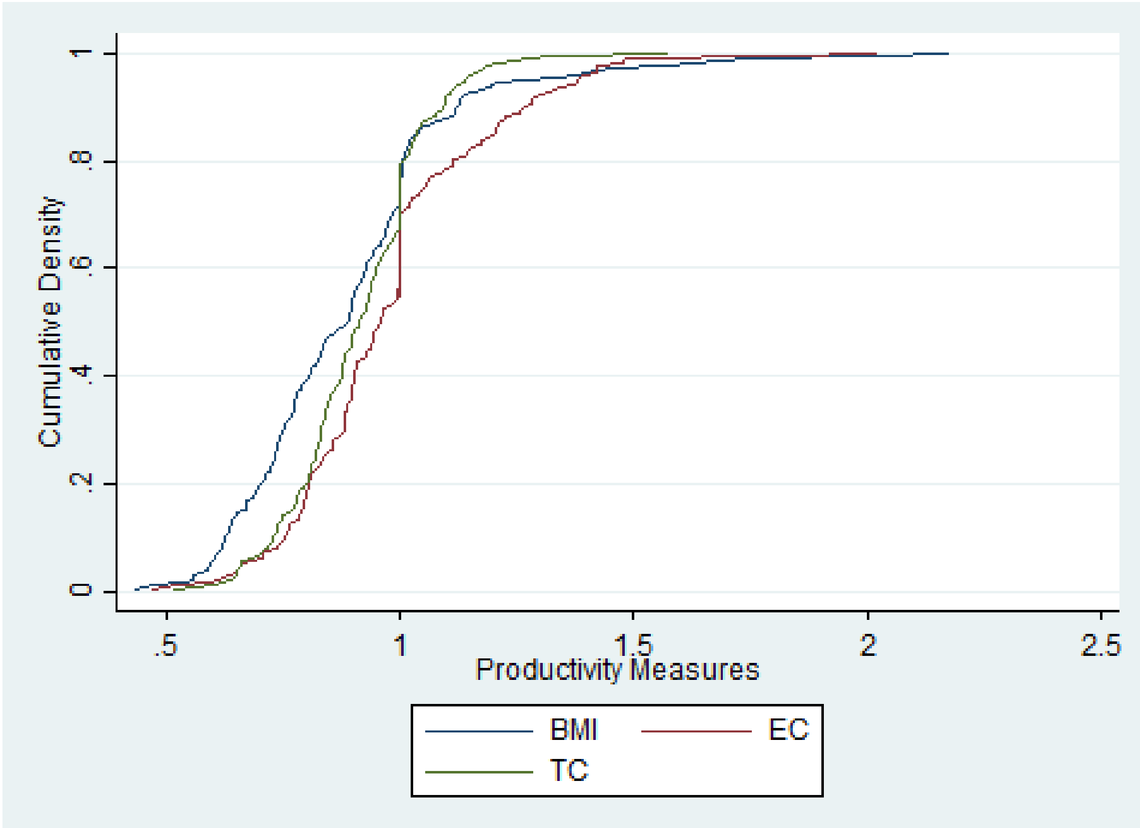

Figure C.4: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2008-2009

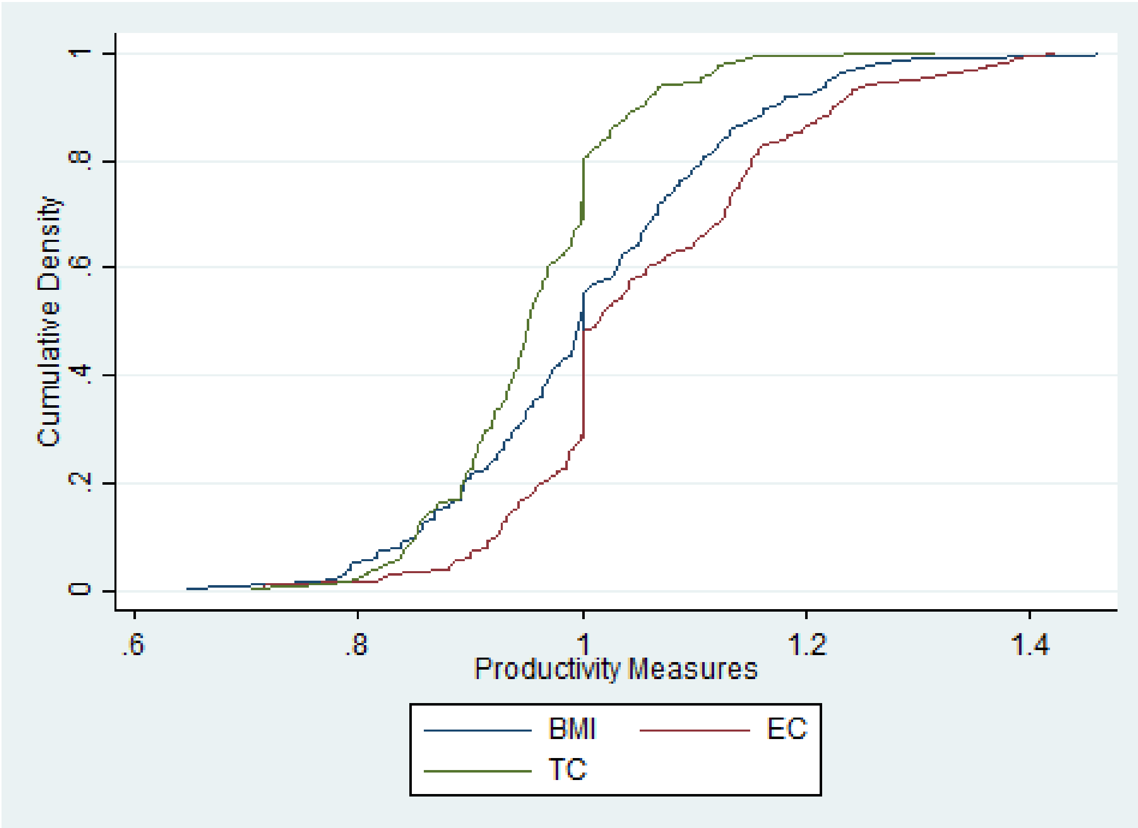

Figure C.5: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2009-2010

