

Using DEA to evaluate the efficiency of secondary schools: the case of Cyprus

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This study utilizes the methodology of data envelopment analysis (DEA) to assess the efficiency of secondary schools in Cyprus. Apart from evaluating the relative efficiency of schools, the study provides recommendations for improvement to inefficient schools and discusses managerial implications. Furthermore, empirical findings based on an approach to estimate efficiency environmental effects suggest that no efficiency differences exist between schools operating in rural areas compared to those operating in urban areas.

Introduction

Assessing the performance of an educational system is an important but difficult to accomplish task. Educational services feature all the distinctive characteristics of services *vis-à-vis* manufacturing, such as perishability, heterogeneity and simultaneity (Fitzsimmons and Fitzsimmons, 1994; Sasser *et al.*, 1978). Despite the difficulties involved, school performance assessment can, among others, be used to set performance targets, to make resource allocation decisions, and to improve overall school performance.

School units bear further similarities to service organizational units in the sense that they utilize multiple inputs to produce multiple outputs (Cameron, 1978). A number of common problems emerge when attempting to assess service organization and school performance. First, no ultimate criterion of effectiveness exists, since a unit (service organization or school) may typically pursue multiple, and often contradictory goals. Relevant criteria may also change over the lifecycle of the unit. Different units may assign particular importance to different organizational aspects at different times. Moreover, criteria at one organizational level may not be the same as those at another organizational level, while relationships among various effectiveness dimensions may be difficult to discover.

Different criteria have traditionally been defined for assessing school performance. Typically, school effectiveness has been measured in terms of the performance of students in examinations (see Gray, 1981), for a discussion on school outcomes). Other contextual factors such as the students' socioeconomical background and other environmental variables are also considered. In this paper we follow a (popular in the literature) production or "value-added" approach in which the school utilizes some inputs (i.e. number of

instructors, experience of instructors, socioeconomic background of students, etc.) to produce some outputs (i.e. examination scores).

One of the methodologies used in previous studies of school performance evaluation based on input-output analysis has been ordinary least squares (OLS) regression analysis. Such studies have, however, two major disadvantages (Ray, 1991). First, predicted values resulting from a regression model provide the average or expected level of outcome given certain inputs, instead of the maximum achievable outcome. Second, the input/output production function specified by such models may be problematic. Most regression models use a single output production function, which may be unrealistic when assessing school performance[1].

In this paper we focus on the assessment of the efficiency of secondary schools in Cyprus. In a recent study by the International Association for the Evaluation of Educational Achievement, the schools of Cyprus ranked low compared to 41 other countries which also participated in the study. However, examining only the schools' output does not provide a complete picture regarding performance. It is important to know whether schools are actually utilizing their resources in the most efficient way to produce the observed rankings. In addition, it is also important to provide guidelines on how schools can improve further.

Here, we utilize the non-parametric methodology of data envelopment analysis (DEA) (Charnes *et al.*, 1978). DEA, a state-of-the-art non-parametric methodology, can be used to assess performance of homogeneous units utilizing multiple inputs to produce multiple outputs. DEA enjoys a number of advantages over other traditional parametric methods, and has been used extensively to assess school performance (Norman and Stocker, 1991; Sammons *et al.*, 1993; Thanassoulis and Dunstan, 1994). Apart from evaluating the

relative efficiency of secondary schools, this study provides recommendations for improvement to inefficient schools and discusses managerial implications.

The paper is organized as follows. We next provide a description of the data envelopment analysis methodology. A brief literature review on the DEA applications in educational settings follows. Next, we describe an empirical study which utilizes DEA to assess the efficiency of secondary schools in the country of Cyprus. Additional insights to the problem of school evaluation are presented by benchmarking the effect of the external environment through the comparison of urban and rural school efficiency. Managerial implications, limitations and future research are also discussed. Concluding remarks follow.

Data envelopment analysis

The methodology of data envelopment analysis, initially introduced by Charnes *et al.* (1978), is a mathematical programming technique used to evaluate the relative efficiency of homogeneous units. This efficiency evaluation derives from analysing empirical observations obtained from decision-making units (DMUs), a term coined by Charnes *et al.* (1978) to define productive units which are characterized by common multiple outputs and common designated inputs.

