Estimating Economic Efficiency under Risk for Agricultural Cooperatives

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Abstract

This study examined the impact of downside risk on cost efficiency (CE) and revenue efficiency (RE) for a sample of agricultural cooperatives. Downside risk is an appropriate measure of risk as it accounts for loss below the target return level regardless of individuals' risk preference. The semi-variance of return on equity was used a measure of downside risk. CE and RE were estimated using data envelopment analysis (DEA) without adjusting for downside risk and then re-estimated adjusting for downside risk. The average CE and RE scores were higher with the inclusion of downside risk than the scores without downside risk. The DEA method without accounting for risk overestimates inefficiency and may misguide managers on adjustments needed to improve performance.

1. Introduction

Agricultural cooperatives are an integral part of production agriculture and agribusiness in supporting farmers in the United States. These cooperatives have gone through significant market fluctuations since 2005 due to the high volatility of commodity prices, increased competition, and consolidations (USDA, 2016). Recent trends in the agricultural cooperative sector include large investment in infrastructure due to changes in their business environments, changes in strategies for profit distributions and equity creation, and rapid consolidations through mergers and acquisitions that result in a lower number of agricultural cooperatives (Briggeman et al., 2016). These changes illustrate the importance of efficiency (performance) analysis. Moreover, high commodity price volatility and uncertain market situations introduce risk in the operation of agricultural cooperatives. Therefore, it is important to include risk in estimating and comparing efficiency among agricultural cooperatives. Failure to consider a risk factor may underestimate economic efficiency (Yeager and Langemeier, 2013). Efficiency estimation for cooperatives accounting for risk has not been adequately examined in the literature.

The most commonly used method for measuring risk in economics and finance is the mean-variance or expected value (E) - variance (V) approach. The EV efficient frontier shows different combinations of minimum variance for an alternative level of expected returns (Markowitz, 1952; Robinson and Barry, 1987). However, the limitations of the EV model are that it penalizes upside potential in the same way as downside loss and assumes that returns follow a multivariate normal distribution or the investor's utility function is quadratic, conditions that rarely hold in practice (Hoe et al., 2010). An alternative to the E-V approach for measuring risk is an asymmetric measure of risk (downside risk) or lower partial moments. Downside risk is an appropriate measure of risk for businesses or investors because businesses are more concerned about losses below the target return or benchmark return level (Markowitz, 1959; Tauer, 1983).

The objective of this study was to examine the impact of downside risk on cost efficiency (CE) and revenue efficiency (RE) for agricultural cooperatives. Downside risk was measured as the semi-variance of return on equity. CE and RE were estimated with standard inputs and outputs and then re-estimated including downside risk using data envelopment analysis (DEA). This article complements previous studies by identifying an appropriate measure of risk that is of concerns to agribusiness and investors and comparing economic efficiency without and with risk.

Literature showed that “individuals generally avoid situations which offer the potential for substantial gains but which also leave them even slightly vulnerable to losses below some critical level” (Menezes et al., 1980, p. 921). Moreover, downside risk can be used to represent downside risk aversion for both risk-averse and risk-plunging individuals. Individuals can be characterized with downside risk aversion whose utility function has a positive third derivative (Menezes et al., 1980).

Tauer (1983) and Watts et al. (1984) developed models that account for downside risk. Tauer (1983) used the weighted sum of the deviations below a target return level ($1000) for a five year period as a measure of downside risk. Yeager and Langemeier (2013) investigated a sample of Kansas farm efficiency accounting for downside risk. Yeager and Langemeier (2013) used the equally weighted summation of net farm income below the amount needed to cover unpaid labor for 10 years as a measure of downside risk.

