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Earnings and Schooling: an Overview of Economic Research Based on the Australian Twin Register

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Abstract. This paper reviews four economic studies of aspects of earnings and schooling conducted by the authors using data from the Australian Twin Register. First, estimates of the economic returns to schooling made using fixed effects and selection effects regression models incorporating an instrumental variables approach to correct for measurement error in self-reported schooling levels are examined. The finding is that up to 30 per cent of the estimated return to schooling may be due to family effects and the remainder to pure educational effects. Second, comparisons are made between the economic model of Ashenfelter and Krueger (1994) and that of DeFries and Fulker (1985) and the results obtained from each are shown to be similar. Third, gender differences in returns to schooling are estimated and family effects are found to be a more important influence in the case of males. Fourth, the influence of family effects on educational attainments is considered and it is found that around one-half of educational attainment is accounted for by genetic inheritance and up to another quarter due to shared environment effects.

Key words: Earnings, Schooling, Twins

Discovering the ingredients of the economic success of individuals has long been a matter of interest to economists. These ingredients can be categorised into three main groups: first, the natural ability with which one is born; second, the family environment which shapes one's subsequent development; and third, productivity enhancing characteristics which one may choose to acquire, such as education and training. Each set of influences may affect measures of economic success directly (e.g. natural ability may affect income), or they may interact with each other in affecting economic outcomes (e.g. family background may affect the amount of schooling which one undertakes and schooling, in turn, may affect economic success). Generating clear hypotheses concerning the determinants of economic success within this framework is therefore fairly straightforward, but discriminating between them empirically and measuring their relative impacts has been much more difficult.

The essence of the problem of empirical analysis is the difficulty of identifying the separate individual and interactive influences of the various ingredients in this complex set of relationships. Two types of approach to the problem can be found in the economics literature that examines income as a measure of economic wellbeing.

The first approach has involved augmenting conventional earnings functions to incorporate the influence of ability and family environment [6, 9]. Conventional economic models relate schooling and labour market experience to subsequent income and this permits a "rate of return to schooling" to be computed. While it is recognised that such models are incomplete because they do not expressly incorporate the influence of natural ability or family environment, they have nevertheless assumed a central role in the analysis of economic success and have been viewed as providing the critical elements in the calculus facing policy makers. Such models have, however, sometimes been augmented with variables which attempt directly to introduce natural ability and family environmental factors into the process by which economic outcomes are determined. Estimates from models of this kind generally indicate a role for family environment and natural ability as well as education and labour market experience in determining income. Typically, in such studies, family environment is found to play a considerably larger role than natural ability in determining income for a given level of education. However, studies of this kind invariably suffer from difficulties in obtaining data on all the relevant variables or employ variables which are poorly measured. Accordingly, only limited reliance can be placed on their findings.

The second approach has involved analysis of data on twins. Analysis of data on twins provides a natural experiment where it is possible to control for ability and shared family environment [3]. This literature has used the method of variance decomposition to attribute the variance in measures of earnings to ability, shared environmental influences and to environmental influences specific to individuals. However, the variance decomposition methodology has been severely criticised on the grounds that it imposes arbitrary identifying restrictions [8].

Analysis of data on twins, however, clearly has the potential to provide us with the means to gain powerful insights into the determination of economic success. Two methodological advances, one from economics and the other from medicine, have provided more flexible approaches that can overcome many of the problems encountered when modelling socio-economic success.

Economists have approached the issue in recent times by seeking to assess the extent of bias in conventional rates of return to schooling associated with the failure to control adequately for genetics and common environment [1]. Within this line of research, two models have been used. The first is a fixed effects model wherein the difference in the earnings of members of a set of twins is related, in a regression framework, to differences in characteristics of the same individuals. Estimation of separate equations for monozygotic (MZ) and dizygotic (DZ) twins is equivalent to holding constant, in the first instance, genetic endowments and common environment, and, in the second instance, common environment influences only [3]. This amounts to an implicit control for these factors. Alternatively, a structural model that explicitly accounts for family effects (genetic endowments and common environment) through the inclusion in the estimating equation of information on a respondent's co-twin has also been applied [1]. In Ashenfelter and Krueger (1994), information on the respondent's co-twin's educational attainment is used to capture family effects. Both of these economics models have been used in our work on data from a large sample of Australian twins.

