Examining the Productivity Growth of Agricultural Cooperatives

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Abstract

This research examines productivity growth of agricultural cooperatives using the Malmquist productivity index (MI) under constant returns to scale and the biennial Malmquist productivity index (BMI) assuming variable returns to scale. A nonparametric data envelopment analysis approach is used to calculate both the MI and BMI. Results from the two methods are compared to evaluate whether the decomposition into technical and efficiency changes are similar under the MI and BMI methods.

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. In other words, productivity growth occurs due to increasingly efficient operations or technical change or a combination of both. 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).

An agricultural cooperative is a prominent institutional form in supporting farmers in the United States. Cooperatives have gone through significant changes after 1990s due to increased competition, high commodity prices, international trade of agricultural products, mergers and acquisitions etc. These changes forced the cooperatives to be more sensitive towards their cost structure and gain productivity over time (Ariyaratne, Briggeman, and Mickelsen 2014). Therefore, efficiency and productivity growth are critical factors for survival in the business. 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 literature that calculates productivity using the Malmquist index in a data envelopment framework mainly assumes constant returns to scale (CRS) and decompose the Malmquist index into technical change and efficiency change (Ariyaratne, Featherstone, and Langemeier 2006; Umetsu, Lekprichakul, and Chakravorty 2003). The assumption of CRS may be valid even when the true technology is variable returns to scale (VRS) for calculating the overall Malmquist index. However, the decomposition of the Malmquist index into technical change and efficiency change is misleading under CRS because if CRS is assumed, technical change shows the shift in frontier, but scale efficiency does not exist if the global technology is CRS (Ray and Desli 1997). Recently Pokharel and Featherstone (2016) show that agricultural cooperatives experience scale economies. Thus, the use of biennial Malmquist index under VRS is appropriate to decompose productivity into technical change and efficiency change.

The objective of this study is to compare the productivity growth of agricultural cooperatives using the Malmquist productivity index (MI) under constant returns to scale (CRS) and the biennial Malmquist productivity index (BMI) assuming variable returns to scale (VRS). A nonparametric data envelopment analysis (DEA) approach is used to calculate the MI and BMI. Results from the two methods are compared to evaluate whether the decomposition into technical and efficiency changes are similar under the MI and BMI methods.

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 period using the MP index has substantially changed when a third time period is added to the dataset while the BMI gives consistent results (Pastor, Asmild, and Lovell 2011). Funk (2015) uses the MI and BMI indices to compare the productivity growth of biotechnology adopted and non-adopted farmers in the United States. The results show that technical change is biased if it is selected under MI CRS.

2 Productivity Growth

This section of research emphasizes on efficiency and productivity of firms using the Malmquist productivity index under CRS and biennial Malmquist index under

VRS. Since the Malmquist index can be measured using stochastic frontier or DEA methods, this part focuses only on the nonparametric DEA Malmquist method.

Berg, Førsund, and Jansen (1992) measure productivity growth of the Norwegian banking sector during the deregulation period of the 1980s using the Malmquist productivity index within the DEA framework. The results show that large banks have rapid productivity growth, which happened due to increased domestic competition after the deregulation in the banking area. Worthington (1999) uses the nonparametric Malmquist index to examine the productivity growth for Australian credit unions. The results show that technical change was the driving factor for productivity gain rather than scale efficiency.

Das (2002) examines the relationship among risk (credit risk and leverage), capital, and productivity for commercial public sector banks in India. The author uses the Malmquist index to calculate productivity change and employs two-stage least squares regression to evaluate the impact of financial variables on productivity change. The results indicate that productivity is negatively related to credit risk while it has a positive correlation with bank capitalization.

Zhengfei and Lansink (2006) examine the impact of capital structure on the performance of Dutch farms using the Malmquist productivity growth index as a proxy for the performance of farms using agricultural data. They find that debt has no impact on return on equity (a measure of farm performance) whereas debt positively affects productivity growth. Similarly, Chen et al. (2007) construct the adjusted Malmquist-Luenberger productivity index to account for the effects of environmental variables, undesirable outputs, and statistical noise for farmer credit unions in Taiwan. The measurement of productivity are affected by the environmental variables and statistical noise. The results indicate that regression in technology decreases productivity, though efficiency increases over the study period.

