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Researching the Links between School Resources and Student Outcomes in the UK: A Review of Issues and Evidence

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ABSTRACT *Knowledge of the effect of school resources on student outcomes is important for policy decisions concerning expenditure on schools. However, empirical research has so far produced equivocal findings. This paper examines the methodological and data requirements for good quality estimation of the education production function and reviews four UK studies that use pupil-level longitudinal data with a range of resource and control variables. These have produced some evidence of small resource effects on student outcomes and indicate the importance of model specification in affecting reported findings. If research in this area is to progress, high quality datasets are essential.*

Introduction

The UK government is strongly committed to improving educational attainment (Department for Education and Employment, 1997, 2001b), and one of its three central objectives for education relates to schools. This is 'to ensure that all young people reach 16 with the skills, attitudes and personal qualities that will give them a secure foundation for life long learning, work and citizenship in a rapidly changing world' (HM Treasury, 2000). To support this policy, revenue funding per pupil is planned to rise from an average of £2710 in 1997/98 to £3470[1] by 2003/04 (Department for Education and Employment, 2001a, p. 35). As well as increasing overall expenditure on schools, the government is committed to ensuring more effective use of existing resources, and is promoting evidence-informed policy and practice in education (Sebba, 2000; Secretary of State for Education, 2000).

To achieve these policy goals, there is a need for more robust research evidence on the relationship between school resourcing and student attainment. Indeed, despite the strong belief among parents and educational professionals that expenditure is causally and positively related to student outcomes, the research evidence for this is

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equivocal (Hanushek, 1986, 1997; Burtless, 1996; Laine *et al.*, 1996). This clearly requires further investigation and, in the UK at least, there has been a renewed interest in education production function research. The present paper is based on a more detailed survey of the literature (Vignoles *et al.*, 2000) that was commissioned by the Department for Education and Skills (DfES)-sponsored Centre for the Economics of Education, and is part of the drive to extend research in this field. The paper reviews the main theoretical and methodological issues relating to education production function research, as a prelude to reviewing UK research in this area. Although we focus on education production function research specifically, we attempt to put this particular strand of the literature in some sort of context, particularly in relation to other associated research areas, such as 'school effectiveness'. The paper is intended for both an economics and education audience, and attempts to use terminology that is understandable to those working in both fields.

We focus specifically on education production research for a number of reasons. First, if robust evidence on school production function relationships were more widely available, decisions concerning the adequacy, efficiency and equity of school resource allocations would be much more soundly based. For instance, the DfES intends to set further national targets for student levels of achievement at Key Stages 2, 3 and 4 (Department for Education and Employment, 2001b). Yet, at present, the government has to decide how much extra to spend to achieve these targets, without the benefit of any research evidence as to the level of additional expenditure that is likely to be required. In general, to improve the efficient allocation of resources both 'between' and 'within' schools, we need to know with greater precision the extent of efficiency differences between schools, and to learn from the practices of more efficient schools. As the Audit Commission and OFSTED (2000) noted, school managers making internal resource allocation decisions currently have to rely on their professional judgement with almost no evidence-base on the relative efficiency of alternative input mixes.

A second reason to focus on this literature relates specifically to equity concerns. The horizontal and vertical equity of the allocation of resources, both to schools and to individual students within schools, are much debated and rouse considerable passions. Yet there is no research evidence from the UK on, for example, the effects of additional average per-pupil expenditure as compared with extra expenditure targeted at students with special educational needs (SEN). Certainly Crowther *et al.*'s (1998) study *Costs and Outcomes for Pupils with Moderate Learning Difficulties* emphasized the absence of evidence on the effects of additional resources for SEN on student attainment, and recommended that a database be created to support such research. Equally, while the perceived differences in per-pupil funding between similar schools in different local education authorities (LEAs) (i.e., horizontal inequity) has been strongly criticized, particularly by headteacher associations (for example, West, 1994; Downes, 2000; West & Pennell, 2000), we do not know whether such differences in funding contribute to differences in student performance. Although the government does not appear to favour a national school funding formula to remove any horizontal inequity, one option being considered is for central government to set a basic per-pupil expenditure entitlement for LEAs to adopt, and to publicize this in comparison with LEAs' actual funding (Department of Environment, Transport and the Regions 2000; Department for Education and Employment, 2001b). Yet without evidence on school production functions, we do not know what level of spending is related to particular levels of student achievement.

Finally, the education production function literature can provide evidence on more fundamental questions about our school system. In particular, the literature is relevant to the ongoing debate about private provision within the state-funded education system and the effectiveness of recent changes to the UK secondary school system, such as greater parental choice, reduced local education authority power over schools and the improved accountability of schools. Although we do not review the growing literature on market-oriented reform in education and the creation of so-called quasi-markets (Glennester, 1991; Johnes, 1993, chapter 6; Adnett & Davies, 1999), education production function research is pertinent to many of the arguments put forward in favour of quasi-markets. Specifically, it is argued that schools are likely to be inefficient because they often have monopoly power in a particular geographical area and have insufficient market incentives to act in the interests of pupils. Education production function research has been used to support this view because the lack of evidence of a strong relationship between resource levels and pupils' academic success might suggest that schools use their resources inefficiently.