Relative homogeneity of organizational units such as schools, bank branches or hospitals, provides instances for implementation of the DEA methodology. In a more general manner, DEA is most useful in cases where accounting and financial ratios are of little value, multiple outputs are produced through the transformation of multiple inputs, and the input-output transformation relationships are not known (Charnes *et al.*, 1978).

In a broad sense, efficiency of a single DMU k_0 operating in a homogeneous set of N DMUs, utilizing multiple inputs I to produce multiple outputs R , can be defined as follows :

$$E_{K_0} = \frac{\sum_{r=1}^R u_{rK_0} y_{rK_0}}{\sum_{i=1}^I v_{iK_0} x_{iK_0}} \quad (1)$$

where,

E_{K_0} = efficiency of unit K_0 ,

y_{rK_0} = amount of output $r = 1, \dots, R$ produced by DMU K_0 ,

x_{iK_0} = amount of input $i = 1, \dots, I$ consumed by DMU K_0 ,

u_{rK_0} = weight given to output r ,

v_{iK_0} = weight given to input i ,

R = number of outputs,

I = number of inputs.

As long as the unit under consideration remains a single DMU, we could retain the preceding definition. However, an attempt of defining efficiency for a group of DMUs simultaneously is not possible using just definition (1), since a common set of weights is difficult to be set among all DMUs of a service organization or system.

Each DMU can be allowed to choose its own set of weights based on its own value system (Charnes *et al.*, 1978) in an attempt to appear as efficient as possible. The following model is formed based on definition (1):

(M1)

$$\text{Maximize } E_{K_0} = \frac{\sum_{r=1}^R u_{rK_0} y_{rK_0}}{\sum_{i=1}^I v_{iK_0} x_{iK_0}} \quad (2)$$

subject to:

$$\frac{\sum_{r=1}^R u_{rK_0} y_{rj}}{\sum_{i=1}^I v_{iK_0} x_{ij}} \leq 1 \quad \text{for all } j = 1, \dots, N, \quad (3)$$

$$u_{rK_0}, v_{iK_0} \geq 0 \text{ for all } r = 1, \dots, R, \text{ and } i = 1, \dots, I, \quad (4)$$

Through **M1**, each DMU K_0 analysed will specify the particular input and output weights (u and v respectively), which maximize its own ratio of weighted output to weighted input, subject to the constraint that no other unit utilizing the same weights could exceed an efficiency rating of 1. A DMU with efficiency rating of 1 will be given the characterization of efficient relative to other DMUs. Vice versa, an efficiency rating of less than 1 will lead us to characterizing this specific unit as inefficient in relation to others.

(M1) represents a fractional linear programming (LP) model. This can be easily transformed into a simple linear program, as follows:

(M2)

$$\text{Maximize } E_{K_0} = \sum_{r=1}^R u_{rK_0} y_{rK_0} \quad (5)$$

subject to:

$$\sum_{i=1}^I v_{iK_0} x_{iK_0} = 1 \quad (6)$$

$$\sum_{r=1}^R u_{rK_0} y_{rj} - \sum_{i=1}^I v_{iK_0} x_{ij} \leq 0 \text{ for all } j \quad (7)$$

$$u_{rK_0}, v_{iK_0} \geq 0 \text{ for all } j \quad (8)$$

where,

E_{K_0} = efficiency of unit K_0 ,

y_{rK_0} = amount of output r produced by
DMU K_0 ,

x_{iK_0} = amount of input i consumed by
DMU K_0 ,

u_{rK_0} = weight given to output r ,

v_{iK_0} = weight given to input i ,

The transformation is obtained by setting the denominator of (2) to an arbitrarily selected constant. A similar manipulation of equation (2) can result in an input minimization oriented linear programming model[2].

The dual formulation of (M2) can provide additional insights and is computationally less expensive:

(M3)

$$\text{Minimize } H_{K_0} - \varepsilon \left(\sum_{r=1}^R s_r^+ - \sum_{i=1}^I s_i^- \right) \quad (9)$$

subject to:

$$H_{K_0} x_{iK_0} - \sum_{j=1}^N \lambda_{K_0j} x_{ij} - s_i^- = 0, \quad (10)$$

for all $i = 1, 2, \dots, I$,

$$\sum_{j=1}^N \lambda_{K_0j} y_{rj} - s_r^+ = y_{rK_0}, \quad (11)$$

for all $r = 1, 2, \dots, R$,

$$H \text{ free and } \lambda_{K_0j} \geq 0, \forall j \quad (12)$$

$$s_i^-, s_r^+ \geq 0, \quad 0 < \varepsilon \ll 1. \quad (13)$$

where s_r^+ and s_i^- represent the slack variables corresponding to the outputs and inputs respectively.