Markowitz (1959) proposed semi-variance as a measure of downside risk to overcome the limitation of the EV approach. Markowitz (1959) argued that semi-variance is more appropriate than variance as it only accounts for negative deviations (the variability of return below the average). Grootveld and Hallerbach (1999, p.317) argued that “from a decision-theoretic point of view, lower partial moment efficiency is more appealing since it implies third order stochastic dominance”. Grootveld and Hallerbach (1999) empirically analyzed the differences between U.S. asset allocation portfolios using variances and downside risk measures and found that the downside risk approach tends to yield slightly higher bond allocation than the mean-variance method, on average.

2. Research Methods

This section is divided into two parts: efficiency without risk and efficiency with risk. CE and RE are estimated using a non-parametric approach. DEA is a linear programing (LP) approach that uses input and output to construct a piece-wise linear surface over the data points. The piece-wise frontier surface is constructed using the optimal solution obtained for the LP model for each cooperative. A cooperative's efficiency is compared with the efficiency of frontier cooperatives (the "best practice" cooperatives) from the sample. The DEA approach helps to identify inefficiencies for individual cooperatives. The advantage of the DEA method is that it does not impose any functional form on technology and is less prone to misspecification error (Färe et al., 1985). However, 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).

2.1 Efficiency without risk

Cost efficiency is a ratio of minimum cost (C_i) to the total cost (TC_i) observed by individual cooperatives for producing a given output bundle. Mathematically,

$$CE = C_i/TC_i = w_i'x_i^*/w_i'x_i \qquad (1)$$

where w_i is a vector of input prices for the ith cooperative, x_i and x_i^* are vectors of observed input and optimal input levels, respectively (Coelli et al., 2005; Färe et al., 1985). The CE score ranges between zero and one and a CE score of one indicates that the cooperative is on the cost frontier or is cost efficient. A CE score of less than one indicates that the cooperative has costs 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. Cooperatives above the cost frontier can reduce cost by changing input bundles. The minimum (optimal) cost is estimated using the following LP program.

$$\text{Min } C_i = w_i' x_i^* \qquad (2)$$

subject to

$$x_{11}z_1 + x_{12}z_2 + \cdots + x_{1k}z_k \leq x_{1i}^*$$

$$x_{21}z_1 + x_{22}z_2 + \cdots + x_{2k}z_k \leq x_{2i}^*$$

$$\ldots\ldots$$

$$x_{n1}z_1 + x_{n2}z_2 + \cdots + x_{nk}z_k \leq x_{ni}^*$$

$$y_{11}z_1 + y_{12}z_2 + \cdots + y_{1k}z_k - y_{1i} \geq 0$$

$$\ldots\ldots$$

$$y_{m1}z_1 + y_{m2}z_2 + \cdots + y_{mk}z_k - y_{mi} \geq 0$$

$$z_1 + z_2 + \cdots + z_k = 1; \;\; z_k \in R^+$$

where y_i a vector of output levels for the *i*th cooperative, *k* is the number of cooperatives, and z is an intensity vector (i.e. the weight of each cooperative) and the remaining notations are as previously defined. The sum of the intensity vector is one under variable returns to scale (VRS). Model (2) estimates the minimum cost of producing output *y* under the constant returns to scale (CRS) technology when the intensity constraint ($\sum z = 1$) is removed from the model (Coelli et al., 2005).

Revenue efficiency is a ratio of observed total revenue (TR_i) to the optimal revenue (R_i) obtained from the LP program as given in equation (4). The RE score lies between zero and one. A cooperative with a RE score of one is operating on the production possibility frontier, which indicates that the cooperative is producing the optimal output mix (Coelli et al., 2005).

