Fiona Steele, Anna Vignoles and Andrew Jenkins

The effect of school resources on pupil attainment: a multilevel simultaneous equation modelling approach

Article (Accepted version)
(Refereed)

Original citation:
Steele, Fiona, Vignoles, Anna and Jenkins, Andrew (2007) The effect of school resources on pupil attainment: a multilevel simultaneous equation modelling approach. Journal of the Royal Statistical Society, series A, 170 (3), pp. 801-824.

DOI: 10.1111/j.1467-985X.2007.00476.x

The Impact of School Resources on Pupil Attainment: A Multilevel Simultaneous Equation Modelling Approach

Fiona Steele*
Centre for Multilevel Modelling, Graduate School of Education
University of Bristol

Anna Vignoles and Andrew Jenkins
Bedford Group for Lifecourse and Statistical Studies
Institute of Education, University of London

Summary

Improving educational achievement in UK schools is a priority, and of particular concern is the low achievement of specific groups, such as those from lower socio-economic backgrounds. An obvious question is whether we should be improving the outcomes of these pupils by spending more on their education. The literature on the effect of educational spending on pupil achievement has a number of methodological difficulties, in particular the endogeneity of school resource levels, and the intra-school correlations in pupil responses. In this paper, we adopt a multilevel simultaneous equation modelling approach to assess the impact of school resources on pupil attainment at age 14. This paper is the first to apply a simultaneous equation model to estimate the impact of school resources on pupil achievement, using the newly available National Pupil Database/Pupil Level Annual School Census (NPDB/PLASC).

Keywords: education production function, multilevel simultaneous equation model, school resources

**Address for correspondence*: Fiona Steele, Centre for Multilevel Modelling, Graduate School of Education, University of Bristol, 2 Priory Road, Bristol BS8 1TX, Email: Fiona.Steele@bristol.ac.uk

1. Introduction

For policy-makers and parents alike, improving educational achievement in UK schools is a policy priority. There is certainly an economic imperative to raise educational achievement, given that an additional year of education in the OECD area is estimated to increase economic output by between 3 and 6% (OECD, 2004). Currently, the UK spends around 5% of its annual Gross Domestic Product on education, including primary, secondary and postsecondary (compared to an OECD mean of 5.6%), and expenditure has been increasing since the mid 1990s. Nonetheless, spending in UK secondary schools (US$5933) is below the OECD mean of US$6510 (OECD, 2004). However, lower expenditure does not necessarily mean lower achievement, at least in aggregate. The UK, along with countries such as Australia, Finland, Ireland and Korea, spends a lower than average amount on secondary schooling but its pupils perform relatively well in international tests of pupil achievement, such as the Programme for International Pupil Assessment (Machin and Vignoles, 2005). An obvious policy question is therefore whether an increase in per pupil expenditure on education, or a reduction in the average pupil-teacher ratio in schools, is a viable means of improving pupil attainment across the board. There are a number of reasons why this may not in fact be a feasible policy option. One possibility that is much discussed in the literature, and which has hugely important policy implications, is that state schools are inefficient in their use of resources, so that higher spending schools do not systematically have better pupil outcomes (Hanushek, 1997). This paper not only aims to provide empirical evidence to guide policy-makers on this issue, but also seeks to overcome some important methodological difficulties that plague many of the previous studies in this area of research.

Another policy issue of particular concern in the UK is the low achievement of specific groups of pupils, such as those from lower socio-economic backgrounds and certain gender/ ethnic groups. Again, an obvious question is whether we should be improving the outcomes of these pupils by spending more on their education. This research question is explored in our previous work on this issue (Levačić et al., 2005), which used an instrumental variable approach, and some preliminary simultaneous equation modelling, to examine the relationship between school resourcing levels and the attainment of different subgroups of English pupils. Here, we extend the multilevel simultaneous equation model used in this earlier work to try to accurately ascertain the direction and magnitude of any links between school resources – as measured by per student expenditure and the school pupil-teacher ratio

– and the mean educational attainment of pupils in England.

There is a large and controversial literature analysing the relationship between school resourcing levels and pupil achievement, dating back to the pioneering work by Coleman et al. (1966). Early work on this issue using US data suggested a weak and somewhat inconsistent relationship between school resources and pupil achievement (Burtless, 1996; Hanushek, 1979, 1986, 1997; see also Volume 78 of the *Review of Economics and Statistics* for a range of articles on this issue). International research confirms this view (Wößmann 2003). However, this view was disputed by some, including Laine et al. (1996), Card and Krueger (1992) and Krueger (2003). A recent and comprehensive summary of a range of evidence on the impact of class size is Averett and McLennan (2004). They found the evidence base to be mixed, in terms of methodologies and results, and were unable to reach a definite conclusion about the impact of smaller classes on pupil achievement.

One possible explanation for finding a weak relationship between classroom and school resourcing levels and pupil achievement is that schools are inefficient, lacking the competitive pressures required to make them use resources more effectively. Thus the issue of resourcing also relates to a large and growing body of work that has investigated, either theoretically or empirically, the impact of increased competition and quasi-market forces in education (for example, Glennerster, 1991; Cohn, 1997; and Bradley et al., 2000). Another possible explanation for the insignificant relationship between resourcing levels and pupil achievement is that the way in which education is delivered, i.e. the technology of education production, may need to vary across pupil types. Lazear (2001), for example, found evidence that optimal class sizes were much larger for better-behaved pupils. This too might explain why it is difficult to find significant class size effects.

Largely however, the controversy in this literature centres on the extent to which studies that show no significant relationship between school resources and pupil achievement are able to overcome a number of methodological difficulties. One major methodological difficulty in the literature is the problem of the endogeneity of school resources due to the non-random way in which funds are allocated across schools. In the UK, schools with higher concentrations of lower attaining pupils receive more funding per pupil. If this feature of resource allocation is ignored, a true positive effect of increasing resources will be understated. In addition, there may be unobservable or poorly measured characteristics of schools, and also of local education authorities (LEAs), which influence both resource allocation and pupil attainment. For example, one factor in the funding allocation formula used by LEAs is the proportion of socially disadvantaged pupils in a school, which is also associated with pupil outcomes. If a model for pupil attainment does not include adequate measures of pupils' social background, a true positive resource effect will be diluted or may even appear negative.

There are a number of potential methods that might be used to overcome this endogeneity problem, including random assignment. For example, the Tennessee STAR class size experiment randomly allocated children in primary school to small and large class sizes. Results from STAR suggest that smaller classes do increase pupil attainment and that gains persist to the school leaving age and college (Krueger and Whitmore, 2001). Another method that is used to overcome the endogeneity problem is a natural experiment. The international literature using natural experiments, such as rules on class size, or court-imposed policies to raise spending on schools, has produced mixed results. Angrist and Lavy (1999) and Jepson and Rivkin (2002) found positive effects of smaller class size on pupil attainment for Israel and California respectively. However, Hoxby (2000) found no effect of class size in Connecticut, while Dobbelsteen et al. (2002), instrumenting on teacher allocation rules, reported a significant positive effect of larger class size on attainment for the Netherlands.

