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Aspirations, Expectations and Education Outcomes for Children in Britain: Considering Relative Measures of Family Efficiency.

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Abstract.

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We apply the distance function methodology to the analysis of household production functions. In particular, the family's ability to efficiently and simultaneously generate a dual education (mathematics and reading) output for their child subject to multiple, constrained input availability is addressed. A stochastic production frontier model is estimated and significant shortfalls from the productive ideal are established, indicating that there is substantial scope for improvement in the production of childhood education outcomes amongst British families. There is also substantial variation across families in the efficiency of their production. Implementing a conditional mean model, inefficiency is shown to be strongly related to both family and child-centric variables and, in particular, to the educational aspirations of the parents for their child.

Keywords: childhood education, family, performance, production efficiency, aspirations, expectations.

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1. Introduction

The essence of human capital theory is that expenditures on education and training are investments individuals make in themselves to increase their marketable skills, productivity and earnings (Becker, 1963; Mincer, 1974; Hanushek, 1986). The creation of human capital is not restricted to formal schooling, however, much of it takes place in the home (Schwarze, 2004), particularly during the preschool stage of the life cycle and throughout childhood (Raaum et al., 2003; Tam et al., 2004), implying that the family may play a major role in the acquisition of human capital for children.

Empirical studies of intergenerational influences on educational attainments have established a positive relationship between the education outcomes of parents and those of their children (Dearden et al., 1997; Gdde and Schnabel, 1998; Meghir and Palme, 2003). This may be interpreted in many ways, for example, as evidence of the transmission of parental aspirations (Farr and Vella, 2007), of the greater propensity of more educated parents to invest in the education of their children (Blundell et al., 2005; Blow et al., 2005), and/or a combination of both (Dearden et al., 2002; Heckman and Li, 2004). It would also seem that the educational aspirations of parents, and a positive expectation from the child themselves, may play a strong role in the child's success at school (Carneiro and Heckman, 2003).

The family may therefore be the relevant unit of analysis in this process and can be viewed as an economic unit sharing consumption and allocating production at home and in the market (Hess and Shin, 2000; Haveman and Wolfe, 1995). In this paper, we consider what determines positive education outcomes for children in Britain (at 11 and 16 years of age) within this family context. There have been many studies of similar outcomes for children in the past (a recent survey is provided by Blundell et al., 2005); our contribution is to consider how the family acts to produce these outcomes simultaneously and efficiently by applying the distance function methodology¹ to the analysis of household production functions. In particular, the family's ability to efficiently generate education output for their children subject to multiple (but constrained) input availabilities is addressed.

The distance that the observed family's combined output sits from the estimated

¹ Shephard, 1970; Luenberger, 1992; Chung and Fare, 1995; Chambers et al., 1998; Coelli, 2000.

production frontier can be interpreted as a measure of their technical inefficiency or, alternatively, an indication of how much more output they could have had if they had used their input mixture differently (Lovell, 1993; Coelli and Perelman, 2000). This provides a comparable measure, with a natural interpretation, that can be used to make relative statements concerning successful childhood education outcomes across families.

The distance function methodology has been used in a small number of influential papers for the analysis of industries characterized by jointness in production, such as fisheries (a survey is provided in Bjorndal et al., 2002) and railways (Coelli and Perelman, 2000). A recent study by Jorgenson et al., (2007) finds that the approach is also useful for explaining total factor productivity across industries in the United States. Applications to family based production functions are rare, (an example is provided in Agee et al., 2005); perhaps reflecting the scarcity of relevant family based longitudinal data sources.

This paper therefore helps to fill a gap in this area of the literature by applying efficiency methods to evaluate the family's production of their child's education; by explicitly considering the role of parental aspirations and child expectations in the performance of the family's production of education (math and reading) for the child; and by relating this performance to the family's technical efficiency. The distance function is discussed in section 2 of the paper, the modelling and estimation procedures are considered in section 3, the data and variable definitions are described in section 4, results are presented in section 5, and section 6 concludes.

2. The distance function

The distance function provides a very general description of the technology required and, as the dual to the cost function, has well established theoretical interpretations (see Cornes, 1992 page 125). With a given technology and observed input quantity, the output distance function provides the maximum proportional amount that output can be expanded (or, alternatively, the minimum scalar division of output that is consistent with implied input and production levels).

Following Shephard (1970, chapter 9), let x denote a vector of inputs $x = (x_1, x_2, \dots, x_n)$ with $x \geq 0$, and let y denote a vector of outputs with $y \geq 0$. Let

$X = \{x / x \geq 0\} = R_+^n$ and $Y = \{y / y \geq 0\} = R_+^m$, then $P: X \rightarrow Y$ is the production correspondence mapping points of X into subsets of Y (Shephard 1970, page 179).