Mathematically,

$$\text{RE} = TR_i/R_i = p_i'y_i/p_i'y_i^* \tag{3}$$

where p is a vector of output prices, y_i^* is a vector of optimal output, and the remaining notations are as previously defined. The optimal revenue under VRS is estimated using the following LP program (Coelli et al., 2005; Färe et al., 1985).

$$Max\ R_i = p_i'y_i^* \tag{4}$$

subject to

$$x_{11}z_1 + x_{12}z_2 + \cdots + x_{1k}z_k \leq x_{1i}$$

$$x_{21}z_1 + x_{22}z_2 + \cdots + x_{2k}z_k \leq x_{2i}$$

$$\ldots\ldots$$

$$x_{n1}z_1 + x_{n2}z_2 + \cdots + x_{nk}z_k \leq x_{ni}$$

$$y_{11}z_1 + y_{12}z_2 + \cdots + y_{1k}z_k - y_{1i}^* \geq 0$$

$$\ldots\ldots$$

$$y_{m1}z_1 + y_{m2}z_2 + \cdots + y_{mk}z_k - y_{mi}^* \geq 0$$

$$z_1 + z_2 + \cdots + z_k = 1;\ \ z_k \in R^+$$

The notations are as previously defined. CE without risk is computed by dividing optimal cost obtained from equation (2) by observed total cost of cooperatives, while RE without risk is computed by dividing observed total revenue by optimal revenue obtained from equation (4).

2.2 Efficiency with risk

This study used the semi-variance (SV) of return on equity (ROE) as a measure of downside risk for estimating CE and RE following the approach of Markowitz (1959). Mathematically,

$$SV = \frac{1}{k}\sum_{n=1}^{k}(ROE - \overline{ROE})^2 \quad (5)$$

$$= \begin{cases} ROE - \overline{ROE} & if\ ROE - \overline{ROE} \leq 0 \\ 0 & if\ ROE - \overline{ROE} > 0 \end{cases}$$

where $\overline{ROE}$ is the average rate of return on equity (i.e. $\overline{ROE} = E(ROE)$) and the remaining notations are as previously defined.

Economic efficiencies without risk are first estimated for each cooperative using traditional inputs and outputs. Efficiency scores are then re-estimated including a non-discretionary input (risk) in the optimization. A non-discretionary input is equivalent to a “bad output”, which shows that managers have little or no control over. The optimization model is constructed in a way that only accounts for inputs that managers have control over (Coelli et al., 2005).

The minimum cost under VRS including downside risk is estimated using equation (6) that is the modification equation (2).

$$\text{Min } C_i = w_i' x_i^* \tag{6}$$

subject to

$$x_{11}z_1 + x_{12}z_2 + \cdots + x_{1k}z_k \leq x_{1i}^*$$

$$x_{21}z_1 + x_{22}z_2 + \cdots + x_{2k}z_k \leq x_{2i}^*$$

$$\ldots\ldots$$

$$x_{n1}z_1 + x_{n2}z_2 + \cdots + x_{nk}z_k \leq x_{ni}^*$$

$$r_1z_1 + r_2z_2 + \cdots + r_kz_k \leq r_i$$

$$y_{11}z_1 + y_{12}z_2 + \cdots + y_{1k}z_k - y_{1i} \geq 0$$

$$\ldots\ldots$$

$$y_{m1}z_1 + y_{m2}z_2 + \cdots + y_{mk}z_k - y_{mi} \geq 0$$

$$z_1 + z_2 + \cdots + z_k = 1; \;\; z_k \in R^+$$

where r is a measure of downside risk and the remaining notations are as previously defined.

Downside risk is included as an input constraint, but it is allowed to change during cost minimization.

The following LP program includes the risk constraint, which is the modification of revenue maximization under VRS from equation (4).

$$Max\ \ R_i = p_i' y_i^* \tag{7}$$

subject to

$$x_{11}z_1 + x_{12}z_2 + \cdots + x_{1k}z_k \le x_{1i}$$

$$x_{21}z_1 + x_{22}z_2 + \cdots + x_{2k}z_k \le x_{2i}$$

$$\ldots\ldots$$

$$x_{n1}z_1 + x_{n2}z_2 + \cdots + x_{nk}z_k \le x_{ni}$$

$$r_1z_1 + r_2z_2 + \cdots + r_kz_k \le r_i$$

$$y_{11}z_1 + y_{12}z_2 + \cdots + y_{1k}z_k - y_{1i}^* \ge 0$$

$$\ldots\ldots$$

$$y_{m1}z_1 + y_{m2}z_2 + \cdots + y_{mk}z_k - y_{mi}^* \ge 0$$

$$z_1 + z_2 + \cdots + z_k = 1;\ \ z_k \in R^+$$

where *r* is downside risk and the remaining notations are as previously defined. CE and RE with downside risk can be calculated by dividing optimal cost obtained from equation (6) by observed total cost and observed total revenue by optimal revenue obtained from equation (7), respectively.

