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An Empirical Survey of Frontier Efficiency Measurement Techniques in Education

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ABSTRACT *Educational institutions worldwide are increasingly the subject of analyses aimed at defining, measuring and improving efficiency. However, despite the importance of efficiency measurement in education, it is only relatively recently that the more advanced econometric and mathematical programming frontier techniques have been applied to primary and secondary schools, university departments and degree programs, and universities as a whole. This paper attempts to provide a synoptic survey of the comparatively few empirical analyses in education using frontier efficiency measurement techniques. Both the measurement of inefficiency in education and the determinants of educational efficiency are examined.*

Introduction

One of the most common conceptual frameworks employed in the economic analysis of education takes the form of a production function. Here the educational institution (as variously defined) is seen as analogous to a firm transforming inputs into outputs through a production process. Typical inputs in the education production function are the characteristics of the teaching and learning environment, while outputs are generally defined in terms of students' test scores. It follows that a strong assumption held in this type of analysis is that technical relationships are of central importance in the educational process. If such relationships exist and can be quantified, policy can be constructed so as to maximize some preferred conceptual outcome. Much of the empirical research in this area has focused on identifying these technical relationships. However, a disturbing pattern in the multitude of studies of this type is that no strong empirical evidence exists to support the contention that

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traditional educational inputs have the expected positive influence on educational outcomes (Pritchett and Filmer, 1999, p. 223).

The failure of educational production functions to identify the purported relationship between key policy variables (such as resource spending) and educational achievement has been the subject of much inquiry. Four key reasons have been advanced. The first reason questions the validity of the educational production function framework itself. It is argued that many empirical studies are *ad hoc* in their selection of methodology, and in particular, choose input and output variables that are at odds with the production function approach itself. The second reason centres on the possibility that public policy does not have any measurable impact on educational outcomes. This line of reasoning suggests that innate ability, combined with the influence of socioeconomic background, may dominate the educational production process (Deller and Rudnicki, 1993).

The third reason follows from Mayston's (1996) argument that the lack of a positive relationship between educational outcomes and educational expenditure is the result of schools balancing off demand-side considerations of 'willingness to pay' for additional educational attainment against supply-side factors related to the genuine underlying production function. Mayston (1996, p. 141) concludes:

> The associated econometric problems that follow from the neglect of the demand side mean that one cannot legitimately interpret an estimated single equation between test scores and expenditure per pupil as telling us directly about the true underlying education production function.

Finally, it has been reasoned that the educational production function approach relies on an assumption of efficiency. Put differently, it is generally assumed that all institutions in a given context are able to transform educational inputs into academic outputs at the same rate. If this is not the case, and inefficiencies are present in the educational process, then the empirical application of the conceptual model may collapse (Hanushek, 1986). This last line of reasoning forms the subject of the survey that follows.

A large number of empirical studies to date have already considered the possibility that inefficiency exists in education. These studies have used a variety of empirical techniques to identify 'efficient' educational institutions and compare them with 'inefficient' institutions. This work is obviously important because in most developed economies an emphasis has been given to issues of accountability, value-for-money, and cost-effectiveness in education. The measurement of organisational efficiency is thus recognised as an essential part of the implementation, monitoring and evaluation of these public sector reforms.

However, in recent years an increasing number of these analyses have used the more advanced econometric and mathematical programming frontier efficiency measurement techniques. These studies have in common the fact that they focus attention on educational institutions that produce the highest levels of achievement given their inputs: that is, they focus on institutions on the efficient or 'best-practice' frontier. These frontier techniques are generally recognised as having a closer correspondence with the theoretical framework underlying production economics, and are therefore more consistent with the overall education production function approach. With these potentialities in mind, this paper attempts to provide a synoptic survey of the comparatively few empirical analyses of educational efficiency using frontier efficiency measurement techniques.

The paper itself is divided into four main areas. The first section briefly discusses the theoretical basis of frontier efficiency measurement techniques. The second section examines the literature in the empirical measurement of inefficiency in education. The third section discusses the determinants of educational efficiency. The paper ends with some brief concluding remarks.

The Theory of Microeconomic Efficiency Measurement

Economists have developed three main measures of efficiency. Firstly, *technical efficiency* refers to the use of productive resources in the most technologically efficient manner. Put differently, technical efficiency implies the maximum possible output from a given set of inputs. Within the context of education, technical efficiency may then refer to the physical relationship between the resources used (say, capital, labour and equipment) and some education outcome. These educational outcomes may either be defined in terms of intermediate outputs (generally standardized test scores) or a final education outcome (such as graduates' employment rates, starting salaries or acceptance rates into higher education).

Secondly, *allocative efficiency* reflects the ability of an organisation to use these inputs in optimal proportions, given their respective prices and the production technology. In other words, allocative efficiency is concerned with choosing between the different technically efficient combinations of inputs used to produce the maximum possible outputs. Consider, for example, a policy of changing from direct teacher instruction to computer-aided learning. Computer-aided learning uses less teaching input but it requires the use of another resource; namely, computer hardware and software. Since different combinations of inputs are being used, the choice between educational technique is based on the relative costs of these different inputs (assuming outputs are held constant).

Finally, and when taken together, allocative efficiency and technical efficiency determine the degree of *productive efficiency* (also known as total economic efficiency). Thus, if an organisation uses its resources completely allocatively and technically efficiently, then it can be said to have achieved total economic efficiency. Alternatively, to the extent that either allocative or technical inefficiency is present, then the organisation will be operating at less than total economic efficiency.

The recent history of microeconomic efficiency measurement begins with Farrell (1957) who defined a simple measure of firm efficiency that could account for multiple inputs within the context of technical, allocative and productive efficiency. In this approach, Farrell (1957) proposed that the efficiency of any given firm consisted of two components: technical efficiency, or the ability of a firm to maximise output from a given set of inputs, and allocative efficiency, or the ability of a firm to use these inputs in optimal proportions, given the respective prices. Combining the two measures provides the measure of productive efficiency.