The regression model proposed by DeFries and Fulker (1985) in the genetics literature is similar in design to the structural model of Ashenfelter and Krueger (1994). The former model was devised to provide tests of the relative importance of genetic and shared environmental factors within a multiple regression framework, and has a more scientific foundation than the selection effects model. It can be readily augmented with various independent variables to assess the effect of education while simultaneously providing estimates of heritability and of the influence of shared environmental factors. Our research on Australian twins has included estimation of this model and drawn comparisons of the results with those from the economics models [17].

While the programme of research which we have conducted on the sample of Australian twins covers the same issues as are addressed in the paper by Ashenfelter and Krueger (1994), it does not end there. One issue of considerable interest which was the subject of further research concerns the roles of education, ability and family environment in determining income by gender. Specifically - do family environment and natural ability have different relative effects in the determination of income between males and females with a given level of education? We have addressed this issue by estimating the model of Ashenfelter and Krueger (1994) separately for males and females [15].

In the studies mentioned above the main focus has been the roles of ability and family background in the relationship between education and income. In Miller, Mulvey and Martin (1995c) we investigate the relative roles of ability and family background in directly determining educational attainment.

In the remainder of this paper we report on ths procedures used and the findings obtained in each of these aspects of our research. In Section 1 of the paper we discuss the basic model of Ashenfelter and Krueger (1994) and the results from estimating it with Australian data. In Section 2 we discuss the differences between the Ashenfelter and Krueger (1994) model [1] and the DeFries and Fulker (1985) model [7] and the results of estimating both with Australian data. In Section 3 we summarise results obtained when the A&K model is estimated separately for males and females in order to determine whether family effects have differential impacts on the schooling/earnings relationship for these groups. In Section 4 we report on research that utilises the DFF model to investigate the relative roles of ability and family environment in determining educational attainment. In Section 5 we briefly draw some conclusions from the findings of our research programme.

1. Estimating the models of Ashenfelter and Krueger

There are two models within the Ashenfelter and Krueger (1994) approach, the Fixed Effects Model and the Selection Effects Model. Moreover, a problem of measurement error in respect of self-reported schooling levels may exist and can be approached using instrumental variables methods of estimation.

The fixed effects model

To begin with, we specify the estimating equation in the following general form:

$$(1) \qquad Y_j = \alpha_0 + \alpha_1 A_j + \alpha_2 E_j + \alpha_3 S_j + \alpha_4 G_j + \alpha_5 AGE_j + \alpha_6 M_j + \upsilon_j$$

where Y_j denotes an index of the economic wellbeing or occupational status of individual j, A_j denotes the ability of the jth individual, E_j denotes the home environmental factors that influence the occupational rank of individual j, S_j, G_j, AGE_j and M_j are, respectively, the educational attainment, gender, age and marital status of individual j, and υ_j is a stochastic error term.

Most interest in economics centres on the profitability of education, and a measure of this is provided in equation (1) by α_3. Both ability and shared environmental influences are generally unobserved and hence the estimated impact of education, $\hat{\alpha}_3$, may be biased. The challenge for empirical researchers is to find ways of controlling for the influence on occupational status of these omitted variables.

When the data used in the analysis are supplied by twins, equation (1) needs to be written in the following form:

$$(2) \qquad Y_{ji} = \alpha_0 + \alpha_1 A_{ji} + \alpha_2 E_{ji} + \alpha_3 S_{ji} + \alpha_4 G_{ji} + \alpha_5 AGE_{ji} + \alpha_6 M_{ji} + \upsilon_{ji}$$

where subscript j now refers to the family and subscript i refers to the twin member (i = 1, 2).