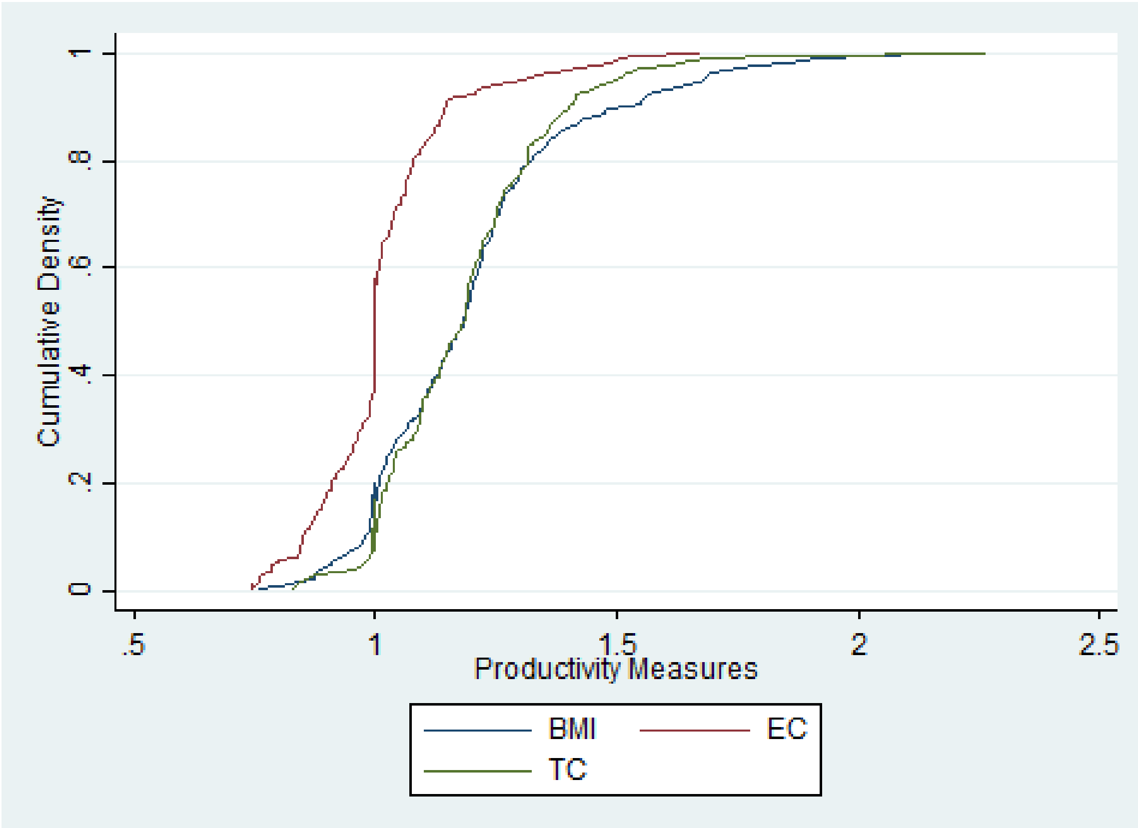

Figure C.6: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2010-2011

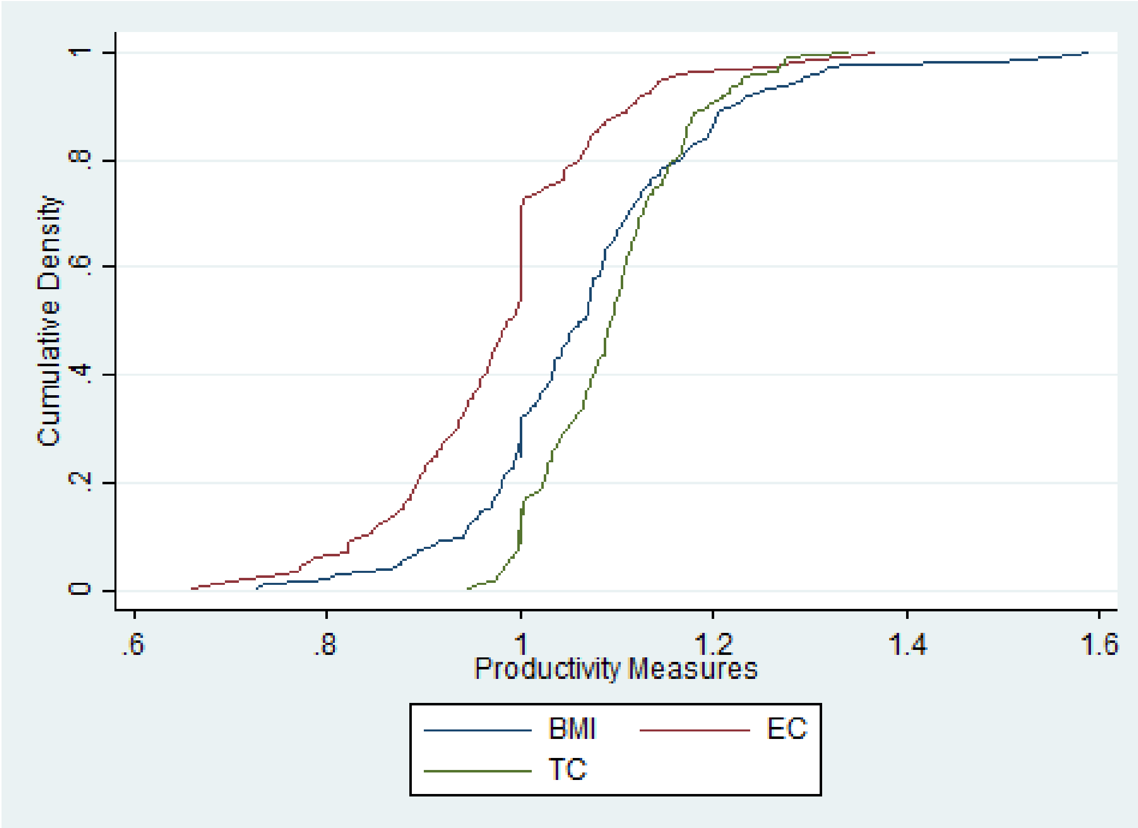

Figure C.7: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2011-2012