Based on model (M3) we can characterize DMU K_0 efficient as long as the value of H_{K_0} is equal to 1. If H_{K_0} exceeds the lower limit of 1, the DMU under assessment is characterized inefficient in comparison to other DMUs. That is, there exists a weighted combination of actual performance of other units, such that no output of unit K_0 exceeds that of the weighted output of the weighted combination. At the same time, we could reduce all inputs of K_0 by the proportion H_{K_0} without any input falling below that of the corresponding weighted combination of other units. If DMU K_0 is deemed inefficient, management could decrease all the inputs of K_0 in the same proportion, in order to achieve the desired weighted combination performance.

The size of the necessary decrease is indicated by the value of H_{K_0} .

From the scope of computational effort, the fact that (M3) has only $(I + R)$ constraints compared to $(N + R + I + 1)$ constraints of model (M2) and N is typically much larger than $I + R$, deems (M3) easier to solve in comparison to (M2). An additional advantage of (M3) is the provision of target values for inefficient units by comparing them against a composite unit constructed by the actual performance of the rest of the units (Boussofi-ane *et al.*, 1991). These targets can provide guidelines for improvement to inefficient units. At optimality, the following input/output values occur:

$$x_{iK_0}^{\text{target}} = H_{K_0}^* x_{iK_0} - s_i^{*-},$$

for all $i = 1, 2, \dots, n \quad (14)$

$$y_{rK_0}^{\text{target}} = y_{rK_0} + s_r^{*+},$$

for all $r = 1, 2, \dots, m \quad (15)$

where * indicates optimality. These are input-oriented targets since the attempt here is to minimize inputs. Output-oriented targets can also be derived by dividing both

$$x_{iK_0}^{\text{target}} \text{ and } y_{rK_0}^{\text{target}} \text{ by } H_{K_0}^*.$$

Model (M3) was introduced by Charnes *et al.* (1978) based on the assumption of constant returns to scale. However, while this assumption could often be legitimate, it may not be valid in cases where the scale of operations could influence a DMU's efficiency rating, such as, for example, when assessing school performance. Moreover, information concerning the amount of inefficiencies owing to the scale of operations would prove to be very useful for managerial decisions. Appendix 1 presents a model described by Banker *et al.* (1984) to cover the issue of inefficiencies due to scale of operations, through an extension of model (M3).

Applications of DEA in education

Applications of DEA to measure the efficiency of educational production have extensively been reported in literature, beginning with the introductory paper of DEA (Charnes *et al.*, 1978), which introduced the DEA methodology by demonstrating it in a school setting. The aim of this section is not to present a thorough literature review of DEA applications in education, but rather to present some of the more relevant studies to this work.

Charnes *et al.* (1981) also used data from the education sector. The authors concentrated in the comparison of the programme follow

through (PFT) and non follow through (NFT) schemes for primary school children in the USA. Participants in PFT were children who came from less advantaged backgrounds, while the experiment also included a control group of NFT children for each district that participated in the PFT. DEA was used in order to assess the efficiencies of policies within which managers operate while eliminating the inefficiencies originating from the managers themselves.

An alternative use of DEA is presented by Bessent and Bessent (1983). More specifically, DEA is used for resource allocation of various programs in the environment of a community college. The main contribution of the study was the recognition that, in spite of some limitations, DEA could prove helpful in resource allocation. DEA cannot, however, provide an answer to the question of allocating total organizational resources in order to obtain maximum output from the units.

Boussofiane *et al.* (1991) utilize the context of comparing schools for the purpose of demonstrating practical issues encountered in selecting and qualifying inputs and outputs. Schools were chosen as an illustration mainly due to the importance of environmental factors in their operation. An important observation of the authors is the effect of the selection of inputs and outputs in the discriminatory power of DEA, which more specifically is related to the number of selected inputs and outputs. As a minimum number of units that will be given the tag of efficient, authors set the product of the number of inputs and outputs.