Yet another approach to tackling endogeneity is to include a large number of control variables to reduce the possibility of covariance between resources and any unobserved variables that affect attainment. For example, Wilson (2000) using extensive data on family and neighbourhoods for the US found school spending to be positively related to high school graduation and years of schooling. Another method tried by Hakkinen et al. (2003) is to use panel data over a number of years to difference out school and district effects. They find no effects on exam scores in Finnish upper secondary schools of changes in per pupil spending from 1990-98.

It is fair to say, however, that the vast majority of school resource effect studies have not been able to address the endogeneity problem. This is certainly the case in the UK (Levačić and Vignoles, 2002). UK studies that have made some attempt to address endogeneity have generally found small but statistically significant positive effects from school resource variables on educational outcomes (Dearden et al., 2001; Dolton and Vignoles, 2000; Dustmann et al., 2003; Iacovou, 2002).

Endogeneity issues are not the only methodological difficulty in this literature. For example, much of the work on resourcing has had to rely on quite aggregated data, rather than data at the level of the individual pupil. Aggregation bias is therefore a problem for some of the studies in this field (Hanushek et al., 1996). Only recently in the UK has large-scale nationally representative pupil level data become available with which one can address the resourcing issue.

Another important methodological issue to be considered is the intra-school correlations in pupil responses. The need to control for clustering in the analysis of hierarchically structured data is well known (see, e.g., Goldstein, 2003). One consequence of ignoring clustering is the underestimation of standard errors due to the decrease in the effective sample size, and in general the underestimation is most severe for explanatory variables defined at the cluster level. In the present case, it is especially important to adjust for clustering because the variables of major interest, measures of school resources, are school-level characteristics.

In this paper, we adopt a multilevel simultaneous equation modelling approach to assess the impact of school resources on pupil attainment at age 14. A multilevel model is used to allow for clustering of pupil outcomes by school and LEA, and clustering of school resources by LEA. A simultaneous equation model is used to adjust for the endogeneity of school resource allocation. In this approach, pupil attainment and a measure of school resources are treated as a bivariate response. A multilevel model is defined for each response with LEA and school level random effects included in each; these random effects may be correlated across the attainment and resource equations, which allows explicitly for correlation between the unobserved LEA and school characteristics that influence each response. Our approach differs from the instrumental variable (IV) method traditionally used to account for endogeneity in the assumptions made about the level at which selection effects operate. The standard approach involves estimating equations for the outcome of interest and the endogenous regressor, either simultaneously or more commonly in two stages, but the equations are linked via correlated residuals defined at the lowest level of observation, in this case the pupil. This method may be inappropriate on two counts: first, it incorrectly treats school resources as a pupil-level variable and, second, it does not recognise that endogeneity arises due to correlation between unobservables at the school or LEA level rather than at the pupil level.

Thus our approach takes account of observable and unobservable selection processes at the level of the school and LEA that determine resourcing levels. We also recognise that there are potentially pupil-level selection processes: good students may choose better schools and these schools will on average be less well funded. We do allow for pupil selection of schools on the basis of observable characteristics. In particular we control for prior achievement (akin to the value-added model) and socio-economic status of the pupil, as well as some other pupil characteristics that may determine school choice. This study therefore goes a long way to redress the methodological difficulties of earlier work, which we anticipate will lead to resource effects becoming more apparent. Nevertheless, we do not control for selection of schools by pupils on the basis of unobservables. Thus, given the negative correlation between school performance and school resourcing, our estimates may still be conservative and understate the effects of resourcing.

This paper is the first to apply a simultaneous equation model to estimate the impact of school resources on pupil achievement, using the newly available National Pupil Database and Pupil Level Annual Schools Census (NPDB/PLASC) data sets. The NPDB/PLASC data sets contain information on the characteristics and achievement of every pupil in an English school, as well as characteristics of the schools themselves. The NPDB/PLASC data are supplemented by information on schools' levels of resourcing, derived from data submitted to the Department for Education and Skills by local education authorities. NPDB/PLASC provides information on individual pupils' attainment at age 14 (Key Stage 3) in 2003 and their attainment at age 11 (Key Stage 2) in 2000, enabling us to control for prior attainment in our model. Previous work in this area has been restricted to using either more aggregated data (at the school or LEA level) or relying on the National Child Development Study data set that, whilst rich, is somewhat dated in terms of providing empirical evidence to inform education policy today (its sample consists of a cohort born in 1958).

2. Background on the Secondary Education System in England

In England, educational spending on both primary and secondary schooling is administered by 150 local education authorities (LEAs), which are under local government control.

However, in the years for which our study data were collected, the majority of the money for education came from central government via a block grant (the Revenue Support Grant) to these LEAs for all local services. LEAs could spend this grant more or less according to their own priorities, and decide to spend more or less than the amount notionally allocated per pupil in the block grant. The amount of money received by a particular LEA from central government nominally for education, which until recently was known as the Education Standard Spending Assessment (SSA), depends on a number of factors that influence the expected educational costs in an LEA. For example, the education SSA takes account of pupil numbers, socio-economic factors (e.g. the number of immigrants in the area, the proportion of the local population in lower socio-economic groups and the numbers of families on state benefit), population density and cost of living in the area.

The fact that socio-economic factors partly determine the SSA implies that in the UK greater school resources are allocated to areas of greater educational need. This is reinforced by the fact that the actual block grant given to LEAs takes account of the potential in the LEA to raise local tax for educational spending. Thus prosperous areas tend to receive less from central government since they can potentially raise more revenue from local taxation. The actual expenditure per pupil also varies systematically by LEA according to factors such as the political party in control of the local authority and their educational priorities. The fact that LEAs have some discretion over how to spend the grant they receive again reinforces the point that endogeneity is likely to be a problem in any analysis of the influence of educational expenditure on pupil achievement.

Unfortunately our data restrict us to looking at the effect of school resourcing on pupils and schools in the state education system. More than half a million pupils in England are, however, educated in private schools. Such schools are more highly resourced, with funding levels being, on average, nearly 50% higher in the private sector. Pupils in private schools are needless to say more advantaged, coming from higher socio-economic backgrounds. To the extent that they are also more able and may also come from families that place a particularly high value on education, they are not representative of the entire population of pupils. Our estimates do not therefore address the issue of the impact of school resourcing for all pupils but only those educated in the state education system.

3. Methods

3.1 The standard multilevel modelling approach

We denote by y_{ijk} the attainment at age 14 in maths, English or science of pupil i (i=1, . . ., n_{jk}; $n = \sum_{j,k} n_{jk}$) in school j (j=1, . . ., J_k; $J = \sum_k J_k$) in LEA k (k=1, . . ., K). The standard approach to modelling attainment, allowing for clustering at the school and LEA levels, would be to fit a three-level random effects model. The simplest such model allows the regression intercept to vary randomly across schools and LEAs (Snijders and Bosker, 1999: 63-66):

$$y_{ijk} = \boldsymbol{\alpha}^T \mathbf{x}_{ijk} + \beta z_{jk} + v_k^{(y)} + u_{jk}^{(y)} + e_{ijk} \qquad (1)$$

where $\mathbf{x}_{ijk}$ is a vector of explanatory variables defined at the pupil, school or LEA level, $\boldsymbol{\alpha}$ is a vector of associated coefficients, z_{jk} is a measure of school resources with coefficient β, and $v_k^{(y)}$, $u_{jk}^{(y)}$ and e_{ijk} are residuals for LEAs, schools and pupils respectively. Typically, the residuals are assumed to be normally distributed: $v_k^{(y)} \sim N(0, \sigma^2_{v(y)})$, $u_{jk}^{(y)} \sim N(0, \sigma^2_{u(y)})$ and $e_{ijk} \sim N(0, \sigma^2_{e(y)})$.

