Journal of Economic Perspectives—Volume 16, Number 3—Summer 2002—Pages 3–30

The Inheritance of Inequality

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People differ markedly in their views concerning the appropriate role of government in reducing economic inequality. Self-interest and differences in values explain part of the conflict over redistribution. But by far the most important fault line is that people hold different beliefs about why the rich are rich and the poor are poor. Survey data show that people—rich and poor alike—who think that "getting ahead and succeeding in life" depends on "hard work" or "willingness to take risks" tend to oppose redistributive programs. Conversely, those who think that the key to success is "money inherited from family," "parents and the family environment," "connections and knowing the right people" or being white support redistribution (Fong, 2001; Fong, Bowles and Gintis, 2002). Handing down success strikes many people as unfair even if the stakes are small, while differences in achieved success may be unobjectionable even with high stakes, as long as the playing field is considered level.

How level is the intergenerational playing field?[1] What are the causal mechanisms that underlie the intergenerational transmission of economic status? Are these

[1] See Bowles and Gintis (2001) for the relevant formal models and other technical aspects of this research, also available at ⟨http://www.santafe.edu/sfi/publications/working-papers.html⟩. Arrow, Bowles and Durlauf (1999) and Bowles, Gintis and Osborne (forthcoming) present collections of recent empirical and theoretical research.

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mechanisms amenable to public policies in a way that would make the attainment of economic success more fair? These are the questions we will try to answer.

No one doubts that the children of well-off parents generally receive more and better schooling and benefit from material, cultural and genetic inheritances. But until recently, the consensus among economists has been that in the United States, success is largely won or lost in every generation. Early research on the statistical relationship between parents' and their children's economic status after becoming adults, starting with Blau and Duncan (1967), found only a weak connection and thus seemed to confirm that the United States was indeed the "land of opportunity." For example, the simple correlations between parents' and sons' income or earnings (or their logarithms) in the United States reported by Becker and Tomes (1986) averaged 0.15, leading the authors to conclude: "Aside from families victimized by discrimination . . . [a]lmost all earnings advantages and disadvantages of ancestors are wiped out in three generations." Becker (1988) expressed a widely held consensus when, in his presidential address to the American Economics Association, he concluded (p. 10): "[L]ow earnings as well as high earnings are not strongly transmitted from fathers to sons."

But more recent research shows that the estimates of high levels of intergenerational mobility were artifacts of two types of measurement error: mistakes in reporting income, particularly when individuals were asked to recall the income of their parents, and transitory components in current income uncorrelated with underlying permanent income (Bowles, 1972; Bowles and Nelson, 1974; Atkinson, Maynard and Trinder, 1983; Solon, 1992, 1999; Zimmerman, 1992). The high noise-to-signal-ratio in the incomes of both generations depressed the intergenerational correlation. When corrected, the intergenerational correlations for economic status appear to be substantial, many of them three times the average of the U.S. studies surveyed by Becker and Tomes (1986).

The higher consensus estimates of the intergenerational transmission of economic success has stimulated empirical research. The relevant facts on which most researchers now agree include the following: brothers' incomes are much more similar than those of randomly chosen males of the same race and similar age differences; the incomes of identical twins are much more similar than fraternal twins or non-twin brothers; the children of well-off parents obtain more and higher quality schooling; and wealth inheritance makes an important contribution to the wealth owned by the offspring of the very rich. On the basis of these and other empirical regularities, it seems safe to conclude that the intergenerational transmission of economic status is accounted for by a heterogeneous collection of mechanisms, including the genetic and cultural transmission of cognitive skills and noncognitive personality traits in demand by employers, the inheritance of wealth and income-enhancing group memberships, such as race, and the superior education and health status enjoyed by the children of higher status families.

However, the transmission of economic success across generations remains something of a black box. We find that the combined inheritance processes operating through superior cognitive performance and educational attainments of those with well-off parents, while important, explain at most three-fifths of the intergenerational transmission of economic status. Moreover, while genetic transmission of earnings-enhancing traits appears to play a role, the genetic transmission of IQ appears to be relatively unimportant.

It might be thought that the black box is an artifact of poor measurement of the intervening variables relative to the measurement of the income or earnings of parents and offspring. But this does not seem to be the case. Years of schooling and other measures of school attainment, like cognitive performance, are measured with relatively little error. Better measurements will of course help; but we are not likely to improve much on our measures of IQ, and recent improvements in the measurement of school quality have not given us much illumination about what's going on inside the black box. The fundamental problem is not that we are measuring the right variables poorly, but that we are missing some of the important variables entirely. What might these be?