The present paper therefore seeks to evaluate existing school production function research, with the ultimate aim of encouraging further research in this field. It is divided into three sections. First, there is a discussion of how the concept of an education production function relates to the school effectiveness framework used by many educationalists. The following section presents a consideration of key econometric issues in estimating education production functions, and then there is a review of the UK literature.

Education Production Functions and the School Effectiveness Framework

Starting from a common root in the Coleman Report (Coleman *et al.*, 1966), two somewhat separate research traditions, both using statistical estimation, developed: school effectiveness, and education production function studies. School effectiveness research, largely conducted by educationalists, has been concerned with measuring the effect of different schools on student attainment, specifically searching for school process factors associated with differential effectiveness. An example of a school process would be the headteacher's leadership style or the extent to which there is order/discipline within the classroom.[2] Apart from class size, however, this body of research has largely neglected school resources as explanatory factors for student attainment.

By contrast, education production function research has largely focused on testing the hypothesis of a causal relationship between school resources and student outcomes. In this approach, factors other than resource inputs that are associated with student attainment are often described merely as confounding variables, although as in the school effectiveness research individual student characteristics are acknowledged to be critically important. Education production function research has largely used multivariate regression techniques or data envelopment analysis to analyse the effects of resource inputs and to investigate school efficiency. Apart from some studies that have included variables that attempt to measure teacher quality, production function research has paid little attention to internal school processes, typically treating the school as a black box. This suggests one avenue for future research. If the education production function literature is to avoid omitting variables that school effectiveness research indicates are important, such as the use of different teaching techniques, it must start to take account of school contexts and processes.

Indeed, the 'context–input–process–outcome model' of school effectiveness[3] is now well established as the general framework for school effectiveness research (Teddlie & Reynolds, 1999). It is summarized in Figure 1, which singles out the main groups of variables. The dependent or response variable is a measure of one or more student outcomes at the individual level. It is hypothesized that these outcomes are determined by the interaction of school context, student inputs (in particular prior attainment or ability and home background) and resource inputs. The latter include both expenditure and real resource variables, such as class size. In this framework, the postulated causal links are from the context and input variables to school processes, which in turn determine student outcomes. Processes act at school, class/teacher and individual pupil level.

From a methodological perspective, a key characteristic of school effectiveness research is the importance attached to studying the inter-relationships between the nested levels of pupil, class and school. The clustering of pupils within classes, classes within schools, and schools within LEAs is generally analysed by educationalists using multilevel modelling.[4] The school effectiveness literature also emphasizes the importance of investigating the relative effectiveness of schools and teachers on the attainment of pupils with different characteristics (gender, ability, social class or ethnic origin), by testing for interaction effects. Data on school processes are generally collected from surveys or direct observation and can be transformed into quantitative variables for inclusion as independent variables (for example, Sammons *et al.*, 1997; Hofman *et al.*, 1999; Muijs & Reynolds, 2000). Alternatively, examples of schools with differential effectiveness are identified and their processes studied qualitatively in order to understand the factors associated with differential effectiveness (for example, Gray *et al.*, 1999). The school processes that have been found to be important are listed in the school process box in Figure 1. The importance of school processes in accounting for differences in school effectiveness could well explain why education production function studies that ignore such processes have not, in general, managed to detect systematic resource effects.

The usual education production function approach follows the school effectiveness framework already described in that it relates student outcomes to school resources, school context and student input variables. However, the production function literature generally does not include any process variables. It is thus a simplification of the school effectiveness framework while also being more rigorous in specifying the structure of the model and acknowledging the likely presence of two-way causality—from resources to outcomes, but also from student outcomes to resource inputs. A standard specification of the model of the school as a production system is:

$$O_{hij} = f(R_{1hij} \dots R_{Mhij}, X_{1ij} \dots X_{Nij} \dots C_{1j} \dots C_{Lj})$$

where $O_{hij} \dots O_{Hij}$ are H educational outcomes for the i^{th} student at school j (where the outcomes are assumed to be independent of one another or orthogonal), $R_{1hij} \dots R_{Mhij}$ are M resource inputs allocated to the production of O_{hij}, $X_{1ij} \dots X_{Nij}$ are N student background variables, and $C_{1j} \dots C_{Lj}$ are L context variables for school j.