3. Data

This study used financial data from CoBank, a part of the Farm Credit System. CoBank provides loans and financial services to agricultural cooperatives and agribusinesses in the United States. The data consisted of agricultural cooperatives from 36 states from 2005 to 2014. In order to compute CE and RE, the data for inputs, input prices, outputs, and output prices were required. All nominal values of input expenses and output revenues were converted to 2014 constant dollar values using gross domestic product (GDP) price deflator (BLS, 2016). Annual producer price indices (PPI) for inputs and outputs (BLS, 2016) were used to convert expenses and revenues to input and output quantities (indices). Three inputs were used in the analysis: labor, capital, and variable (other) expense. Labor expense consisted of wage expense and fringe benefit expense. Average hourly earnings for the manufacturing sector (BLS, 2016) were used to transform labor expense to labor quantity (index). Total assets were used as the quantity (index) of capital and the U.S. real interest rate (World Bank, 2016) was used as the cost of capital. The other (variable) expense consisted of utility cost, advertising cost, lease, and rent, etc. The other quantity (index) was obtained by dividing other expense by general PPI (BLS, 2016).

The four outputs used in the analysis were grain sales (aggregation of sales commodities and grain), farm input supply sales (aggregated form of fertilizer, chemicals, petroleum, etc.), service income (aggregated form of storage and handling revenues), and other product sales. All output revenues were converted to quantities (indices) using PPI. To be specific, the PPI for grains, PPI by commodity for crude materials for further processing, PPI by commodity for finished goods, and general PPI (BLS, 2016) were used to convert grain sales, farm input supply sales, other product sales, and service income into output quantities (indices), respectively. The details about input and output data can be found in Pokharel (2016).

4. Results

Table 1 presents the summary statistics of input expenses, output revenues, and financial ratios. The cost of labor accounted for more than 45% of total input cost. Labor and other expense showed an increasing trend over the study period while capital showed an increasing trend from 2005 to 2007 and a decreasing trend after 2008 (Figure 1). The largest revenue was obtained from grain sales while the contribution of service income was lowest on total revenue, on average. The income obtained from farm input sales showed an upward trend except in 2009 and 2010 whereas the income received from grain had significant variations over the sample period. Grain sales decreased from 2009 to 2010 and after 2013 (Figure 2). The average return on equity, return on assets, and profit margin were 13%, 8%, and 3%, respectively for the sample period.

The efficiency scores were computed for 3511 observations from 2005 to 2014. Efficiency scores were first estimated using standard inputs and outputs and then re-estimated including the semi-variance of return on equity as a measure of downside risk. T-test was used to examine if the CE and RE scores without risk were different from the CE and RE scores including risk.

The cumulative density graphs showed that CE and RE scores increased for most of the firms with the inclusion of downside risk (Figures 3 and 4). Table 2 reports the summary statistics of CE and RE without and with risk. The average CE scores without and with risk were 0.39 and 0.44, respectively. The number of cost efficient agricultural cooperatives increased from 41 to 79 with the inclusion of risk (Table 2). Similar results hold for RE. The average RE scores increased from 0.20 to 0.25 with the inclusion of risk. The number of revenue efficient agricultural cooperatives increased from 18 to 42 with the inclusion of risk (Table 2). In general, the CE and RE scores increased with the inclusion of risk. The findings of this study are consistent with the results of Yeager and Langemeier (2013) for a sample of Kansas farms from 2003 to 2010, who found that CE and RE increased with downside risk.