Whilst there may be many possible combinations of input and outputs, only those laying on the boundary (the frontier) are contained in the efficient subset. The distance function $D_o(x, y)$ of the output set $P(x)$, $x \in X$ of the production correspondence $P: X \rightarrow Y$ is:

$$D_o(x, y) = \text{Min}\{\theta : (y / \theta) \in P(x)\} \quad (1)$$

The output distance can be described as the ratio of the actual output to the maximum output that can be obtained with given inputs. It is non-decreasing; positively linear homogeneous and convex in y , and decreasing in x . It is smaller or equal to 1 (Coelli, 1998; page 328). An output vector y belongs on the output boundary for an input vector x such that $P(x) \neq \emptyset$ if and only if $D_o(x, y) = 1$. The properties of the function are commonly discussed in the literature (see Shephard 1970, page 180).

The relative distance between the operating point and the boundary can be interpreted as a measure of technical inefficiency (Farrell, 1957) or as effective resource utilization (Debreu, 1951, pages 284-5). When operating on the output frontier, $D_o(x, y) = 1$ and efficiency is said to be 100%; as productivity falls short of the frontier, $D < 1$ and efficiency is less than 100%. The relative measure of this efficiency in the production of education outcomes for children across families is the major focus of the empirical analysis below.

3. Model and Estimation

Following Kumbhakar and Lovell (2000, page 64), $y_i = f(x_i; \beta) \exp(-u_i)$ where β is the vector of technology parameters to be estimated and u_i captures technical inefficiency for family i . Note that $\exp(-u_i)$ is equal to the ratio of actual output to maximum possible output, $y_i / [f(x_i; \beta)]$, which is less than 1 (Kalarajan and Shand, 1999, page 152). As mentioned above, if the family is fully technically efficient, output will lay on the production frontier, $y_i / [f(x_i; \beta)] = 1$ and $D_o(x_i, y_i; \beta) = \exp(-u_i) = 1$.

So far this production process is deterministic, allowing for family specific random shocks (v_i), distributed exponentially, provides for a stochastic production function (Aigner et

al., 1977; Meeusen and van den Broeck, 1977):

$$y_i = f(x_i; \beta) \cdot \exp(-u_i) \cdot \exp(v_i) \quad (2)$$

with two error terms (u_i and v_i). The stochastic error term (v_i) may be interpreted as bad states of the world facing the family, and u_i measures technical inefficiency for the family. Adopting the popular Cobb-Douglas specification², stochastic production is given by:

$$\ln(y_i) = \alpha_0 + \sum_{j=1}^k \beta_j \ln(x_{ij}) + v_i - u_i \quad (3)$$

Where α is the intercept term; and x is a vector of j regressors measuring a range of family input characteristics.

Estimating a relationship with a composed error term ($\varepsilon_i = v_i - u_i$) raises complications as it is important to have an accurate measure of one error separate to the other. Jondrow et al., (1982) show that it is possible to extract information about u_i contained in ε_i conditional on the distribution of v_i . Kumbhakar and Lovell (2000) and Coelli (2000) discuss alternative specifications. The truncated normal model is adopted here and the following distributional assumptions are made (following Kumbhakar and Lovell 2000, page 83):

- i. $v_i \sim \text{iid } N(0, \sigma_v^2)$.
- ii. $u_i \sim \text{iid } N^+(\mu, \sigma_u^2)$.
- iii. v_i and u_i are distributed independently of each other, and of the regressors.

Where μ is the non-zero mode of the normal distribution assumed for u (truncated below at zero). The relevant density functions are presented and discussed in Kumbhakar and Lovell (2000). Jondrow et al., (1982) provide the conditional distribution of u given ε , and show that the mean (or the mode) of $f(u|\varepsilon)$ can be used to estimate the technical efficiency of each family: $TE_i = \exp\{-\hat{u}_i\}$

To reiterate, the stochastic distance function allows for the existence of technical inefficiency in the production process and focuses attention on the error term (the inefficiency term u) rather than the estimated input coefficients. Following Battese and Coelli (1993, 1995), an inefficiency term with mean conditional on a set of variables can be introduced into

² Log-likelihood ratio tests reject the Translog in favour of the Cobb-Douglas stochastic frontier model (these results are available from the authors on request).

the stochastic frontier function thereby enabling the mean of the inefficiency term to vary with a set of explanatory variables. The inefficiency term u_i is:

$$u_i = \delta_0 + \delta_i z_i + w_i \quad (4)$$

Where δ_0 is the constant term, z_i is a vector of explanatory variables potentially associated with technical inefficiency of production, and δ_i is a vector of estimated coefficients. The random variable w_i follows a truncated normal distribution with zero mean and variance σ_u^2 .

Using longitudinal panel data allows us to account for unobservable individual heterogeneity more comprehensively. It also enables us to explore family efficiency in the longer run. The intertemporal conditional mean model is specified as:

$$\ln(y_{it}) = \alpha_0 + \beta_1 \ln x_{1it} + \beta_2 \ln x_{2it} + \dots + \beta_n (Year_{it}) + v_{it} - u_{it} \quad (5)$$

with inefficiency term:

$$u_{it} = \delta_0 + \delta_1 z_{1it} + \delta_2 z_{2it} + \dots + \delta_n (Year_{it}) + w_{it} \quad (6)$$

where t is time, the $Year_{it}$ term in equation (5) captures the change in output between different time periods, and $Year_{it}$ in equation (6) captures the change of inefficiency with respect to time.