Implicitly, the school is assumed to know the form of the production function and to maximize outputs, subject to a resource constraint or budget. Thus, schools are engaged in multi-product or joint production of a range of cognitive, affective

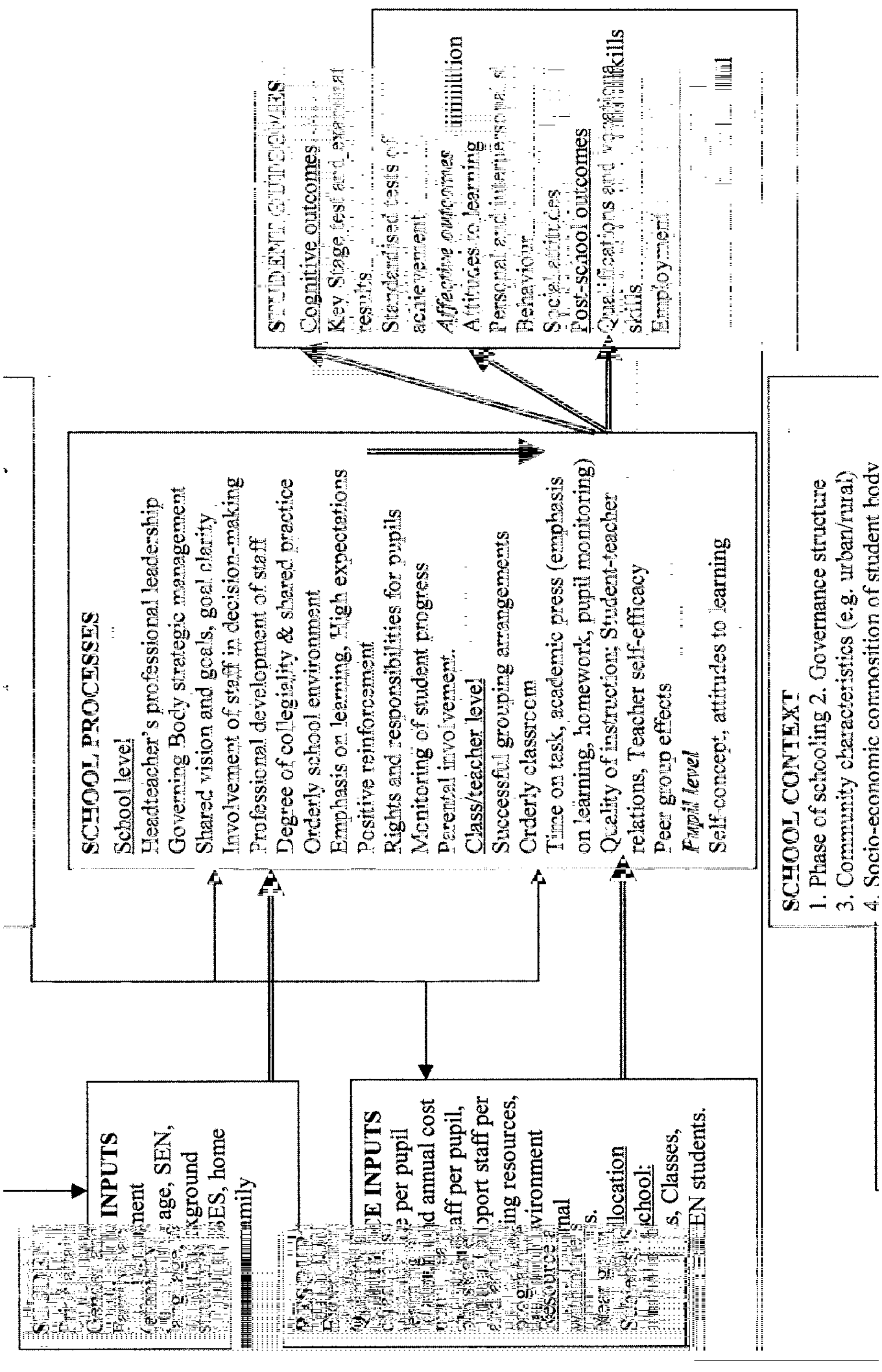

Fig. 1. A context–input–process–outcome framework for school effectiveness.

and social outcomes (of which the cognitive are much more amenable to quantitative measurement). The resources designated for each student, R_{mhij}, may be separable (as with time spent on particular curricular activities) or shared (e.g., capital expenditure on school infrastructure). The model can be made more complex by differentiating input and output flows by time, so that there are time lags between outputs in time t and the use of inputs in time $t - u$.

The school's utility function is assumed to be of the form:

$$U_j = g \mathop{\wedge}\limits_{h=1}^{h=H} \mathop{\wedge}\limits_{i=1}^{i=1} O_{hij}$$

and it is maximized subject to:

$$O_{hij} = f(R_{1hij} \ldots R_{Mhij}, X_{1ij} \ldots X_{Nij}, C_{1j} \ldots C_{Lj})$$

and

$$\mathop{\wedge}\limits_{m}^{M} P_m R_m - B_j = 0$$

where P_m is the price of input R_m and B_j is school j's budget.

Two key assumptions are required. First, that all members of the school community, in particular the staff, subscribe to the school's utility function. Different utility functions, pursued by different members of the school, can result in x-inefficiency from the consumer perspective (this may be the parent, student or government on behalf of society). The second is that a specified school utility function is an expression of a particular set of preferences with respect to 'a particular set of outputs' for 'a particular group of students'. For example, if a school wishes to maximize the sum of the progress of students in a measured cognitive outcome, then this might imply investing very little in students who are predicted to make slow progress. However, this type of utility function would conflict with one that values social equity and thus greater expenditure on pupils who have learning difficulties, despite their slower progress. Hence, internal resource allocation within a school reflects a set of preferences, which may be those of a single decision-maker or like-minded group, or which may emerge from overt and covert bargaining among decision-makers in the school community.