Most economic models treat one's income as the sum of the returns to the factors of production one brings to the market, like skills, or capital goods. But *any* individual trait that affects income and for which parent-offspring similarity is strong will contribute to the intergenerational transmission of economic success. Included are race, geographical location, height, beauty or other aspects of physical appearance, health status and personality. Thus, by contrast to the standard approach, we give considerable attention to income-generating characteristics that are not generally considered to be factors of production. In studies of the intergenerational transmission of economic status, our estimates suggest that cognitive skills and education have been overstudied, while wealth, race and noncognitive behavioral traits have been understudied.

Measuring the Intergenerational Transmission of Economic Status

Economic status can be measured in discrete categories—by membership in hierarchically ordered classes, for example—or continuously, by earnings, income or wealth. The discrete approach allows a rich but difficult-to-summarize representation of the process of intergenerational persistence of status using transition probabilities among the relevant social ranks (Erikson and Goldthorpe, 1992; this issue). By contrast, continuous measures allow a simple metric of persistence, based on the correlation between the economic status of the two generations. Moreover, these correlations may be decomposed into additive components reflecting the various causal mechanisms accounting for parent-child economic similarity. Both approaches are insightful, but here we will rely primarily on the continuous measurement of status. For reasons of data availability, we use income or earnings as the measure of economic status, though income (the more inclusive measure) is preferable for most applications.

We use subscript p to refer to parental measures, while y is an individual's economic status, adjusted so that its mean, $\bar{y}$, is constant across generations, β_y is a constant, and ε_y is a disturbance uncorrelated with y_p. Thus,

$$y - \bar{y} = \beta_y(y_p - \bar{y}) + \varepsilon_y;$$

that is, the deviation of the offspring's economic status from the mean is β_y times the deviation of the parent from mean economic status, plus an error term. In the empirical work reviewed below, earnings, income, wealth and other measures of economic success are measured by their natural logarithm unless otherwise noted. Thus, β_y, termed the intergenerational income elasticity, is the percentage change in offspring's economic success associated with a 1 percent change in parents' economic success. The influence of mean economic status on the economics status of the offspring, $1 - \beta_y$, is called *regression to the mean,* since it shows that one may expect to be closer to the mean than one's parents by the fraction $1 - \beta_y$ (Goldberger, 1989).

The relationship between the intergenerational income elasticity and the intergenerational correlation is given by

$$\rho_y = \beta_y \frac{\sigma_{y_p}}{\sigma_y},$$

where σ_y is the standard deviation of y. If y is a natural logarithm, its standard deviation is a common unit-free measure of inequality. Thus, if inequality is unchanging across generations, so $\sigma_{y_p} = \sigma_y$, then $\rho_y = \beta_y$. However, the intergenerational income elasticity exceeds ρ_y when income inequality is rising, but is less than ρ_y when income inequality is declining. In effect, the intergenerational correlation coefficient ρ is affected by changes in the distribution of income while the intergenerational income elasticity is not. Also, ρ^2 measures the fraction of the variance in this generation's measure of economic success that is linearly associated with the same measure in the previous generation.

Estimates of the intergenerational income elasticity are presented in Solon (1999, this issue) and Mulligan (1997). The mean estimates reported in Mulligan are as follows: for consumption, 0.68; for wealth, 0.50; for income, 0.43; for earnings (or wages), 0.34; and for years of schooling, 0.29. Evidence concerning trends in the degree of income persistence across generations is mixed. Most studies indicate that persistence rises with age, is greater for sons than daughters and is greater when multiple years of income or earnings are averaged. The importance of averaging multiple years to capture permanent aspects of economic status is dramatized in Mazumder (forthcoming). He used a rich U.S. Social Security Administration data set to estimate an intergenerational income elasticity of 0.27, averaging son's earnings over three years and father earnings averaged over two years. But the estimate increases to 0.47 when six years of the fathers' earnings are averaged and to 0.65 when 15 years are averaged.