A further assumption of the standard multilevel model is that the residuals at each level are uncorrelated with the predictor variables $\mathbf{x}_{ijk}$ and z_{jk}. For the reasons given in Sections 1 and 2 above, however, this assumption is questionable because the mechanisms by which resources are allocated to schools are likely to be related to the unobserved determinants of pupil attainment; these unobserved factors may be acting at the school or LEA level or both, leading to nonzero correlations between z_{jk} and either or both of $u_{jk}^{(y)}$ and $v_k^{(y)}$.

3.2 A simultaneous equation model for attainment and resource allocation

One way to allow for the potential endogeneity of resources z_{jk} with respect to attainment y_{ijk} is to model the resource allocation process jointly with attainment. A two-level random intercept model for school resources is

$$z_{jk} = \boldsymbol{\gamma}^T \mathbf{w}_{jk} + v_k^{(z)} + u_{jk}^{(z)} \qquad (2)$$

where $\mathbf{w}_{jk}$ is a vector of explanatory variables defined at the school or LEA level, $\boldsymbol{\gamma}$ is a vector of coefficients, and $u_{jk}^{(z)}$ and $v_k^{(z)}$ are school and LEA level residuals with variances $\sigma_{u(z)}^2$ and $\sigma_{v(z)}^2$.

Equations (1) and (2) define a simultaneous equation model. The equations are linked via the school and LEA residuals and must therefore be estimated jointly. At each level, we assume that the residuals follow bivariate normal distributions, i.e. $\mathbf{u}_{jk} = [u_{jk}^{(y)} \quad u_{jk}^{(z)}]^T \sim N_2(\mathbf{0}, \boldsymbol{\Omega}_u)$ and $\mathbf{v}_k = [v_k^{(y)} \quad v_k^{(z)}]^T \sim N_2(\mathbf{0}, \boldsymbol{\Omega}_v)$. We denote the covariances at the school and LEA level by $\sigma_u^{(yz)}$ and $\sigma_v^{(yz)}$ respectively. Likelihood ratio tests may be used to test whether either $\sigma_u^{(yz)}$ or $\sigma_v^{(yz)}$, or both, are equal to zero. A covariance that is significantly different from zero implies that z_{jk} is endogenous, and the nature of the selection effect is given by the direction of the covariance estimate.

3.2.1 Identification

In order to identify the simultaneous equation model given by (1) and (2), the vector $\mathbf{w}_{jk}$ must contain at least one variable, called an *instrument*, which is not contained in $\mathbf{x}_{ijk}$. To qualify as an instrument, a variable must predict the allocation of resources across schools, but should not have a direct effect on attainment.

Finding adequate instruments in this area of research is quite problematic (Burtless, 1996). Given that school funding varies by LEA, and that LEAs are subject to political control, the political party in control of the local authority is one potential instrument. We argue that political control of the local authority will affect educational spending in that LEA but will not directly impact on pupil achievement. The first instrument is therefore a variable indicating the political control of the local authority, i.e. whether Labour, Conservative, Liberal or other (including no overall political control by one party). The mean raw expenditure per pupil is highest in Liberal and Labour controlled local authorities (£3037 and £2980 per pupil respectively), and lowest in Conservative controlled authorities (£2762 per pupil).

It is possible that residents who place greater emphasis on education (and hence whose children tend to do better in school) will vote for parties that advocate higher educational spending. However, residents vote for a party that has policies on a number of different issues, not just educational spending. It is not clear that residents will vote purely, or even primarily, on the basis of parties' educational spending plans, especially as in the UK local elections are generally dominated by national politics. It is therefore unlikely that educational spending is a major issue in most local elections.

Our second instrument is lagged school size, which is an instrument that has been used by others in the field (Iacovou, 2002). School size (in terms of pupil numbers) is a key factor predicting the per capita level of funding in a school. The correlation between lagged school size and expenditure per pupil is –0.30 and significant at the 5% level. The correlation between lagged school size and the pupil-teacher ratio is +0.11 and significant at the 5% level.

For school size to be an adequate instrument it must not impact directly on pupil achievement. In the US, a review by Cotton (1996) could find no evidence that school size has a direct impact on pupil attainment (see also studies such as Griffiths (1996) and Luyten (1994)), although there are some US studies that suggest small or medium schools are more effective (Lee and Leob, 2000; Borland and Howsen, 1992). As argued by Borland and

Howsen (1992), however, many US studies have failed to account for individual pupil ability. In any case the effect of schools size may be institutionally and country specific, particularly given that processes that determine both funding and the allocation of pupils to schools vary by country (and even within countries).

In the UK, two studies that have relied on school-level data and that do not control for pupil-level characteristics, have found larger schools to have better pupil attainment (Bradley and Taylor, 1998; Barnett et al., 2002). However, studies that have relied on individual-level regressions of pupil performance in the UK have not found school size to be a significant determinant of pupil attainment (Gibbons et al., 2006; Taylor and Nguyen, 2006). Even studies using school-level data such as Bradley et al. (2000) have found small effects. For example, Bradley et al. use school-level data to examine the determinants of school-level exam performance, admission numbers, school size and school capacity. They suggested a number of potential determinants of school size, including demographic factors, prior school performance and the physical capacity of the school, as well as LEA policy. Their empirical work suggested that although higher performing schools did expand at a faster rate, the effect was very small. Generally they concluded that school performance had a minimal effect on school size particularly for large schools, possibly because schools and LEAs are reluctant to expand schools and partly because physical capacity constraints are genuinely binding.

Thus an argument can be made that in the UK context more effective schools tend to be bigger because they attract more pupils, thereby causing a positive relationship between school size and pupil achievement. Although empirical evidence from Bradley et al. (2001) suggests this effect is small, in our data we are able to control for this by including an indicator of how popular and ‘full’ the school is as well as a measure of lagged school performance. (The school's percentage capacity utilization is calculated as the actual number of students in years 7-11 compared to the maximum physical capacity in terms of student numbers, as determined by the Department for Education and Skills.) As a further robustness check, we also re-estimated our models using lagged school capacity, rather than lagged school size. This was on the grounds that school capacity is simply a function of the physical construction of the school, unrelated to current pupil enrolment (although Bradley et al. (2000) find small positive effects from an excess demand for pupil places on schools' expansion of their capacity). There is little change in the results when this alternative instrumental variable is used. Our results were also robust to excluding very large and very small schools from the sample.

Finally, likelihood ratio tests were used to determine whether the chosen instruments are significantly related to the school resource measures. Taking each resource variable as a dependent variable, as in (2) above, two models were fitted and compared: the full model with instruments, and the model omitting instruments. We find that political control of the local authority and lagged school size are jointly significant predictors of both expenditure per pupil and the pupil-teacher ratio (p<0.001 for each resource measure).