Consider identical twins (reared together). The fixed effects model to explain the difference in occupational status between the members of the twin pair (Y_{ji} - Y_{j-i}) can be written as:

$$(3) \qquad (Y_{ji} - Y_{j-i}) = \alpha_3(S_{ji} - S_{j-i}) + \alpha_6(M_{ji} - M_{j-i}) + (v_{ji} - v_{j-i})$$

where the subscript -i refers to the co-twin of respondent i. Note that as identical twins reared together have, by definition, the same ability, family environment, gender and age, these variables disappear from the fixed effects version of the model. In other words, in this version of the model, relating the difference in the occupational status of the twins to the difference in their educational attainments and marital states provides an estimate of the impact of education on earnings (α_3) that is not biased by the omission of the ability and family background variables. Comparison with estimates of α_3 derived from estimation of equation (1) provides an indication of the extent of ability and family background bias in the estimates typically generated.

In summary, the major feature of the fixed effects model is that genetic resemblance and common environment influences are held constant implicitly. This method of estimation will also net out of the estimated impact of schooling the compounding effects of any other fixed effects that affect earnings (e.g., race, possibly some affective characteristics such as motivation).

Estimation of α_3 using equation (3) with data on the earnings of twins has provided a range of values, including 2.7 per cent by Behrman, Taubman and Wales (1977) and 9.2 per cent by Ashenfelter and Krueger (1994). The first estimate is suggestive of family effects being quite important when estimating the return to schooling while the latter estimate is consistent with a minor influence of the family in this respect.

Our estimates of the same model were made using data drawn from an exceptionally large and representative sample of twins. The data begin with a mail survey undertaken in 1980-82 of all 5967 twins aged over 18 years enrolled in the Australian National Health and Medical Research Council Twin Registry at that time. Joining this registry and responding to the survey were both voluntary. Replies were received from 3808 complete pairs. In 1988-89 this sample was followed up and 2934 twin pairs responded. Most of the data used in our research programme are derived from the follow-up survey.

Only sets of twins where each member responded to the questions used in the study are included in the sample. Moreover, to be included in the sample the twins needed to be 20-64 years of age, and employed on a part-time or full-time basis. 1170 pairs met these requirements.[1] The measure of occupational status employed in the study is average occupational earnings.

Estimating the fixed effects model using these data indicates that the true impact of schooling may be about 2.5 per cent rather than the range. 6 to 7 per cent conventionally estimated [14]. Moreover, the difference of 4.5 per cent between these estimates may be decomposed into amounts of 2 percentage points attributable to family background and 2.5 percentage points attributable to natural ability. Hence our findings from this model are closer to those reported in the earlier study by Behrman et al (1977) than to the more recent results of Ashenfelter and Krueger (1994).

The selection effects model

In contrast to the fixed effects model, the selection effects model explicitly incorporates family effects in the earnings equation. Hence, in this model, the earnings of twin i who is a member of family j (Y_{ji}) depends on variables that vary across families but not between twins (in this instance age), on individual-specific variables (education), and on unmeasured family effects (μ_j). The unmeasured family effects are modelled as depending on the educational attainments of each twin member, and on the age of the twins. Hence, the model is given as:

$$(4) \qquad Y_{ji} = \alpha\, AGE_j + \beta EDUC_{ji} + \mu_j + \varepsilon_{ji} \qquad i = 1, 2; j = 1, n.$$

$$(5) \qquad \mu_j = \gamma EDUC_{j1} + \gamma EDUC_{j2} + \delta AGE_j + \omega_j \qquad j = 1, n.$$

Substitution for the μ_j term in the earnings equation results in the reduced form:

$$(6) \qquad Y_{ji} = (\alpha + \delta)\, AGE_j + (\beta + \gamma)\, EDUC_{ji} + \gamma EDUC_{j\text{-}i} + \varepsilon_{ji} \qquad i = 1, 2; j = 1, n.$$

In this equation the coefficient on the co-twin's educational attainment (γ) provides an estimate of the impact of family effects which can be subtracted from the coefficient on the own-education variable ($\beta + \gamma$) to derive an estimate of the pure return to schooling.

Estimating the selection effects model using Australian data indicates that the return to schooling net of the effects of natural ability and shared family background for identi-

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[1] Following Ashenfelter and Krueger (1994), both males and females are included in the sample selected for analysis. This restriction is relaxed in Section 3.

cal twins is again 2.5 per cent. The results for non-identical twins from the selection effects model are similar to those obtained from the fixed effects model, with the returns to education, including effects due to natural ability, being estimated at 4.5 per cent. This implies that family background accounts for the remaining 2 percentage points of the conventionally estimated overall return of 6.5 per cent. These findings contrast with those of Ashenfelter and Krueger (1994) who conclude from their estimates of the selection effects model that family background and natural ability play virtually no role in determining earnings [3].