Estimation of Education Production Functions

The theoretical framework already discussed provides some guidance as to the desirable characteristics of an estimated education production function, although any estimated form of the function is inevitably a simplification of the underlying theoretical relationships. In the present section, we discuss some of the practical estimation difficulties that the education production function literature has encountered:[5]

- *Endogeneity* between school resources and student outcomes, which means that the error term in the estimated equation is correlated with one or more of the independent variables and the resulting estimates are biased (see later for examples).

- *Omitted variables*, which if they are correlated with the included independent variables will also give rise to biased estimates. The absence of data at student level, particularly for ability/prior attainment and resource inputs, is a problem for many education production function studies.
- *Levels of analysis*, not taking account of the hierarchical nature of the data (pupils nested in classrooms, with teachers, in a school, in an administrative district) and using 'aggregated' data.
- *Functional form* of the production, not being linear and additive as most frequently assumed for ease of estimation.
- *Criteria*, identifying the appropriate dependent variables. There is a range of possible outcomes from schooling, in addition to students' cognitive attainment, and it is not always clear which outcomes are of greatest interest to pupils, parents, teachers, schools and policy-makers.

Endogeneity

The education production function describes the supply side of a model of school production in which both supply and demand factors interact (Mayston, 1996; Dewey *et al.*, 2000). So the school budget, B_j, in the equation given earlier is actually dependent on factors such as the number and characteristics of pupils, and hence on the demand for places at the school. A further consideration is when, as in England and Wales, school funding formulae allocate more to schools with higher portions of pupils with low cognitive attainment scores and/or who come from socially deprived families. Thus, schools with lower measured educational achievement have systematically higher funding per pupil. Therefore, ordinary least-squares (OLS) regressions are likely to find a spurious negative correlation between outcomes and resources per pupil. An alternative endogenous relationship is that better-off parents select, often by choice of residential area, better quality schools. These parents are most likely to select schools with higher concentrations of socially advantaged pupils. An OLS regression may then attribute pupil cognitive achievement to higher resources, when in fact part of this estimated effect is due to parental inputs not directly observed in the available data.

A limited amount of research has attempted to tackle the endogeneity problem using simultaneous equation models that explicitly model the resource allocation between schools, and between students within schools. If such models are to be used in the UK context, we need a better understanding of the resource allocation process within schools and LEAs. Researchers need to identify and model the determinants of school resources per pupil, as a first stage in a full structural model of the effects of school inputs on learning outcomes. In the simultaneous equations approach, the structural relationships are made explicit and form a system of equations that permit the structural associations between multiple inputs and multiple outputs to be identified. In particular, if properly specified, the simultaneous equations approach can enable researchers to identify both the impact of the various factors that influence the level and mix of educational resourcing a child receives and the effect of these resource levels and mixes on educational outcomes. The main drawback of this approach is the identification problem. To solve the equation system, the researcher must find a factor that influences the amount of resourcing a child receives without also influencing that child's educational performance directly. The more equations there are in the system (as would be the case if the researcher were attempting to model multiple inputs and outputs), the more identification restrictions one requires and therefore the more difficult the identification problem is to solve.

Probably a more practical alternative to the simultaneous equations model is to find an instrument (or instruments) for the potentially endogenous school resources variable(s), rather than specifying the full set of equations, complete with feedback mechanisms between different dependent variables. Of course, the use of instruments raises the same identification issue discussed earlier (i.e., one needs a variable that exerts no direct influence on outputs and only works indirectly through its role as a predictor of resources). This often proves difficult theoretically and in practice. However, in the absence of experimental data on this issue, the instrumental variables (IV) method provides perhaps the most fruitful prospect for good quality research. It is also notable that a number of influential papers that have used IV have found positive effects from school inputs (Akerheim, 1995; Figlio, 1997; Angrist & Lavy, 1999; Dewey *et al.*, 2000).

A further problem with using IV models is that they can only identify the effect of a change in school inputs for the particular sub-set of the pupil population that has experienced the variation in school inputs predicted by the instrument. For example, one might use random changes in the birth rate to instrument for primary school class sizes. However, an unexpected change in the birth rate/population is likely to have a bigger impact on class sizes in smaller schools and school districts, where administrators cannot smooth out the effect of sudden changes in enrolments. These small schools and districts are not representative of all schools and districts, so the results from studies that use this instrument should be interpreted with care. Another example comes from studies that have used rules about maximum class size as instruments. Such studies are actually measuring the effect of a random change in class sizes around the maximum possible class size (40 in the case of Angrist and Lavy (1999)). It is quite possible that changes in class size from 40 to 41 may have a significant effect, even if changes in class size from 30 to 31 (the range more relevant to the UK) do not. Furthermore, particular students may be clustered in the classes most affected by class size rules. If the characteristics of the target population (children in classes affected by class size rules at the margin) are not representative of the total population, results may be biased.