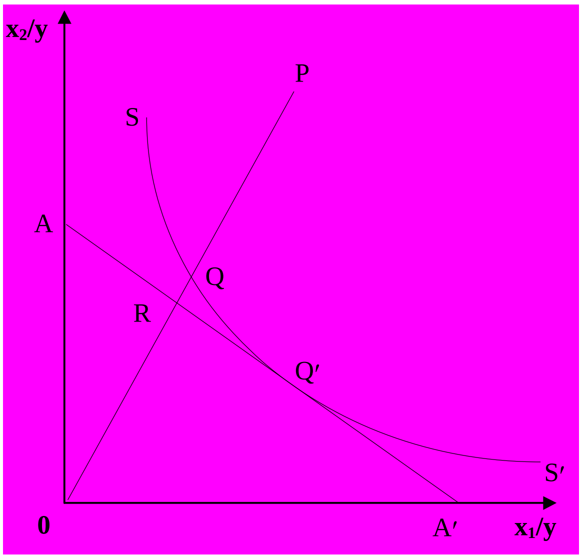

Figure 1. Technical, allocative and total productive efficiency

In parenthesis for technically inclined readers, Farrell's (1957) argument is contained in Figure 1. Here two inputs, x_1 and x_2, are utilised to produce a single output y, so that the production frontier is $y = f(x_1, x_2)$. If we assume constant returns to scale (where the relationship between output y and inputs x_1 and x_2 does not change as the inputs increase), then 1 = $f(x_1/y, x_2/y)$. The isoquant (showing the alternative combinations of inputs which can used to produce a given level of output) of the fully efficient firm *SS*' permits the measurement of technical efficiency. Now, for a given organisation using quantities of inputs (x_1* x_2*) defined by point *P* (x_1*/y, x_1*/y) to produce a unit of output y*, the level of technical efficiency, or the ability of a organisation to maximise output from a given set of inputs, may be defined as the ratio *OQ*/*OP*. This ratio measures the proportion of (x_1, x_2) actually necessary to produce y*. Thus 1 - *OQ*/*OP*, the technical inefficiency of the organisation, measures the proportion by which (x_1*, x_2*) could be reduced (holding the input ratio x_1/x_2 constant) without reducing output. It accordingly measures the possible reduction in the cost of producing y*. Furthermore, given constant returns to scale, it also roughly estimates the proportion by which output could be increased, holding (x_1* x_2*) constant. Point *Q*, on the other hand, is technically efficient since it already lies on the efficient isoquant (note that *OQ*/*OQ* = 1).

If the input price ratio *AA*' is known (showing the different combinations of inputs that can be purchased with a given cost outlay), then allocative efficiency [referred to by Farrell as price efficiency] can be calculated. The ability of an organisation to use the inputs in optimal proportions, given the respective prices at point *P*, is the ratio *OR*/*OQ*, and correspondingly the allocative inefficiency is 1 - *OR*/*OQ*. The distance *RQ* is the reduction in production costs which would occur if production occurred at *Q*' – the allocatively and technically efficient point, rather than *Q* – the technically efficient, but allocatively inefficient point. Hence, total economic or productive efficiency [referred to by Farrell as overall efficiency] is the ratio *OR*/*OP*, and total inefficiency is therefore 1 - *OR*/*OP*. The cost reduction achievable is the distance *RP* which is obtained from moving from *P* (the observed point) to *Q*' (the cost minimising point).

Of course, these efficiency measures assume the production function of the fully efficient firm is known. As this is usually not the case, the efficient isoquant must be estimated using sample data. Farrell (1957) suggested the use of either: (i) a nonparametric piecewise-linear convex isoquant constructed such that no observed point should lie to the left or below it (known as the *mathematical programming* approach to the construction of frontiers); or (ii) a parametric function, such as the Cobb-Douglas form, fitted to the data, again such that no observed point should lie to the left or below it (known as the *econometric* approach). These approaches use different techniques to envelop the observed data, and therefore make different accommodations for random noise and for flexibility in the structure of the production technology.

First, the econometric approach specifies a production function and normally recognises that deviation away from this given technology (as measured by the error term) is composed of two parts, one representing randomness (or statistical noise) and the other inefficiency. The usual assumption with the two-component error structure is that the inefficiencies follow an asymmetric half-normal distribution and the random errors are normally distributed. The random error term is generally thought to encompass all events outside the control of the organisation, including both uncontrollable factors directly concerned with the 'actual' production function (such as differences in operating environments) and econometric errors (such as misspecification of the production function and measurement error). This type of reasoning has primarily led to the development of the 'stochastic frontier approach' (SFA) which seeks to take these external factors into account when estimating the efficiency of real-world organisations, and the earlier 'deterministic frontier approach' (DFA) which assumes that all deviations from the estimated frontier represent inefficiency. A number of studies have used these approaches to estimate the efficiency of educational institutions. These include Sengupta (1987), Barrow (1991), Deller and Rudnicki (1993), Cubbin and Zamani (1996) and Bates (1997).

Second, and in contrast to the econometric approaches which attempt to determine the *absolute* economic efficiency of organisations against some imposed benchmark, the mathematical programming approach seeks to evaluate the efficiency of an organisation *relative* to other organisations in the same industry. The most commonly employed version of this approach is a linear programming tool referred to as 'data envelopment analysis' (DEA). DEA essentially calculates the economic efficiency of a given organisation relative to the performance of other organisations producing the same good or service, rather than against an idealised standard of performance. A less-constrained alternative to DEA sometimes employed in the analysis of efficiency (though presently unapplied to education) is known as 'free-disposal hull' (FDH). Both DEA and FDH are nonstochastic methods in that they assume all deviations from the frontier are the result of inefficiency. Charnes, Cooper and Rhodes (1981), Sengupta and Sfeir (1988), Ganley and Cubbin (1992), Beasley (1995) and Haksever and Muragishi (1998) have applied these approaches to educational institutions. More detailed theoretical introductions to frontier efficiency measurement techniques may be found in Fried, Lovell and Schmidt (1993), Charnes, Cooper, Lewin and Seiford (1995) and Coelli, Rao and Battese (1998).

The discussion thus far has addressed three separate, though conceptually similar, theoretical approaches to the assessment of productive efficiency in education. These are the deterministic frontier approach, the stochastic frontier approach, and the mathematical programming approach. Whilst the selection of any particular approach is likely to be subject to both theoretical and empirical considerations, it may be useful to summarise the strengths and weaknesses of each technique. The emphasis here is not on selecting a superior theoretical approach, as it should be emphasised that the mathematical programming and econometric approaches address different questions, serve different purposes and have different informational requirements.

The first approach examined was the construct of the deterministic statistical frontier [see, for example, Barrow (1991) and Cubbin and Zamani (1996)]. Using statistical techniques a deterministic frontier is derived, such that all deviations from this frontier are assumed to be the result of inefficiency. That is, no allowance is made for noise or measurement error. In the primal (production) form, the ability to incorporate multiple outputs is difficult, whilst using the dual cost frontier, such extensions are possible. However, if the cost frontier approach is employed, it is not possible to decompose inefficiency into allocative or technical components, and therefore all deviations are attributed to overall cost inefficiency.

In terms of computational procedure, the deterministic frontier approach necessitates a large sample size for statistical reasons. In addition, it is generally regarded as a disadvantage that the distribution of the technical inefficiency has to be specified, ie. half-normal, normal, exponential, log-normal, etc. Ideally this would be based on knowledge of the economic forces that generate such inefficiency, though in practice this may not be feasible. If there are no strong *a priori* arguments for a particular distribution, a choice is normally made on the basis of analytical tractability. Similarly, the choice of a particular technology is imposed on the sample, and once again this may be a matter of empirical convenience (ie. Cobb-Douglas, translog, etc). Moreover, the choice of a particular production function may place severe restrictions on the types of analysis possible, and therefore the content of policy prescriptions, using this particular approach.

