MEASURING PRODUCTIVE EFFICIENCY AND COST OF PUBLIC EDUCATION

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ABSTRACT

This study examines the relationship between school districts' spending and various school and non-school factors including productive efficiency. An average cost function and a production function for education are estimated. Empirical estimation uses three years panel data from unified school districts in Kansas. An efficiency index is constructed and the total factor productivity is measured. This study found existence of significant economies of scale for Kansas school districts. However, inefficient districts had to spend more to achieve a given performance standard for its students. The average school district is 89.6 percent efficient and there was no growth in total factor productivity over the entire period of study.

INTRODUCTION AND BACKGROUND

With a view to improving the quality of public education in the U.S. over the past few decades researchers have been investigating two fundamental aspects of the education system: impact of class size on student learning; and factors directly and indirectly influence student performance. The former category of study mainly investigated the relationship between class size and expenditure per student, and students' academic achievement. The second category of study investigated how effective are the teacher, school, and non-school inputs for improving students' achievement scores. The literature on public education has mixed responses for both of these groups. Studies by Hanushek et al [17, 18, 19, 20, 21, and 22], Riew [27] and Walberg and Fowler [30] found no consistent relationship either between school inputs and student performance or class size and student achievement.

Currently, the issue of economies of scale and efficiency in public education is under continued scrutiny and plays a vital role in the formulation of a sound education policy in Kansas. In the 1998-99 academic year Kansas enrolled one percent of the pupils in the nation but had 1.62 percent of the nation's schools and 2.10 percent of the school districts in the United States (Augenblick and Myers, [1]). Between 1966-67 and 1998-99 the number of school districts in Kansas dropped from 348 to 304. Consolidation or merger for low performing and high cost school/district has been recommended for economies of scale but often one vital question remains unanswered: will reduction in cost improve the performance level of the students? In an attempt to find a school/district optimal size, past studies have estimated an average cost function for education. However, recent studies have found that in reality, there is no optimum size that can deliver a required performance standard with minimum cost. Some of the factors that influence students' learning process are not captured in a conventional cost function. Before formulating any policy for reorganizing schools it is essential that the policymakers and the school administrators understand the complexities underlying educational production and cost functions.

Building upon the study by Duncombe and Yinger [9] this study estimates an educational cost function that is controlled for productive inefficiency of the district. The expenditure per student in a district depends not only on the cost of inputs and the educational environment within which it operates but also on the efficient utilization of its resources by the district administrators. The objectives of the current study are two folds: (1) to measure the productive efficiency and total factor productivity for the Kansas' school districts; and (2) to estimate an average cost function depicting the relationship between the operating cost per student and various school and non-school factors including the districts' inefficiency effect. This paper is organized as follows. The next section develops the conceptual framework for an educational production function and cost function followed by a section on the dataset and variables used in this study. Fourth section analyzes the empirical results, followed by the summary and conclusion section.

EDUCATIONAL PRODUCTIONAND COST FUNCTION

School districts are impacted by various school and non-school inputs to produce multiple outputs that are assumed to be measurable by achievement test scores. The purpose of education is to transmit knowledge and develop the student's basic cognitive skills. These abilities often are measured by the scores in standardized tests such as, reading, writing, and mathematics. School inputs that are associated with achievement scores are generally measured by the student-teacher ratio, the educational qualifications of teachers, teaching experience, and various instructional and non-instructional expenditures per student (Chakraborty et al [2]). Non-school inputs generally include socioeconomic status of the students and other environmental factors that influence students' productivity. Variables identifying socioeconomic status of the students are family income, number of parents in the home, and parental education. Environmental factors are often measured by geographic location (e.g., rural vs. urban) and net property assessed value per student. Most of the studies in educational production found an insignificant relationship between school inputs and outputs. In contrast, Walberg et al [30], Hanushek [16, 17], Deller and Rudnicki [5], Cooper and Cohn [4], and Faire et al [12] found that socioeconomic and environmental factors significantly affect achievement scores. Using a vary large and unique dataset from Texas public schools Rivkin et al [28] found that teacher quality rather than family factor is more important for raising the achievement for low income students.