4. The data.

The data are taken from the National Child Development Survey (NCDS) which is an ongoing longitudinal study of children born in Britain (England, Scotland and Wales) between March 3 and 9, 1958. This study concentrates on child education outcomes at 11 and 16 years of age and uses information from the initial Perinatal Survey and subsequent three waves of data: NCDS1 collected in 1965 when the children were aged 7; NCDS2 collected in 1969 (aged 11); and NCDS3 collected in 1974 (aged 16). In these waves of the NCDS data, information was collected by surveying parents, head and class teachers, school health visitors and the subjects themselves (who also sat aptitude tests). Retaining only those families who have complete information for the variables used in the analysis below leaves 5624 families with NCDS children at age 11, and 4298 families with NCDS children at age

16.³ Of which 3100 families appear in both samples, generating a balanced panel data set for these children when they were aged 11 and 16. Brief variable definitions and sample statistics are presented in Table 1.

The NCDS dataset is well suited for exploring issues to do with education and there have been many studies of single educational outcomes and/or returns from education using these data (Blundell et al., 2005, page 45). A few of these studies also consider aspirations and effort on behalf of the child, parents, or both (a recent survey is provided by Todd and Wolpin, 2003, see also De Fraja et al., 2006). Our contribution to this research area is to apply the distance approach to investigate families' relative efficiency in producing a combined childhood education outcome.

4.1 Education outcomes

Our analysis of the efficiency of the family's production function considers two educational outcomes simultaneously and uses the mean of the average percentage of correctly answered items in each of two tests as the dependent variable. The two tests are: (i) a math test and (ii) a reading score test the cohort members took when they were (a) aged 11 and (b) aged 16 years old.

The test results for the 11 year old children (recorded in NCDS2) are generated from tests that were given to the children by their school teachers: a reading comprehension test (35 items); and a mathematics test (40 items). In order to ensure comparability, candidates were issued with exactly the same instructions so that no child would start with an advantage over the next. The tests were given on two separate days of the week: reading on the first day, and math on the second day⁴. The reading and math tests at age 16 (NCDS3) were similarly administered following the same instructions.

The reading comprehension tests at age 11 and 16 were actually the same: they had the same questions and required the child to choose words that appropriately completed given

³ The NCDS is not a perfect data source. Perhaps its most serious limitation is attrition between the waves. There is a tendency for this attrition to be concentrated amongst those individuals displaying lower ability and educational qualifications, in particular as the cohort ages into post-childhood years (Dearden et al., 1997). This attrition is typically assumed to be exogenous (Dearden et al., 2002). We similarly assume random attrition (especially given that the focus here is on childhood education success), some of the implications of this assumption are further explored with the balanced panel data analysis below.

⁴ A more detailed description of tests questions how they were administered can be found on the CLS website. All the tests were devised by the National Foundation for Education Research.

sentences. The test was designed to parallel the Watts-Vernon 1947 test of reading ability⁵. There were 35 items in total: correct answers received one point, incorrect answers received no points. When the children were aged 11, the math test contained 40 items involving numerical and geometric work and 31 items when the children were aged 16. Most of the questions at age 11 were answer-directly questions with only a few being involving multiple-choice answers. The test at age 16 contained more advanced math problems and was suitable for children who had studied a wider mathematics curriculum. It contained both numerical and geometric questions with twenty-seven multiple-choice questions and four true-or-false questions. The maximum available scores for the math tests were 40 for the 11 year olds and 31 for the 16 year olds.

Brief variable definitions and sample statistics are presented in Table 1. On average, the younger children do marginally better in the reading test than the math test (49% compared to 46%), this gap across skills widens for the older children (to 77% and 45%, respectively). Reading and math test results are also, unsurprisingly, positively correlated at both age levels for the cohort child (0.679 at age 11 and 0.612 at age 16) as is shown in Table 2.

4.2. The inputs

The factors of production to be included as determinants of the education outcome are two family capital input measures and a family labour input measure. There are very many inputs that could be considered to be relevant and there is a vast literature discussing a range of these.⁶ Todd and Wolpin (2003: page F14) argue, however, that including a range of variables to proxy family inputs may confound interpretation rather than aide it. Furthermore, measures of inputs with a natural physical unit have the important advantage of being comparable across region or time without the need for questionable transformation (Ruggiero, 1996; Afonso and St. Aubyn, 2006).

The two measures of family capital input included in the analysis below are the: number

⁵ Originally developed by Watts and Vernon in 1947 to measure relative reading standards across the UK.