In a similar manner, Golany and Tamir (1995), utilize hypothetical data taken from an evaluation of some elementary schools in a school district. Aim of the illustration is the distinction between different aspects evaluated by efficiency, effectiveness and equality, in addition to specifying potential trade-off among them. In another recent study, Thanassoulis (1996) demonstrated how to use DEA to set targets for differentially effective schools.

Johnes and Johnes (1993) refer to an application of the methodology in universities. In the particular study, DEA is used for assessing the research performance of UK departments of economics during 1984–88. DEA was especially valuable since no universally accepted importance weights exist regarding the relevant inputs and outputs. The problem was addressed through the allowance of DEA for each unit to determine its own set of input and output weights such that it maximizes its efficiency. However, each unit is not completely free to define its set, since it is subject to the constraint that no other unit could accomplish an efficiency rating that exceeds

unity, based on the same set of weighted inputs and outputs.

Ray (1991) utilized the DEA methodology in combination to regression analysis in order to assess relative efficiency in public school districts in Connecticut, USA. Through his analysis he pointed out the effect of socio-economic variables in productivity variations. A relative paper, in the sense that it refers to combined use of DEA with regression analysis, is presented by Sexton and Sleeper (1994), aiming at facing the lack of homogeneity between DMUs involved.

Assessing the effectiveness of schools in Cyprus

Model description

Studies of educational production function define two major ways of describing the influences of schooling on student achievement. Either take into account the cumulative influence of family background, peers, school input and innate abilities on student achievement at certain time points or measure these factors during the period student is attending school.

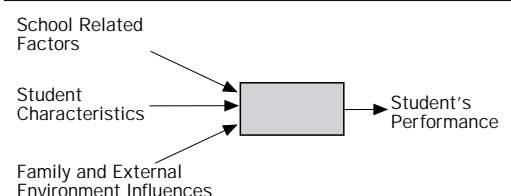
Our study uses the second alternative, also known as the *value added* model. This model is convenient in the sense that it reduces data requirements, since school-level aggregated data can be used. Moreover, educational achievement is a product of both inputs controllable by the school but also of other factors such as family background, innate abilities, peers and former outcomes.

Figure 1 presents the theoretical framework underlying the developed models.

Three generic determinants drive school performance (Thanassoulis, 1996). First, school-specific factors such as the size of the school, and the number and quality of the teachers; second, factors which are family and external environment specific, such as for example, the students' socioeconomic background or the location of the school; and finally, the abilities of the student him/herself.

Three models, as presented in Table I were constructed, based on the above framework and on data availability. The small number of

Figure 1
Generic drivers of school performance



schools available limited the number of input and output variables, in order to preserve the DEA model's discriminatory power. The models presented in Table I proceed from a simple (Model 1) to a more complicated input set (Model 3). All models include a single, common output, consisting of the score from standardized examinations such as the TIMSS, to be discussed in the next section.

The first model uses inputs which can be obtained from teachers' and students' questionnaires. More specifically, it includes the age and educational level of teachers, in addition to the parents' education and the socioeconomic status of the family. Model 2 also includes school data. That is, the size of the school, defined as the students' population was included. An additional input is considered by Model 3 to capture the socioeconomic background of students. The number of books at student's home was used as a proxy for that. A description of all the variables included in all the models is shown in Appendix 2.

Data

The Third International Mathematics and Science Study (TIMSS) was conducted during the months of May-June 1995. TIMSS is conducted by the International Association for the Evaluation of Educational Achievement (IEA), in a total of 45 countries, covering more than half a million students at five grades levels in more than 15,000 schools. The main goal of TIMSS is to provide international benchmarks regarding school performance. Data were collected using standardized questionnaires, adjusted to reflect cultural differences, completed by school principals, teachers and students.

TIMSS provides the various participating countries a vehicle with which to investigate a variety of issues, including what concepts students understand, how well they can apply their knowledge in problem-solving situations, and whether they can communicate their understandings. Information regarding

these issues is very important. Skills in mathematics and science are becoming critical to economic progress due to the transformation of modern societies into more technologically based, where higher levels of technical competence and flexible thinking are required[3].