In the measure of technical efficiency a school district is considered technically efficient if it achieves the highest possible output (i.e., achievement score) from a given amount of resources used or, conversely, uses minimum resources to produce a given level of output. In this study, output of the educational production function is measured as the district level average test scores for mathematics and reading. A mathematical programming technique, called data envelopment analysis (DEA), is used in this study to constructs the best practice production frontier. Some of the major advantages of using DEA for measuring efficiency are its ability to handle multiple outputs, it is nonparametric, and it does not require input prices. In DEA the performance of a district is evaluated in terms of its ability to either reduce an input vector or expand an output vector subject to the restrictions imposed by the best-observed practice. This measure of performance is relative in the sense that efficiency in each school district is evaluated against the most efficient district and measured by the ratio of actual observed output to maximal potential output. The ratio can take the values between zero and one and one being perfectly efficient. However, if a school/district is found efficient does not necessarily imply that it produces the maximum level of output given the set of inputs. It implies that it is a ‘best practice’ district in the sample (Noulas and Ketkar, [24]). (The construction of a simple output oriented DEA model and the total factor productivity index is produced in the Appendix.)

Previous studies have found that cost of achieving a performance standard varies across school districts (Ruggiero, [29]). A poor school district generally needs a higher level of per-student expenditure to achieve a performance standard equal with that of a wealthy district. A district is thought of as productive and efficient if it achieves the standard level of performance while utilizing the minimum of resources when compared to its peer districts. The expenditure per student for a district depends on the output level it chooses and on the price of inputs. Because of the unique nature of the educational production process where output is the amount of learning rather than amount of instruction, environment is a vital input in achieving a standard performance for any district (Hanushek [17]; Ratcliffe et al [26]; Downes and Pogue [6]; Duncombe et al [7]; Chakraborty et al [3]). Borrowing from the Duncombe and Yinger [9, 8], this study estimates a cost function expressed as:

$$C=\alpha+\beta_1 X+\beta_2 P+\beta_3 N+\beta_4 F+\beta_5 D+\varepsilon \qquad (1)$$

where C is the expenditure per student in the district; X is the various measures of students’ performance (math and reading scores); P is the price of various inputs the district pays, such as teachers’ salaries; N is the district size; F is the students’ socioeconomic status; D is the other student characteristics; and ε is the unobserved district characteristics.

One of the crucial unobserved factors in the above equation is district efficiency. Holding other things constant, a more efficient district most likely would spend less per student to achieve the same standard. In order to capture the effect of unobserved factors on district spending, Duncombe and Yinger included a district efficiency index as one of the independent variables in their cost function using New York data. A similar approach has been undertaken in this study. A technical efficiency index for each school district is estimated using DEA and this efficiency index is included as one of the independent variables in the cost function. Duncombe and Yinger used dummy variables identifying types of districts (i.e., rural/urban) in order to capture the effects of unobserved district characteristics in their cost function. This study uses linear fixed and random effect models, designed for panel data analysis, to estimate the cost function. In the estimation of an educational cost function it is very important that proper variables are included and the regression equation is correctly specified. A proper specification of a cost function should avoid including any expenditure related variable(s) as independent variable. Krueger [23] opined that if expenditure per student is used as an explanatory variable in a cost function that would create an interpretative problem for the effect of class size.

The specification and estimation of the cost function in this study is based on sound econometric consideration and is linked to an educational production function. Although each school district in this study is observed over a period of three years a pooled OLS regression (with 912 observations) would not be an efficient estimator because it assumes that both intercept and slope coefficients are same for all districts. Initially, the linear models for panel data, both fixed effect and random effect models were applied to estimate the cost function. Based on the Hausman test, we failed to reject the hypothesis that the district specific effects are fixed. Further, in order to determine whether the one-way or the two-way fixed effect model represent the data best, the r-squares and Hausman test statistics obtained from each model were compared. The two-way fixed effect model produced the better results for this data. Theoretically, the one-way fixed effect model assumes that the intercepts vary, but the slope coefficients are same; and the two-way fixed effect model has an overall constant as well as a 'group' effect for each group and a 'time' effect for each time. The modified cost function estimated in this study is written as:

$$C_{it} = \alpha_0 + \alpha_i + \gamma_t + \beta_k \sum Z_{it} + \varepsilon_{it} \qquad (2)$$

where *i* is the number of districts; *t* is the number of periods; α_i is the group effect; γ_t is the time effect; β_k are the unknown coefficients to be estimated; vector Z represents original variables X, P, N, F, and D from equation (1). Z also includes an efficiency index for each district for each year under study.

In the cost function estimation it is hypothesized that the coefficient of the measure of output (X) would be positive, enrollment would be negative (N), enrollment square would be positive (signifying U-shape average cost curve), teachers salary (P) would be positive, and percent of students qualified for free and reduced lunch (F) would be positive. It is hypothesized that the districts' efficiency index would be negatively related to expenditure per student implying higher cost for inefficient districts.