⁶ It is non-trivial to address the relevant confounding factors that may impact on children's cognitive and behavioural development (Björklund et al., 2007). Amongst the determinants often included in studies of education outcomes are parental social class, parental education, regional location (including the quality and availability of neighbouring schools, Hastings and Weinstein, 2007), local facilities, ethnic background and language spoken at home (Levitt and Dubner, 2005), current and future family disposable income (Acemoglu and Pischke, 2001; Plug, 2005; Blanden et al., 2002; Blow et al., 2005), number and placement of siblings (Ginther and Pollack, 2003; Black et al., 2004), the occurrence of family restructuring (Galdeano and Vuri, 2004), and a range of child ability measures (Blundell et al., 2005).

of rooms in the accommodation; and the number of facilities in the accommodation (including bathrooms, indoor lavatories, kitchen and hot water supply). The family labour input is measured as the number of adults in the household⁷. As there are no children in the sample living in a family without at least one adult present; the family labour input variable accordingly ranges from 1 to 7.

4.3. Aspirations, expectations and other control variables in the inefficiency term

As discussed above, a distinction of the stochastic distance function is the focus on the error term (in particular, the efficiency term) as well as the potential impact of the productive inputs. Following Battese and Coelli (1995), an efficiency term with a mean conditioned on a set of variables is introduced into the stochastic frontier function to explore factors that may be associated with differences across families' productive efficiencies. The explanatory variables included are family based (parental aspirations, level of parental education, family structure, family financial situation) and child-centric (child expectations, child's sibling position in the household, child's innate ability, child's innate health, and the child's gender).

4.3.1. Family based.

Parental aspirations

A major aim of this paper is to consider the relationship between parental aspiration and the family's child education production. Many papers stress the important potential effects of parental aspirations on child educational attainment and find a strong positive relationship between the two (e.g. Weiner and Murray 1963; Vollmer, 1986; Jayaratne, 1987; Kan and Tsai 2005). A binary variable is constructed: equal to zero if the parent expected the child to leave school at the minimum legally determined school leaving age; and equal to one if the parent expects the child to remain enrolled in full time education until or after 18 years of age.⁸ A positive relationship between parental aspirations and family efficiency is expected.

Considering the summary statistics reported in Table 1 in more detail, of the variables reported both when the cohort child is aged 11 and aged 16, the largest change is reported for

⁷ As discussed in Jacobs, Smith and Street (2006, page 30), unless there is a specific interest in the deployment of different labour types, it may be appropriate to aggregate into a single measure of labour input, using appropriate weighting. In addition, when the evidence for weighting is not strong, simple aggregation of inputs leads to a more parsimonious model.

⁸ Perhaps surprisingly, there is little correlation between the mother's education and the parental educational aspirations for the child in the NCSD data: a 5% correlation between mother's school-leaving age and the parental aspiration towards child education at age 11, and a 28% correlation at age 16.

parental aspiration. When the cohort child is aged 11, 98% of the parents wanted their child to stay at school up to or after 18, when the child is aged 16 this percentage has halved to 49% (these values are 98% and 52%, respectively, for the balanced samples). Table 2 provides correlation results for parental aspirations and the cohort child's test results across time (using the balanced samples). Perhaps unsurprisingly, reading scores and the mathematics scores are highly correlated in both time periods or, in other words, children who get a high score in the math test are more likely to obtain a high score in the reading test and vice versa. Similarly, test results tend to be correlated across ages (children who do well in a test when they are 11 years old tend to do well in the test when they are 16 years old).

Table 2 also reveals that parental aspiration and test scores have little correlation when the child is 11 years old (7.7% and 7%, respectively for the math and reading test respectively), but have a comparatively large correlation when the child is 16 years old (45.1% and 47.0%). As children age, their parents appear to adjust their aspirations to be more consistent with their child's actual test score status. There is little difference, however, in the correlation between parental aspiration when the child is aged 16 and the 11 year old tests results, and the correlation between parental aspiration when the child is aged 16 and the 16 year old tests results.

In other words, children who do well in their 11 year old tests typically do well in the 16 year old tests and parents are revising their aspirations substantially post the 11 year old test results. These relationships are explored more fully below.

Level of parental education

As discussed above, empirical studies of intergenerational influences on educational attainments have established a positive relationship between the education outcomes of parents and those of their children (Dearden et al., 1997; Gödde and Schnabel, 1998; Meghir and Palme, 2003). Years of schooling for each of the NCDS child's parents are proxied by assuming the parent entered school at age 5, and subtracting this from the information that is available on the parent's school leaving age. We expect a positive relationship between either parents' education and the family's performance at producing child educational output.

Family structure

Family structure is generally categorised into intact family structure (coded as one) or non-intact family structure (coded as zero). Intact structure is defined here to be families

where both the biological mother and the biological father are present at the time of surveying. Non-intact family structure includes all the other family types. In the NCDS surveys non-intact families make up a small proportion of the whole sample (8% of families for the 11 year olds and 7% per cent for the 16 year olds). It is expected that intact families will produce more efficiently than non-intact families.

Family financial situation

A direct pecuniary measure of the family financial situation is not available in the NCDS survey, however, information on whether the NCDS child was currently in receipt of free school meals is available. This is a commonly used proxy in the literature for family financial difficulties as only children from low income families are entitled to free school meals (Blanden and Gregg, 2004; Dearden, 1999; Ermisch and Francesconi, 2001). Families encountering financial difficulties are expected to be less efficient producers of childhood education outcomes.