TIMSS utilized information from students, teachers and school principals as follows:

- *Principal questionnaire.* This instrument was administered to the school's principal. It obtained general information about the school, i.e. school size, number of teachers teaching at school for five or more years, information on the school's community and on the number of department heads.
- *Teacher of mathematics and science questionnaire.* Data collected through this instrument, which was administered to teachers, include the teacher's educational background, co-operation with other teachers for lesson enhancement, and teaching methodologies.
- *Student information.* Information on such variables as the socioeconomic status of student's family, parents' education and number of books at home was gathered via a questionnaire. Furthermore, math tests which covered six content areas (fractions and numbers (34 per cent), measurement (12 per cent), proportionality (7 per cent), data representation, analysis, and probability (14 per cent), geometry (15 per cent), and algebra (18 per cent)) were also administered to seventh and eighth grade students.

Our study was based on the Mathematics TIMSS data as collected in Cyprus with the collaboration of the Ministry of Education and Culture, the Pedagogical Institute, and the University of Cyprus. Data were gathered from 55 high schools, which reflects the total of lower secondary schools (gymnasiums) in Cyprus. In terms of students population, 5,852 out of a total of 19,694 students participated in the study, from both the seventh and eighth grades of high school (ages 13-14 years old). Data are aggregated to the school level. Furthermore, no data were used in this study from the principals' questionnaire because of the very low response rate observed, regarding fully completed questionnaires (less than 10 per cent). School size was obtained from secondary sources through the Ministry of Education and Culture.

For the purposes of this study, a distinction was made between schools located in urban areas (33 schools) and those located in rural areas (22 schools). Thus, two separate groups were formed, and assessed separately. This distinction provides two desirable outcomes. First, the coverage of DEA's homogeneity of units requirement is maintained. Second, the

Table I

Variables used in the DEA efficiency measurement

	Model 1	Model 2	Model 3
Inputs			
Age of teacher	✓	✓	✓
Education level of teacher	✓	✓	✓
Parents' education	✓	✓	✓
Socioeconomic status	✓	✓	✓
School size		✓	✓
Number of books at student's home			✓
Output			
International mathematics score	✓	✓	✓

two groups will be used to demonstrate possible environmental effects on the efficiencies of schools through a benchmarking approach which will be discussed later. Table II presents descriptive statistics on the data collected from the two groups.

Results and discussion

All three models were run under both constant returns to scale (CRS) and variable returns to scale (VRS), separately for the urban and rural group. Furthermore, both input minimization and output maximization DEA models were run for each school in each group, in order to identify inefficient and best-practice schools. The output maximization model provides information on how much the average student performance on

the TIMSS test could be improved, given its inputs. The input minimization model provides information on how much an inefficient school could further reduce some of its inputs while maintain the current level of performance. Table III provides descriptive statistics on the resulting efficiency distributions of input minimization models.

It is noteworthy that even though some inefficiencies are evident, the overall efficiencies observed are high. Assuming, for example, CRS and using Model 2, we have a mean efficiency value of 96.56 for urban area schools and 94.82 for rural area schools. A possible explanation of this may involve the tight control exhibited by the Ministry of Education with respect to teaching curricula, school activities and overall performance.

Table II

Descriptive statistics of data collected for urban and rural area schools

	Maximum	Minimum	Mean	Median	Std Dev
Urban area schools					
<i>Inputs</i>					
Age of teacher	5	3	3.857	4	0.571
Education level of teacher	8	5	6.018	6	0.523
Parents' education	7.852	3.484	5.330	5.128	1.255
Socioeconomic status	12.073	9.020	10.572	10.582	0.730
School size	625	160	390.939	408	119.720
Number of books at student's home	3.977	2.846	3.393	3.408	0.271
<i>Output</i>					
International mathematics score	527.598	439.184	482.727	482.233	26.852
Rural area schools					
<i>Inputs</i>					
Age of teacher	4.5	3	3.55	3.5	0.486
Education level of teacher	6.5	5	5.789	6	0.445
Parents' education	4.853	2.5	3.518	3.4	0.690
Socioeconomic status	10.732	8.674	9.665	9.753	0.605
School size	504	134	308.773	345	146.0053
Number of books at student's home	3.413	2.839	3.158	3.179	0.184
<i>Output</i>					
International mathematics score	484.511	418.969	455.740	454.123	18.327

Note:

See Appendix 2 for variable definition

Table III

Descriptive statistics on efficiency distributions obtained by the three models

	Model 1				Model 2				Model 3			
	CRS		VRS		CRS		VRS		CRS		VRS	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Mean	95.95	94.34	97.00	96.71	96.56	94.82	97.94	96.71	97.10	96.78	98.11	98.50
Minimum	86.82	83.68	88.96	86.67	87.31	83.68	92.33	86.67	90.30	88.13	91.75	90.04
Maximum	100	100	100	100	100	100	100	100	100	100	100	100
Percentage share of efficient schools	27.3	27.3	33.3	59.1	33.3	31.8	36.4	59.1	36.4	45.5	39.4	68.2

Table IV presents input minimization sample results and suggested improvement guidelines for one of the inefficient schools, school X, that could bring it in line with its peer group. According to the table, another school (or combination of other schools) exists, in which the teachers are on average younger, the parents' education, the socioeconomic status and the teachers' education is lower, but the average score on the TIMSS exam was equally good. The model points towards areas which may need improvement, such as, for example, the quality of the teachers as it relates to their age and education, and the resulting implications for on-going teacher training.

Clearly, not all the recommendations of the model are feasible. Improving the students' socioeconomic status is not a short-term effort, neither is a feasible effort by the principal of the school alone. Other recommendations, such as the quality of the teachers can be implemented with the collaboration of the authorities. Such a possible strategy could involve the rotation of teachers among different schools[4]. The feasibility of the models' recommendations must be examined on a school basis in collaboration with the principal of the school and the proper authorities. The output maximization version of the model can also provide the exam score level which could be achieved by the school, given its current inputs.

We also observe in Table IV that the target school constructed by the model – which is a linear combination of existing schools – is smaller in size compared to school X. This can, to some extent, explain why the virtual school performs better since smaller schools may perform “better”. On the other hand, such size difference may deem the comparison unfair. Examination of the peer schools of school X can help identify “well-behaved” schools and provide the means for a more fair comparison. For example, Table V presents actual data from school Y, one of the peer

Table IV

Actual and target values for all variables as indicated by DEA for school X

	School X	
	Actual value	Target value
Socioeconomic status	10.00	8.60
Teachers' age	4.50	3.00
Teachers' education	6.00	5.00
Parents' education	4.10	3.20
Students' population	344.00	69.00
International mathematics score	450.10	450.10

Table V

Comparison of an inefficient school with a school similar in size

	School X (actual)	Peer for X (actual)
Socioeconomic status	10.00	8.90
Teachers' age	4.50	4.00
Teachers' education	6.00	5.00
Parents' education	4.10	3.90
Students' population	344.00	337.00
International mathematics score	450.10	463.10

schools of school X. The two schools are similar in size.

We observe that the average education of teachers, for example, at the peer of school X is lower than that observed at X. Further investigation into how can school X capitalize on the advantage of its teachers to increase the TIMSS examination score should be initiated.

Benchmarking the effects of the environment

One of the primary goals of the study is to benchmark the possible environmental effect on the efficiencies of schools. Based on the distinction of our data set into two homogeneous subgroups – urban and rural area schools – we will utilize an approach proposed by Charnes *et al.* (1981) which isolates and evaluates school programme efficiency. Here, we follow the approach in a similar manner to isolate and assess the environmental impact on school efficiency.

The approach (also described in Zenios *et al.*, 1995), proceeds in three steps:

Step 1. Run the DEA model on two groups operating in two different environments.

Step 2. Project inefficient units on their corresponding efficient frontier. Combine projected and efficient units from both groups and run the DEA again on the pooled data set.

Step 3. Examine whether the resulting efficiency distributions in each group are different. This can be done by using Mann-Whitney non-parametric tests, since the resulting distributions are not likely to follow normality.

The urban and rural area schools were pooled together and the above procedure was followed. The resulting efficiencies suggest that there is no statistically significant efficiency differences between urban and rural area schools ($p < 0.001$).

The TIMSS scores shown in Table II suggest that urban schools indeed outperformed rural schools ($p < 0.05$). The above result, however, suggests that differences in inefficiency of schools cannot be attributed to environmental influences. Thus, any corrective actions should be aimed at changing the internal rather than the external environment.