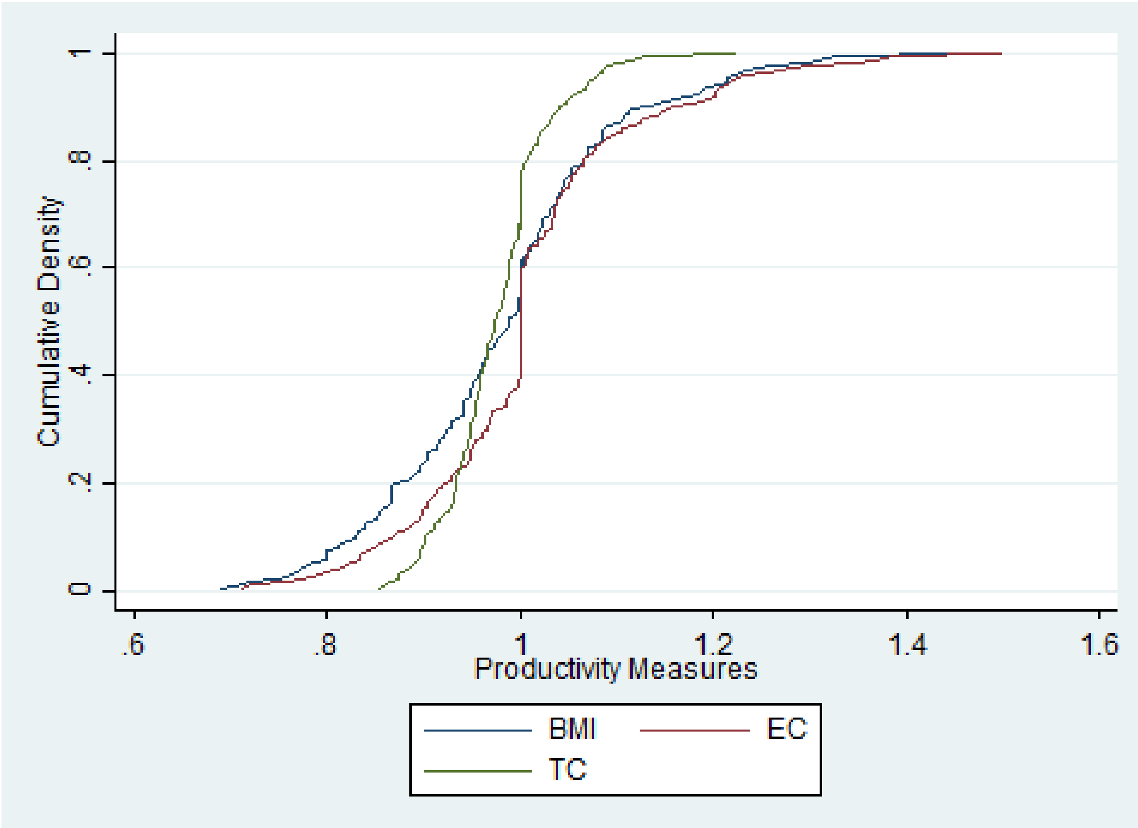

Figure C.8: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2012-2013

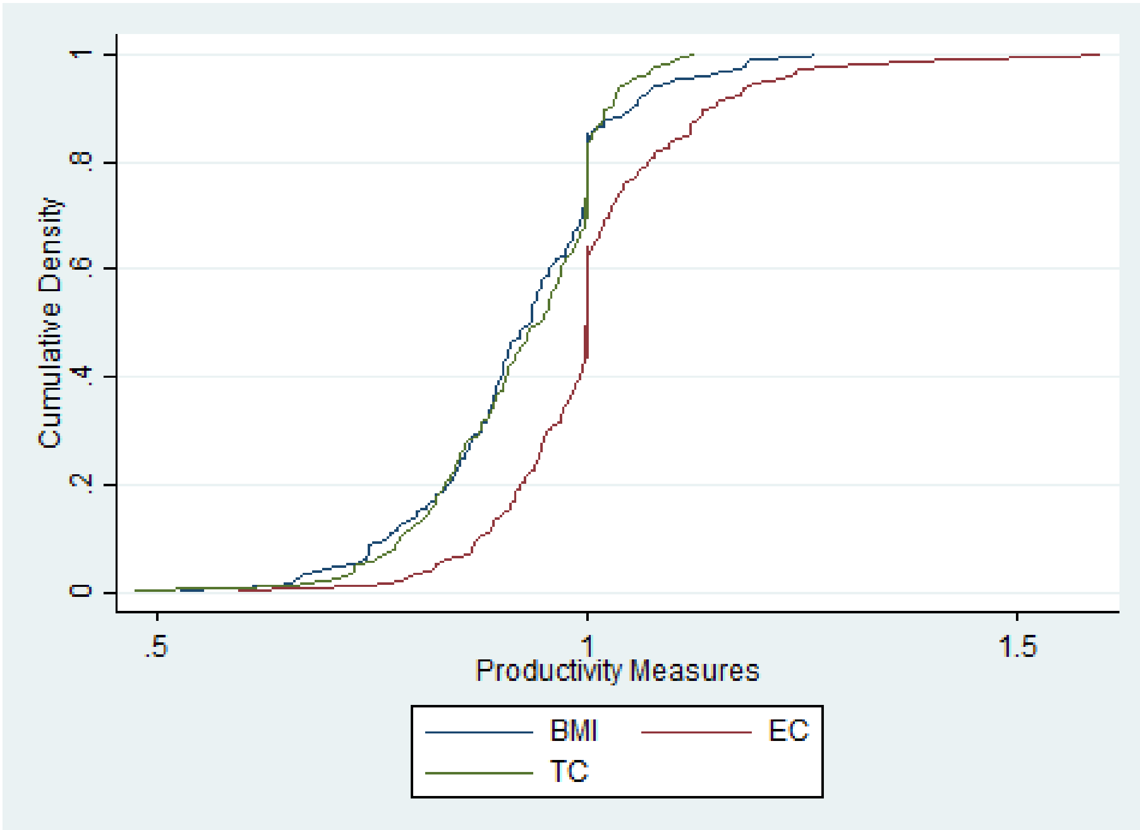

Figure C.9: The decomposition of the biennial Malmquist