The percentage of inefficiency explained by downside risk was calculated as the change in inefficiency between inefficiency without and with downside risk dividing by inefficiency without downside risk for all agricultural cooperatives. The results showed that downside risk accounted for 8.9% and 7.3% of cost and revenue inefficiencies, on average for all cooperatives, respectively.

The paired t-test showed that the average CE and RE scores without and with downside risk were significantly statistically different (Table 3). The results indicate that failure to account for risk in estimating economic efficiency using DEA overestimates inefficiency which may misguide managers and stakeholders of agricultural cooperatives on actions needed to improve performance.

Past studies have shown that larger firms are more efficient than smaller firms (Ariyaratne et al., 2000; Yeager and Langemeier, 2013). This study divided agricultural cooperatives into four categories based on their asset values to evaluate how efficiency changes with respect to size. The categories 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, cooperatives with greater than $50m in assets. If cooperatives are taking benefits of economies of scale, larger cooperatives are expected to be more efficient than smaller cooperatives.

Table 4 presents CE and RE scores based on the size of cooperatives. Larger cooperatives had higher CE and RE scores than smaller cooperatives without and with downside risk. In other words, larger cooperatives were taking advantage of economies of scale. The result is consistent with

Ariyaratne et al. (2000), who found that larger grain marketing and farm supply cooperatives were more scale efficient (X-efficient) than smaller ones from 1988 to 1992. Similarly, profit margin, return on equity, and return on assets ratios were higher for larger cooperatives than smaller cooperatives. This may indicate that the agricultural cooperative sector tends to increase the size of cooperatives in the future to benefit from economies of scale.

5. Conclusions

This study used the semi-variance of return on equity as a measure of downside risk. Cost and revenue efficiencies were first computed using traditional inputs and outputs and then re-computed accounting for downside risk. Downside risk was included in the estimation of CE and RE as a non-discretionary input. Downside risk is an appropriate measure of asymmetric risk as it focuses on return below a specified target return level. The semi-variance of return on equity incorporates all deviations below average return on equity and individual agricultural cooperatives with the rate of return on equity below the average of the sample may experience financial stress.

The average CE score was 0.39 without risk and increased to 0.44 with the inclusion of downside risk. Likewise, the average RE score was 0.20 without risk and the downside risk adjusted RE score was 0.25. The number of cost and revenue efficient agricultural cooperatives increased when CE and RE were adjusted for downside risk. This indicates that the DEA method for estimating CE and RE without accounting for risk overestimates inefficiency. Larger cooperatives were more efficient than smaller cooperatives. This indicates that the agricultural cooperative sector tends to increase the size of the operation to take advantage of economies scale.

The inclusion of risk in estimating cost and revenue efficiencies provides a relatively accurate measure since it helps explain inefficiency. Measuring efficiency without including risk attributes inefficiency to inadequate operations. Understanding the impact of risk in efficiency analysis helps to improve the performance of agricultural cooperatives using optimal inputs to produce outputs or maximize revenue with optimal outputs.