4.3.2. Child-centric measures.

Child's expectations

Unlike other outputs produced in industry, a child's educational output may also be affected by their own expectations (Behnke, Piercy and Diversi, 2004; Carneiro and Heckman, 2003). With given inputs, a positive expectation towards study from the child themselves may facilitate the education production process and vice versa. In the NCDS2 survey (when the cohort children are 11 years old), there is not a specific question asking students what their longer term educational expectations were. We instead took whether the child is reluctant to go to school or not as a measure of the child's attitude and created a suitable binary variable. In the NCDS3 survey (when the cohort children are aged 16), information about "whether the student wants further education" is available. A binary variable is included in the analysis which is set equal to one for those children who want to stay in school and zero those who want to leave school.

Child's sibling position in the household

Children in different sibling positions in a household may receive different care and attention from parents and thus have different child outcomes (Becker and Tomes, 1976; Heer, 1985). In particular, recent studies have found first born children receive more quality time with their parents (Price, 2008) and that higher sibling positions (ie., having more older brothers or

sisters) are associated with lower educational attainment (Black et al., 2005). We use the NCDS sample child's position amongst their siblings to control for this possible inefficiency effect. Four binary variables are created indicating the child's sibling position being: the first child, the second child, the third child, the fourth child or after. We expect to observe higher family productive efficiency for a child in a lower sibling position in the household (children who are the first born in their household are the omitted category in the analysis below).

Child innate ability

Innate ability could reasonably be expected to have a major influence on the educational production process (Becker and Tomes, 1979) and there may be substantial variation in the innate abilities of children (Deller and Rudnicki, 1993). Information on the NCDS children's oral, reading, creativity and number work abilities when they were 7 years old was provided by schoolteachers via school questionnaires as part of the NCDS1 survey. Teachers were asked to grade students as having poor, below average, average, good or excellent abilities in each of these four tasks. By assigning scores of one to five to each ability to indicate poor, below average, average, good or excellent abilities (and giving the four types of abilities - oral, reading, creativity and number work - an equal weight), an total innate ability score is calculated. The score ranges from 4 to 20, with a median of 12. A binary integrated innate ability variable is then created: if the child's innate ability score is below the median (coded as one) or above the sample median (coded as zero).

Child innate health

There have been many studies finding a relationship between children's health status and childhood education outcomes (Behrman and Rosenzweig, 2004; Case et al., 2005). The birth weight of the NCDS child is used here as an indicator of their early health status. Information on specific birth weights was recorded in the initial Perinatal Mortality Survey of the NCDS. A binary variable indicating low birth weight is included, where a birth weight less than 2500g is considered to be a low birth weight indicative of potential problems in later life (Conley and Bennett, 2000; Olsén, Myhrman and Rantakallio, 1994). A negative relationship between low birth weight and efficiency is predicted.

Child gender

Boys and girls may perform differently in tests and they may have different relative educational attainments at different ages (e.g. Stobart et al, 1992; Charles et al., 2003;

Burgess et al., 2004). The relative efficiency levels for male and female education outcomes are considered here by including a male indicator variable (male is coded as one and female is coded as zero).⁹

5. Results

Results for the frontier estimation are presented in Table 3: columns (1) and (2) present the results at age 11 for the unbalanced cross sectional sample; columns (3) and (4) provide analogous cross sectional results at age 16; columns (5) to columns (8) provide the corresponding balanced sample cross-sectional estimates; and columns (9) and (10) report balanced panel estimates. The results for the Coelli (1995) one-sided test for the existence of the efficiency term (results shown in the final row, of the third panel, of Table 3) consistently indicate heterogeneity across families in the production process and support extending the stochastic frontier model to consider the determinants of this productive efficiency. The presence of technical inefficiency is also indicated by the significant estimates of gamma ($\gamma = \sigma_u^2 / (\sigma_u^2 + \sigma_v^2)$): the null hypothesis of no inefficiency ($\gamma = 0$) in families' production of child education is rejected. The estimated values of gamma also suggest a reasonable proportion of the variation in the output among the sampled families is due to differences in their technical efficiencies.

The final panel of Table 3 reports the family efficiency measures for the NCDS children. When the NCDS children are 11 years old (column 1) the average family efficiency is 58.3%, when they are aged 16 (column 3) the average family efficiency has increased to 64.9%. There are clearly sizeable shortfalls from the productive ideal amongst British families. There is also substantial variation across families in the efficiency of their production (families range from 5.4% of possible efficiency to 97.4% when the child is aged 11; and 10.7% to 98.7% when the child is aged 16).

Comparisons of families with different child education production efficiencies are provided in Table 4, the families at the two ends of the efficiency distribution are considered in this table: Group 1 contains families with efficiencies below 25%; and Group 2 contains families with efficiencies above 75%. Columns 1 and 2 list the comparisons of the two groups for the families when the children are 11 years old (NCDS2). Columns 3 and 4

⁹ The initial Perinatal Mortality Survey records the gender of NCDS children.

provide analogous comparisons when the children are 16 years old (NCDS3).

