REFEREED ARTICLE

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Risk adjusted cost efficiency indices

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ABSTRACT

This paper examines the impact of risk on cost efficiency for a sample of farms. Cost efficiency was estimated using traditional input and output measures, and then re-estimated including each farm's downside risk measure. Downside risk was defined as the percent of years in which a farm's net farm income did not cover unpaid family and operator labour. Comparisons were made with and without a change in efficiency when each farm's downside risk measure was included in the analysis. As expected, downside risk plays an important role in explaining farm inefficiency. Failure to account for downside risk overstates inefficiency, particularly for farms with low downside risk measures.

KEYWORDS: Efficiency; downside risk; data envelope analysis

1. Introduction

Cost efficiency indices are used to examine resource use and product mix. Farms that are cost efficient are using the optimal mix of inputs and outputs. Inputs and outputs of inefficient farms are typically compared to the cost of efficient farms. Through this process, benchmarks are created and suggestions for improvements on inefficient farms can be made.

Even though risk can have a large impact on decision making, previous literature that adjusts cost efficiency scores for differences in risk among farms is very limited. Only a small handful of studies have examined risk or undesirable outputs (Mester, 1996; Chang, 1999; Färe, Grosskopf, and Weber, 2004; Färe and Grosskopf, 2005). These studies focused on banking and environmental issues. None of these studies examined the impact of risk on efficiency scores for a sample of farms.

The primary objective of this paper is to examine the impact of risk on cost efficiency for a sample of farms. Cost efficiency for farms with various degrees of risk was compared. Cost efficiency indices were also compared across farm size and farm type categories. This paper adds to the existing literature by providing a justification for adjusting cost efficiency scores for downside risk, illustrating a method to do so, and making comparisons of efficiency scores with and without risk considerations.

2. Methods

Various methods can be used to measure cost efficiency. Data envelope analysis (DEA) or the nonparametric approach is used to measure cost efficiency in this paper because it does not impose restrictions on the underlying technology set that would be imposed if a parametric approach was used and is flexible in calculating and decomposing efficiency measures. DEA is a linear programming technique used to measure relative efficiencies where the estimated efficiencies represent upper bounds to the true efficiencies. DEA is chosen because it does not impose a functional form on the relationship between outputs and inputs, thus mitigating errors associated with imposing an inappropriate model structure (Färe and Grosskopf, 1996; Coelli *et al.*, 2005).

Cost efficiency measures are relative to other farms in the data set. Even though risk often impacts the input and output mix chosen by decision makers (Robison and Barry, 1987), risk is typically not included in efficiency estimates. Inefficiency estimates that do not include risk may overstate the degree of inefficiency exhibited by individual farms, particularly if risk varies substantially among farms. With this in mind, a risk measure is included in cost efficiency analysis in this paper to disentangle risk and inefficiency.

Cost efficiency (CE) can be determined by dividing the minimum cost under variable returns to scale by the actual cost observed by the farm:

$$CE = c_i' x_i^* / c_i' x_i \tag{1}$$

where c is a vector of input prices, x is a vector of input levels used, i signifies the firm of interest, and * indicates the optimal value (Färe, Grosskopf, and Lovell, 1985; Coelli *et al.*, 2005).

The denominator in equation (1) is the actual cost for the individual farm, the numerator is determined for each farm using the following linear programme:

$$Min_{x^*} c_i' x_i^* \tag{2}$$

subject to:

$$x_{11}z_1 + x_{12}z_2 + \ldots + x_{1k}z_k \leq x_{1i}^*$$
$$x_{21}z_1 + x_{22}z_2 + \ldots + x_{2k}z_k \leq x_{2i}^*$$
$$\ldots$$
$$x_{n1}z_1 + x_{n2}z_2 + \ldots + x_{nk}z_k \leq x_{ni}^*$$
$$y_{11}z_1 + y_{12}z_2 + \ldots + y_{1k}z_k - y_{1i} \geq 0$$

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$$\dots$$

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

$$z_1 + z_2 + \dots + z_k = 1$$

where *c, x,* and *i* are as previously defined; *y* is a vector of outputs; the subscript *k* denotes the number of farms; the subscript *n* is the number of inputs; the subscript *m* is the number of outputs; $z_k \in \Re^+$, measures the intensity of use of the kth farm's technology; and * indicates the optimal value (Färe, Grosskopf, and Lovell, 1985; Coelli *et al.*, 2005).

Farms with a cost efficiency index of 1 are producing on the production possibility and cost frontiers, and are using the optimal mix of inputs. Inefficient farms have a cost efficiency index between 0 and 1, with a lower index indicating a greater degree of inefficiency.