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Figures

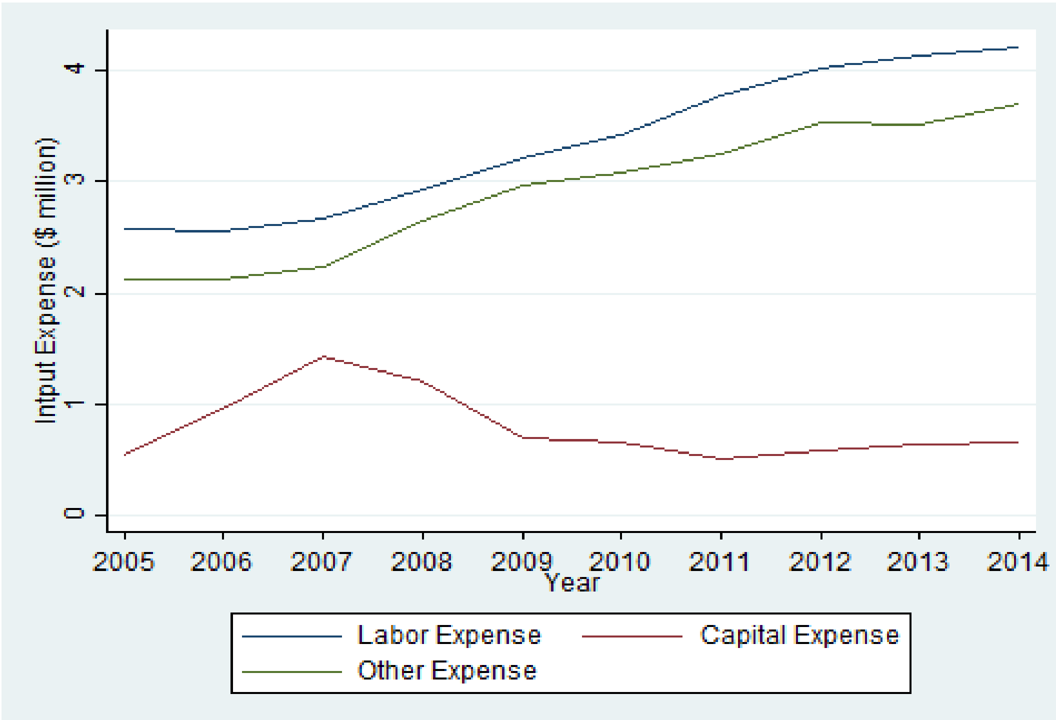

Figure 1. Annual average of input expenses for agricultural cooperatives

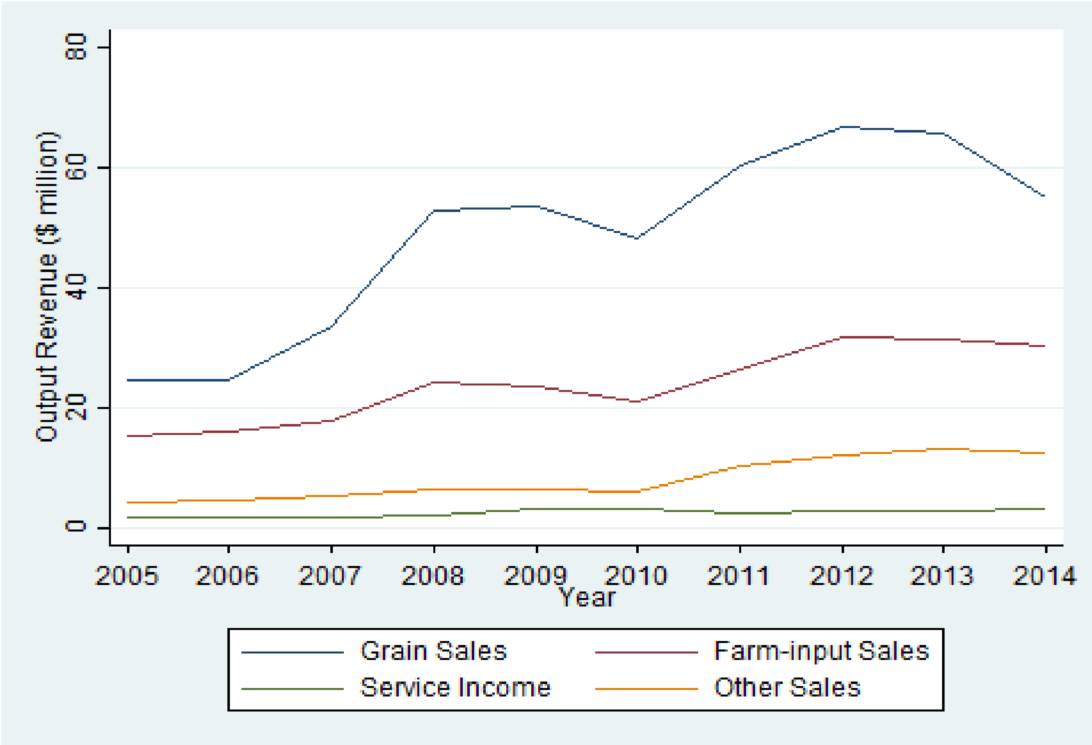

Figure 2. Annual average of output revenues for agricultural cooperatives

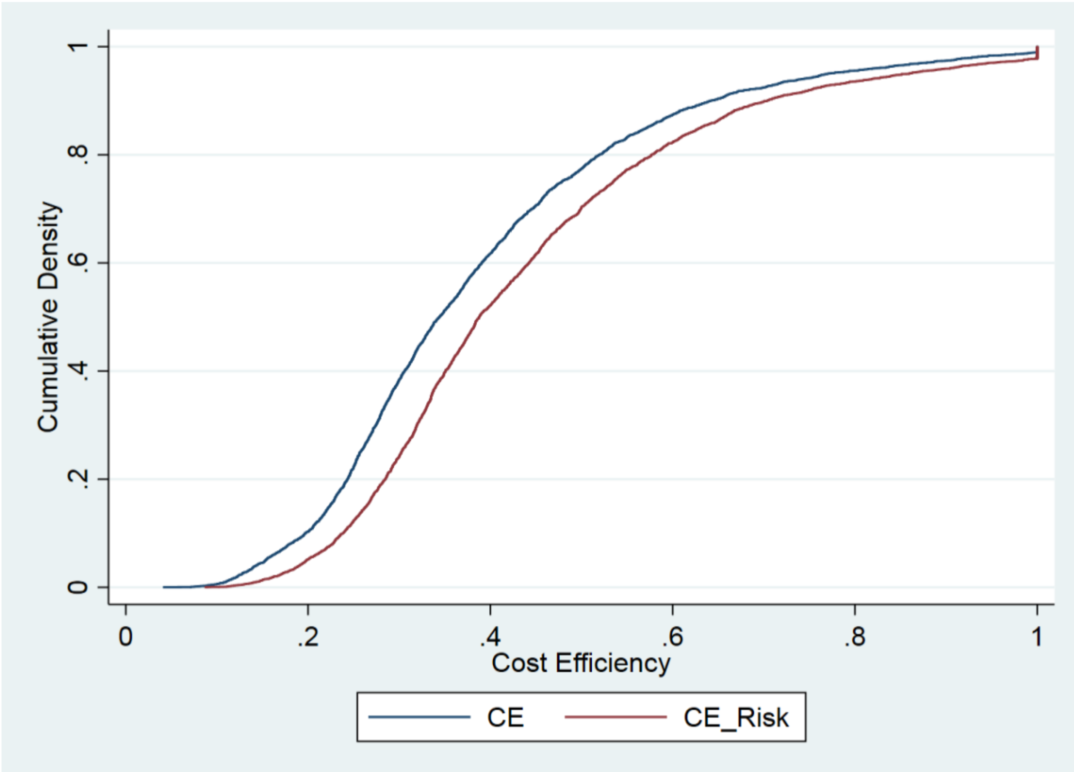

Figure 3. Cumulative density of cost efficiency without and with risk

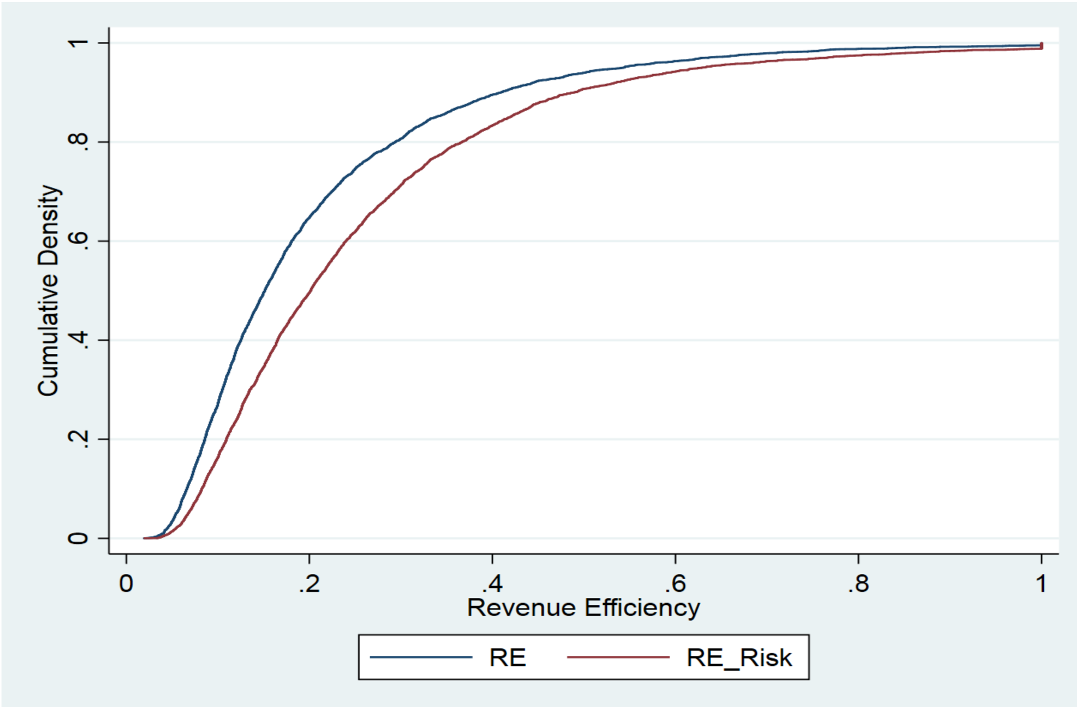

Figure 4. Cumulative density of revenue efficiency without and with risk

Tables

Table 1. Production and financial measures for agricultural cooperatives, 2005-2014

	N	Average	Median	Std. Dev.
Inputs ($ million)				
Labor expense	3511	3.50	1.62	5.21