Measurement error

It has long been suspected that measurement error may be present in self-reported schooling data. In order to take account of this possibility, Ashenfelter and Krueger (1994) collected data on the schooling level of each twin from the co-twin. This information was also available in the Australian twin survey. The problem of measurement error can be approached by using an instrumental variables technique of estimation in which

Table 1 - Estimates of Identical Twins Model of Log Annual Earnings: Results from Ashenfelter and Krueger (1994), Behrman, Taubman and Wales (1977) and Estimates from Australian Twins Survey

	OLS			Fixed Effects			Selection Effects**	
	A&K	BT&W*	MMM	A&K	BT&W	MMM	A&K	MMM
Own	0.084	0.080	0.064	0.092	0.027	0.025	0.088	0.048
Education	(6.00)	(32.4)	(26.64)	(3.83)	(3.6)	(4.92)	(5.87)	(16.65)
Co-twin's							–0.007	0.023
Education							(0.47)	(7.90)
Married			0.035			0.037		0.040
			(2.64)			(1.86)		(2.83)
Age	0.088		0.002				0.090	0.002
	(4.63)		(2.54)				(3.91)	(2.83)
Age^2	–0.087						–0.090	
	(3.78)						(3.10)	
Male	0.204		0.231				0.206	0.223
	(3.24)		(18.47)				(2.67)	(15.85)
White	–0.410						–0.424	
	(3.23)						(2.94)	
Sample Size	298	3852	1204	149	1019	602	298	1204
R^2	0.260	0.20	0.510	0.092	0.1	0.05	0.219	0.535

* Estimates from pooled sample of identical and non-identical twins.

** Estimates unavailable for Behrman, Taubman and Wales (1977).

the co-twin's report on their twin's schooling level is employed as an instrument for self-reported schooling. When this method is applied to the selection effects model for identical twins in the Australian sample the estimated return to education is 7.8 per cent. This is almost the same as the conventional estimate of the gross returns to schooling and suggests that family effects have little influence on the schooling – earnings relationship. Applying the same method to the fixed effects model for identical twins produces the same result. Ashenfelter and Krueger (1994) also find that correction for measurement error in their sample of US twins increases the estimated rate of return to schooling (from 9.2 per cent to 16.7 per cent in the fixed-effects model and from 8.8 per cent to 11.6 per cent in the selection effects model). These findings suggest a limited or nonexistent role for family effects in the relationship between schooling and earnings.

Finally, it is possible that the errors of measurement between the reports of the twin and the co-twin on education level are correlated and this will result in inconsistent estimates within the framework of the conventional IV estimator. Ashenfelter and Krueger (1994) have developed an IV estimator for handling such a problem which is consistent in the presence of correlated measurement error. When this method is applied to the Australian twins data, the estimated return to schooling for identical twins in the fixed effects model falls to 4.5 per cent, which is several percentage points less than the conventional estimate. Analysis of the data for fraternal twins yields broadly similar conclusions. The application of the estimator which is robust to correlated measurement errors to the US sample by Ashenfelter and Krueger (1994) results also in a decline in the estimated rate of return to schooling, from 17 to 13 per cent.

In summary, our OLS estimates are similar to those of Behrman, Taubman and Wales (1977), one-third of the overall return to schooling is due to education *per se,* one-third to ability and one-third to shared family environment. However, when we replicate the analysis of Ashenfelter and Krueger (1994) by estimating both fixed effects and selection effects models, and after correction for measurement error in self-reported schooling levels, we find a much more modest role for ability and family environment in the relationship between schooling and income. Moreover, as in Ashenfelter and Krueger (1994), after correcting for measurement error in the fixed effects model for identical twins, our estimate of the return to schooling increases considerably, rising from 2.5 percent to between 5 and 8 per cent. While these returns are lower than those reported by Ashenfelter and Krueger (1994) (13 per cent), this is largely due to the fact that rates of return to schooling in Australia are lower than in the US because of differences in the dispersion of the distribution of income. Our finding that the usual OLS estimates may not be unduly biased upwards by the omission of family effects mirrors the major conclusion of Ashenfelter and Krueger (1994). In both cases it is clear that the findings suggest a more limited role for family effects in the schooling-earnings relationship than has previously been accepted, though our findings are much weaker in this respect than those of Ashenfelter and Krueger (1994).