Limitations and future research

The models developed in the study we described above were limited by data availability, and thus myopic in nature. Only a single output was considered, based on a single exam on a single subject, given to eighth graders. The output set should be expanded to reflect more desirable school outcomes. Thus, outputs which include other subjects should also be incorporated in the set, representative of the whole body of students. Music and athletics outputs should also be considered. The input set should also include further information on the teachers' training and quality, the schools' resources, and the socioeconomic environment.

Furthermore, this was a cross-sectional study conducted at a single point in time. Studies of a dynamic nature should also consider changes over time. As data availability through studies such as TIMSS increases, such dynamic studies will also be made possible.

Finally, of extreme interest will be studies which will focus on international comparisons. The focus of TIMSS for example was to provide the means to communicate knowledge across countries. School performance can greatly benefit from international studies which will examine both the input and the output side of the school effectiveness picture. It would be of great interest to examine how the efficiency of schools change as they are compared against schools operating in different educational systems.

Conclusion

In this paper we develop DEA models to assess the efficiency of secondary schools in Cyprus. We demonstrate how inefficient units can benefit from such analysis and be directed towards areas which may require improvement.

One of the major findings was that in the case of Cyprus, room for school efficiency improvement exists, even though not great. Despite the low rankings schools in Cyprus obtained during the TIMSS, most of the schools find themselves very close to the efficient frontier. These results emphasize the existing homogeneity between schools as far

as efficiency is concerned, and underline the importance of future international efficiency studies. As international data availability through studies such as TIMSS increases, such studies will also be made possible.

Furthermore, we found no efficiency differences which can be attributed solely to the environment, despite the lower scores observed in rural areas. This is an important finding for schools in Cyprus, since the efforts towards improvement can now focus on the school level alone.

Notes

- 1 Even though not as popular, simultaneous equation models to estimate multiple output production technologies, and thus overcome this problem, have been proposed by Levin (1970) and Michelson (1970).
- 2 This can be achieved by setting the numerator of (2) to a constant and minimizing the denominator
$$(\text{Minimize } K_0' = \sum_{i=1}^n v_{iK_0} x_{iK_0} .)$$
- 3 Further information on the TIMSS study is provided in the following Internet address <http://wwwwcsteep.bc.edu/timss>
- 4 Although teacher rotation among different schools is currently observed, efficiency findings such as the ones obtained here are not considered when making decisions on these rotations.

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Appendix 1 Variable returns to scale model

(M4)

$$\text{Minimize } H_{k_0} - \varepsilon \left(\sum_{r=1}^m s_r^+ - \sum_{i=1}^n s_i^- \right) \quad (16)$$

subject to:

$$H_{k_0} x_{ik_0} - \sum_{j=1}^N \lambda_{k_0j} x_{ij} - s_i^- = 0,$$

for all $i = 1, 2, \dots, I$, (17)

$$\sum_{j=1}^N \lambda_{k_0j} y_{rj} - s_r^+ = y_{rk_0},$$

for all $r = 1, 2, \dots, R$, (18)

$$\sum_{j=1}^N \lambda_{k_0j} = 1, \quad (19)$$

$$H \text{ free and } \lambda_{k_0j} \geq 0, \forall j \quad (20)$$

$$s_i^-, s_r^+ \geq 0, \quad 0 < \varepsilon \ll 1. \quad (21)$$

Comparing (M4) to (M3), we notice that their only difference is estimated in the inclusion of constraint (18). This convexity constraint requires that multipliers λ_j should add up to 1, thus ensuring the comparison of DMUs against a composite unit of similar size.

Appendix 2 Variables used

Inputs

Age of teacher	1. Below 25 years 2. 25-29 3. 30-39 4. 40-49 5. 50-59 6. 60 and above
Education level of teacher	Categories include options such as BSc/BA, MA, PhD etc.
Parents' education	Categories include secondary education, university or postgraduate studies, etc.
Socioeconomic status	Data are obtained from questioning the student about the existence of a variety of things at his home, such as tape recorder, computer, speed boat, satellite antenna
School size	Measured by student population
Number of books at student's home	Existence of five categories: 1. 0-10 books 2. 11-25 3. 26-100 4. 101-200 5. More than 200 books

Output

International mathematics score	Average score achieved at the school level in the mathematics section of the TIMSS study
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