3.2.2 Estimation

The simultaneous equation model can be framed as a multilevel bivariate response model. For each individual, we can define a bivariate response y_{rijk} (r =1, 2) where $y_{1ijk} = y_{ijk}$ and $y_{2ijk} = z_{jk}$. In addition, we define two response indicators as follows:

$$I_{rijk}^{(y)} = \begin{cases} 1 & \text{if } y_{rijk} = y_{ijk} \\ 0 & \text{if } y_{rijk} = z_{jk} \end{cases}, \qquad I_{rijk}^{(z)} = 1 - I_{rijk}^{(y)}.$$

Equations (1) and (2) can then be written in the form of a single equation for the stacked responses { y_{rijk} } as

$$
\begin{aligned}
y_{rijk} &= \boldsymbol{\alpha}^T \mathbf{x}_{ijk} I^{(y)}_{rijk} + \beta z_{jk} I^{(y)}_{rijk} + v^{(y)}_k I^{(y)}_{rijk} + u^{(y)}_{jk} I^{(y)}_{rijk} + e_{ijk} I^{(y)}_{rijk} \\
&\quad + \boldsymbol{\gamma}^T \mathbf{w}_{jk} I^{(z)}_{rijk} + v^{(z)}_k I^{(z)}_{rijk} + u^{(z)}_{jk} I^{(z)}_{rijk}.
\end{aligned}
\tag{3}
$$

The way in which the responses are stacked is unimportant provided that values of y_{ijk} and z_{jk} are sorted by LEA and by school within LEA. In the standard bivariate model, both responses are at the individual level and therefore the bivariate response vector will be of length $2n$ (Goldstein, 2003; Chapter 6). In the present case, however, the responses are defined at different levels of the hierarchy: y_{ijk} is a pupil-level response, while z_{jk} is at the school level. While we could replicate values of z_{jk} for pupils in the same school, it is more computationally efficient to restructure the data so that there is a single observation of z_{jk} for each school, leading to a response vector of length $n+J$ with $n_{jk}+1$ records per school. The explanatory variables in (3) are the two-way interactions between $I^{(y)}_{rijk}$ and each element of $[\mathbf{x}^T_{ijk} \quad z_{jk}]$, and between $I^{(z)}_{rijk}$ and the elements of $\mathbf{w}^T_{jk}$. The random effects in the attainment and resource equations are fitted by allowing the coefficient of $I^{(y)}_{rijk}$ to vary across pupils, schools and LEAs, and the coefficient of $I^{(z)}_{rijk}$ to vary across schools and LEAs.

We estimated model (3) using reweighted iterative generalised least squares (RIGLS) as implemented in *MLwiN* v2.0 (Rasbash et al., 2004).

4. Data

The data for this paper come largely from the National Pupil Data Base (NPDB) and the Pupil Level Annual School Census (PLASC). The NPDB contains information on pupil achievement as they progress through the school system, including their scores on the various tests taken at Key Stage 1 (age 7) through to Key Stage 4 (GCSE). NPDB information on individual pupils is merged into PLASC, which contains data on school characteristics (size, type, pupil-teacher ratio etc.) and pupil characteristics (age, gender, ethnicity, eligibility for free school meals etc.). (Further information on the NPDB/PLASC datasets and how to access them can be found at http://www.bris.ac.uk/Depts/CMPO/PLUG/whatisplug.htm.) We then merged additional data into NPDB/PLASC on school expenditure (from Department for Education and Skills Section 52 data) and political control of the local authority, as well as 2001 Census information on the socio-economic characteristics of each child's neighbourhood. The analysis sample contains 430,061 pupils who are nested within 2,950 schools in 147 local education authorities.

Our model estimates the impact of school resources on pupil achievement in English, mathematics and science at age 14, i.e. Key Stage 3 in 2002/3. We include as an explanatory variable each pupil's prior achievement at Key Stage 2 (age 11) on entry to secondary school, i.e. in 1999/2000. The dependent variables are the age 14 test scores. The raw scores vary from 0 to almost 9 for maths, and from 0 up to almost 8 for science and English; standardised scores were used in the analysis.

The resource variables we use are all at school level, namely expenditure per pupil (deflated by an indicator of the cost of living in the area, the Area Cost Adjustment), the average pupil teacher ratio in the school and the ratio of pupils to non-teaching staff. The resource variables were averaged over the three years that the sample was in secondary school. We estimated separate models for the expenditure and the staffing resource variables, since the majority of school spending is on teachers. Teacher salary costs are on average 61% of secondary schools' expenditure (OFSTED, 2003). If expenditure per pupil and the pupil-teacher ratio are included in the same model, then the effect of the pupil-teacher ratio is biased downwards because a lower pupil-teacher ratio for a given level of spending automatically implies that there are less resources available for other inputs (Todd and Wolpin, 2003).

We control for a range of pupil and school variables (details given in the Appendix), as described in Levačić et al. (2005). In particular, in the attainment models we control for the prior achievement of the pupil at Key Stage 2 (age 11). Thus we are estimating a model of the impact of resources on pupil progress between age 11 and age 14. Including pupil prior achievement also allows for observable pupil-level selection processes that may cause more or less able pupils to be selected into different schools, as discussed earlier. We also control for pupils' gender, age, whether they have any special educational needs, whether they are eligible for free school meals and their ethnicity.

At the school level, we have a rich set of controls that are included in both the attainment and the resource equations, including various descriptors of school type, gender and age mix of the school, as well as the socio-economic status of the school as measured by the proportion of children eligible for free school meals. In addition we include in the resource equations a measure of lagged school performance, i.e. the proportion of pupils achieving 5+ grade A*-C GCSEs in 1999, which predates the point at which this cohort of pupils entered the school. This is included to account for the fact that, in general, higher levels of resources are allocated to lower performing schools. Lastly, in the attainment model we also include a number of controls derived from the 2001 Census, which are designed to capture characteristics of the pupil's neighbourhood. For example, we control for the proportion unemployed in the pupil's postcode area. These Census controls are particularly useful given the rather limited measures of socio-economic background for the individual. Full descriptive statistics are given in Table 1.

5. Results

We begin by examining the extent to which pupil attainment scores are clustered within schools and LEAs, and school resources are clustered within LEAs. Table 2 shows estimates of the residual variance at each level, from which estimates of the intra-school and intra-LEA correlations have been calculated. The estimates for attainment are from fitting separate three-level models for attainment at age 14 in maths, science and English, adjusting for attainment at age 11 in the same subjects. Thus the variance components represent the variances at each level in the progress between entry into secondary school and age 14. The estimates for school resources are from fitting separate two-level models to the expenditure and staffing measures. At this stage of the analysis, no pupil or school characteristics have been included, with the exception of prior attainment in the achievement models.

In a random intercept model, the intra-LEA (school) correlation can be interpreted as the proportion of the total variance that is due to differences between LEAs (schools), or the correlation between the expected progress of two randomly selected pupils from the same LEA (school). The intra-school correlations for attainment show that there are moderate school effects on adjusted performance in all three subjects, with the strongest effect on English scores; 22% of the total variance in English progress is due to differences between schools. After taking into account school effects on progress, LEA effects are very weak. Turning to the school resource measures, we find that 16% of the total variance in expenditure per pupil can be explained by differences between LEAs. This moderately high intra-LEA correlation implies that while LEAs vary in their mean expenditure per pupil (averaging across all schools in an LEA), there is similarity in the expenditure of schools in the same LEA. There is rather less homogeneity within LEAs in pupil-teacher ratios. This is a reflection of the fact that, whilst overall per pupil spending in each school is determined at LEA level, schools themselves have much more discretion over how this money is spent, and in particular they have some control over the pupil-teacher ratio in each class and year in the school.