DATASET

The district level data for all educational inputs and outputs were provided by the Kansas State Department of Education, Topeka. Information on inputs and outputs were obtained for the academic years 1996-97, 1997-98, and 1998-99. The outputs for our educational production function are measured as the standardized test scores for mathematics and reading. These tests are administered to all districts for students at the 4th, 7th and 10th; and 3rd, 7th, and 10th grade, respectively. Since the information on most of the variables are available at the district level, estimating separate cost functions for each of those grade levels are not possible. Hence, district level average aggregated scores for math and reading were generated and used in this study. It is recognized that by aggregation of test scores some information is lost, which is one of the limitations of this study. Standardized tests for science and social science were not introduced for Kansas' public schools until academic year 2000. The rationale for using only math and reading scores is that the math and reading skills are recognized as the two most powerful determinants for future success and earning potential in the public education literature (Murnane et al [24]. Krueger [23] found that one standard deviation increase in either math or reading scores in elementary schools was associated with about 8 percent higher earning in jobs.

School and non-school inputs used in this study are measured as operating expenditure per student; student-teacher ratio; average contacted salary for teachers; and percent of district students receiving free or subsidized lunch. Operating expenditure includes expenditure for instruction, administration, and plant, maintenance and operation. It is recognized that information on some of the major instructional inputs such as teachers' educational qualification and years of teaching experience are missing from this study. This is because information on these variables at the district level is not readily available from the Kansas state department of education. Our educational production function uses math and reading scores as two outputs; and operating expenditure per student, teacher-student ratio, teachers' salary, and percent of student qualified for free and reduced lunch (AFDC) as inputs. The inclusion of non-controllable inputs for measuring technical efficiency using DEA is not very common in the literature; however, this study follows Duncombe and Yinger [8, 9], who have used exogenous variables in measuring technical efficiency of New York school districts. The descriptive statistics of the data are presented in Table 1.

Table 1
Descriptive Statistics of the Data (obs = 912)

Variables	Mean	Minimum	Maximum
Math Composite (4^{th}, 7^{th}, and 10^{th})	50.66	34.37	67.87
Reading Composite (3^{rd}, 7^{th}, and 10^{th})	64.72	51.50	78.97
Operating expenditure per student ($)	5,979	3,555	13,416
Student-teacher ratio	13.70	5.50	91.90
District enrollment	1,544	73	47,778
Average contacted teacher's salary ($)	35,610	25,463	44,993
Percent of students receiving Free and subsidized lunch (AFDC)	33.11	1.79	73.19

ANALYSIS OF RESULTS

The technical efficiency scores from DEA estimation for all 304 districts are not reported in this paper[1]. However, a summary of the efficiency scores is produced in Table 2. Only 4 out of 304 districts were found fully efficient. Technical efficiency for 53 districts is between 99.9 and 95.0 percent. On average, school districts in Kansas are 89.2 percent efficient implying districts would be able to produce the same standard of educational output using 89.2 percent of their current level of input usage. The least efficient district is Washington, which is 70.1 percent efficient. More than half of the districts in Kansas (160) are operating at an efficiency level 90 percent or below.

Column 3, 5, and 7 of Table 2 present the summary of the indices for efficiency change, technological progress, and total factor productivity change[2] detail results are not reported in the paper. For any of these ratios a value less than one implies deterioration or decrease, and grater than one denotes growth or improvement. On the average, annual decrease in total factor productivity for districts in Kansas is 1.5 percent. The cause of decrease in total factor productivity is

Table 2
Summary of Mean Technical Efficiency, Efficiency Change, Technological Change, and Total Factor Productivity Change Indices, 1997-99

Mean Efficiency (1)	Nos USD (2)	Percent Growth EFFCH (3)	Nos USD (4)	Percent Growth TECHCH (5)	Nos USD (6)	Percent Growth TFPCH (7)	Nos USD (8)
1.000	4	1.134 – 1.109	6	104.5 – 100.1	18	1.134 – 1.109	6
0.999 – 0.950	53	1.108 –105.0	39	___		1.108 – 105.0	19
0.949 – 0.900	87	114.9 – 100.1	125	___		104.9 – 100.1	83
0.899 – 0.850	90	1.000	12	___		1.000	0
0.845 – Below	70	1.000 – 0.892	122	1.000 – 0.964	286	1.000 – 0.939	196
AVG = 0.892	304	AVG = 1.006	304	AVG = 0.979	304	AVG = 0.985	304

USD-unified school district
EFFCH-efficiency change
TECHCH-technological progress/change
TFPCH-total factor productivity change

further analyzed by breaking it into indexes of technological change and efficiency change. The decrease in total factor productivity (1.5 percent) is the net effect of technological change (-2.1 percent) and growth in efficiency change (0.6 percent). Negative technological change can occur due to net out migration of skilled and trained personnel for the State or region causing inward shift of the production frontier. Another explanation could be a measurement error for input and output variables used in the study or due the presence of outliers in the data.