One virtually guaranteed way to overcome the endogeneity issue, and avoid the problems of IV, is to use randomized or experimental data (Krueger, 1999). The 'STAR' class size experiment in the US is the prime example of the use of experimental research in education. The advantages of this methodology are clear. With a carefully constructed experiment, the potential for endogeneity bias is limited (although probably not altogether eliminated). However, there are some disadvantages associated with random experiments. From a practical point of view, they are costly and may raise ethical issues. For example, parents may feel they do not want their children to be subjected to 'experimentation'. Also, random experiments are so rare that their results are often cited in the literature and extrapolated to other, sometimes very different, institutional settings.

The most serious criticism of random experiments is that the individuals (students, parents, and school staff) involved in the experiment are generally aware of it. This may lead to 'Hawthorne' effects, whereby students perform better just because they are the subject of an experiment, rather than due to the educational intervention itself. In particular, as the experiment may lead to a particular policy recommendation (smaller classes), all involved have an incentive for the experiment to 'work'. Equally, individuals involved in the experiment may tend to subvert the random nature of the experimental design. For example, parents may lobby for their children to be put in the smaller classes. Teachers may put certain students, whom they feel would benefit most, in the smaller classes. All this is really to say is that even random experiments may not totally eliminate the endogeneity problem. Efforts to find natural random variation in school inputs (to be used as instruments) may therefore be not only more feasible, but also advantageous from a methodological point of view.

Omitted Variables

The solution to this problem, in the absence of a random experiment, is to have a rich data set and hence to include all the variables that educational theory suggests may have an impact on student outcomes. However, many data sets lack sufficient information on pupil, family and school characteristics, and this problem therefore needs to be fully acknowledged and discussed in any research in this field. Specifically, many education production function studies omit adequate measures of: (i) student inputs, particularly family background/income and the pupils' innate ability; (ii) class inputs, specifically the socio-economic composition of the classroom (to measure peer effects) and the resources used at the level of the classroom (e.g. class size[6]); and (iii) school context and processes, in particular the teaching methods being applied, teacher quality, the socio-economic composition of the student body and information on school management.

Levels of Analysis

A considerable proportion of education production function studies, particularly earlier ones, has used outcome data at the school, rather than the pupil level, and has used resource data at the LEA level. However, estimates using aggregate level data are likely to be biased (Goldstein, 1995; Hanushek *et al.*, 1996). Alternatively, there are numerous studies that have used standard regression techniques to analyse school resource effects using pupil level data. However, many of these studies have failed to take account of the hierarchical nature of the data (i.e., the fact that pupils are nested in classes in schools that are nested in different LEAs). If the school or class that a pupil attends has a common effect on all pupils in that school/class, then the OLS assumption of homoskedasticity (equal variance of disturbance term for all cases) is violated and standard regression estimates will be inefficient (the standard error too small) (Goldstein, 1997). Multilevel models, or similar econometric techniques, enable the variance due to class, teacher, school or LEA effects to be identified separately from factors that exert a genuinely common effect on all pupils, such as prior attainment and home background. Therefore, such models can potentially identify differential school effectiveness, in terms of given outcome measures, and relate this to differences in resourcing.[7] The main criticism made of multilevel modelling is that it is unnecessarily complicated given that it has been shown to produce similar estimates to OLS for the same data sets (e.g. de Leuuw & Kreft, 1995; Rogosa & Saner, 1995). The practical use of multilevel models in education production research is still, however, relatively limited.

Functional Form

Most regression models in the literature assume a linear (or log-linear) functional form. This assumption implies that the effect of an additional unit of school inputs is the same both at very low and at very high initial levels of school inputs. Yet this linear functional form has been statistically rejected by the data in some instances (Figlio, 1999), suggesting it is overly restrictive because it does not allow for non-linear effects. Indeed, Figlio (1999) using a trans-log functional form, and Eide and Waehrer (1998) using quantile regression techniques, found evidence of non-linearity in the relationship between educational expenditure and student attainment. It is difficult to determine whether functional form is a major issue, in terms of the wider empirical findings in the literature. Figlio (1999) for example, rejects the assumption of linearity in the effects of school inputs, but equally finds that any positive effects from school inputs are still small. However, high-quality research in the future would clearly benefit from more rigorous statistical testing of the functional forms used.

Another way of allowing for non-linearity is to test interactions between the independent variables (e.g., between home background and input per pupil). Certainly much of the empirical work in this field has assumed that school resources have the same effect on learning outcomes for all students, regardless of the family background or initial ability of the pupil. Yet studies that have examined the impact of school resources for students of differing levels of ability or of differing socio-economic background have often found some significant results (Dearden *et al.*, 1997; Wright *et al.*, 1997; Figlio, 1999). Further work needs to build on this approach to answer many more complex questions, such as do smaller class sizes benefit lower-ability or higher-ability children?