Likewise, Sufian (2011) evaluates the impact of risk on productivity change of banks in China using the Malmquist productivity index. Other studies, such as Umetsu, Lekprichakul, and Chakravorty (2003) and Quintana-Ashwell and Featherstone (2014) estimate productivity using the DEA Malmquist productivity index in the agriculture sector. One of the findings of these studies is that the agricultural sector experiences productivity growth mainly due to the improvements in technology.

3 Data and Research Methods

We obtained data from CoBank, a part of the Farm Credit System. The data contain annual financial records with complete balance sheet and income statement from audited financial statements of agricultural cooperatives. The input data are labor and capital expenses. The output data are grain sales, farm input supply sales and other products sales. All expenses of inputs and outputs are converted to 2014 constant dollar values using gross domestic product (GDP) price deflator.

Since inputs and outputs are reported in dollar expenses, input and output expenses are transformed into respective quantities (indices). For example, average hourly earnings for the manufacturing sector (BLS 2015) and GDP price deflator (BLS 2015) were used to convert labor expenses to labor index (quantity). The real value of total assets is used as the quantity of capital.

Outputs expenses are transformed into output quantities (indices) by dividing the expense of a output by the respective price index. For instance, the nominal dollar expenses are transformed into real values for all outputs using GDP price deflator. Then, producer price index (PPI) by commodity for crude foodstuffs and feedstuffs, PPI by commodity for crude materials for further processing and PPI by commodity for finished goods (BLS 2015) are used to convert grain sales, farm input supply sales, and other products sales into output quantities (indices), respectively.

The productivity growth for agricultural cooperatives are estimated using the traditional Malmquist index under CRS and biennial Malmquist index under VRS. Since the Malmquist index is a primal index of productivity change, there is no need of calculation of cost or revenue shares (Färe and Grosskopf 1994). The Malmquist productivity index allows to distinguish the catching up to the frontier from the shifts of the frontier (technical change).

The Malmquist index was proposed by Caves, Christensen, and Diewert (1982a,b) as a ratio of distance functions. Distance functions represent the functional relation of output and input technologies and are equivalent to the reciprocal measure of input orientated technical efficiency of Farrell (1957). This measure of technical efficiency shows that "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.

The improvements in the Malmquist index could be due to the efficiency change or improvements in the underlying production technology. Technical change shifts the production function to a higher level with a given set of inputs. An important point to be noted here is that the improvement (change) in the Malmquist index may happen even when firms are operating inefficiently (Coelli et al. 2005).

When all firms are operating at an optimal scale, the CRS assumption is appropriate, but due to government regulations, imperfect market, financial constraints may cause a firm to 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). In addition, the assumption of CRS may be valid even when the true technology is VRS for calculating the overall Malmquist index. However, the decomposition of the Malmquist index into technical change and efficiency change is misleading under CRS because scale efficiency does not exist if the global technology is CRS (Ray and Desli 1997).

Pastor, Asmild, and Lovell (2011) proposed a biennial Malmquist index (BMI) which avoids linear programming infeasibilities under VRS. The BMI allows for technical regress and does not need to recompute when a new time period is added to the data set. The authors 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.

3.1 Malmquist Index Derivation

The following steps are used to compute the Malmquist index with input orientation. First, define input distance functions, which represent multiple outputs and multiple inputs technology with respect to two time periods. Assume there are n inputs: $x = (x_1, \ldots, x_n) \in \Re^+$, m outputs: $y = (y_1, \cdots, y_m) \in \Re^+$, the k number of cooperatives ($k = 1, 2, \ldots, K$), and t time periods ($t = 1, 2, \ldots, T$). The production technology (P^T) is a set of feasible input and output vectors: $P^t = [(x^t, y^t)|\ x^t$ can produce $y^t]$. The production set is assumed to be nonempty, closed, and convex and inputs are freely disposable.