2. Estimating the DeFries and Fulker Model

Unlike the fixed-effects model that has traditionally been estimated in the economics literature, the model of DeFries and Fulker (1985) provides explicit controls for genetic and shared environmental factors. This model focuses on the situation where one twin, termed the proband, has a deviant score on a continuous variable. This could be tests of literacy, or, in the current application, average occupational income. It follows that if the condition that led to the lower occupational income for one twin (the proband) is inherited, the co-twins of DZ probands are expected to have higher occupational income than co-twins of MZ probands. To test for heritability and shared environmentality, the DFF model suggests that the average occupational income of the high-status twin be regressed on the income of the low-status twin, a coefficient of genetic relationship, defined to equal 1.0 for MZ twins and 0.5 for DZ twins, and an interaction term between these variables. Thus, the regression model they propose is:

$$Y_{ji} = \beta_0 + \beta_1 Y_{j-i} + \beta_2 R_{ji} + \beta_3 Y_{j-i} R_{ji} + \upsilon_{ji} \quad (7)$$

where:

Y_{ji} is the average occupational income of the high-income member of twin set j;

Y_{j-i} is the average occupational income of the low-income member of twin set j;

R_{ji} is the coefficient of genetic relationship for twin set j.

By construction, β_3 is twice the difference between the MZ and DZ regression coefficients, and, given the standard assumptions in the variance decomposition models, provides a direct estimate of heritability, conventionally labelled h^2. [Behrman and Taubman (1976) list the main assumptions as: the model is additive, mating is random, non-common environment of a DZ twin is not correlated with his/her co-twins' genes.] β_1 records twin resemblance that is independent of genetic resemblance as indexed by the interaction term. Hence, it provides a measure of common environmental influences, conventionally labelled c^2.

While the DFF model was initially developed for the situation where one twin had a deviant score on the variable of interest, it has subsequently been extended to random samples and a number of methods are available to accommodate this extension. Cherny, Cardon, Fulker and DeFries' (1992) double entry method is used in Miller, Mulvey and Martin (1996). This method involves entering each twin's score twice, once as proband and once as co-twin. All "t" statistics are adjusted for the correct degrees of freedom [5].

DeFries and Fulker note that their regression model can be extended to include other independent variables, such as gender, age, ethnicity and environmental indices. The additional variables considered for inclusion in this analysis are the age, gender, marital status and educational attainment variables included in the previous model. Hence, the specification of the DFF model employed in Miller, Mulvey and Martin (1996) is:

$$Y_{ji} = \beta_0 + \beta_1 Y_{j-i} + \beta_2 R_{ji} + \beta_3 Y_{j-i} R_{ji} + \beta_4 S_{ji} + \beta_5 G_{ji} + \beta_6 AGE_{ji} + \beta_7 M_{ji} + \upsilon_{ji} \quad (8)$$

This augmented specification of the estimating equation provides an estimate of the impact of schooling (β_4) that is excised of the influences of genetics and common environmental factors. It is important to note that the estimate of the impact of schooling on occupational attainment obtained through the DFF model may differ from that obtained with A&K's selection effects model as the common environmental influences control is mediated through the co-twin's indicator variable in their model.

Comparison of the value for β_4 computed on the basis of equation (8) with the results from equation (3) permits discussion of the relative impacts of explicit (DeFries and Fulker) and implicit (fixed effects) controls for family effects.

Estimating the DFF model using data from the Australian twin survey yields an estimated return to education of 5.3 per cent [17]. Whereas this estimate is 1 to 2 percentage points lower than conventional estimates of the effect of education, it is almost three percentage points higher than the estimates obtained through application of the fixed effects model.