The second approach discussed, namely the stochastic frontier, removes some of the limitations of the deterministic frontier [see, for example, Deller and Rudnicki (1993), Cubbin and Zamani (1996) and Bates (1997)]. Its biggest advantage lies in the fact that it introduces a disturbance term representing noise, measurement error, and exogenous shocks beyond the control of the production unit. This in turn permits the decomposition of deviations from the efficient frontier into two components, inefficiency and noise. However, in common with the deterministic approach, an assumption regarding the distribution (usually normal) of this noise must be made along with those required for the inefficiency term and the production technology. The main effect here is that under both approaches, especially the stochastic frontier, considerable structure is imposed upon the data from stringent parametric form and distributional assumptions. In addition, stochastic frontier estimation uses information on prices and costs, in addition to quantities, which may introduce additional measurement errors.

The final programming approach differs from both statistical frontier approaches in that is fundamentally nonparametric, and from the stochastic frontier approach in that is nonstochastic [see, for example, McCarty and Yaisawarng (1993), Thanassoulis and Dunstan (1994), Chalos (1997) and Madden, Savage and Kemp (1997)]. Thus, no (direct) accommodation is made for the types of bias resulting from environmental heterogeneity, external shocks, measurement error and omitted variables. Consequently, the entire deviation from the frontier is assessed as being the result of inefficiency. This may lead to either an under or over-statement of the level of inefficiency, and as a nonstochastic technique there is no possible way in which probability statements of the shape and placement of this frontier can be made.

In view of erroneous or misleading data, some critics of DEA have questioned the validity and stability of measures of DEA efficiency. For instance, Smith and Mayston (1987) evaluated the sensitivity of DEA measures of local education authority efficiency to omissions of outputs, inputs and selected efficient authorities. Finding that “the exclusion of an important output will clearly distort the results of the analysis” Smith and Mayston (1987, p. 188) concluded *inter alia*:

> [T]he choice and relative importance of outputs is ultimately a political judgement, and no amount of mathematical analysis can reconcile the diversity of views concerning priorities in the public sector. The user of DEA has to recognise this limitation, and at the very least it would seem sensible to test the implications of a variety of output sets.

However, there a number of benefits implicit in the programming approach that makes it attractive on a theoretical level. Given its nonparametric basis, substantial freedom is given on the specification of inputs and outputs, the formulation of the production correspondence relating inputs to outputs, and so on. This is seen as especially useful in education production function where the usual axioms of production activity breakdown (ie. profit maximisation). The programming approach may then offer useful insights into the efficiency of these types of services [some assumptions regarding the production technology are still made regardless, such as that relating to convexity]. Similarly, it is entirely possible that the types of data necessary for the statistical approaches are neither available nor desirable, and therefore the imposition of as few as possible restrictions on the data is likely to be most attractive. Simulation studies [see, for instance, Banker, Charnes, Cooper and Maindiratta (1988)] have indicated that the piecewise linear production frontier formulated by DEA is generally more flexible in approximating the true production frontier than even the most flexible parametric function form.

An important aspect of DEA concerns the calculation and interpretation of ‘slack’ variables. One obvious benefit of DEA is that it provides a single index number indicating the proportional reduction of inputs (or augmentation of outputs) necessary (or desirable) for an institution to reach the efficient frontier. In a single-input, single-output case, a proportional reduction of inputs is always achievable, and therefore the value of the slack variables will always be zero. However, in multiple-input, multiple-output situations, positive input and output slacks are frequently necessary to reach the envelopment surface and achieve full efficiency. In other words, it may be desirable to further augment particular outputs or necessary to further reduce particular inputs (rather than all) even though an educational institution has already reached the frontier of the production set.

The interpretation of educational slacks has been undertaken by several studies. In an analysis of Houston elementary schools Bessent *et al*. (1982, p. 1362) reasoned that relocatable inputs (as suggested by input slacks) could be transferred from ‘high-achieving, near-efficient schools’ to ‘efficient, low-achieving schools’. These ‘relocatable inputs’ included more experienced and more highly qualified teachers. Alternatively Jesson, Mayston and Smith’s (1987) study of English local education authorities (LEAs) uses slacks as an aid to the interpretation of efficiency scores. In this case, the full scope of projected improvements for an inefficient LEA includes improvements in particular outputs over and above the proportional reduction of inputs. Jesson, Mayston and Smith (1987) also use slacks to evaluate the sensitivity of efficiency scores to environmental influences on educational outcomes, including the proportion of single-parent families and low socioeconomic families in the authority’s catchment area. A similar analysis of specific inputs and outputs as derived from input and output slacks is made in McCarty and Yaisawarng’s (1993) study of New Jersey school districts.

These theoretical and empirical considerations explain at least part of the dominance of DEA in education efficiency measurement studies. The obvious desirability of quantifying inputs and outputs in different units of measurement, even within a single study, is one consideration. For example, most educational studies define inputs as the number of teaching, support and administrative staff along with non-labour inputs in dollar or index terms. These may include administrative, operational and transportation expenditures per student (Smith and Mayston, 1987; Engert, 1996), indexes of physical facilities (Fare, Walters and Wood 1993) and the numbers of library holdings and personal computers (Ruggiero, 1996). Correspondingly, and at the other end of the production process, outputs can be variously defined as either the number of graduating students (Madden, Savage and Kemp, 1997), the percentage with a specified level of attainment (Bates, 1997), an index of their socioeconomic status (Engert, 1996) or the average graduate salary (Haksever and Muragishi, 1998). Likewise the difficulty in defining input costs in many public sector contexts may account for the emphasis of education efficiency studies on measuring technical efficiency alone, for which the DEA approach is especially appropriate [see, for example, Ray (1991), Johnes and Johnes (1995), Bates (1997) and Chalos (1997)]. Finally, and once again in a public sector context where the usual axioms of production activity breakdown, there is the ability to define inputs and outputs depending on the conceptualisation of education performance thought most appropriate.

Apart from the econometric frontier approaches, DEA also offers a number of advantages over the more traditional (non-frontier) regression-based analyses in educational performance measurement. For example, Mayston and Jesson (1988, p. 328) argue that regression analysis is limited by the lack of allowance for the trade-off between different educational outcomes and the fact that the regression line represents a statistical average, not what is theoretically achievable. Similarly, unit changes in expenditure are assumed to have a constant impact on educational outcomes and expenditure itself is assumed to be independent of changes in the level of other variables, such as environmental factors. Nevertheless, while Mayston and Jesson (1988, p. 333) found that both techniques provided broadly comparable results, there were "…sufficient differences between the two methods to suggest that the choice of the performance assessment technique can make significant differences to the extent of the signalled performance shortfall". Mayston and Jesson (1988) identified the sensitivity of frontier methods to outlying observations as one particular area where conflicts between the competing methods could arise.