Table 3
Educational Cost Function Estimates, Kansas School Districts 1997-99. Dependent variable Ln (operating expenditure per student)

Variables	Coefficient	t-statistics
Math Composite (4th, 7th, and 10th)	0.00111	2.447*
Reading Composite (3rd, 7th, and 10th)	0.00129	2.122*
Ln(enrollment)	-2.03889	-11.061*
Ln(enrollment)^2	0.10829	7.135*
Ln(teacher's salary)	0.03738	0.896
Percent of students receiving Free and subsidized lunch (AFDC)	0.00030	0.670
Efficiency (percent)	-0.00216	-6.516*
Constant	16.91	23.87*
R-square	0.9882	
Hausman test statistics	280	

*-indicates significant at 5 percent or below level

Table 3 presents the coefficient estimates from the cost function using a two-way fixed effect model (using district and time dummy variables). Large value of Hausman test statistics suggests fixed effect model is more appropriate for our data. Overall, the regression equation has a good fit. The coefficients on all explanatory variables have expected sign. Except for the coefficient on teachers' salary and AFDC, all coefficients are significantly different from zero at the 5 percent or below level. The results obtained from this study are very similar to the one obtained by Duncombe and Yinger [8, 9] for the New York data.

Positive coefficients on the variable math and reading score (measure of outputs) suggest that it costs more to generate a higher level of output. Highly significant and negative coefficient on enrollment, and positive and significant coefficient on enrollment-squared suggests per student expenditure decreases initially reaching a minimum as enrollment increases, and then increases as enrollment increases. This is typical for a U-shaped average cost function. The elasticity for teachers' salary is 0.3, which implies that a one percent increase in teachers' salary would cause 0.3 percent increase in expenditure per student. The effect of socioeconomic status of the students did not appear to be significant in this study though positive coefficient implies it costs more for the poor school districts to educate its students.

The negative and highly significant coefficient on the efficiency variable suggests an inverse relationship between districts' efficiency and per student expenditure. For example, one percent increase in efficiency would cause two percent decease in expenditure per student. This is one of the most important findings from this study.

SUMMARY AND CONCLUSION

This study measured technical efficiency and total factor productivity and estimated an average cost function using three-year panel data for 304 school districts in Kansas. The efficiency measure used a multi-output and multi-input model applied to data envelopment analysis. The study found that on average districts are 89.2 percent efficient. Comparison of total factor productivity (TFP) change across district and over time showed significant differences across districts however, on average most of the districts experienced a decrease in TFP growth.

One of the interesting results found in this study is that, districts with low technical efficiency at the beginning of the period experienced the highest growth in TFP at the end. For example, Bazine (ID-D0304), Jayhawk (ID-D0346), and Vermillion (ID-D0380) had the lowest technical efficiency scores in 1997 (0.885, 0.814, and 0.793, respectively[3]) but in 1999 these districts achieved one of the highest TFP growths (11.1, 12.7, and 11.8 percent, respectively[4]). This confirms one of the established facts in productivity analysis across time that districts with low productivity or efficiency at the beginning would gain most from the diffusion of technological knowledge available in the later years. As a result, these districts would be able to push their production frontier farther during the study period than those who were more efficient at the beginning.

The regression results from the cost function that accounts for efficiency differences indicate that it costs less per students for efficient districts to achieve a set of standards. The implication of the result is especially important for Kansas' policymakers and school administrators when formulating a policy for reorganizing school districts and revising school funding formula. One other interesting result found in this study is the existence of significant economies of scale in the production of education in the state. Although, this study does not identify which district(s) will achieve cost reduction from consolidation, the results confirm overall economies of scale in public education in Kansas. At the current state of our economy when most of the states are experiencing budget cuts in public education, consolidation will definitely save some tax dollars. However, in order to achieve maximum effectiveness from district consolidation it is very essential that a portion of the saved money be spent on hiring, retention, and training and development of the teaching personnel and for the improvement of technology in schools. This will eventually improve the overall students' performance both for the consolidated and the existing school districts. Otherwise, it is more likely that through consolidation we will be sacrificing quality for cost in our public education system.