Children from families with low childhood education production efficiency tend to have lower average educational attainment than children from families with high efficiencies when the children are 11 years old (14.8% of average correctly answered items in Group 1 and 69.7% in Group 4). The input variables do not reveal noteworthy changes across the groups (consistent with the assumption that the inputs are independent of technical efficiency). As efficiency increases (from column 1 to column 2), parental aspiration increases substantially, as does parental education, the child's expectations and being male. The other variables tend to decrease from Group 1 to Group 2, these findings are consistent with the expected relationships discussed in section 4 above. Analogous, but typically stronger, results are found comparing the two extreme efficiency groups when the children are 16 years old (NCDS3). This is particularly so for parental aspiration, child expectation, receiving free school meals, and child innate ability.

5.1. Producing education outcomes

Returning to consider the results for the maximum likelihood estimation of the production of childhood education (panel 1 of Table 3), strict interpretation of estimated parameters is rarely carried out in the literature on production functions (an exception is provided in Agee et al., 2005). In part this may be due to each parameter representing both the marginal productivity of the relevant input and its relative factor usage (Tyler and Lee, 1979; page 438).

The family capital inputs are significantly related to the test results; more rooms and more facilities in the family accommodation are both found to be associated with higher test results. In contrast, the family labour input (the number of adults in household) is not found to be significantly related to the family's production of child education outcomes. This is true at both age levels, for the cross-sectional (unbalanced and balanced samples) and for the panel analysis.

It may be argued that the relationship between the child and the adult is important with respect to the labour input the adult makes in the child's education. For example, the child's parents may be willing to devote more time to the child, in which case, the aggregation of all adults present in the household into a single labour input measure may not be the most

suitable measure. However, when efficiency is estimated with the number of parental figures as the labour input in childhood education production, rather than the number of adults in the household, the efficiency results are not found to be significantly different.¹⁰ The aggregation of all adults into a single labour input measure does not generate substantially different results in this case: the presence of additional adults (parental or otherwise) in the household is not found to be directly related to childhood education outcomes in the family.

5.2. Explaining inefficiency

As discussed above, the inefficiency term and its determinants are of particular interest to this study. The second panel of Table 3 presents results when the explanatory variables are included in the conditional mean model. It should be noted that the dependent variable measures inefficiency (rather than efficiency) and the results need to be interpreted accordingly. In general, the estimated coefficients are consistent with the prior expectations discussed in section 4 above.

Considering these results in more detail, higher parental aspiration is consistently found to be significantly related to lower inefficiency indicating that parents who want their child to stay at school after the minimum school leaving age are more efficient producers of childhood education. Similarly, the negative coefficients for the parental education variables imply that families containing parents with more education tend to be less inefficient producers of their child's education. This is true for both mothers and fathers, although, the relationship is particularly strong between mother's schooling and child education production when the child is 11 years old. Intact families (with two biological parents present) produce child educational outcomes more efficiently than non-intact families, whilst families with financial difficulties (as measured by the child receiving free school meals) produce less efficiently.

Of the child-centric explanatory variables, greater educational expectations from the child are found to be related to higher family efficiencies implying that children with higher expectations are facilitating the family's production of their education. Higher sibling order is also found to have an important detrimental association with child education production for

¹⁰ The efficiency results from the unbalanced cross-sectional samples when using the number of parental figures as the labour input are 57.2% at age 11 and 64.9% at age 16.

cohort children with more than one elder sibling. Families with male children are found to be more efficient producers, whereas, children with a lower birth weight are found to be present in families that are operating with less efficiency. When the child is aged 11 (column 1) the cohort child's innate ability presents the strongest association with the family's productive efficiency, unsurprisingly, families are less likely to produce education output efficiently if the child has below median innate ability. These results are also consistent with the expected relationships discussed above. In general, the impacts of the explanatory variables in the inefficiency term lessen as the child ages to 16 (column 3), this is especially true for innate ability. An exception occurs for parental aspiration which becomes more strongly associated with increasing family productive efficiency.

It may be argued that sample attrition (or at least, imbalance) is partially driving the different cross sectional results reported in Table 3. Columns (5) to (8) provide analogous results for the smaller, but balanced, cross sectional samples when the children are aged 11 and 16, respectively. In general, the results are not significantly different from those found using the unbalanced cross sectional samples. There is some evidence of the number of facilities in the family's accommodation having a weaker relationship with production and father's years of schooling being more strongly associated with the family's efficiency. The efficiency levels in the separate age periods are also found to be similar to those estimated in the unbalanced cross-sectional analysis (final panel of Table 3).