index (BMI) into efficiency change (EC) and technical change (TC): 2013-2014

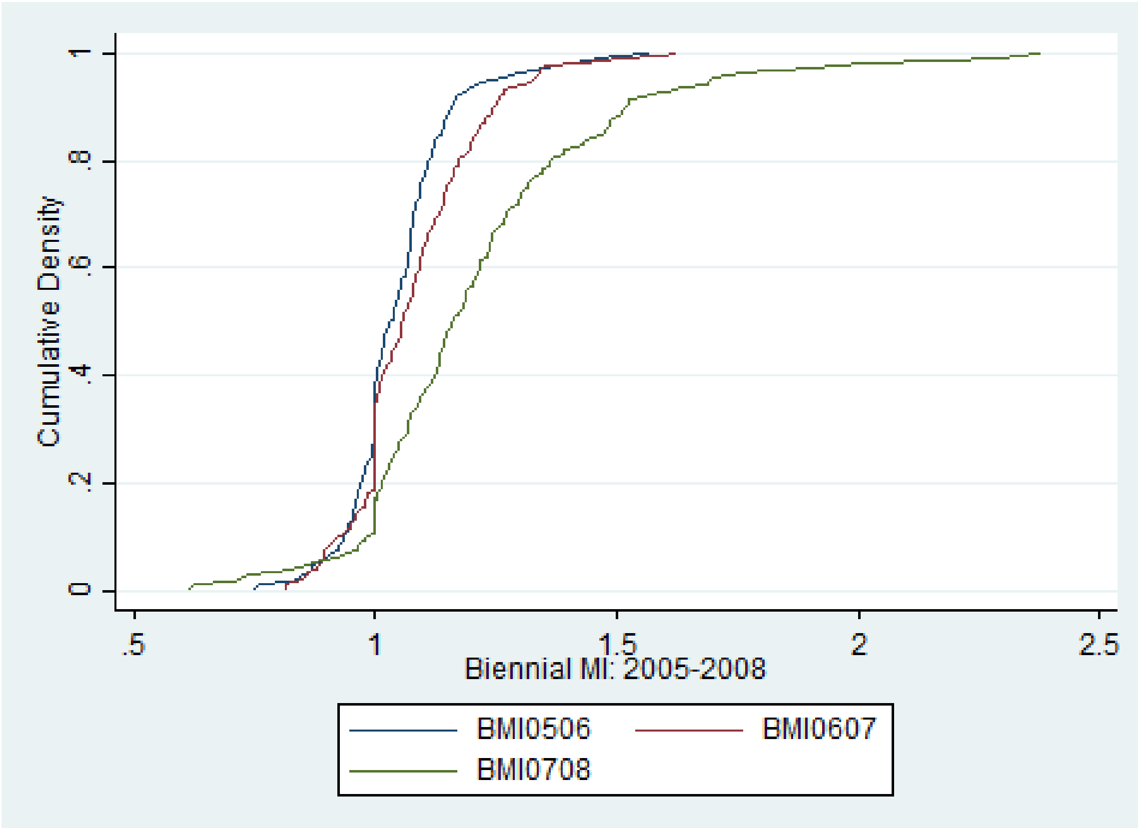

Figure C.10: The biennial Malmquist index (BMI) for three periods: 2005-2006, 2006-2007, and 2007-2008