Measuring Inefficiency in Education

Within the broad scope of education, frontier efficiency measurement techniques have been applied to many different types of institutions. As detailed in Table 1, these include primary and secondary schools (Bessent *et al*., 1982; Deller and Rudnicki, 1993; Chalos and

Cherian, 1995), universities (Athanassopoulos and Shale, 1997), university departments (Sinuany-Stern *et al*., 1994; Johnes and Johnes, 1993, 1995; Beasley, 1990, 1995; Madden *et al*., 1997) and training and enterprise councils (Cubbin and Zamani, 1996). And while the literature has been predominantly concerned with the efficiency of North American institutions, applications in the United Kingdom (Smith and Mayston, 1987; Jesson *et al*., 1987; Barrow, 1991; Bates, 1997), Australia (Madden *et al*., 1997), Taiwan (Kao and Yang, 1992) and Norway (Bonnesrøning and Rattsø, 1994) have also been made. As also indicated, the primary frontier technique employed in assaying the efficiency of education programs has been the data envelopment analysis or DEA approach (Charnes, Cooper and Rhodes, 1981; Diamond and Medewitz, 1990; Ray, 1991; McCarty and Yaisawarng, 1993; Thanassoulis and Dunstan, 1994; Chalos, 1997).

The study by Sengupta and Sfeir (1986) makes an interesting starting point for the survey of frontier efficiency measurement techniques in education. While a non-frontier cost function approach was employed, this study was one of the earlier attempts to investigate technical inefficiency in educational production, and the same data set was subsequently analysed using both the deterministic frontier approach and DEA. Using a sample of 25 Californian school districts, Sengupta and Sfeir (1986, p. 297) held the premise that "the total cost of a given quality of schooling is minimised by expanding the school size until the increase in average transportation cost is just offset by the decrease in average instructional cost". In other words, substantial scale economies were thought to exist in elementary education. Using a production function approach that focused on immediate student test scores as output, Sengupta and Sfeir (1986) found support for increasing returns to scale in schools. Sengupta (1987, p. 98) subsequently concluded that the frontier technique appeared to be more stable than non-frontier techniques, especially in light of variation in inputs.

Following Sengupta (1987), a number of other studies used econometric approaches to appraise technical efficiency in education. Barrow (1991) employed a deterministic frontier to estimate the cost inefficiency of local education authorities in England. The measures of output employed were student grades and the inputs of the authorities depended not only on the number and growth rate of the student population, but also on the overall socioeconomic background of the student body. Variables hypothesised to exert a positive influence on cost included the proportion of students from low socioeconomic backgrounds and those receiving free meals, and an index of additional educational needs. In each case, the *ex post* results supported the conjectured higher costs of educating pupils with these characteristics, with estimated cost inefficiencies ranging from 11 to 20 percent. In a stochastic production frontier approach, Deller and Rudnicki (1993) likewise examined the impact of nondiscretionary factors (or those factors beyond managerial control) on the educational production process. However, in this case they incorporated a measure of both family influence (proxied by family income and the proportion of parents with a university education) and peer influence (proxied by the unemployment rate). The results supported the incorporation of family and peer influences on educational attainment, and once these factors were quantified, the estimated technical inefficiencies fell in the range of 2.79 to 22.51 percent.

However, most of the studies of technical inefficiency in education have used DEA. Perhaps the best-known and earliest work in the area of measuring education production was conducted by Bessent *et al*. (1982). Employing the well-known Charnes, Cooper and Rhodes (1978) constant returns-to-scale DEA model, they examined the productive efficiency of Houston's 241 school districts. Bessent *et al*. (1982) was one of the first studies to point out some advantages of DEA over previously used techniques. These included the incorporation of multiple outputs, the fact that a parametric functional form does not have to be specified for the production function, and the ability to identify sources of inefficiency for individual schools. In addition, Bessent *et al*. (1982) enshrined the use of standardised test scores as the measure of educational attainment, incorporated issues relating to local, state and federal funding, and proxied the quality of teaching inputs with teaching experience, training and qualifications. Finally, Bessent *et al*. (1982, p. 1366) cogently listed the major problems found in educational efficiency studies:

> (1) obtaining data to specify adequate input measures, (2) obtaining data to specify outputs that were not limited to cognitive test results, and (3) difficulties in communicating the results of a complex quantitative process to those affected by the results.

Several other DEA studies of primary and secondary schools have followed. Smith and Mayston (1987) used DEA to assess the performance of U.K. local education authorities. Sengupta (1987) and later Sengupta and Sfeir (1988) used identical Californian data to the earlier Sengupta and Sfeir (1986) production function analysis, to compare DEA and the deterministic frontier approaches. Sengupta (1987, p. 98) concluded that although the two approaches differ in many respects, "in the case of suitable stochastic data variations they may yield identical efficiency rankings of different DMUs". Cubbin and Zamani (1996) also compared the efficiency measures obtained from DEA and the deterministic frontier approach, adding a stochastic frontier as well. However, in contrast to a later study by Bates (1997), they concluded that while a high correlation (0.89) existed between the deterministic and stochastic frontier measures of efficiency, the correlations between these and the DEA approach were much lower (0.44 and 0.28 respectively).

A large number of DEA studies have followed. Fare, Grosskopf and Weber (1989) used DEA to assess the performance of school districts in Missouri. They not only allowed for variable returns-to-scale by employing the Banker, Charnes and Cooper (1984) formulation, but also used 'jack-knifing' techniques to reduce the impact of outliers on efficiency measures. Similar methodologies were employed by Ray (1991) in a study of Connecticut high schools, Ganley and Cubbin (1992), Thanassoulis and Dunstan (1994), and Bates (1997) using U.K. local education authorities, and Ruggiero (1996), Engert (1996), Duncombe, Miner and Ruggiero (1997), Chalos and Cherian (1995), and Chalos (1997) in studies of New York and Illinois school districts. Mean efficiencies in these studies range from 78.4 percent in Duncombe, Miner and Ruggiero (1997), 89.5 percent in Chalos and Chekrian (1995), 75.7 to 89.3 percent in Engert (1996), and up to 90.8 percent in Chalos (1997). Though these studies vary enormously in their chosen contexts and overall results, there is broad agreement regarding their conceptualization of the educational process itself: that is, the process by which the education process transforms selected inputs into desired outputs.