Criteria for High-Quality Education Production Function Studies

Given these methodological considerations, a production function study would ideally have the following features:

1. Data at pupil level on measured achievement, with controls for prior attainment and home background, and resource data at least at school level should be used.
2. The endogeneity problem should be addressed by, for example, using instrumental variables.
3. Functional forms other than linear, additive ones should be tested as well.
4. Multilevel modelling or equivalent econometric models should be used to ascertain whether taking account of the hierarchical structure of the data makes any difference to the estimated coefficients and their standard errors.

UK Education Production Function Studies: A Review

Despite the introduction in the past decade of extensive delegation of resource management to school level, and national testing of pupils, there is still a paucity of UK research evidence on the relationship between school resources and student outcomes. Most of the UK studies do not meet the ideal criteria. In selecting studies for review, we have used less demanding criteria so that there is a corpus of work to review, and from which we can appreciate the data and estimation problems that have beset this field of research.

The UK studies reviewed meet the following criteria:

- They are published in refereed journals or, for very recent research, have been submitted to journals.

- They use pupil level data[8] and have information on at least one of the following output measures: examination attainment, cognitive test scores, continuation at school, drop out, truancy, attendance, or earnings.
- They include estimates of the impact of any of the following resource/input measures: expenditure per student, pupil–teacher ratio (PTR), class size, teacher costs per student, non-teaching staff costs per student, non-staff costs per student, and measures of teacher quality such as teacher ability, experience and qualifications.
- They include prior attainment or family background and personal variables as controls (i.e., a value-added specification).
- They use a clearly identified method of estimation.
- They report the magnitude of the effects of input measures on output variables, including significance or standard errors.

The UK literature has relatively few methodologically strong studies. The literature lacks both depth and breadth of coverage with respect to the different phases of education, and the research has also been restricted by the lack of suitable and accessible data (Mayston & Jesson, 1999). The most recent and most econometrically sophisticated studies using pupil level data are to be found in four papers utilizing the National Child Development Study (NCDS) data. The studies reviewed are Dearden *et al.* (1997), Dolton and Vignoles (1999), Dustmann *et al.* (1998) and Feinstein and Symons (1999).

The main features of these four studies are summarized in Table 1, and an assessment of their methodologies is presented in Table 2. The NCDS provides individual level data on educational outcomes, prior attainment at 7 and 11, family background, and school quality (in particular, type of school attended, its PTR, and the child's class size at age 16 for mathematics and English). The data are supplemented by other information on expenditure and resourcing at LEA level (from LEA returns) and by census data on SES (socio-economic status) variables at LEA level. All four studies use slightly different measures of examination results as output variables, as presented in Table 1.

The studies do differ in key respects. Dearden *et al.* (1997) and Dolton and Vignoles (1999) estimate earnings equations as a function of qualifications (i.e., highest educational attainment), family and individual characteristics and school quality variables (including LEA level inputs). Dustmann *et al.* (1998) include career choice as a school outcome variable, where the choice is between staying on at school, training (full or part time) or entry into the labour market. Only Feinstein and Symons (1999) include peer-group effects.

All these studies try to address the problems of omitted variables and endogeneity, as presented in Table 2. They all attempt to address the endogeneity problem by adding sufficient explanatory variables to control for all observable differences between individuals. Specifically, in an attempt to isolate the effect of the school quality variables, explanatory variables are included to control for ability/prior attainment, family background and local environment.[9]

The summary of findings in Tables 3 and 4 reports coefficients on the school quality variables from model specifications that include the largest range of control variables. The studies confirm the overwhelming importance of prior attainment/ability and family background variables in determining educational attainment at school. Dolton and Vignoles (1999) reported no significant relationship between school resource variables and 'labour-market' outcomes, even after trying a variety

Table 1. Student level education production function studies: main features

Study	Output measure	School quality variables	Controls	Data	Statistical technique
Feinstein and Symons (1999)	Exams: 1. English: highest grade attained in national examinations in English up to age 21 (has eight categories) 2. Mathematical ability at age 16 measured by NCDS test 3. Index of overall examination performance in all subjects	School type (single sex, private, grammar, comprehensive, technical, secondary modern) PTR at school level Pupil in top stream Not in top stream of streamed classes	Prior attainment: NCDS 'ability' tests in mathematics at age 11 Family background: parent interest variable; father in top or middle SES; father and mother stayed on at school; number of older and younger siblings; father plays role in upbringing Peer group, composite variable made up of: per cent of children in class with fathers in non-manual occupations; per cent of children in class only taking GCE examinations; per cent of children in class only taking CSE examinations; per cent of children in previous year's class taking who stayed on in education Environment: local unemployment rate; per cent of unskilled manual	NCDS General population census	OLS and 2SLS* Monte Carlo simulations: sensitivity analysis to check effect of low correlation in 2SLS between instruments and endogenous variables
Dustmann *et al.* (1998)	Exams: number of O-level and CSE grade 1 passes Destinations: career choice (staying on, full-time and part-time training, labour market)	School type PTR at school level	Prior attainment: NCDS 'ability' tests in mathematics and English at age 7 and 11 Family background: family income; parents working; parents' education; child has separate room; number of older and younger siblings; parental interest; parents want child to sit A-levels/go to university Environment: local unemployment rate; per cent of unskilled manual workers	NCDS General population census	OLS (ordered probit) Varied specifications Two-stage estimates with instrumental variables