We next consider the evidence for the endogeneity of school resources with respect to pupil attainment. Table 3 shows the results from likelihood ratio tests comparing, for each subject and resource measure, a standard multilevel model and a simultaneous equation model. All models include a number of controls for pupil background and school characteristics, as described in Section 4. In the standard model, the covariances between the school and LEA residuals across the attainment and resource equations are constrained to equal zero, while in the simultaneous equation model these covariances are freely estimated. Thus we are testing the null hypothesis that $\sigma_u^{(yz)} = \sigma_v^{(yz)} = 0$, which is a test of the exogeneity of the relationship between attainment and resources. Rejection of the null implies that school resources are endogenous to attainment, in which case estimates of the impact of resources on attainment from the standard multilevel model will be biased. We find strong evidence that both per pupil expenditure and the pupil-teacher ratio are endogenous to attainment in science. There is also evidence that staffing and, at the 10% level, expenditure are endogenous to maths attainment. We conclude, however, that both resource variables are exogenous to English attainment.

Having established that both of our school resource indicators are endogenous to attainment in maths and science, we can examine estimates of the residual correlations to assess the direction of selection effects and whether they operate at the school or LEA level or both. The correlation at the LEA level is interpreted as the (residual) association between the LEA mean level of resources (expenditure or staffing) and LEA mean attainment. A strong correlation at this level would suggest a selection effect that is driven by the way in which central government allocates resources to local authorities. The residual correlation at the school level measures the within-LEA association between school resources and school mean attainment. A strong correlation at the school level implies a selection effect that is due to the nature of resource allocation among schools within an LEA, i.e. non-random allocation within LEAs. A dominant LEA-level correlation would suggest that selection is largely the result of central government policy and political choice at local level, as Conservative LEAs tend to be lower spending authorities.

Table 4 shows estimates of the correlation between the school and LEA residuals across the resource and attainment equations in the simultaneous equation model. We discuss only the interpretation of the correlations between resources and attainment in maths and science, since exogeneity tests (Table 3) suggest that resources may be assumed exogenous to English scores. The school and LEA-level correlations between the residuals for expenditure per pupil and attainment in maths and science are negative; these correlations are strongest for science and, for both subjects, the LEA-level correlation is the largest. A negative correlation at the LEA level implies that unobserved LEA factors influencing school expenditure are negatively correlated with the unobserved LEA-level determinants of pupil attainment. Equivalently we may conclude that, even after controlling for a rich set of explanatory variables, there is a negative association between the mean level of expenditure in an LEA and the LEA mean attainment. A negative selection effect is consistent with the policy of compensatory funding where schools with greater learning needs receive more funding per pupil (see Section 2). The evidence suggests that the selection effect is stronger at the LEA level, which is as one would expect, given that the expenditure for education that is notionally allocated to each LEA (the education Standard Spending Assessment discussed in Section 2) is determined by central government on the basis of a formula that explicitly includes many factors likely to be highly correlated with pupil attainment. For example, central government takes the following factors into account when determining the level of each LEA's education SSA: the proportion of immigrants in the area, the proportion of the resident population on benefits and indicators of deprivation. The selection effect is greatest for science, particularly at LEA level. It appears that the socio-economic factors that determine each LEA's allocation for expenditure on education are also more highly correlated with science achievement. Further investigation is required as to why this might be the case but our results clearly indicate that resourcing effects vary across subjects.

The residual correlations between maths and science attainment and the pupil-teacher ratio follow a similar pattern to those for attainment and expenditure, although the correlations are now positive because a high pupil-teacher ratio is an indicator of lower resources. However, the correlations at both levels are stronger than for expenditure, particularly at the school level. The fact that the selection effect is greater for the pupil-teacher ratio, as compared to expenditure, indicates that there is more autonomy for schools to determine how they spend their resources. The large positive selection effect is consistent with the widely held view that education professionals tend to allocate poorer performing pupils into smaller class sizes. This phenomenon may also occur at LEA and school level, whereby schools with lower performing pupils either are allocated or opt for lower pupil teacher ratios. This would come about by LEAs systematically attempting to reduce the pupil-teacher ratio in their most disadvantaged schools and by schools with disadvantaged pupils opting to have a lower pupil-teacher ratio for a given level of expenditure, as compared to their more prosperous counterparts.

In Table 5 we demonstrate the impact of adjusting for endogeneity on estimates of the effects of school resources on pupil attainment. For each subject and resource indicator, standardised coefficients are presented for two models: the standard multilevel model denoted in (1), which assumes that resources are exogenous, and the simultaneous equation model denoted jointly by (1) and (2), which allows for endogenous resource effects. Based on the results from either model, we would predict a statistically significant, though small, improvement in pupils' maths and science progress for an increase in the expenditure per pupil or a decrease in the pupil-teacher ratio, *et ceteris paribus*. When we allow for endogeneity, however, the magnitude of these effects increases substantially. The increase in effect size is expected due the nature of selection implied by the direction of the residual correlations between resources and attainment (Table 4).

To assess the effects of school resources on English attainment, we may interpret the estimates from the standard multilevel model due to the lack of significance of the residual correlations in the simultaneous equation model (Table 3). We find a counter-intuitive negative effect of expenditure per pupil on English progress, and no significant effect of the pupil-teacher ratio. It has been suggested that the school environment has a lesser effect on progress in English than in other subjects, partly because the home environment is relatively more important in determining language development. This might explain why the pupil-teacher ratio does not have a significant impact on pupil progress in English, particularly at the relative low levels of pupil-teacher ratio found in the English education system (relative to world standards). However, it does not explain why expenditure might be negatively related to English progress.

6. Discussion

This paper has adopted a multilevel simultaneous equation modelling approach to determine the impact of school resources on pupil attainment at age 14. The primary objective of the paper was to determine whether additional expenditure on education would lead to improved pupil attainment, clearly an important issue for policy makers attempting to raise standards in education and improve the performance of low achieving groups. The paper, building on previous work using an instrumental variable approach (Levačić et al., 2005), addresses a number of methodological difficulties in this literature, in particular the endogeneity of school resource levels, and the intra-school correlations in pupil responses.

In policy terms our results suggest the following. First, additional resources do have a positive impact on attainment in mathematics and science but not for English. These positive resource effects are particularly strong once we account for the endogeneity of school resources, i.e. once we allow for the fact that in the UK education system more resources are systematically allocated to LEAs and schools that have lower attaining pupils. The magnitude of the effects from the simultaneous equation model suggest that an additional £1000 per pupil in the funding level would increase pupil achievement by on average 0.07 of a level in mathematics and just under 0.2 of a level in science. In contrast, a reduction in the pupil teacher ratio of one would increase pupil achievement by between 0.12 and 0.13 of a level in mathematics and science. To put these potential increases in achievement into context, pupils are expected to improve their achievement by 0.5 of a level each year. Thus one can conclude that these resource effects are important but relatively modest. As has already been discussed a related and important policy question is how the impact of additional resources on educational attainment may differ across different types of student, e.g. those from lower socio-economic backgrounds, different ethnic groups and such like. These questions are addressed in Levačić et al. (2005).