Cost efficiency indices are first estimated without the inclusion of a risk measure. The efficiency scores are then estimated a second time including each farm's risk measure as a non-discretionary input. A non-discretionary input is equivalent to a ''bad output'' and represents an input the manager has little to no control over. Therefore, the model is structured to seek a reduction in the inputs over which the manager does have control (Coelli *et al.*, 2005). To incorporate risk, the linear program (2) is modified by adding the additional constraint below:

$$r_1z_1 + r_2z_2 + \dots + r_kz_k \leq r_i \quad (3)$$

where *i, k,* and z_k are as previously defined; and *r* is a measure of risk. Note that the risk measure is included as an input constraint, but it is not a choice variable in the optimization.

Downside risk is used as the risk measure in this study. Measuring downside risk, an asymmetric measure of risk that focuses on the left tail of the return distribution, may more accurately address producers' concerns because it identifies returns below a specified target or benchmark return level which is often more troublesome than the traditional variance or standard deviation measure (Hardaker *et al.*, 2004). Downside risk typically focuses on the probability of having low outcomes or the magnitude of low outcomes below a target threshold (Barry, 1984; Hardaker *et al.*, 2004). In this study, operations with no downside risk have a net farm income large enough to cover all cash costs and depreciation plus unpaid family and operator labour. However, if an operation is not able to cover all of their unpaid family and operator labour, they may be currently covering all cash and depreciation expenses, but they do not have a positive return to equity and are at risk because they cannot operate without covering all costs indefinitely.

Following Langemeier and Jones (2001), downside risk is defined as the percent of years in which a farm's net farm income does not cover unpaid family and operator labour. For example, a downside risk score of 0.50 would indicate that in 50 percent of the years in the sample, the farm's net farm income was not high enough to cover unpaid family and operator labour. The downside risk measure captures ten years of data in an attempt to mitigate the effects of weather, yields, and prices from one or two years and instead illustrates risk over time. This contributes to the importance of this measure because not covering unpaid family and operator labour for 1-3 years while difficult, is likely still sustainable. Not being able to cover unpaid family and operator labour for a majority of the years, indicates a significant problem.

Cost efficiency scores with and without downside risk are computed for each farm using the equations above. Following equation (1), cost efficiency without risk is computed by dividing (2) by actual cost. Cost efficiency with risk is computed by adding the additional constraint (3) to linear program (2) and dividing by actual cost.

Cost efficiency scores or indices with and without downside risk are compared among farms with different levels of downside risk and among farm size categories. Farms are further divided into two categories, farms with no change in cost efficiency with the inclusion of risk and farms with a change in their cost efficiency index with the inclusion of risk, to determine whether farm size, income shares, cost shares, and financial measures vary among farms with and without a change in cost efficiency with the inclusion of downside risk. T-tests are used to determine whether the differences among the two categories are significant at the five percent level.

3. Data

The 649 farms included in this study were members of the Kansas Farm Management Association (KFMA) and had continuous whole-farm data for the 2002 to 2011 period. Efficiency estimates required data on total cost, outputs, inputs, and input prices. Data pertaining to total cost, outputs, and inputs for the 649 farms were obtained from the Kansas Farm Management Association (KFMA) databank. With the exception of the labour input, USDA price indices were used to develop an input price index for each input. The price for labour was obtained from the KFMA databank. Though annual data were available for each farm, ten-year average data were used in this study to reduce the impact of weather in a particular year on efficiency estimates. Downside risk, the percent of years in which a farm's net farm income did not cover unpaid family and operator labour, was computed for each farm using all ten years of data.

Five inputs were used in the analysis: labour, crop input, fuel and utilities, livestock input, and capital. All costs, including those for machinery and land, were annualized. Labour was represented by the number of workers (hired labour, and unpaid family and operator labour) on the farm and labour price was obtained by dividing labour cost by the number of workers. Implicit input quantities for the crop input, fuel and utilities, the livestock input, and capital were computed by dividing the respective inputs' costs by USDA input price indices. The crop input consisted of seed; fertilizer; herbicide and insecticide; crop marketing and storage; and crop insurance. Fuel and utilities were comprised of fuel, auto expense, irrigation energy, and utilities. The livestock input included dairy expense; purchased feed; veterinarian expense; and livestock marketing and breeding. The capital input included repairs; machine hire; general farm insurance; property taxes; organization fees, publications, and travel; conservation; interest; cash rent; depreciation; and interest charge on net worth (Langemeier, 2010).