Intertemporal changes can be further explored in the balanced panel analysis. The cross sectional analyses reported in Table 3 reveal that technical efficiency levels for the family production of childhood education outcomes in Britain increased as the child ages (rising from 58.3% at age 11 to 64.9% at age 16 of possible efficiency). The average estimated efficiency level from the balanced panel analysis is 63.6% (column 9) with a slightly narrower, but still substantial, range of efficiency levels across families. The positive coefficient for *Year* in column (9) of panel 1 indicates that the cohort child's family production of educational output increased over the time period, consistent with Hicks neutral technological improvement (Coelli, 1995, page 329). The negative coefficient for "*Year*" in the conditional mean model (panel 2) reveals that the family inefficiency in the production of childhood education also declines over time.

In both the cross-sectional and panel data estimation, parental aspirations and child

expectations are significantly related to family productive efficiency. However, parental aspirations consistently reveal a greater association with childhood education production than do the cohort child's expectations in the cross sectional analyses and this difference increases as the child ages from 11 to 16. The balanced panel data analysis reveals an even stronger relationship between parental aspiration and efficient education production by the family.

6. Conclusions

The distance function methodology is applied to the analysis of household production functions to address the relative ability of British families' to efficiently generate a dual education (mathematics and reading) output for their child subject to multiple constrained input availabilities. A stochastic production frontier model is estimated and significant shortfalls from the productive ideal are established amongst British families. On average, British families are only operating at some 64% of the ideal possible production level suggesting that there is significant scope for improvement in the production of childhood education outcomes.

Substantial variation across families in the efficiency of their production is also established (families range from 5% of possible efficiency to 97% when the child is aged 11 and 11% to 99% when the child is aged 16). Implementing a conditional mean model, positive relationships are established between the efficiency of child education production and both the family (parental aspirations; parental education; intact family structure; and the family not encountering financial difficulties) and child-centric (child's expectations; low sibling order; being male; innate health; and innate ability) explanatory variables. Panel analysis further reveals the typical cohort child's family production of educational output increases over the time period (consistent with Hicks neutral technological improvement), and that the average family inefficiency in the production of childhood education declines.

Of particular interest to this study, both the educational expectations of the child and the aspirations of parents towards their child's education are found to have strongly significant and substantial relationships with the family's production of childhood educational outcomes (even after controlling for other family and child-centric variables): higher parental aspirations and greater child expectations are both related to lower family inefficiency. Parental aspirations consistently reveal a greater association with childhood education

production, however, than do the cohort child's expectations and this difference increases as the child ages from 11 to 16 years old.

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Table 1. Variable Definitions and Summary Statistics.

Variable Definition	At Age 11				At Age 16			
	Mean	Std Dev	Min	Max	Mean	Std Dev	Min	Max
Output:								
Average percentage of correct answers (y)	0.46	0.18	0.04	0.95	0.60	0.17	0.09	1
Physical Inputs:								
No. of rooms in accommodation (x ₁)	4.94	1.27	2	15	4.98	1.49	1	32
No. of facilities in accommodation (x ₂)	3.86	0.51	1	4	3.95	0.30	1	4
Labour Inputs:								
Number of adults in household (x ₃)	2.09	0.47	1	7	2.20	0.54	1	7
Inefficiency Term:								
Higher parental aspiration (z ₁)	0.98	0.16	0	1	0.49	0.50	0	1
Father's years of schooling (z ₂)	9.46	2.97	0	28	10.01	2.32	7	28
Mother's years of schooling (z ₃)	10.95	1.85	0	20	11.06	1.61	10	20
Intact family with two biological parents (z ₄)	0.92	0.28	0	1	0.93	0.25	0	1
Receive free school meal(z ₅)	0.08	0.28	0	1	0.05	0.22	0	1
<i>Child-centric measures</i>								
Higher child expectation(z ₆)	0.93	0.25	0	1	0.78	0.42	0	1
Oldest child in the household (base group)	0.43	0.50	0	1	0.63	0.24	0	1
Second oldest child in the household (z ₇)	0.36	0.48	0	1	0.31	0.46	0	1
Third oldest child in the household (z ₈)	0.14	0.35	0	1	0.05	0.22	0	1
Fourth (or after) child in the household (z ₉)	0.08	0.27	0	1	0.01	0.09	0	1
Below median child innate ability(z ₁₀)	0.37	0.48	0	1	0.37	0.48	0	1
Low birth weight(z ₁₁)	0.04	0.20	0	1	0.05	0.21	0	1
Boy(z ₁₂)	0.52	0.50	0	1	0.50	0.50	0	1

Data Source: National Child Development Survey (NCDS). The output is indexed as y; Inputs are $x=(x_1, x_2, x_3)$; Variables that predicted to be correlated with inefficiency term are indexed as z_1, z_2, \dots, z_{12} .

Table 2. Correlations between Parental Aspiration and Test Scores (Balanced Samples).

		Age 11 (NCDS2)			Age 16 (NCDS3)		
		Reading Score	Math Score	Parental aspiration	Reading Score	Math Score	Parental aspiration
Age 11 (NCDS2)	Reading Score	1					
	Math Score	0.676	1				
	Parental aspiration	0.077	0.070	1			
Age 16 (NCDS3)	Reading Score	0.748	0.633	0.115	1		
	Math Score	0.585	0.730	0.065	0.602	1	
	Parental aspiration	0.425	0.420	0.072	0.451	0.470	1

Data Source: National Child Development Survey (NCDS).