Capital expense	3511	0.74	0.32	1.21
Other expense	3511	3.04	1.33	4.75
Outputs ($ million)				
Grain sales	3511	51.36	14.61	104.65
Farm-input sales	3511	25.07	10.20	42.67
Service income	3511	2.59	1.10	4.41
Other sales	3511	8.93	1.77	36.13
Financial measures				
Return on equity	3511	0.13	0.13	0.11
Return on assets	3511	0.08	0.08	0.05
Profit margin	3511	0.03	0.02	0.03

Table 2. Summary statistics of economic efficiency for agricultural cooperatives, 2005-2014

	Efficient observations	Average	Median	Std. Dev.
CE	41	0.389	0.344	0.186
CE with downside risk	79	0.438	0.388	0.192
RE	18	0.203	0.151	0.162
RE with downside risk	42	0.254	0.201	0.186

Total number of observations =3511

Table 3. T-test: comparing economic efficiency without and with risk

	Test-statistic	P-value
Cost efficiency	-39.095	< 0.000
Revenue efficiency	-41.601	< 0.000

Table 4. Cost and revenue efficiencies by the value of assets category, 2005-2014

		Less than $10M*	$10M - $20M	$20M - $50M	Greater than $50M
CE	Average	0.349	0.337	0.391	0.526
	Std. Dev.	0.164	0.144	0.176	0.215
CE with downside risk	Average	0.397	0.382	0.445	0.578
	Std. Dev.	0.167	0.151	0.187	0.217
RE	Average	0.153	0.153	0.196	0.372
	Std. Dev.	0.134	0.103	0.119	0.194
RE with downside risk	Average	0.201	0.200	0.262	0.414
	Std. Dev.	0.157	0.147	0.156	0.214
	Observations	1382	752	712	665

*The value of assets in million (M) dollars.