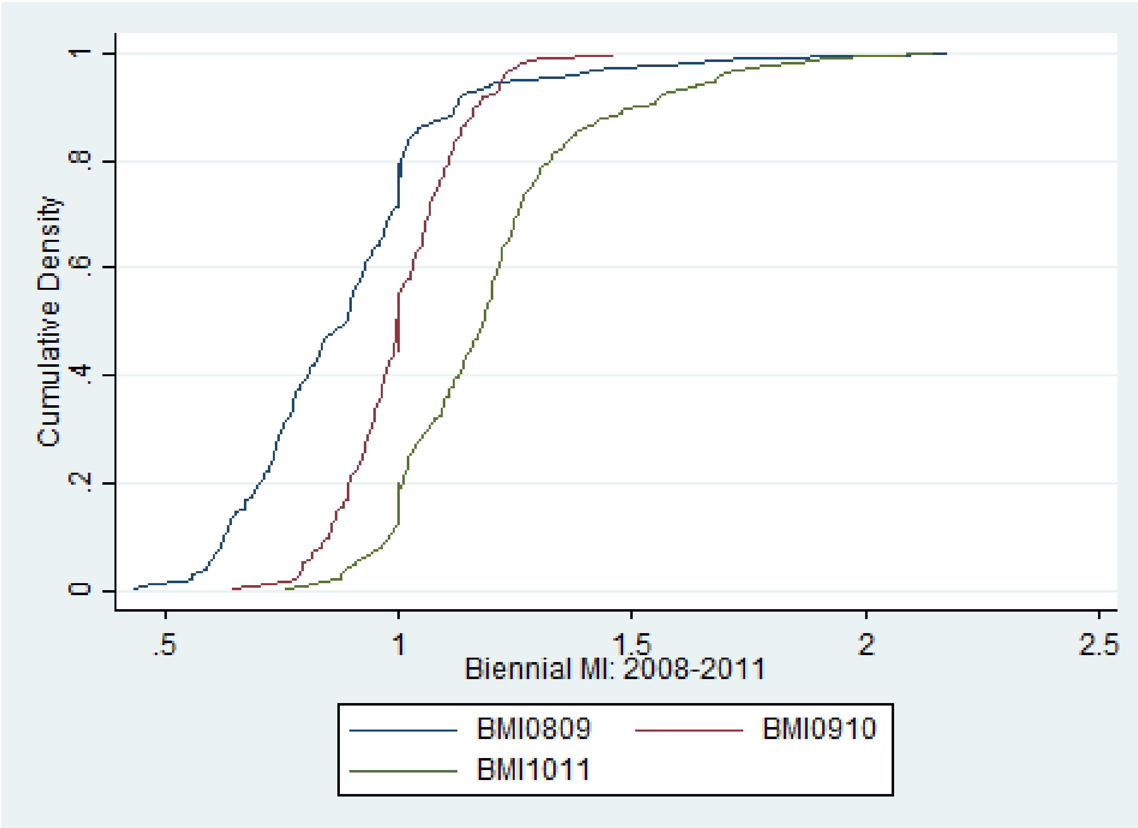

Figure C.11: The biennial Malmquist index (BMI) for three periods: 2008-2009, 2009-2010, and 2010-2011

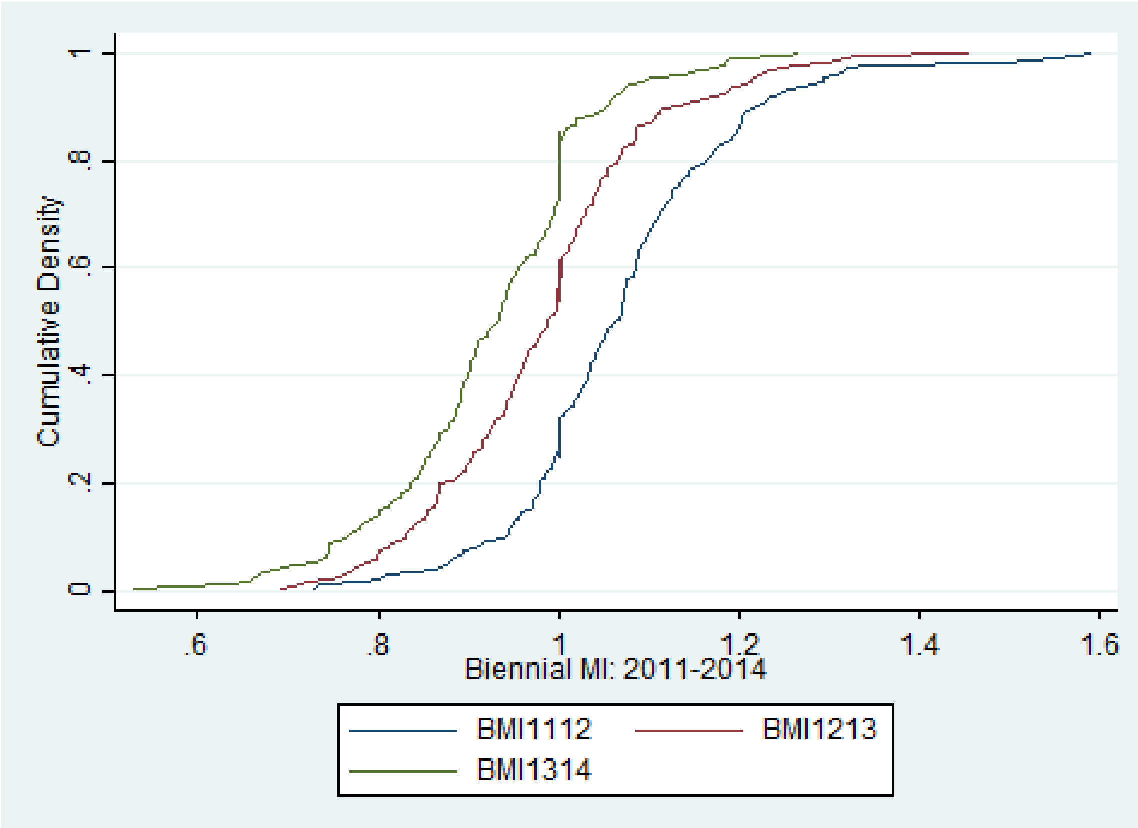

Figure C.12: The biennial Malmquist index (BMI) for three periods: 2011-2012, 2012-2013, and 2013-2014