To start with, the discretionary inputs specified in the education production function (or those factors that are amenable to managerial control) usually include the number of teaching staff and are sometimes also accompanied by the number of support and administrative staff. Ray (1991) for example, specified the number of classroom teachers, support and administrative staff as inputs into the high school education process. In the context of university education, Johnes and Johnes (1993, 1995) also made a distinction between different types of labor, though they split total staff into teaching/research and research staff alone. These are obvious attempts to capture the differing functions of labor in the educational process. However, even within categories of labor, most empirical studies have attempted to incorporate differences in the quality of inputs that may occur across the sample, omission of which would result in misspecification. For instance, Bessent *et al*. (1982) included the number of professional staff, along with measures intended to proxy qualitative differences across schools including the percentage of teachers with masters qualifications and those with three years or more teaching experience. McCarty and Yaisawarng (1993) and Chalos (1997) also incorporated the purported quality of teaching inputs with the percentage of staff with higher degrees.

In addition to direct teaching inputs, several studies have attempted to incorporate non-labor inputs, often with the dollar value of non-teaching expenditure. For example, Smith and

Mayston (1987) divided total expenditure into a teaching and non-teaching component, while Deller and Rudnicki (1993) used categories of instructional, administrative, operational and busing expenditure. While the division of expenditures into finer categories is likely to illuminate particular aspects of educational efficiency that deserve attention, it is important to remember that the inclusion of dollar costs by itself does not encompass the measurement of allocative efficiency, since relative input prices should also be included. In fact, empirical studies in education have generally ignored the notion of allocative efficiency, relying instead upon technical efficiency as a mean of comparing educational institutions. Reasons for this are not hard to find, and often are associated with difficulties in specifying input prices. However, the measurement of allocative efficiency has been investigated in other public sector contexts, notably the local government and health care, and suitable proxies for most input prices are available. For example, Sengupta and Sfeir (1988) used average teaching salaries for the price of labor and Barrow (1991) specified a re-pricing index for educational expenditure.

There is generally greater agreement among educational efficiency studies regarding the specification of outputs. Starting with Charnes, Cooper and Rhodes (1981) and Bessent *et al*. (1982) the preferred specification of educational outcomes in most of the empirical literature has been student test scores. In turn, these test scores have usually placed an emphasis on basic skills. Senupta (1987), for example, used average test scores in reading, mathematics, writing and spelling, McCarty and Yaisawarng (1993) specified passing students in mathematics, reading and writing proficiency, and Chalos and Cherian (1995) and Chalos (1997) employed verbal and math test scores. Exceptions include a study by Ruggiero (1996) of New York State schools that also specified social studies test scores, and Ray (1991) who added language and arts performance in an analysis of Connecticut high schools. However, the specification of output also varies enormously according to the chosen educational context. For instance, Diamond and Medewitz (1990) evaluated an economic education program using the 'Test for Economic Literacy', while most U.K. studies have concentrated upon the percentage of school leavers attaining 'A' levels and graded 'O' levels [see, for example, Smith and Mayston (1987), Ganley and Cubbin (1992) and Bates (1997)].

Of course, all of these outputs concentrate on intermediate educational outcomes, though there is an increasing tendency to specify longer-term educational benefits in more recent work. For example, Fare *et al*. (1993) followed up their study with post-secondary grades, incomes and education, Engert (1996) included post-secondary college entrance, and Haksevevr and Muragishi (1998) viewed starting salaries and the employment of graduating students as the most appropriate output for MBA programs. The Fare, Walters and Wood (1993) study of the 'High School and Beyond' program is particularly interesting in that it simultaneously assessed the performance of schools in generating educational opportunities, as well as intermediate and long-term educational achievement. Educational outcomes were proxied in the short-term by the number of classes taken and extracurricular activity, by follow-up test scores in the intermediate term, and by post-secondary income and educational attainment in the long-term. Fare *et al*. (1993) concluded that schools performed better with these intermediate and long-term outcomes, than with short-term objectives. Engbert (1996) also used a temporal 'value-added' approach to educational output by including basic competency, diploma attainment and college entrance in a study of New York schools. Likewise, Cubbin and Zamani (1996) estimated the longer-term outcomes of U.K. training and enterprise councils by employing vocational qualifications and the median duration of unemployment. Cubbin and Zamani (1996) calculated mean cost efficiencies of 89 percent using DEA, 84 percent from a deterministic frontier and 71 percent from a stochastic frontier.

Another set of frontier efficiency measurement studies that deserves particular attention is the instances where educational outputs are jointly produced with (strictly) non-educational outcomes. This is the case with the small number of studies concerned with either universities or academic departments within universities. Johnes and Johnes' (1993; 1995) studies of U.K. university economics departments and Beasley's (1995) study of U.K. physics and chemistry departments are good examples of this line of inquiry. In all three cases, teaching/research and research only staff and research grants are the inputs, and outputs were measured in categories of published works and refereed journal articles.

The Johnes and Johnes' (1993; 1995) approach does differ somewhat in that no allowance is given for actual teaching outputs, while the Beasley (1995) study incorporates the number of undergraduates and postgraduates. While the DEA approach used in these studies places no particular weighting on outputs (that is, the 'managerial' choice between teaching and/or research performance) the general finding of these studies is that university departments with higher teaching loads have lower research outcomes. A study by Madden *et al*. (1997) also examined the efficiency of university economics departments (though in Australia), but no attempt was made to distinguish between teaching/research and research only staff. This study concluded that 'new' universities (previously Colleges of Advanced Education) were less efficient than older, established universities in the provision of teaching and research outputs. A mean departmental efficiency of 82 percent was found in this particular analysis.

Determinants of Educational Efficiency

The principal analytical focus in the mainstream efficiency literature has been the influence of structural, institutional and legislative factors on efficiency measures. For example, the financial institution efficiency literature has concentrated on issues of competition and deregulation, while the health services literature has emphasised ownership and control structures. However, work on the determinants of educational efficiency has largely focused on disentangling the effects of a single uncontrollable input (namely students' socioeconomic status or similar) from efficiency scores. Whereas ineffective use of inputs, such as labour and capital, may be characterised properly as technical inefficiency, inputs beyond institutional control, such as students' talent and socioeconomic status, may create the appearance of technical inefficiency. Given that student background is universally regarded as an important determinant of educational achievement [see, for instance, Hanushek (1986)], appropriate treatment is of special concern.

Two different approaches for dealing with variance in the 'quality' of student inputs have been employed. The first approach has been to use a 'two-stage' estimation procedure. In the first stage, a frontier model in which only factors under an educational institution's control are included as inputs in computing efficiency scores. Typically, these include the labor, capital and equipment inputs discussed earlier. In the second stage, the efficiency scores obtained are regressed on factors beyond management's control. The difference between the computed efficiency score from the first stage and its predicted value from the second stage (or the residual) is used as an index for measuring the 'pure technical efficiency', which could be attributable to management. The term 'pure technical efficiency' is used here in the sense of efficiency from which the effects of uncontrollable input factors have been eliminated. Examples of this kind of work include Ray (1991), Fare, Walters and Wood (1993) and Duncombe, Miner and Ruggiero (1997).