Dolton and Vignoles (1999)	Exams: English and mathematics examination results at age 16: 1 = no qualifications in English or maths; 2 = unclassified grade; 3 = CSE grade 3 or 4; 4 = O-level grade D or E; 5 = O-level grade C or CSE grade 1; 6 = O-level grade A or B Wages: Log of gross hourly pay at age 33 for employed males	School type: English and maths class sizes (at age 16) Square of class size PTR at school level; school size Per cent students staying on LEA expenditure per pupil Teachers' salaries per pupil PTR at LEA level Child setted or streamed	Prior attainment: NCDS 'ability' tests in maths and English at 11 Family background: gender; race; social class; home ownership; number of. siblings; father present; parental attitude to staying on at school Peer group: attended school where < 20% pupils non-manual or > 80% pupils non-manual	NCDS LEA education statistics	OLS (ordered logit) Varied specifications
Dearden *et al.* (1997)	Exams: Highest qualification obtained at school (A-level, 5+ O-level grades A–C or CSE grade 1; 1+ O-level grades A–C or CSE grade 1, CSE grades 2–5, none). Highest educational qualification obtained at age 23 or 33 Wages: Wages at age 23 and 33, hourly real gross wage rate in 1995 prices (of those in employment in 1981 and 1991)	School type PTR at child's school at ages 11 and 16 LEA expenditure per pupil LEA average teacher salaries in primary and secondary schools in 1969 and 1974	Prior attainment: NCDS 'ability' tests at age 7 in verbal and mathematics ability Family background: parental interest; father's social class; father's and mother's education; in receipt of free school meals; family financial difficulties; number of siblings; and number of older siblings Environment: regional school dummies (11); Census (1971) SES variables of enumeration district in which child lived; social deprivation level of LEA (1971); size of LEA and its spending needs	NCDS LEA education statistics General population census	OLS (ordered probit) Varied specifications, including interaction terms between PTR and school type, and PTR and ability

* two stage least squares.

Table 2. Student level education production function studies: methodology

Authors	Methodological issue			
	Endogeneity	Aggregation bias	Functional form	Omitted variable bias
Feinstein and Symons (1999)	✓	✓	✗	✓
Dustmann *et al.* (1998)	✓	✓	✗	✓
Dolton and Vignoles (1999)	✓	✓	✗	✓
Dearden *et al.* (1997)	✓	✓	✓	✓

✓ Attempt to overcome methodological difficulty; ✗, no attempt to overcome methodological difficulty.

of specifications (e.g., including only comprehensive school pupils). They also sought to overcome endogeneity bias using, as an instrumental variable, the random variation in educational resourcing levels that followed a change in LEA organization in 1974, and yet they still found no relationship between resource levels and labour-market outcomes.

Dearden *et al.* (1997), however, found some school quality variables to be significant and correctly signed in wage equations (see Table 4). This finding came out of specifying interactions between PTR and school type, and PTR and ability. The PTR did have significant and negative effects for men who attended secondary modern schools and for lower-ability women. Thus, the Dearden *et al.* study indicates the importance of model specification and the use of interaction terms to probe how resources may be differentially effective for different types of student.

Dustmann *et al.* (1998) found that the PTR has significant effects on career choice after controlling for school type. A lower PTR increases the probability of a student staying on at school after age 16. The PTR also has a significant effect on examination results, although this becomes insignificant when school type is included. Dolton and Vignoles (1999) report that the PTR is significant and correctly signed in their examination equations, which include school type, while Feinstein and Symons (1999) find it to be insignificant. Only Dolton and Vignoles include class size as a regressor in school attainment equations, where it was significant but wrongly signed, probably because of its association with pupil ability.

In summary, three of the four studies find some evidence of a positive effect from school resource variables on school attainment, and one of them of an effect on wages. Fewer school quality variables are reported as significant when a larger number of explanatory variables are included, indicating that omitted variables bias is likely to be a problem in studies that use only a few control variables. Inclusion of interaction terms to enable the differential effects of resources for different types of student to be explored also appears to be important. We conclude that some positive effects from school quality variables on educational outcomes have been found using UK data, although there is little evidence of strong resource effects.