Re-estimation of the fixed effects model and the DFF model using IV estimators results in sets of findings where the impact of education is several percentage points higher.[2] Thus, within this framework, the fixed effects model yields an impact of education of between 5 and 8 per cent, and the DFF model an impact of 6.4 per cent whereas the return computed in more conventional methods of analysis is in the range of 7 to 8 per cent. Shared-environmental influences apparently have a minor role. This evidence from the study of twins is in agreement with the findings from studies that include measures of family background in the earnings equation.

The weight of the evidence from estimation of the two models considered is that the impact of education in Australia, holding constant genetic and shared environmental factors, is of the same order of magnitude as that estimated in studies that do not take account of these factors: at most ability and shared environmental factors contribute 1 to 2 percentage points to the gross return to education. The similarity of the results computed for the different models employed is reassuring, and suggests that reliable controls for the omitted genetic and shared environment variables are obtained through these indirect methods.

3. Gender, earnings and schooling

There are some a *priori* reasons for enquiring as to whether there may be differences between males and females in the role of family background in the schooling/income relationship.

At its simplest, there is the commonly held view that families frequently consider that it is less important to ensure that girls obtain an education than boys, since boys are conventionally expected to be breadwinners for a family and girls are expected to get married, play the role of housewife and mother and perhaps take a job which is complementary to this role. Moreover, the range of jobs considered appropriate for girls to aspire to has largely been restricted to those traditionally female occupations such as nursing, office work etc. Although such attitudes may not be as widespread today as they once were, a substantial proportion of workers undoubtedly entered the labour market at a time when they were prevalent. To the extent that this view actually guides families in their attitudes to their children's careers, it will tend to result in girls spending less time

[2] In this situation, the downward bias in the fixed effects estimator, where two schooling variables are measured with error, will be greater than in the model of DeFries and Fulker, where there is only one schooling variable that is prone to measurement error.

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in education than boys and undertaking programmes of education which lead to employment in the traditionally female occupations.

On this basis it might also be argued that the influence of family background has tended to be of less importance in the schooling/income relationship for girls than for boys. Family influence might be regarded as a passive factor in respect to the choices made by girls since powerful conventions within the family, as well as within the broader society, have tended to govern their aspirations and the choices which will realise them. In contrast, boys are more likely to be subject to active encouragement by their parents to high achievement by undertaking as much education as they are capable of benefitting from and by selecting programmes of education which lead to employment in high income occupations.

Miller, Mulvey and Martin (1995b) estimate fixed effects and selection effects models separately for males and females using data from the Australian twin survey. In summary, the findings of this analysis suggest that:

1. the pure returns to schooling are greater for females than for males;
2. the family background effect for males is modest and that for females is negligible;
3. the ability effect is modest (around 1.5 percentage points) and is about the same for males and females.

There are several implications of these results. First, the higher net return to schooling for females compared to males is an intriguing feature of the labour market. In this regard it is noted that the types of post-school qualifications that women acquire are quite different from those acquired by men [13]. Hence, around one-quarter of the female workforce in Australia hold post secondary certificates compared with only 10 per cent of males. These certificates, which are often vocationally orientated, may provide a more accurate indicator of productivity than the qualifications held by males. A differential in the reliability of the indicator of productivity of this nature would generate a wage differential under statistical theories of discrimination. Second, the difference between males and females in the bias in the return to education associated with family background is considerable. It suggests that there is some inter-generational transmission of inequality for males, but this is not an obvious feature of the female labour market.

The lower degree of inheritance of inequality among females may be associated with the family being a passive factor in respect of the choices made by females.

4. Educational attainment, ability and family environment

The economist's approach to the study of schooling decisions has generally held family background to be the key to understanding a decision that apparently determines much of the individual's success in later life. Examples of this approach are Rice (1987) and Micklewright (1989) for the U.K., Miller and Volker (1989) and Williams *et al.* (1987) for Australia, and Mare (1980) for the U.S.. The typical finding from this research is that of Micklewright (1989, p. 36) "Not surprisingly, family background as measured by parent's education, class and numbers of siblings was found to have a substantial impact. Of more interest and immediate policy relevance is the fact that between half and two-thirds of this effect remains when controls for the children's academic ability and type of school are introduced". A major problem with this type of study is that many of the models estimated have important variables that are either poorly measured (e.g., the income variable in Micklewright's study) or are omitted from the estimating equation (e.g., wealth/income and ability in Miller and Volker's (1989) study). The policy relevance of the results is therefore uncertain.