The second, and much more common, approach takes uncontrollable factors directly into account when computing efficiency scores. All factors that might affect output, whether or not they are controllable by management, are included in the model. A number of computational extensions to DEA allow efficiency to be the determined only with respect to the subvector composed of discretionary inputs. Thus, the influence of nondiscretionary factors is recognised as an influence on efficiency, though not taken into account when calculating possible efficiency improvements [see Charnes *et al*. (1993) for further discussion]. Charnes, Cooper and Rhodes (1981), Smith and Mayston (1987), Deller and Rudnicki (1993), Thanassoulis and Dunstan (1994), Ruggiero (1996), and Chalos (1997) have employed this approach.

Within both approaches, a number of variables have been employed to quantify uncontrollable educational inputs. Some studies, such as Sengupta and Sfeir (1988) and McCarty and Yaisawarng (1993), have used an index of parental socioeconomic background. Where this is not available, a number of proxies have been used, all of which are presumed to exhibit a high correlation with students' socioeconomic status. Oft included measures include: (i) the proportion of minority and/or non-English speaking students (Sengupta and Sfeir, 1986; Ray, 1991; Fare, Walters and Wood, 1993; Chalos and Cherian, 1995), (ii) the number of students receiving free school meals (Barrow, 1991; Thanassoulis and Dunstan, 1994) and (iii) the proportion of students from single-parent households (Smith and Mayston, 1987; Bates, 1997).

Still others have attempted to recognise the role of both family influences and peer influences on educational outcomes. For example, Ruggiero (1996) included the proportion of parents with a university education, and Deller and Rudnicki (1993) added the unemployment rate. Justifying this approach, Ruggiero (1996, p. 563) argued that the percentage of adults graduating from university, as a proxy of parental education, has been consistently found to influence student performance, and "the only variable that can be used to represent all exogenous community characteristics that influence educational production". Similarly, Charnes, Cooper and Rhodes (1981) constructed an index of parental interaction that incorporated school visits and counselling sessions. In general, the results support the contention that "variation in socioeconomic backgrounds will have a large impact" on educational outcomes, and thereby measured efficiency (Bates 1997, p. 92).

Despite the interest in the impact of uncontrollable inputs on observed educational efficiency, only one study has compared the results obtained from the two alternative approaches. Using a sample of 27 poor, urban New Jersey school districts, McCarty and Yaisawarng (1993) explored both ways of incorporating students' socioeconomic status into a DEA model. The first model used the two-stage approach in which tobit analysis was employed to eliminate the effects of socioeconomic status on a particular district's efficiency scores. The second model incorporated both controllable and uncontrollable inputs in the DEA computation of efficiency scores. McCarty and Yaisawarng (1993, p. 285) found that the two models produced "similar results in the sense that the rankings of their efficiency scores are positively and significantly correlated". McCarty and Yaisawarng (1993, p. 286) also observed that the two-stage approach could be problematic when there is strong correlation between the first-stage inputs and the second-stage independent variables:

> If these variables were strongly correlated, then the claim that the two stages incorporate fundamentally different types of inputs, controllable and uncontrollable, becomes untenable. In this case, the DEA scores computed in the first stage are likely to be biased in the sense that they would actually reflect the effects of both categories of inputs.

Apart from the several studies that have attempted to reflect uncontrollable student inputs, a much smaller number of efficiency analyses have sought to associate variation in efficiency with institutional factors. Duncombe, Miner and Ruggiero (1997), for example, formulated a model of bureaucratic inefficiency in New York State school districts. They hypothesised that inefficiency in education would depend on four factors: competition, government size, external factors and internal characteristics. First, the existence of a city (non-referendum) school district was posited to be negatively associated with a higher efficiency score. It was argued that lack of control on the behaviour of self-maximising government officials would imply higher levels of inefficiency. Second, the size of a school district's bureaucracy was also believed to exert a negative influence on educational efficiency. In support of this, they conceptualised a Niskanen-type, budget-maximizing, principal-agent relationship.

Third, factors reflecting monitoring costs and the ability and interest of citizens/voters to put pressure on school boards to monitor school performance may also affect efficiency. They proposed that incentives for such involvement may be lower for wealthier districts or those whose composition of taxable property permitted greater tax exporting because easier financial constraints diminished political pressure for efficiency. Finally, administrative pressures regarding inputs and provision of labour contracts was also thought to influence cost efficiency. For example, Oliver Williamson's framework suggests that budget maximization by public managers most often takes the form of expansion of staff, since these are the resources they most directly control (Duncombe, Miner and Ruggiero, 1997). Duncombe, Miner and Ruggiero (1997, p. 15) concluded:

> Efficiency is negatively related to school district size, percent tenured teachers, district wealth, non-residential property values and labour intensity, and positively related to the percent of adults who are college educated. Contrary to expectations, efficiency is found to be negatively associated with the relative number of private school students and percent of households with school-age children.

Some of these issues were also developed in Fare's *et al*. (1993) study of efficiency in U.S. high schools. They posited that significant efficiency differences may exist between private, Catholic and rural schools, and whether the school was in a separate tax district or in an area with a heavily unionised workforce. However, as a general rule efforts to explain variation in educational efficiency (beyond student characteristics) are generally underdeveloped when compared to the wider efficiency measurement literature, with most studies to date content to merely compare efficiencies in different groups within the sample.

Conclusions

The measurement of efficiency in educational settings has been difficult. Hanushek (1986, p. 1142) acknowledges this difficulty, noting that efficiency is “a concept which has a very clear meaning in textbook analyses of the theory of the firm but that becomes quite cloudy in the world of public schools”. Engert (1996, p. 250) persuasively summarizes the three main characteristics of the educational process that complicate the evaluation of efficiency. Firstly, educational organisations have multiple objectives and multiple outputs or outcomes. Moreover, there are often conflicting opinions regarding the goals, and the relative importance of these goals, by the stakeholders of education. For example, emphasis could be placed on short-term cognitive results, intermediate ‘follow-up’ tests, or long-term employment outcomes and prospects in higher education.

Secondly, many of the outputs of an educational organisation cannot be unambiguously measured or quantified. For example, many educational outputs are non-separable such that improvements in skills in one area may lead to improved skills in another, and/or be associated with an enhancement of self-esteem (Engert 1996, p. 250). Still other educational outcomes, such as socialisation, appear to defy parameterisation (McCarty and Yaisawarng, 1993, p. 275). Finally, and much more fundamentally, our limited knowledge of the true correspondence relating inputs to outputs in the educational production process is a major problem (Hanushek, 1986). While numerous studies have dealt with the educational production function, for a variety of reasons, not least behavioural complexities, the true relationship may never be known.