Table 1: Summary statistics for sample of Kansas farms

	Units	Average	Standard Deviation
Inputs			
Labor	Number of workers	1.38	0.83
Crop	Implicit quantity	139,445	128,919
Fuel and Utilities	Implicit quantity	43,403	46,332
Livestock	Implicit quantity	47,801	173,518
Capital	Implicit quantity	204,818	145,748
Outputs			
Crop	Implicit quantity	505,976	483,287
Livestock	Implicit quantity	98,473	221,113
Risk Measure			
Downside Risk	Percent of years	44.48%	30.09%
Farm Characteristics			
Value of Farm Production	Dollars	360,023	308,968
Net Farm Income	Dollars	88,322	94,915
Corn Income	Dollars	74,374	140,558
Grain Sorghum Income	Dollars	21,412	31,711
Hay and Forage Income	Dollars	13,054	34,441
Oilseed Income	Dollars	77,166	93,286
Small Grains Income	Dollars	61,813	69,380
Beef Income	Dollars	73,523	178,913
Dairy Income	Dollars	471	4,972
Swine Income	Dollars	2,147	18,653
Financial Measures			
Operating Profit Margin Rate	Ratio in decimal form	0.0629	0.2333
Asset Turnover Ratio	Ratio in decimal form	0.3321	0.2017
Rate of Return on Investment	Ratio in decimal form	0.0307	0.0651

Source: Kansas Farm Management Association Databank, 2012.

Outputs included crop and livestock. Implicit crop and livestock quantities were computed by dividing crop income and livestock income by USDA crop price and livestock prices indices for Kansas.

The summary statistics are presented in Table 1. On average, 44 percent of the time the farms' net farm income was not large enough to cover unpaid family and operator labour. The average value of farm production for the sample farms was $360,023[3]. Net farm income averaged $88,322. Though not shown in Table 1 the average number of hectares (irrigated crop land, non-irrigated crop land, pasture, and farmstead) was 815 and the average amount of unpaid family and operator labour was $49,879. The largest three sources of crop income were oilseeds (which consisted primarily of soybeans), corn, and small grains (which consisted almost exclusively of wheat). Beef income accounted for almost all of the livestock income. The average profit margin and asset turnover ratios were 0.0629 and 0.3321, respectively. The average rate of return on investment was 0.0307. It is important to note that this rate of return excludes capital gains on land.

4. Results

The average cost efficiency for the 649 farms in this study are included in Table 2. The average cost efficiency index without risk was 0.745. With the addition of downside risk, the average cost efficiency index increased to 0.754. In other words, the downside risk measure explained 3.53 percent of the cost inefficiency on average for all farms. Also, the number of farms on the cost frontier (i.e., cost efficiency index of 1) increased from 8 to 23 with the addition of downside risk. Indicating that for 15 farms, downside risk explained their entire relative inefficiency.

[3] At the time of submission (mid-January 2016), $US1 was approximately equivalent to £0.70 and €0.92.

Table 2: Average cost efficiency measures for sample of farms

	Without Risk	With Risk
Efficiency Measures		
Average	0.745	0.754
Standard Deviation	0.109	0.115
Minimum	0.351	0.351
Number Equal to One	8	23
Downside Risk - Number of Years		
0 Years (51 farms)	0.828	0.856
1 to 3 Years (238 farms)	0.797	0.808
4 to 6 Years (181 farms)	0.729	0.739
7 to 9 Years (131 farms)	0.679	0.682
10 Years (48 farms)	0.634	0.634
Farm Size - Value of Farm Production		
Less than $100,000	0.678	0.697
$100,000 to $249,999	0.711	0.723
$250,000 to $499,999	0.768	0.773
$500,000 or More	0.796	0.803

Average cost efficiency decreased as downside risk increased for both the cost efficiency measures with and without risk. Note that less than 10 percent of the farms had either no downside risk or downside risk in all ten years. In other words, it was common to have at least some downside risk. It is clearly evident in table 2 that the difference between cost efficiency with and without downside risk widened as downside risk decreased. There was not a difference in the measures for the farms with downside risk in every year. In contrast, the difference between the two measures for farms with no downside risk averaged