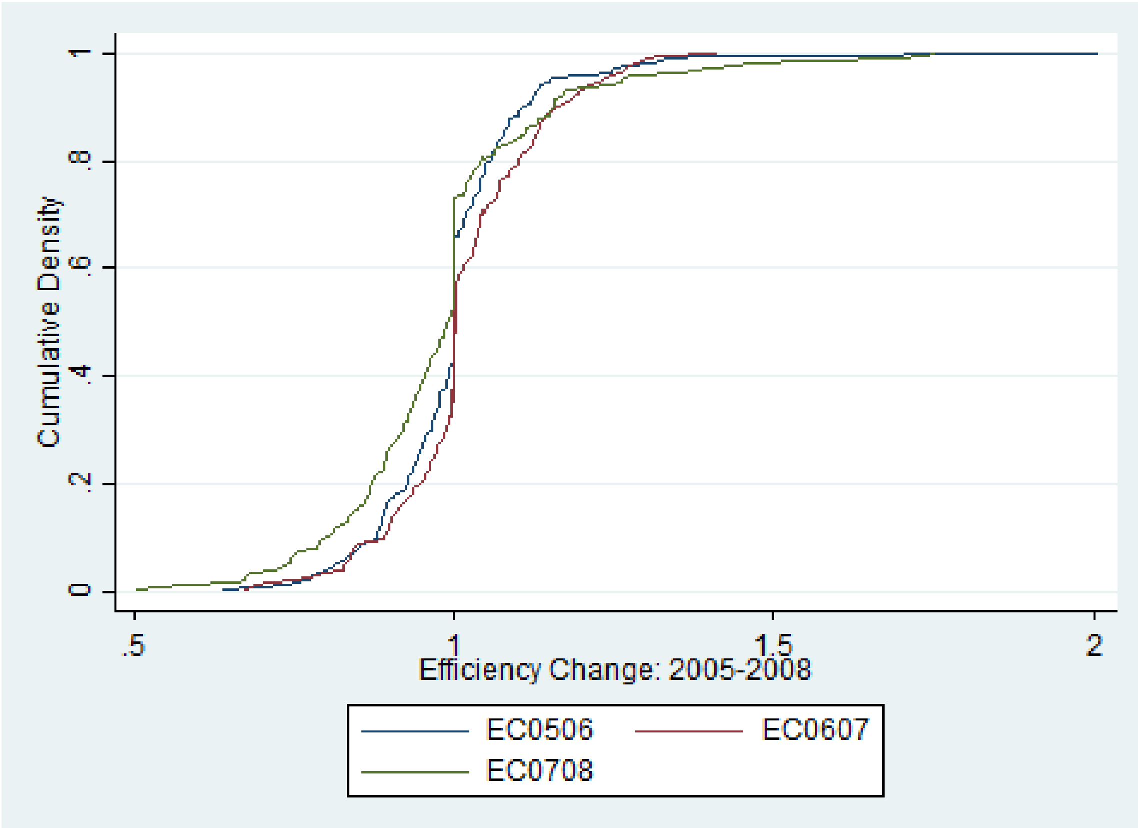

Figure C.13: Efficiency change (EC) for three periods: 2005-2006, 2006-2007, and 2007-2008

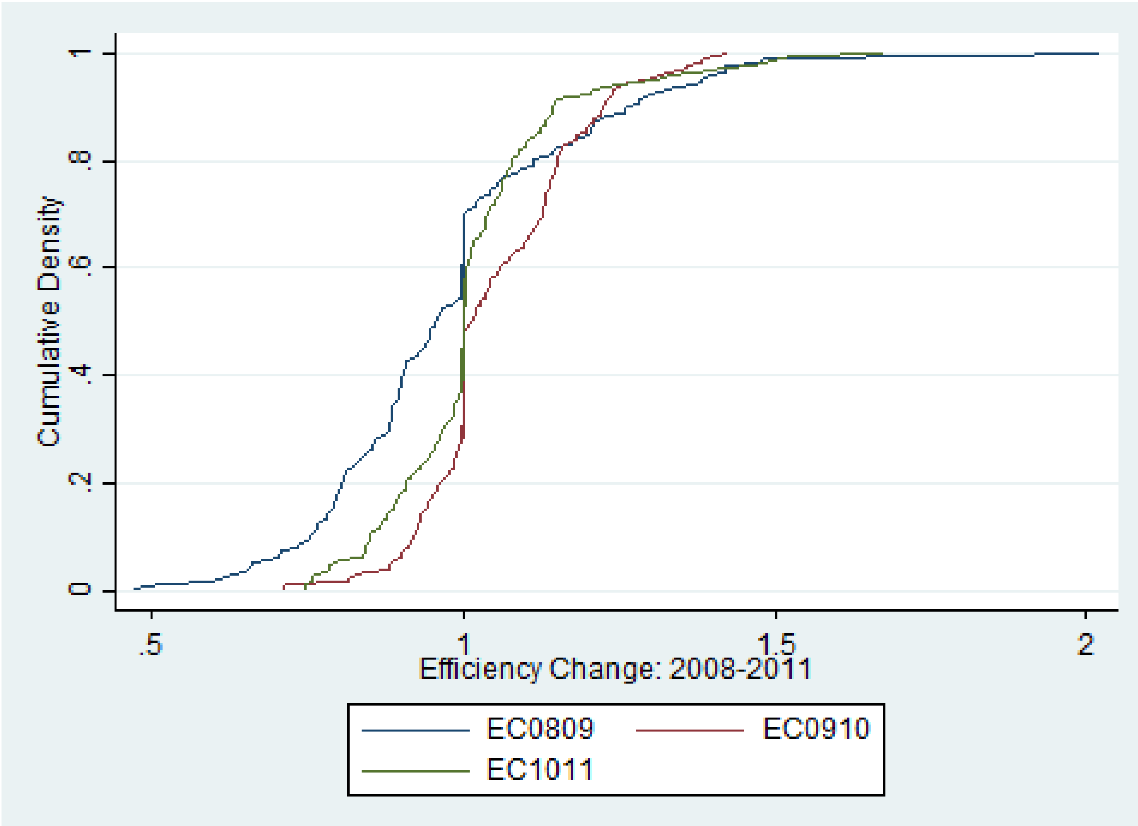

Figure C.14: Efficiency change (EC) for three periods: 2008-2009, 2009-2010, and 2010-2011