While there is merit in the suggestion that these problems complicate the analysis of educational efficiency, it is unlikely that education forms a sufficiently different case to isolate it from the substantial advances made in equally complex empirical contexts such as financial, health and general public sector services. The last two areas in particular are likely to have much in common with education in a number of respects. For example, in healthcare services the problem of correctly defining output in terms of intermediate (number of patient days, surgeries and visits, etc.) and final outcomes (longer life expectancy and lower mortality) has been investigated. Likewise, public sector applications of frontier efficiency measurement techniques have much in common with education regarding ill-defined input prices, non-competitive markets and imposed environmental conditions. Valuable lessons in frontier efficiency measurement techniques can thus be learned from outwardly different contexts.

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Table 1. Frontier efficiency applications in education

Author(s)	Methodology[a]	Sample[b]	Inputs, outputs, explanatory variables (if applicable)[c]	Analytical technique	Main findings
Charnes, Cooper and Rhodes (1981)	DEA	49 U.S. 'Program Follow Throughs', 1967-77	Percentage of mothers who are high school graduates, highest occupation of a family member on a rating scale, parental school visit index, parent-counselling index, number of teachers at site. Reading and mathematics test scores, 'Coopersmith Self-Esteem Inventory' scores.	Descriptive analysis.	Application of DEA to a variety of public programs where profit and cost are not directly applicable.
Bessent, Bessent, Kennington and Reagan (1982)	DEA	167 Houston elementary schools, 1978.	Previous years test scores, percentage nonminority, students paying full lunch price, and attendance, number of professional staff per 100 pupils, local, state and federal expenditures per pupil, number of special programs operated, percent of teachers with masters and more than three years experience, and number of full-time equivalent teaching days. Aggregated basic skills test and sub-tests.	Descriptive analysis, tables of input/output slacks, diagrammatic analysis.	Major problems in DEA include obtaining data on inputs and outputs, and communicating the results.
Smith and Mayston (1987)	DEA	96 U.K. local education authorities, 1982/83.	Teaching and non-teaching expenditure, percentage of pupils from a high socioeconomic group, and not living in poor housing or single-parent families. Percentage of maintained school leavers attaining 'A' levels and passed and graded 'O' levels.	Descriptive analysis and sensitivity to input-output formulation.	Sensitivity of DEA to exclusion of important outputs, possible use of cluster analysis to identify separate analyses.
Sengupta (1987)	DEA and DFA	25 Californian school districts, 1976/77.	Average instructional expenditure, proportion of minority students, average class size, index of assessed school quality. Average tests scores in reading, mathematics, writing and spelling.	Descriptive analysis.	Production frontier techniques appear more stable in respect of input data variations.
Mayston and Jesson (1988)	DEA	96 U.K. local education authorities, 1982/83.	Education expenditure. Percentage of maintained school leavers attaining passed and graded 'O' levels. Percentage of pupils whose household head is in a high socioeconomic group, single parent and unemployed.	Descriptive analysis and correlation between OLS residuals and DEA measures.	Correlation between DEA measures and residuals from regression analysis.
Sengupta and Sfeir (1988)	DEA	25 Californian school districts, 1976/77.	Average teacher salaries, proportion of Anglo-American students, average class size, index of parental socioeconomic background. Achievement scores.	Descriptive analysis of sample disaggregated by quartiles.	DEA robust in situations where input-output combinations concentrated around mean and with non-normal error distributions.
Diamond and Medewitz (1990)	DEA	46 U.S. Developmental, Economic Education Program classes, 1988.	Sum of verbal and math SAT scores, percentage of college graduates amongst student mothers, percentage white, male, previous course in economics, urban area, private/public school, teacher's undergraduate/graduate hours in economics, total annual instruction expenditure per student, DEEP vs. non-DEEP class. Class average test results for Test of Economic Literacy (TEL).	Descriptive analysis across participating and non-participating classes.	Inconclusive evidence supporting instructional program.

Author(s)	Methodology[a]	Sample[b]	Inputs, outputs, explanatory variables (if applicable)[c]	Analytical technique	Main findings
Barrow (1991)	DFA	57 U.K. local education authorities, 1980-1985.	Gross cost per student, number of pupils, number of students receiving free meals, proportion of students from low socio-economic background, index of additional educational needs, growth rate in student numbers, metropolitan vs. non-metropolitan school, re-pricing index for educational expenditure. Student grades.	Descriptive analysis and interpretation of parameter estimates.	Inconclusive evidence supporting the use of panel over cross-sectional data.
Ray (1991)	DEA	122 Connecticut high schools, 1980/81.	Classroom teachers, support staff and administrative staff per pupil. Mathematics, language, arts, writing, and reading score per pupil. Percentage of population with college education, per capita income, median value of owner-occupied housing, percentage of minority students, those receiving welfare, families below poverty line, single parent families.	Second-stage least squares regression. Descriptive analysis.	Efficiency in utilisation of school inputs varies systematically with socioeconomic characteristics.
Ganley and Cubbin (1992)	DEA	96 U.K. local education authorities, 1980-83.	Teaching expenditure per pupil, percentage of pupils living in household with non-manual working head, high occupation density, non-English speaking background, population density. Percentage of school leavers achieving set 'O' level passes.	Descriptive analysis.	Use of DEA in assessing targets and peer groups.
Deller and Rudnicki (1993)	SFA	139 Maine schools, 1988/89.	Family influence (percentage of parents with college education and per capita family income), peer influence (unemployment rate), per pupil instructional, administrative, operational and busing expenditure. Cumulative average test score.	Anova, Wilcoxon, van der Waerden and Savage tests across school administration type and size.	Non-discretionary inputs an important determinant of efficiency outcomes.
Fare, Walters and Wood (1993)	DEA	1032 U.S. high schools, 1979/80.	(i) Total staff, number of library volumes, physical facilities index; (ii) and (iii) average number of maths, science, vocational education and foreign language classes taken, extracurricular activity index, hours of instruction received, average homework time. (i) Average number of maths, science, vocational education and foreign language classes taken and extracurricular activity index times enrolment, school course offering index, total hours of instruction received per student time enrolment (ii) standardised follow-up test score, ratio of follow-up tests score to base-year test score, average GPA, teachers assessment of percentage of pupils likely to attend college (iii) average post-secondary grades, average post-secondary income, average highest educational level attained. Dummy variables for private, Catholic and rural schools, dummy variables if school has separate tax district or unionised workforce, proportion of pupils from black households or with non-high school graduate fathers, percentage of students in remedial education.	Descriptive analysis and second-stage OLS regression.	Schools perform better at intermediate and long-term objectives, (ii) and (iii), than short-term objectives (i). Small proportion of variation explained by second-stage regression.
Johnes and Johnes (1993)	DEA	36 U.K. university economics departments, 1984-88.	Teaching/research and research only staff, per capital research grants and undergraduate student load. Papers and letters in academic journals, articles in professional and popular journals, authored and edited books, published works, edited works.	Descriptive analysis, comparison of efficiency indices across alternative specifications.	Small degree of sensitivity of DEA to changes in input-output specification.