APPENDIX

In a simple output-oriented DEA model, Let

$\mathbf{x}^t = (x_1^t,...,x_n^t) \in \Re_+^N$ be a vector of *n* inputs producing

$\mathbf{y}^t = (y_1^t,...,y_m^t) \in \Re_+^M$ a vector of m outputs in period t.

If we define the production possibility set for x^t as $P(x^t)$ then it gives all possible combinations of y^t that can be produced from input vector x^t. Hence, the output distance function is defined as:

$$D_o^t(x^t, y^t) = \min \theta^t \text{ subject to } \frac{\mathbf{y}^t}{\theta^t} \in P(\mathbf{x}^t) \qquad \text{(A1)}$$

Given the technology in the above specification, the Farrell's (1957) output oriented measure of technical efficiency for activity k is obtained by maximizing the reciprocal of the distance function in equation (1).

$$\underset{\theta,z}{Max}\ D_o^t(\mathbf{x}^t, \mathbf{y}^t)^{-1} = \theta^{-1} \qquad \text{(A2)}$$

Subject to

$$\theta \mathbf{y}_{km} \le \sum_{k=1}^{K} \mathbf{z}_k \mathbf{y}_{km},\ m = 1,2,...,M;$$
$$\sum_{k=1}^{K} \mathbf{z}_k \mathbf{x}_{kn} \le \mathbf{x}_{kn},\ \ n = 1,2,...,N;$$
$$\mathbf{z}_k \ge 0,\ k = 1,2,...,K$$

Hence, $D_o^t(\mathbf{y}^k, \mathbf{x}^k) = 1$ implies district k is the most efficient and lies on the production frontier, and any value less than 1.0 implies the firm is operating below the production frontier. The restrictive assumption of constant returns to scale on the production technology is further relaxed and a variable returns to scale with strong disposability is imposed by the following restriction on the intensity vector, $\sum z_k = 1$.

The Total Factor Productivity (Malmquist Productivity Index)

Over time an increase in efficiency may cause an upward shift in the production frontier leading to growth in productivity. Improvement in total factor productivity (also called Malmquist productivity index) could be due to either improvement in technical efficiency or improvements in technology. Fare et al. [13] decomposed the Malmquist Productivity Index for ith farm in *t*+1 period as the product of an efficiency change index and technological progress. A productivity index is constructed examining the outputs in period *t* and *t*+1 relative to technology available in period t and t+1 and using the geometric mean. The expression for Malmquist productivity index is:

$$MALM_o(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{x}^t,\mathbf{y}^t) = \left[\frac{D_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1})}{D_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t})}\right] * \left[\frac{D_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1})} * \frac{D_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t})}{D_o^{t+1}(\mathbf{x}^{t},\mathbf{y}^{t})}\right]^{\frac{1}{2}} \qquad \text{(A3)}$$

$$MALM_o(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{x}^t,\mathbf{y}^t) = E(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{x}^t,\mathbf{y}^t) * T(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{x}^t,\mathbf{y}^t) \qquad \text{(A4)}$$

Superscript *t* and *t*+1 represent the current and the next period, respectively. The function $E^{t+1}(.)$ represents the productivity change arising from changes in technical efficiency, which is measured by the ratio of two distance functions at two different points in time. The function $T^{t+1}(.)$ represents changes in productivity due to a technological progress. This is composed of distance functions, which mix technology from one time period with observations from another time period, which are then averaged geometrically. For example, the mixed period distance function $D_o^{t+1}(x^t,y^t)$, computes the largest possible contraction of inputs observed in time period t so that the level of output in that period can be produced using technology from time period *t*+1. The technology index captures the shift in technology between period *t* and *t*+1 evaluated at two different data points (x^t,y^t and x^{t+1},y^{t+1}). For a detailed discussion on Malmquist productivity index readers may consult Domazlicky and Weber [11, 10].

ENDNOTES

1. The detail results from DEA model estimating efficiency scores for 304 USD are available from the author upon request.
2. The detail results from Total Factor Productivity Index and its components (efficiency change, technological change, and total factor productivity growth) for each school district are available from the author upon request.
3. See note 1 above.
4. See note 2 above.

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