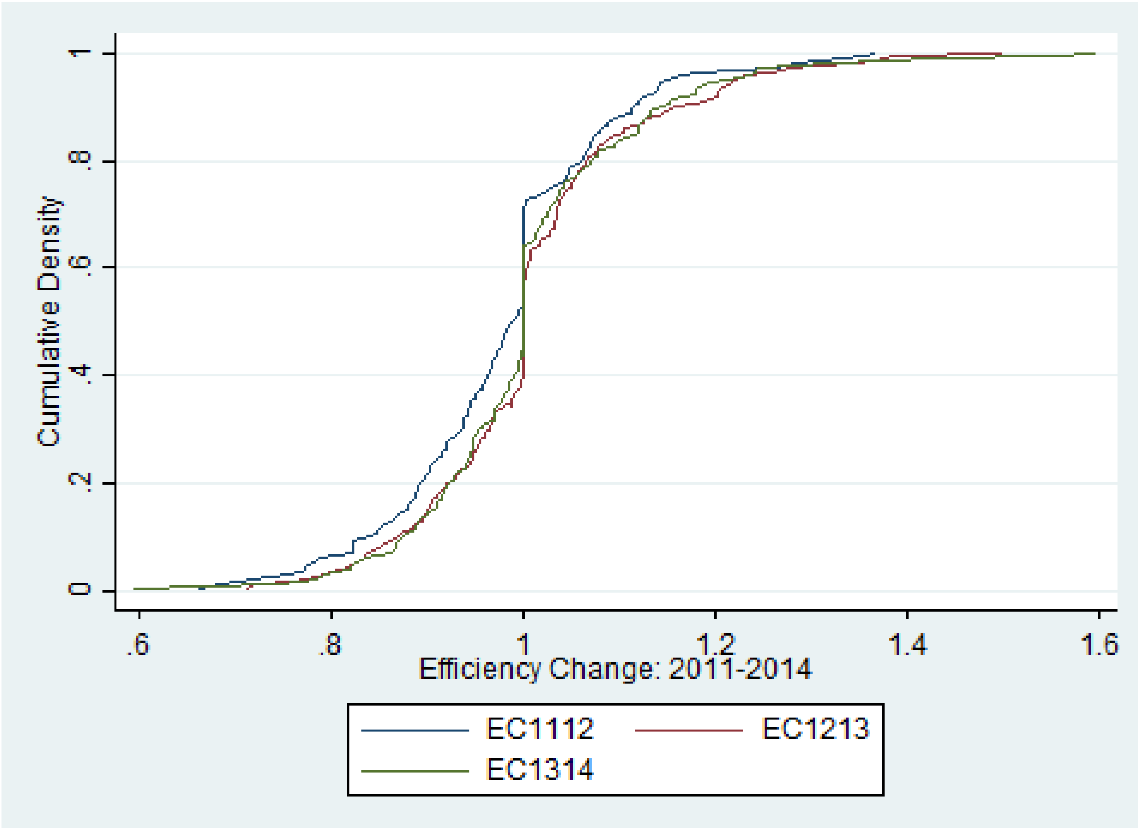

Figure C.15: Efficiency change (EC) for three periods: 2011-2012, 2012-2013, and 2013-2014

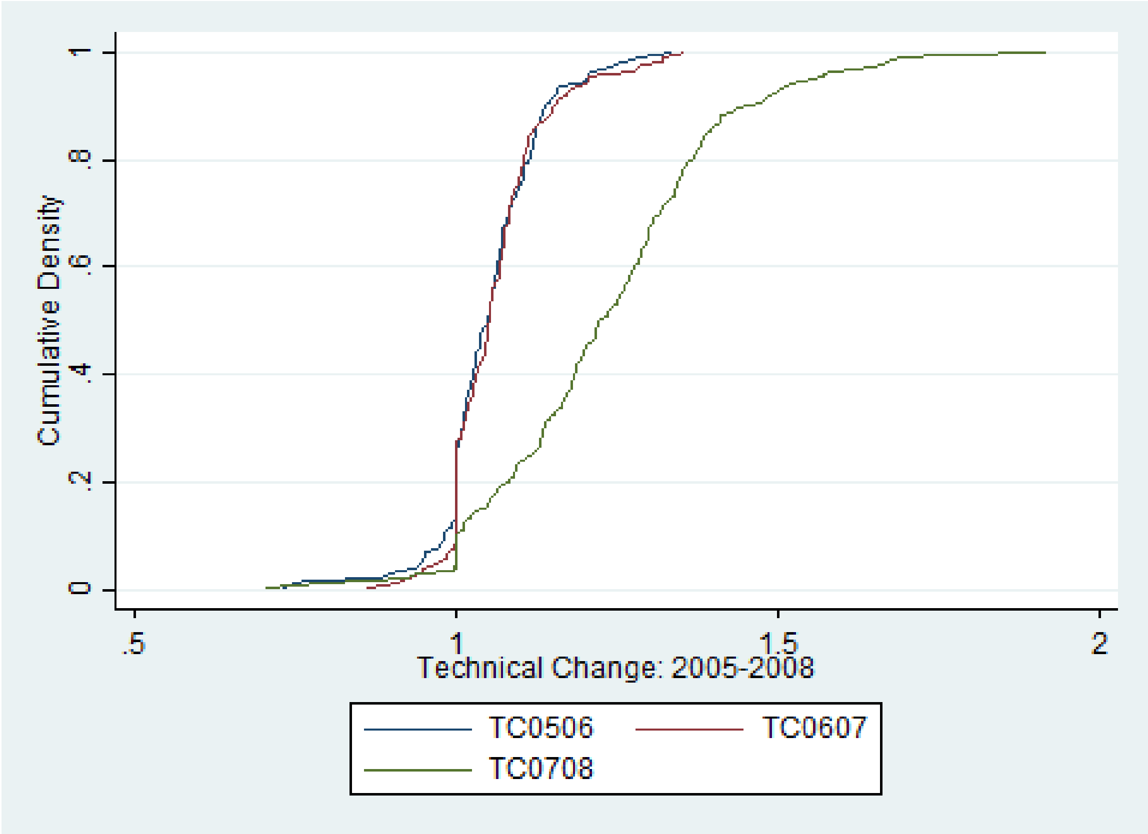

Figure C.16: Technical change (TC) for three periods: 2005-2006, 2006-2007, and 2007-2008