Medical researchers have also devoted considerable research effort towards understanding the determinants of educational attainment, in their case using sets of twins reared together. The main conclusion from this research is in marked contrast to that generated by economists. Thus, Baker et al. (1995) conclude that over 50 per cent of the variance in educational attainments is attributable to genetic factors, while shared family environmental factors account for only 20 percent of the variance in educational attainments. This suggests that the emphasis in the studies by economists may be misplaced.

The research techniques used by the two fields of research are dissimilar, and it is not immediately obvious as to why they arrive at such different conclusions. Economists have largely used regression analysis of some form [10-12, 18, 19] while the medical researchers have typically used analysis of variance methods to provide estimates of the relative importance of genetic and shared environmental factors.

Miller, Mulvey and Martin (1995c) use the model of DeFries and Fulker (1985) in an attempt to provide some common links between the two streams of research. They find that heritability accounts for around 50 percent of the variance in educational attainments in Australia, and shared family factors around 25 percent. Most policy interest centres on the latter, for it is through the study of the direct influence of the family that statements concerning the inheritance of inequality can be made. In this respect the results from estimation of an augmented DeFries and Fulker model shows that the measures traditionally included by economists in models of educational attainment are only crude approximations to the family effects incorporated in the models estimated in the behavioural genetics literature. Thus, the family effects associated with variables like the educational attainments of the parents, the occupational status of the father, the number of siblings etc. in the augmented model of DeFries and Fulker are typically less than 50 percent of those obtained from a model of the type typically estimated by economists. Thus, the bias in the traditional estimates appears to be greater than the one-third to one-half suggested by Micklewright (1989).

From the policy perspective, our study paints a dismal picture. One-half of the variance in educational attainments is accounted for by genetic ability. The contribution of shared family effects to the explanation of the variance in educational attainments is at most one-quarter. But of this total contribution made by shared family background, less than one-half can be sourced to measurable factors (parent's educational levels, father's occupational status, number of siblings). The remainder is unmeasured. In that it can operate on variables which account for so little of the total variation in educational attainments, government intervention in educational decision making is likely to be impotent.

5. Conclusion

We have reported the findings of four studies within the programme of research which has been undertaken using data from the Australian Twin Register. These have all addressed issues which are of special interest to economists but they share much common ground with areas of interest to medical researchers. This common ground refers both to the topic being researched and to the methodology employed. Our work has simultaneously advanced understanding of the relationships between ability, family background, education and income and investigated the implications of the different methodologies employed respectively by economists and medical researchers.

What we have found is that, using the standard economists' approach, both fixed effects and selection effects models indicate that, of the total income return to schooling of around 7 per cent, about 2.5 percentage points are due to education *per se,* 2 percentage points are due to family background and the remaining 2.5 percentage points are due to natural ability. However, if correction is made for measurement error in self-reported schooling level, the portion due to education *per se* appears to rise and the portion which can be attributed to family effects and natural ability appears to fall to between 0 and 3 percentage points. Applying the DeFries and Fulker model to the same problem produces remarkably similar findings notwithstanding the quite different methodology employed. When the DFF model is estimated using an IV estimator it yields a return to education *per se* of 6.4 per cent which leaves only a minor role for shared environmental influences. The coincidence of these findings suggests that some confidence can be attached to them.

Applying the fixed effects and selection effects model, and correcting for measurement error, to males and females separately shows that, while ability is an equally important influence on income for both sexes, the pure returns to education for males are somewhat lower than for females. This implies that the influence of family environment is greater for males than females. We take this to be evidence of a stereotypical tendency for families to more actively encourage boys to undertake programmes of career-intensive education.

Finally, we addressed the issue of what relative roles ability and family environment play in determining educational attainment. Using the DeFries and Fulker model, we find that the economics literature tends to overstate the influence of family background, and to understate the influence of ability, on educational attainments. Our analysis reveals that heritability accounts for around 50 per cent of the variance in educational attainments and that shared family factors account for only 25 per cent. There are some important implications which flow from these findings for the broad thrust of education policy.

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