From a policy perspective, this suggests that better funded schools, and those with lower pupil-teacher ratios, have higher pupil attainment *ceteris paribus* than schools with lower levels of resources. The magnitude of the effects suggests that policies to reduce pupil-teacher ratios in secondary schools may be particularly effective, particularly for improving pupil attainment in science and mathematics. This is reassuring for policy-makers as it suggests that schools do use resources efficiently, at least to some extent, in that we find a systematic positive relationship between resource inputs and pupil outcomes for science and mathematics. However, we find insignificant or even negative resource effects for English. In other words, we find no evidence that schools and LEAs that have higher levels of expenditure per pupil and lower pupil-teacher ratios have better pupil attainment in English. This might imply that schools are not efficient in their use of resources in English. However, an alternative possibility is that family background and home environment play a more important role in determining attainment in English, and that we are unable to fully model this process with the available data. This latter suggestion is conjecture at this point and the issue clearly merits further research. An alternative suggestion is that the KS3 English tests are a poorer measure of pupils' 'real' attainment in English than in science and maths. There is some support for this from the fact that English KS3 is not as well predicted by English KS2, as are Maths and science at KS3 by their respective subjects at KS2.

The first strong methodological message from this paper is that any analysis of the relationship between school resources and pupil attainment needs to allow fully for both variation in resource effects across different subjects and for the endogeneity of resource allocation. The magnitude of the resource effects is considerably larger once endogeneity is allowed for, indicating that studies that do not allow for endogeneity will have estimates that are biased downwards.

The paper also makes another important methodological contribution to the literature. Generally the standard instrumental variable method used in this literature to overcome the endogeneity of school resources assumes that any selection bias is operating at the lowest level of observation. In this paper we allow for selection at both the level of the school and the level of the LEA. In the analysis this turns out to be important as there is selection at both LEA and school level. Furthermore, the extent of the selection bias varies by subject and by the nature of the resource variable being considered. Specifically, the school and LEA-level correlations between the residuals for expenditure per pupil and attainment in maths and science are negative, are particularly strong for science and are larger at the LEA-level. What this result implies is that resource allocation in the UK education system is compensatory, i.e. disadvantaged schools and LEAs have higher levels of spending. Furthermore, there is strong selection at the LEA level, reflecting the fact that central government determines the amount allocated to each LEA to spend on education on the basis of a number of socio-economic indicators of disadvantage, many of which are also negatively correlated with pupil attainment. In terms of the pupil-teacher ratio, the correlations at both school and LEA level are stronger than for expenditure, particularly at the school level. The fact that the selection effect is greater for the pupil-teacher ratio is explained by the fact that schools themselves have much discretion over how this money is spent and disadvantaged schools may be more likely to use their expenditure to reduce their pupil-teacher ratio. In conclusion, in models that do not allow for this endogeneity, or only allow for selection at the level of the school, an important source of selection bias will be ignored.

Acknowledgements

We are very grateful for the helpful comments made by the Joint Editor, Antony Fielding, and two referees.

References

Angrist, J., and Lavy, V. (1999). Using Maimonides' rule to estimate the effects of class size on scholastic achievement. *Quarterly Journal of Economics*, **114**, 533-575.

Averett, S. and McLennan, M. (2004) Exploring the effect of class size on pupil achievement: what gave we learned over the past two decades. In Johnes, G. and Johnes, J. (eds) *International Handbook on the Economics of Education*. Cheltenham: Edward Elgar.

Barnett, R., Glass, C., Snowdon, R. and Stringer, K. (2002). Size, performance and effectiveness: cost-constrained measures of best-practice performance and secondary school size. *Education Economics,* **3**, 291-311.

Borland, M. and Howsen, R. (1992). An examination of the effect of elementary school size on pupil academic achievement. *International Review of Education*, **49**, 463-474.

Bradley, S., Crouchley, R., Millington, J. and Taylor, J. (2000). Testing for quasi-market forces in secondary education. *Oxford Bulletin of Economics and Statistics,* **62**, 357-390.

Bradley, S., Johnes, G. and Millington, J. (2001) The effect of competition on the efficiency of secondary schools in England. *European Journal of Operational Research,* **135**, 545-568.

Bradley, S. and Taylor, J. (1998). The effect of school size on exam performance in secondary schools. *Oxford Bulletin of Economics and Statistics*, **60**, 291-324.

Burtless, G. (Ed.) (1996). Does money matter? The effect of school resources on pupil achievement and adult success. Washington, D.C.: The Brookings Institution.

Card, D. and Krueger, A. (1992). School quality and black-white relative earnings: a direct assessment. *Quarterly Journal of Economics*, **107**, 151-200.

Cohn, E. (1997) *Market Approaches to Education: Vouchers and School Choice.* Oxford: Elsevier.

Coleman, J. S., Campbell, E. Q., Hobson, C. J., McPartland, J., Mood, A. M., Weinfeld, F. D., and York, R. L. (1966). *Equality of Educational Opportunity*. Washington DC: Government Printing Office.

Cotton, K. (1996). School size, school climate and pupil performance. *School Improvement Research Series (SIRS), Close-Up #20*, Northwestern Regional Educational Laboratory, Portland, OR.

Dearden, L., Ferri, J., and Meghir, C. (2001). The effects of school quality on educational attainment and wages. *Review of Economics and Statistics*, **84**, 1-20.

Dobbelsteen, S., Levin, J., and Oosterbeek, H. (2002). The causal effect of class size on scholastic achievement: distinguishing the pure class size effect from the effect of changes in class composition. *Oxford Bulletin of Economics and Statistics,* **64**, 17-38.

Dolton, P., and Vignoles, A. (2000). The effects of school quality on pupil outcomes: an overview. In: H. Heijke (Ed.), *Education, Training and Employment in the Knowledge-Based Economy*, pp. 36-52. Basingstoke: Macmillan.

Dustmann, C., Rajah, N., and van Soest, A. (2003). Class size, education and wages. *The Economic Journal*, **113**, F99-F120.

Gibbons, S., Machin, S. and Silva, O. (2006) Competition, Choice and Pupil Achievement. London School of Economics: Centre for Economic Performance Working Paper.

Glennerster, H. (1991) Quasi-markets for education. *The Economic Journal*, **101**, 1268-1276.

Goldstein, H. (2003) *Multilevel Statistical Models*. 3rd edition. London: Arnold.

Griffiths, J. (1996) Relation of parental involvement, empowerment and school traits to pupil academic performance. *Journal of Educational Research,* **90**, 33-41.

Hakkinen, I., Kirjavainen, T., and Uusitalo, R. (2003) School resources and pupil achievement revisited: new evidence from panel data. *Economics of Education Review,* **22**, 329-335.

Hanushek, E. A. (1979) Conceptual and empirical issues in the estimation of education production functions. *Journal of Human Resources*, **14**, 351-388.

Hanushek, E. A. (1986) The economics of schooling: production and efficiency in public schools. *Journal of Economic Literature*, **24**, 1141-1177.