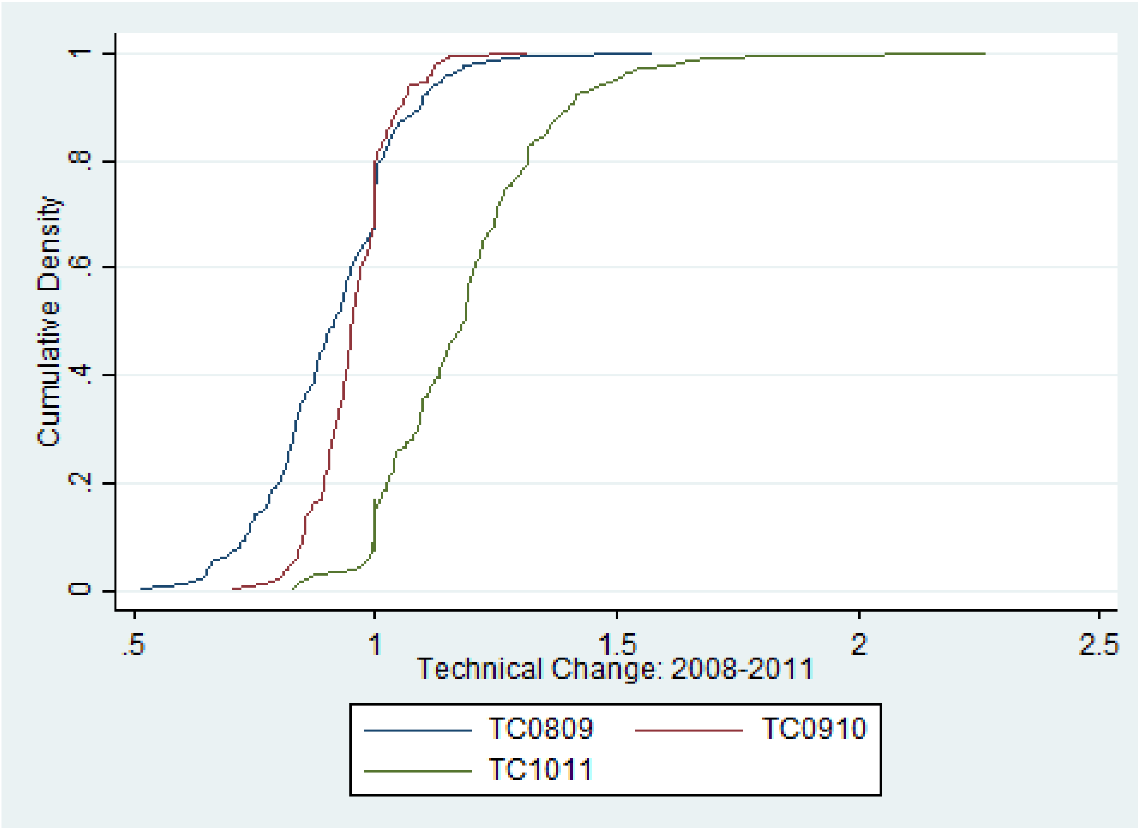

Figure C.17: Technical change (TC) for three periods: 2008-2009, 2009-2010, and 2010-2011

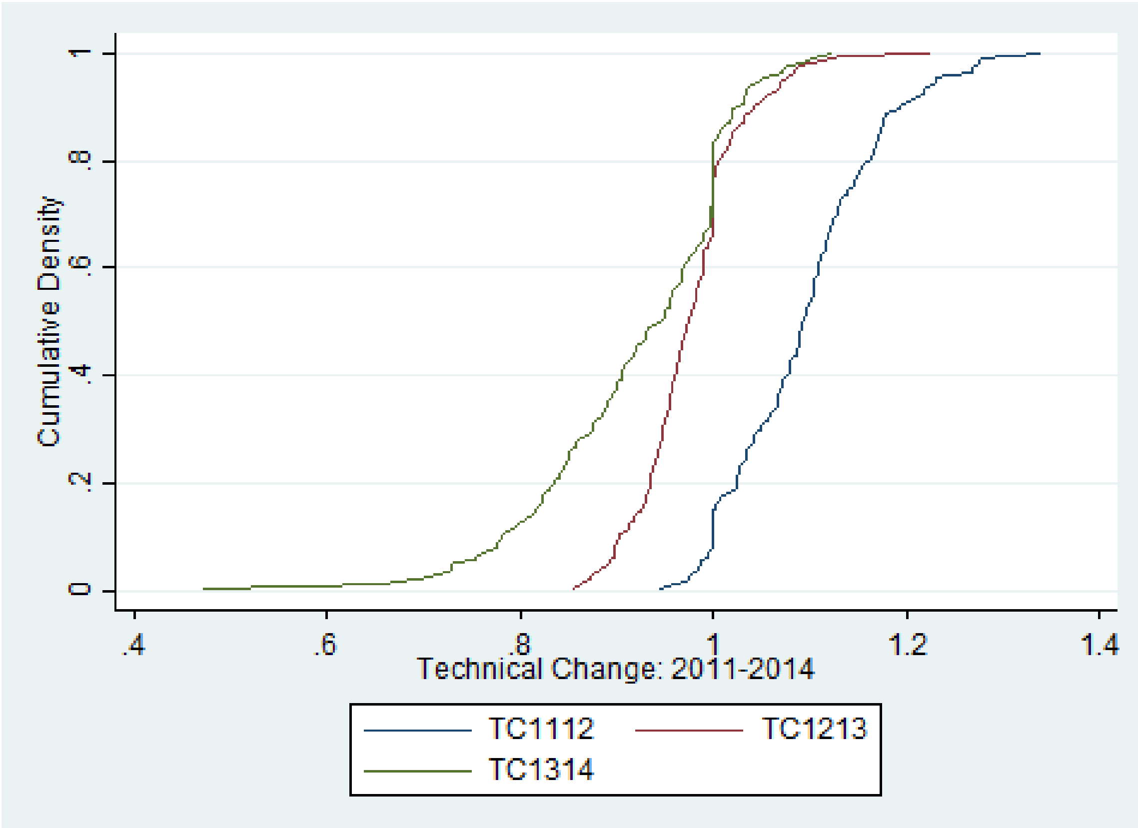

Figure C.18: Technical change (TC) for three periods: 2011-2012, 2012-2013, and 2013-2014