Conclusion

Existing education production function research in the UK has been severely hampered by the lack of good quality data. In particular, work in this field has suffered from data aggregation bias, since most studies have had to rely on LEA or

Table 3. Summary of findings of student level studies on effect of resource variables on examination results

Variable	Feinstein and Symons (1999)	Dustmann *et al.* (1998)	Dolton and Vignoles (1999)	Dearden *et al.* (1997)
Class size	Not included	Not included	Significant but positively signed Square of class size significant negatively signed	Not included
School PTR	Insignificant	Significant when school type not included. Insignificant once school type included	Significant: Mathematics score coefficient = –0.091 English score coefficient = –0.068	Not significant except for negative effect on men attending secondary moderns and lower-ability women
LEA PTR	Not included	Not included	Insignificant	Not used
LEA expenditure per pupil	Not included	Not included	Insignificant	Insignificant
School type	Compared with comprehensive, coefficients for all examinations: Grammar = 7.56 Secondary modern = –2.32 Private is insignificant Peer group = 10.29 Top stream = 7.57 Not top stream = –5.42	Significant Compared with secondary modern, coefficient on examination score: Private = 2.087 Grammar = 1.916 Technical = 1.137 Comprehensive = 0.69	Mathematics (M)/English (E): coefficients compared with comprehensive: Private = 1.168 (M), 0.882 (E) Grammar = 0.585 (M), 0.886 (E) Secondary modern = –0.076 (M), –0.193 (E)	Men: grammar and private school attendance at age 16 has significant and positive effect, secondary modern has negative effect Women: girls' school had significant positive effect

Table 4. Summary of findings of student level studies on effect of resource variables on other outcomes

	Dustmann *et al.* (1998), career choice	Dolton and Vignoles (1999), wages at age 33	Dearden *et al.* (1997), wages at age 23 and 33
Class size	Not included	Insignificant in full specification	Not included
School PTR	Significant. Increase in PTR by 1 SD increases probability of staying on at school by 6–7 percentage points	Not significant once control for ability, qualifications, personal factors and experience	Negative and significant effect on wages at age 33 for women attending grammar schools
LEA PTR	Not included	Insignificant	Not included
LEA spending per pupil	Not included	Insignificant	10% increase in average secondary teachers' salary per pupil leads to 10% higher male wages at age 23; 10% increase in LEA secondary school expenditure per pupil leads to 3.1% higher female wages at age 23
School type	Grammar/private school increases staying on by 16/19 percentage points	Significant	Private school has 9% impact on male wages at age 33; has positive impact on female wages at age 33

school level data. More recent studies utilizing student level data from the NCDS, however, have detected some school resource effects, particularly on pupils' examination results. The large range of control variables available in the NCDS data has enabled these studies to make some progress in reducing omitted variables and endogeneity bias, and they have also used more sophisticated and varied model specifications. In fact, these studies have also produced some evidence of school quality variables impacting positively on 'non-examination' outcomes. However, many of the measures of school outputs used in these studies lack high construct validity and they have not been able to overcome the twin problems of limited resource data and the lack of obvious instruments to overcome endogeneity bias. The interaction effects in Dearden *et al.* (1997) are also indicative of the potential importance of differential resource effects for students, according to their gender and ability. Studies that utilize only more aggregated school or LEA level data would obviously miss such detailed effects.

There is one major caveat to add, however. Since the NCDS studies reviewed here relate to the UK school system in the 1970s, their relevance for relationships between resources and pupils' examination attainment in the current UK education system is questionable. However, if one is interested in robust estimates of the longer-term impact of school quality (and in particular school resourcing) on earnings, there is no alternative to such longitudinal data.

In terms of future work, research must satisfy the criteria for high-quality studies set out earlier, or the research effort will be wasted in producing unconvincing findings. It is essential to have pupil level performance data, with prior attainment and resource variables at school level. The endogeneity problem in studies using survey data also needs to be resolved. In particular, it needs to be established that there exists sufficient variability in funding per pupil at school level, that is not explained by factors related to student outcomes or cost factors (e.g., differences in local wage costs, social disadvantage and school size). Sufficient good quality control variables are also essential, including measures of a student's peer group and teacher and parental inputs. Crucial to this research are high-quality data sets.

Notes

1. In 2001 prices.
2. Quantifying many of these process variables is obviously quite problematic, although there is a large literature.
3. This model provides a framework of possible relationships, identifying factors that may be important influences on student attainment. It does not generate the rigorous mathematical proofs that one associates with many economic models. This framework does provide, however, a useful guide for our discussion of the literature.
4. Obviously other similar econometric techniques may be used to allow for clustering within levels of the data.
5. Given that most of the literature has used multivariate regression techniques, we focus largely on criticism that relates to this choice of technique. Vignoles *et al.* (2000) also consider an alternative technique, namely data envelopment analysis.
6. Many studies only have the average PTR of the school.
7. Nonetheless, multi-level models can suffer from the same endogeneity problems as OLS estimation, as discussed previously.
8. For a review of LEA level education production function studies and information on some school level studies, see Vignoles *et al.* (2000). Because of selecting only studies using pupil level data, we have in this paper omitted recent studies using school level data (Bradley & Taylor, 1998; Bradley *et al.*, 2001), the latter using data envelopment analysis.
9. Various specification tests are undertaken by Feinstein and Symons (1999) (two stage least squares and sensitivity analysis), by Dustmann *et al.* (1998) (simultaneous equation model) and by Dolton and Vignoles (1999) (IV). Dearden *et al.* (1997) also test an additional functional form. These various specification tests suggest that endogeneity bias is not of great importance.

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