Table 3. Cross-Sectional Estimation Results, Stochastic Production Function Analyses for Childhood Education Outcomes.

	Age 11 (NCDS2)		Age 16 (NCDS3)		Age 11 (NCDS2)		Age 16 (NCDS3)		Panel	
	Unbalanced samples				Balanced samples				Balanced	
	Coef.	S. Err.	Coef.	S. Err.	Coef.	S. Err.	Coef.	S. Err.	Coef.	S. Err.
Average percentage of correct answers	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Physical Inputs:										
No. of rooms in accommodation	0.098***	0.015	0.024**	0.010	0.094***	0.019	0.022**	0.010	0.056***	0.011
No. of facilities in accommodation	0.068***	0.020	0.106***	0.024	0.026*	0.014	0.128***	0.034	0.064***	0.022
Labour Inputs:										
Number of adults in household	-0.003	0.020	-0.005	0.014	-0.031	0.028	-0.011	0.016	-0.021	0.015
Year									0.052***	0.008
Constant	-0.446***	0.038	-0.261***	0.036	-0.376***	0.051	-0.287***	0.052	-0.342***	0.035
Inefficiency Term:										
Higher parental aspiration	-0.201***	0.050	-0.276***	0.013	-0.174**	0.070	-0.279***	0.016	-0.367***	0.025
Father's years of schooling	-0.025***	0.004	-0.015***	0.003	-0.043***	0.006	-0.022***	0.004	-0.037***	0.004
Mother's years of schooling	-0.046***	0.006	-0.018***	0.004	-0.038***	0.008	-0.017***	0.005	-0.031***	0.005
Intact family (two biological parents)	-0.082***	0.038	-0.061***	0.020	0.091**	0.041	0.089***	0.026	-0.099***	0.030
Receive free school meal	0.163***	0.032	0.081***	0.021	0.140***	0.046	0.082***	0.027	0.117***	0.028
Higher child expectation	-0.190***	0.034	-0.129***	0.012	-0.143***	0.044	-0.116***	0.015	-0.157***	0.021
Oldest child in household (omitted)										
Second oldest child in the household	0.030	0.021	0.022**	0.011	0.025	0.026	0.018	0.014	0.025	0.016
Third oldest child in the household	0.121***	0.028	0.114***	0.022	0.107***	0.035	0.126***	0.026	0.114***	0.023
Fourth (or after) child in the household	0.164***	0.034	0.108**	0.051	0.174***	0.044	0.120*	0.063	0.150***	0.032
Below median child innate ability	0.695***	0.025	0.265***	0.011	-0.612***	0.030	-0.253***	0.014	0.461***	0.017
Low birth weight	0.149***	0.041	0.080***	0.024	0.176***	0.051	0.091***	0.028	0.148***	0.031
Boy	-0.072***	0.018	-0.082***	0.010	-0.027	0.023	-0.099***	0.013	-0.067***	0.014
Year									-0.606***	0.029
Constant	1.548***	0.072	0.763***	0.050	1.592***	0.094	0.806***	0.060	1.511***	0.060
Gamma	0.975***		0.982***		0.976***		0.974***		0.977***	
Coelli (1995) Efficiency Test	-28.447***		-21.986***		-28.447		-28.447			
Estimated family efficiency	58.3%	0.220	64.9%	0.181	59.5%	0.214	66.4%	0.180	63.6%	0.205
minimum	5.4%		10.7%		7.2%		10.8%		6.9%	
maximum	97.4%		98.7%		97.4%		98.7%		98.0%	
Number of observations	5624		4298		3100		3100		6200	

Data Source: National Child Development Survey (NCDS). *** Statistically significant at 99%, ** at 95%, * at 90%.

Table 4. Comparisons between Different Childhood Education Production Groups, Cross Sectional Unbalanced Samples

Variables	CEP Efficiency of NCDS2		CEP Efficiency of NCDS3	
	<25%	>75%	<25%	>75%
average percent of correctly answered items	0.148	0.697	0.191	0.797
rooms number	4.900	5.154	4.944	5.299
facilities number	3.774	3.900	3.944	3.959
number of adults	2.071	2.093	2.472	2.172
parents wish child to stay at school after min age	0.921	0.989	0.000	0.820
father's years of schooling	8.800	10.259	9.167	10.788
mother's years of schooling	10.384	11.523	10.389	11.627
non-intact families	0.055	0.024	0.056	0.041
free school meal	0.203	0.042	0.139	0.020
child wish to stay at school	0.884	0.964	0.556	0.926
second oldest child	0.358	0.363	0.306	0.304
third oldest child	0.179	0.104	0.222	0.029
fourth or after child	0.145	0.040	0.000	0.002
child innate ability below median	0.866	0.104	0.972	0.119
child had low birth weight	0.082	0.026	0.056	0.035
Male	0.534	0.558	0.639	0.545
No. observations	380	1516	36	1358

Data Source: National Child Development Survey (NCDS).