Table 3: Average farm characteristics by changes in cost efficiency

	No Change with Risk	Change with Risk	Significant
Number of Farms	245	404	
Efficiency Measures			
Cost Efficiency without Risk	0.714	0.763	Yes
Cost Efficiency with Risk	0.714	0.779	Yes
Risk Measure			
Downside Risk	59.67%	35.27%	Yes
Farm Size			
Value of Farm Production	$432,959	$315,792	Yes
Net Farm Income	$85,818	$89,841	No
Income Source			
Percent of VFP from Corn Income	13.88%	15.94%	No
Percent of VFP from Grain Sorghum Income	5.49%	7.47%	Yes
Percent of VFP from Hay and Forage Income	5.03%	3.49%	Yes
Percent of VFP from Oilseed Income	17.29%	22.51%	Yes
Percent of VFP from Small Grain Income	19.10%	18.85%	No
Percent of VFP from Beef Income	30.51%	19.31%	Yes
Percent of VFP from Dairy Income	0.25%	0.10%	No
Percent of VFP from Swine Income	0.74%	0.49%	No
Cost Share			
Percent of Input Cost from Labor	17.79%	17.01%	No
Percent of Input Cost from Crop Input	22.69%	24.81%	Yes
Percent of Input Cost from Fuel and Utilities	6.99%	6.50%	Yes
Percent of Input Cost from Livestock Input	8.21%	4.20%	Yes
Percent of Input Cost from Capital	44.32%	47.48%	Yes
Financial Measures			
Operating Profit Margin Ratio	-0.0333	0.1212	Yes
Asset Turnover Ratio	0.3543	0.3187	Yes
Rate of Return on Investment	0.0084	0.0441	Yes

0.028. Farms with more downside risk remained less efficient while farms with less downside risk saw an improvement in their relative efficiency when risk was considered.

Cost efficiency with and without downside risk is also summarized by farm size category in Table 2. Differences in efficiency between the two cost efficiency measures were largest for the farms in the smallest farm size category and smallest for the farms in the $250,000 to $499,000 farm size category. Cost efficiency increases with farm size for the indices with and without downside risk. This indicates that farms are taking advantage of economies of scale. With the inclusion of downside risk, cost efficiency increases from 0.678 to 0.697 for the smallest farm size category and from 0.796 to 0.803 for the largest farm size category. Once accounting for downside risk, the farms are relatively less inefficient than before and smaller farms based on value of farm production have more room to improve.

To further understand the impact of the inclusion of downside risk, the farms were divided into two categories based on whether the farms experienced a change in cost efficiency with the inclusion of downside risk. Table 3 provides the characteristics of the 245 farms with no change in efficiency and the 404 farms with a change in efficiency as well as statistical significance at the 5 percent level. The change in efficiency for the 404 farms ranged from a very small change (0.001) to a change of 0.254. On average, the farms that experienced a change in their efficiency score had less downside risk; were smaller; had a higher proportion of income from grain sorghum and oilseeds; a lower proportion of income from hay and forage, and beef; higher cost shares for the crop input and capital; lower cost shares for fuel and utilities and the livestock input; and had a higher rate of return on investment.

5. Conclusions

Cost efficiency with and without the inclusion of downside risk was estimated for 649 Kansas Farm Management Association farms with continuous data for the 2002 to 2011 period. Outputs included crop and livestock. Inputs included labour, crop input, fuel and utilities, livestock input, and capital. Downside risk was measured as the percentage of years in which a farm's net farm income did not cover unpaid family and operator labour. The average cost efficiency for the 649 farms was 0.745 and increased to 0.754 with the inclusion of downside risk.

The largest increase in cost efficiency with the inclusion of downside risk was for the farms with lower levels of downside risk. In contrast, the increases for farms with high levels of downside risk were negligible. This suggests that excluding downside risk overstated the relative inefficiency of the farms with low levels of downside risk and understated the relative inefficiency of farms with high levels of downside risk. On average, cost efficiency was higher for larger farms. This is an indication that these farms are taking advantage of economies of scale; however, it does not mean that small farms cannot be efficient. All farms need to focus on controlling expenses in order to increase net farm income and efficiency.

Cost efficiency differences among the farms with no change in efficiency and a change in efficiency with the inclusion of downside risk varied by farm size and type. Farms with a change in cost efficiency with inclusion of downside risk were smaller. These farms also had a lower proportion of their income coming from hay and forage, and beef; a higher proportion of their income coming from grain sorghum and oilseed; and a higher rate of return on investment.

For some farms, downside risk as measured in this study did not affect their cost efficiency. These farms have more opportunities to increase efficiency through better management and utilization. For other farms, risk is a major hindrance and in some instances (15 farms) downside risk explained the entire inefficiency of the farm.

In conclusion, including downside risk had a significant impact on relative cost efficiency measures. Thus, traditional efficiency measures that exclude risk may provide inaccurate benchmarks, particularly for farms with low levels of downside risk.

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Elizabeth Yeager's research interests include the areas of agricultural finance, agribusiness, farm management, and production. Her research has focused on firm productivity and efficiency, repayment risk, and producer's views towards risk on their farm.

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