Author(s)	Methodology[a]	Sample[b]	Inputs, outputs, explanatory variables (if applicable)[c]	Analytical technique	Main findings
McCarty and Yaisawarng (1993)	DEA	27 New Jersey school districts, 1984/85.	Number of staff per pupil, proportion of staff with masters or doctorate, expenditure per pupil excluding staff salaries. Percentage of passing students in mathematics, reading and writing proficiency tests. Index of student socioeconomic status.	Descriptive analysis, interpretation of slacks.	Role of uncontrollable factors in efficiency analysis. Use of two-stage process to eliminate bias.
Bonesrønning and Rattsø (1994)	DEA	34 Norwegian high schools, sample date unknown.	Teacher years. Number of graduates and measure of value-added (difference between high school and junior school test scores). Low and high achieving students.	Descriptive analysis.	Variation in efficiency unrelated to differences in resource use. Systematic differences in handling of low and high achievers.
Thanassoulis and Dunstan (1994)	DEA	42 U.K. local education authorities, 1988-91.	Mean verbal reasoning score per pupil on entry, percentage not receiving free school meals. Average GCSE score per pupil, percentage of pupils not unemployed after GCSE.	Descriptive analysis.	Estimation of targets to improve best-practice performance.
Beasley (1995)	DEA	32 U.K. chemistry and physics university departments, 1992.	General and equipment expenditure, research income. Number of undergraduates, taught and research postgraduates, quantity of research output (proxied by research income), index of departmental research quality.	Descriptive analysis.	Wide applicability of DEA to educational assessment.
Chalos and Cherian (1995)	DEA	207 Illinois school districts, 1989.	Operating expenditure per pupil, pupil attendance rate, percentage of teachers with masters degree, teacher to pupil ratio, years teaching experience, ratio of instructional to operational expenditure, non-controllable inputs of non-low income, non-minority and non-ESL families. Math and verbal scores.	Descriptive analysis.	DEA as a useful tool in educational process assessment.
Johnes and Johnes (1995)	DEA	36 U.K. university economics departments, 1989.	Teaching/research and research only staff, per capital research grants and undergraduate student load. Papers and letters in academic journals, articles in professional and popular journals, authored and edited books, published works, edited works.	Descriptive analysis, comparison of efficiency indices across alternative specifications .	Allowances should be made for differences in the inter-departmental allocation of variable inputs.
Cubbin and Zamani (1996)	DEA, DFA and SFA	75 U.K. training and enterprise councils, 1993/94.	Total costs. Number of leavers and output points. Average unemployment rate, median duration of unemployment, percentage of national vocational qualifications, children with special needs, youth credits, age of TEC, regional dummies for London, social and industrial infrastructure, labour market conditions.	Descriptive analysis across disaggregated classes, correlation coefficients across efficiency measures.	Adjusting for non-controllable factor changes inferences about the level and ranking of efficiency. Approaches analysed give comparable results.
Engert (1996)	DEA	214 New York State school districts, 1989/90.	Administration, instructional, operational, transportation and other expenses. Basic competency, diploma attainment, college entrance. Index of socio-economic status.	Comparison of DEA estimates with financial ratios, descriptive analysis.	Efficiency indices as a valuable supplement to ratio analysis.

Author(s)	Methodology[a]	Sample[b]	Inputs, outputs, explanatory variables (if applicable)[c]	Analytical technique	Main findings
Ruggiero (1996)	DEA	556 New York State school districts, 1990/91.	Teacher salary expenditures, personnel instructional expenditures, all other instructional expenditures, books and microcomputers. Proportion of adults with college education as environmental input. Reading, math and social studies test score, dropout rate.	Descriptive analysis.	Use of nondiscretionary inputs in measuring technical efficiency in education.
Athanass-opoulos and Shale (1997)	DEA	45 U.K. universities, 1992/93.	General academic expenditure, research income, number of FTE undergraduates, postgraduates and academic staff, mean A-level entry score over previous three years, expenditure on library and computing services. Number of successful leavers and higher degrees awarded, weighted research rating. Science, balanced and non-science orientation.	Descriptive analysis.	Use of DEA to complement traditional performance measures. Inefficient universities over-resourced in research.
Bates (1997)	DEA and SFA	96 U.K. local education authorities, 1984.	Teaching and non-teaching expenditure per pupil, proportion of high socio-economic, unemployed, and two-parent households. Percentage of 'A' and 'O' levels.	Correlation between DEA and frontier efficiency and socio-economic background, descriptive analysis.	Measurements of efficiency vary across methods employed. High correlation between relative efficiency measures.
Chalos (1997)	DEA	207 Illinois school districts, 1989/90.	Operating budget expenditure per pupil, ratios of administrative to instructional expenditure and local to total revenue, percentage of pupils from non-minority and non-low income households, attendance rate, percentage of teachers with masters degree, total student enrolment. Verbal and math test scores.	Descriptive analysis.	Budgetary goals in education cannot be determined endogenously, use of DEA to allocate discretionary funds.
Duncombe, Miner, and Ruggiero (1997)	DEA	585 New York State school districts, 1990/91.	Operating expenditures per pupil. Average test scores in reading, math and social studies, drop-out rate. Environmental and teacher salary index, total enrolment, percentage of households with school-aged children, children in poverty, adults with college education, single parent, children at risk, limited English proficiency.	Second stage tobit regression, descriptive analysis.	Failure of standard DEA models to treat non-discretionary environmental factors adequately.
Madden, Savage and Kemp (1997)	DEA	24 Australian university economics departments, 1987/1991.	Number of staff. Amount of research output (core journals, other journals, books, edited books), number of undergraduate and postgraduate students. New and established economics departments.	Descriptive analysis.	Improvements in efficiency following higher education reforms. New departments less efficient than established departments.
Haksever and Muragishi (1998)	DEA	40 U.S. MBA programmes, 1990/91.	Average GMAT, age and GPA of entering students, acceptance rate, total tuition cost per student, staff publication index, percentage of students with work experience, percentage of staff with doctoral qualifications. Average starting salary of graduates, percentage of graduating students with employment, quality score of programme.	Descriptive analysis.	Focus on MBA programme as value-added process. No significant differences in efficiency when MBA programmes are ranked.

Notes: (a) DEA – Data Envelopment analysis, SFA–Stochastic Frontier Approach, DFA–Deterministic Frontier Approach; (b) Singular dates represent calendar or financial year cross-sections, intervals represent time-series; (c) Ranked in order by paragraph.