Hanushek, E. A. (1997) Assessing the effects of school resources on pupil performance: an update. *Education Evaluation and Policy Analysis,* **19**, 141-164.

Hanushek, E.A., Rivkin, S.G. and Taylor, L.L. (1996) Aggregation and the estimated effects of school resources. *Review of Economics and Statistics,* **78**, 611-627.

Hoxby, C. M. (2000) The effects of class size on pupil achievement: new evidence from population variation. *The Quarterly Journal of Economics,* **115**, 1239-1285.

Iacovou, M. (2002) Class size in the early years: is smaller really better? *Education Economics*, **10**, 261-290.

Jepsen, C., and Rivkin, S. (2002) What is the trade off between smaller classes and teacher quality? National Bureau of Economic Research Working Paper 9205.

Krueger, A. (2003) Economic considerations and class size. *Economic Journal*, **113**, 34-63.

Krueger, A., and Whitmore, D. M. (2001) The effect of attending small classes in the early grades of college-test taking and middle school test results: evidence from Project STAR. *The Economic Journal*, **111**, 1-28.

Laine, R. D., Greenwald, R., and Hedges, L. V. (1996) Money does matter: a research synthesis of a new universe of education production function studies. In L. O. Picus, and J. L. Wattenbarger (Eds) *Where Does the Money Go? Resource Allocation in Elementary and Secondary Schools*, pp. 44-70. Thousand Oaks, California: Corwin Press.

Lazear, E.P. (2001) Educational production. *Quarterly Journal of Economics*, **116**, 777-803.

Lee, V. and Leob, S. (2000) School size in Chicago elementary schools: effects on teacher attitudes and pupil achievement. *American Educational Research Journal*, **37**, 3-31.

Levačić, R., Jenkins, A., Steele, F. Vignoles, A. and Allen, R. (2005) *Estimating the Relationship Between School Resources and Pupil Attainment at Key Stage 3.* DfES Research Report 679, http://www.dfes.gov.uk/research/data/uploadfiles/RB679.pdf.

Levačić, R., and Vignoles, A. (2002) Researching the links between school resources and pupil outcomes in the UK: a review of issues and evidence. *Education Economics*, **10**, 312-331.

Luyten, H. (1994) School size effects on achievement in secondary education: evidence from the Netherlands, Sweden and the USA. *School Effectiveness and School Improvement*, **5**, 75-99.

Machin, S. and Vignoles, A. (2005) (Ed.) *What's the Good of Education? The Economics of Education in the UK*. Princeton University Press.

OECD (2004) *Education at a Glance.* Paris: OECD.

OFSTED (2003) *National Summary Data Report for Secondary Schools Data*, 2003 Data Version 1.1. London: OFSTED. http://www.ofsted.gov.uk/publications/index.cfm?fuseaction=pubs.summary&id=3500.

Rasbash, J., Steele, F., Browne, W. and Prosser, B. (2004) *A User's Guide to MLwiN version 2.0*. Bristol: University of Bristol. Downloadable from http://www.cmm.bris.ac.uk.

Snijders, T. and Bosker, R. (1999) *Multilevel Analysis*. London: Sage.

Taylor, J and Nguyen, A, (2006) An Analysis of the Value Added by Secondary Schools in England: Is the Value Added Indicator of Any Value? *Oxford Bulletin of Economics and Statistics*, **68**, 203-224.

Todd, P., and Wolpin, K. (2003) On the specification and estimation of the production function for cognitive achievement. *The Economic Journal*, **113**, 3-33.

Wilson, K. (2000) Using the PSID to study the effects of school spending. *Public Finance Review*, **28**, 428-451.

Wößmann, L. (2003) Schooling resources, educational institutions and pupil performance: the international evidence. *Oxford Bulletin of Economics and Statistics*, **65**, 117-170.

Table 1. Descriptive statistics for attainment at age 14, school resource measures and instruments

	n	Mean	Std. Dev.	Min	Max
Pupil-level variables (2003)					
Key Stage 3 Maths score	430061	6.04	1.22	0.14	8.96
Key Stage 3 Science score	430061	5.74	1.02	0.00	7.96
Key Stage 3 English score	430061	5.60	1.09	0.00	7.97
Key Stage 2 Maths score	430061	4.50	0.76	0.11	7.00
Key Stage 2 Science score	430061	4.76	0.58	0.11	6.78
Key Stage 2 English score	430061	4.52	0.67	0.00	6.89
School-Level Variables					
No of FTE pupils (averaged)*	2950	1010.21	333.17	162.67	2402.33
No of FTE pupils, lagged (1999)	2950	952.72	321.58	142.00	2361.00
Capacity utilisation (averaged)*	2950	0.98	0.15	0.33	2.50
Staffing variables					
Pupil/teacher ratio (averaged)*	2950	16.46	1.27	10.49	21.42
Pupil/Non-teaching staff (averaged)*	2950	56.37	16.51	8.35	161.42
Financial variables					
Expenditure per pupil (averaged)*	2950	2935.13	370.05	2053.60	8992.72
Party in control of LEA	**1998 (%)**	**1999 (%)**	**2000 (%)**	**2001 (%)**	**2002 (%)**
Conservative	10.88	10.20	13.61	19.05	21.77
Labour	58.50	57.82	50.34	49.66	45.58
Liberal Democrats	6.12	7.48	7.48	5.44	4.76
No overall control	24.49	24.49	28.57	25.85	27.89
n	147	147	147	147	147

*Variables are averaged over 2000/01 to 2002/03.

Table 2. Variance components and intra-class correlations for pupil attainment at age 14 and school resources

	Pupil attainment in …					
	Maths		Science		English	
	Est.	(SE)	Est.	(SE)	Est.	(SE)
Pupil attainment						
Between-LEA, $\sigma^2_{v(y)}$	0.009	(0.001)	0.012	(0.002)	0.004	(0.001)
Between-school within-LEA, $\sigma^2_{u(y)}$	0.029	(0.001)	0.034	(0.001)	0.089	(0.002)
Between-pupil within-school, $\sigma^2_{e(y)}$	0.212	(0.000)	0.283	(0.001)	0.330	(0.001)
Intra-LEA correlation[a]	0.036	-	0.036	-	0.009	-
Intra-school correlation[a]	0.152	-	0.140	-	0.220	-

	School resource variables	
	Est.	(SE)
Expenditure per pupil		
Between LEA, $\sigma^2_{v(z)}$	0.165	(0.026)
Between-school within-LEA, $\sigma^2_{u(z)}$	0.871	(0.023)
Intra-LEA correlation[b]	0.159	-
Pupil-teacher ratio		
Between LEA, $\sigma^2_{v(z)}$	0.095	(0.018)
Between-school within-LEA, $\sigma^2_{u(z)}$	0.935	(0.024)
Intra-LEA correlation[b]	0.092	-

[a] The total variance in age 11-14 progress is $\sigma^2_{(y)} = \sigma^2_{v(y)} + \sigma^2_{u(y)} + \sigma^2_{e(y)}$ and the total between-school variance is $\sigma^2_{v+u(y)} = \sigma^2_{v(y)} + \sigma^2_{u(y)}$. The intra-LEA and intra-school correlations are respectively $\sigma^2_{v(y)} / \sigma^2_{(y)}$ and $\sigma^2_{u+v(y)} / \sigma^2_{(y)}$.