The Malmquist index can be defined with the t and $t+1$ periods reference technologies. The Malmquist index with the t period reference technology is given below similar to Caves, Christensen, and Diewert (1982a):

$$M_i^t(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_i^t(y^t, x^t)|CRS}{D_i^t(y^{t+1}, x^{t+1})|CRS}\right] \tag{1}$$

where $D_i^t(y^t, x^t)$ and $D_i^t(y^{t+1}, x^{t+1})$ are the distance functions with respect to the period t and adjacent time period $t+1$ for the reference technology t under CRS. Similarly, the Malmquist index with $t+1$ reference technology can be expressed as follows:

$$M_i^{t+1}(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_i^{t+1}(y^t, x^t)|CRS}{D_i^{t+1}(y^{t+1}, x^{t+1})|CRS}\right] \tag{2}$$

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

$$M_i(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_i^t(y^t, x^t)}{D_i^t(y^{t+1}, x^{t+1})} \frac{D_i^{t+1}(y^t, x^t)}{D_i^{t+1}(y^{t+1}, x^{t+1})}\right]^{0.5} \tag{3}$$

The geometric mean of the Malmquist index can be rewritten following Färe et al. (1994):

$$M_i(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{D_i^t(y^t, x^t)}{D_i^{t+1}(y^{t+1}, x^{t+1})} \left[\frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^{t+1}, x^{t+1})} \frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^{t+1}, x^{t+1})}\right]^{0.5} \tag{4}$$

$$M_i(y^{t+1}, x^{t+1}, y^t, x^t) = \frac{A}{C} \left(\frac{C}{B} \frac{D}{A}\right)^{0.5} \tag{5}$$

The ratios outside the parenthesis (A/C) and inside the parenthesis ($C/B * D/A$) in equation (15) represent efficiency change and technical change, respectively. Technical change indicates the portion of productivity change occur not accounted for efficiency change of the frontier. This equation shows the impact of technical change between two periods, which indicates the shifts in the frontier. If the value of Malmquist index is greater than one, it indicates that there is progress in productivity. If Malmquist index is equal to one or less than one, these imply that there are no change in productivity and a regression in productivity, respectively.

The biennial Malmquist index following Pastor, Asmild, and Lovell (2011):

$$M_i^B(y^{t+1}, x^{t+1}, y^t, x^t) = \left[\frac{D_i^B(y^{t+1}, x^{t+1})|VRS}{D_i^B(y^{t+1}, x^{t+1})|VRS}\right] \tag{6}$$

Pastor, Asmild, and Lovell (2011) define efficiency change under VRS, which is similar under the MI method for VRS defined by Färe et al. (1994).

$$EC_v^B = \left[\frac{D_v^{t+1}(y^{t+1}, x^{t+1})}{D_v^t(y^t, x^t)} \right] = EC_v \tag{7}$$

Similarly, technical change (TC_v^B) under BMI can be defined as follows:

$$TC_v^B = \frac{M_v^B}{EC_v^B} = \left[\frac{D_v^B(y^{t+1}, x^{t+1})}{D_v^B(y^t, x^t)} \frac{D_v^t(y^t, x^t)}{D_v^{t+1}(y^{t+1}, x^{t+1})} \right] \tag{8}$$

The technical change component is the percentage of productivity change not accounted for by efficiency change (Färe et al. 1994). The technical change measure of equation (8) shows the impact of technical change between two periods in the biennial period setting, which results in the shift of the frontier.

Funk (2015) compares the biennial MI under VRS and traditional MI under CRS to examine the productivity change of bio-technology adopted and non-adopted farmers in the United States. The results indicate that the decompositions of MI and BMI into technical change are statistically different, but efficiency changes under MI and BMI are not statistically different.

Note: Empirical results will be presented during the meeting.

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