[b] The intra-LEA correlation in expenditure is $\sigma^2_{v(z)} / (\sigma^2_{v(z)} + \sigma^2_{u(z)})$.

Notes: (1) Attainment and resource variables have been standardised; (2) All estimates are from fitting separate multilevel models for attainment and school resources; (3) Estimates for attainment are adjusted for prior attainment (age 11 subject scores) and therefore represent variance in progress between ages 11 and 14.

Table 3. Results from likelihood ratio tests of the exogeneity of school resource variables by subject

	Maths	Science	English
Expenditure per pupil	5.3	26.8	0.4
	p=0.071	p<0.001	p=0.819
Pupil-teacher ratio	42.5	81.3	1.8
	p<0.001	p<0.001	p=0.407

Note: Figures in each cell are the likelihood ratio test statistic and p-value. Each test is based on 2 degrees of freedom.

Table 4. Covariances (and correlations) between LEA and school level random effects across simultaneous equations for pupil attainment and school resources

	Pupil attainment at age 14		
	Maths	Science	English
	Cov (SE) **Corr**	Cov (SE) **Corr**	Cov (SE) **Corr**
Expenditure per pupil			
LEA level	-0.0033 (0.0012)	-0.0063 (0.0016)	0.0017 (0.0019)
	-0.348	**-0.510**	**0.164**
School level	-0.0055 (0.0014)	-0.0236 (0.0017)	0.0025 (0.0030)
	-0.079	**-0.283**	**0.016**
Pupil-teacher ratio			
LEA level	0.0170 (0.0030)	0.0196 (0.0035)	0.0048 (0.0026)
	0.831	**0.832**	**0.332**
School level	0.0720 (0.0026)	0.0951 (0.0033)	0.0286 (0.0039)
	0.629	**0.681**	**0.141**

<u>Notes</u>: (1) Estimates are from fitting six separate simultaneous equation models, for pupil attainment in each subject paired with a school resource variable; (2) All models include a range of pupil (in the attainment equations), school and LEA characteristics (see Appendix for details).

Table 5. Estimated effects of school resources on pupil attainment at age 14

	Standard multilevel model		Simultaneous equation model	
	Est.	(SE)	Est.	(SE)
Expenditure per pupil				
Maths	0.0081	(0.0037)	0.0224	(0.0037)
Science	0.0084	(0.0043)	0.0695	(0.0043)
English	-0.0177	(0.0076)	-0.0273	(0.0076)
Pupil-teacher ratio				
Maths	-0.0056	(0.0030)	-0.1262	(0.0030)
Science	-0.0097	(0.0034)	-0.1679	(0.0034)
English	-0.0040	(0.0061)	-0.0502	(0.0062)

Notes: (1) Because attainment and resource variables are standardised, coefficients can be interpreted as partial correlations; (2) All estimates are from models that control for a range of pupil, school and LEA characteristics (see Appendix for details), including age 11 subject scores.

Appendix: Explanatory variables in the final model specification

	Model equation	
	Attainment	Resource
School resources[i]		
Expenditure per pupil	X	
Pupil-teacher ratio	X	
Pupil non-teaching ratio	X	
Instruments		
Years of political control of local education authority (LEA) in 2002, by party (Labour, Conservative, Liberal, no overall control)		X
Lagged school size: number of full-time equivalent pupils in school in 1999		X
Pupil characteristics		
Key stage 2 subject score[ii]	X	
Gender	X	
Birth date (measured in days since 1 September 1989)	X	
Special education needs (SEN)Action/Action Plus	X	
SEN statement[iii]	X	
Eligible for free school meals[iv]	X	
Ethnicity (white, Indian, Pakistani/Bangladeshi, other South Asian, Black, Chinese, mixed)	X	
First language not English	X	
School characteristics		
School has sixth form[v]	X	X
Statutory lowest age of pupil (11, 12 or 13)	X	X
School gender (mixed, boy-only school, girl-only school)	X	X
School type (comprehensive, grammar, secondary modern, other)[vi]	X	X
Religious denomination (non-denominational, Catholic, Church of England, other Christian, Jewish)	X	X
Proportion of pupils eligible for free school meals[vii]	X	X
Proportion of pupils with additional educational needs (AEN)[viii]	X	X
Specialist school[ix]	X	X
Special measures school[x]	X	X
School is participant in Excellence in Cities or Education Action Zones (government policy measures which provide additional funding and support for schools in deprived urban areas)	X	X
Beacon school[xi]	X	X
Leading Edge Partnership school[xii]	X	X
Leadership Incentive Grant school[xiii]	X	X
Teachers’ pay ratio averaged[xiv]	X	X
School in urban local authority district	X	X
Capacity utilisation[xv]	X	X
Lagged school attainment: proportion 5+ GCSE grades A*-C in 1999		X
Census output area variables (from 2001)		
Proportion unemployed	X	
Proportion black, Chinese, Bangladeshi/Pakistani, Indian	X	
Proportion lone parent households	X	
Proportion National Vocational Qualification Level 1 or lower	X	

[i] Averaged over 2000/01 to 2002/03.

[ii] English, maths or total KS2 scores included respectively in equations for English, maths and science KS3 attainment.

[iii] Children with learning difficulties or a disability may be classified as Special Educational Needs (SEN). School Action/Action Plus are interventions which provide additional support for pupils not making progress in school. Pupils with more severe special educational needs may be assessed and given a statement of SEN which guarantees extra educational provision which cannot be provided from normal school resources.

[iv] Whether a child is eligible for free school meals is the standard indicator of poverty/deprivation in the English school system.

[v] i.e schools with pupils aged 11 to 18, rather than 11 to 16.

[vi] Note that grammar schools select on the basis of ability at age 11.

[vii] Averaged over the 3 years up to 2003

[viii] Percentage of children with ethnic minority backgrounds identified as underachieving.

[ix] The Specialist Schools Programme provides additional Government funding for schools to establish distinctive identities through their chosen specialisms. There are ten areas of specialism: arts, business & enterprise, engineering, humanities, languages, mathematics & computing, music, science, sports and technology. Specialist schools have a focus on those subjects relating to their chosen specialism but must also meet the National Curriculum requirements and deliver a broad and balanced education to all pupils.

[x] A school judged by inspectors to be "failing or likely to fail to give its pupils an acceptable standard of education" (Schools Inspection Act, 1996).

[xi] The Beacon Schools programme was established in 1998. It identified high performing schools across England (designated as beacon schools) and was designed to build partnerships between these schools and represent examples of successful practice, with a view to sharing and spreading that effective practice to other schools to raise standards in pupil attainment.

[xii] Leading edge partnerships: A central government programme which provides funding for partnerships between schools. The programme encourages partnerships between high-performing schools and weaker schools with the objective of raising standards.

[xiii] Leadership incentive grants: A central government programme which was designed to strengthen leadership within schools, particularly in deprived areas. The programme provided additional funding and encouraged collaboration between schools.

[xiv] Teachers' pay relative to average gross weekly full-time earnings. The variable is at local authority level. It is averaged over the same years as the other variables.

[xv] Averaged over 2000/01 to 2002/03.