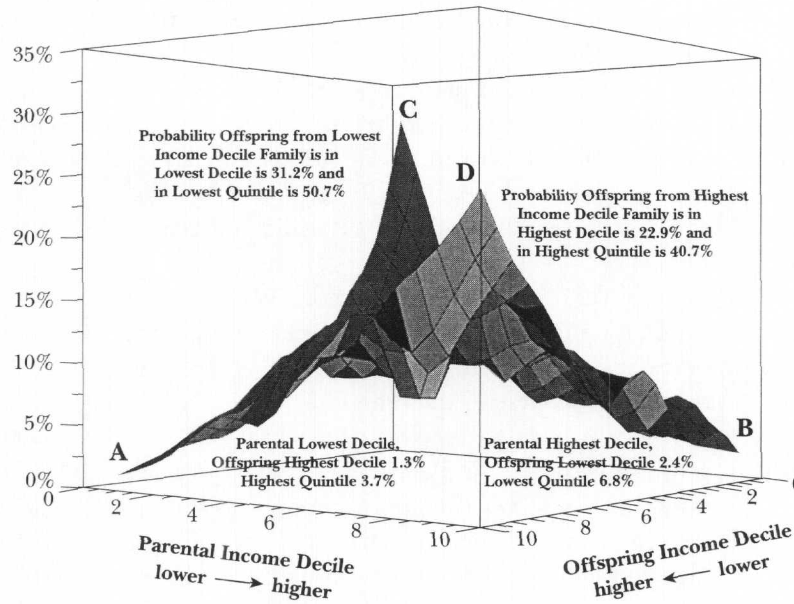
Do intergenerational elasticities of this magnitude mean that "rags to riches" is no more than a fantasy for most poor children? The intergenerational correlation is an average measure and may be unilluminating about the probabilities of economic success conditional on being the child of poor or rich parents. Calculating these conditional probabilities and inspecting the entire transition matrix gives a more complete picture. The results of a study by Hertz (2002) appear in Figure 1 with the parents arranged by income decile (from poor to rich moving from left to right) and with adult children arranged by income decile along the other axis. The height of the surface indicates the likelihood of making the transition from the indicated parents' decile to the children's decile.

Though the underlying intergenerational correlation of incomes in the data set Hertz (2002) used is a modest 0.42, the differences in the likely life trajectories of the children of the poor and the rich are substantial. The "twin peaks" represent those stuck in poverty and affluence (though we do not expect the term "affluence trap" to catch on). A son born to the top decile has a 22.9 percent chance of attaining the top decile (point *D*) and a 40.7 percent chance of attaining the top quintile. *A* indicates that the son of the poorest decile has a 1.3 percent chance of attaining the top decile and a 3.7 percent chance of attaining the top quintile. *C* indicates that children of the poorest decile have a 31.2 percent chance of occupying the lowest decile and a 50.7 percent chance of occupying the lowest quintile, while *B* shows that the probability that a child of the richest decile ends up in the poorest decile is 2.4 percent, with a 6.8 percent chance of occupying the lowest quintile. Hertz's transmission matrix and other studies suggest that distinct transmission mechanisms may be at work at various points of the income distribution (Corak and Heisz, 1999; Cooper, Durlauf and Johnson, 1994; Hertz, 2001). For example, wealth bequests may play a major role at the top of the income distribution, while at the bottom, vulnerability to violence or other adverse health episodes may be more important. Mobility patterns by race also differ dramatically (Hertz, 2002). Downward mobility from the top quartile to the bottom quartile is nearly five times as great for blacks as for whites. Thus, whatever it is that accounts for their success, successful blacks do not transmit it to their children as effectively as do successful whites. Correspondingly, blacks born to the bottom quartile attain the top quartile at one half the rate of whites.

Sources of Persistence: Cultural, Genetic and Bequest

Economic status does persist substantially across generations. We seek to uncover the channels through which parental incomes influence offspring incomes. We do this by decomposing the intergenerational correlation (or the intergenerational income elasticity) into additive components reflecting the contribution of various causal mechanisms. This will allow us to conclude, for example,

Figure 1
Intergenerational Income Transition Probabilities

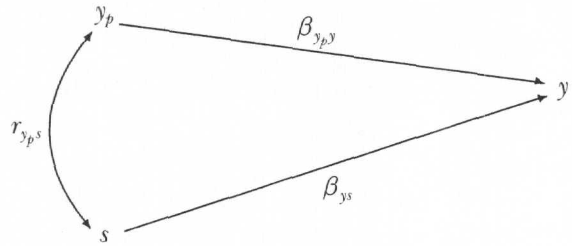


Notes: The height of the surface in cell (i, j) is the probability that a person whose parents' household income was in the ith decile will have household income in the jth decile as an adult. The income of the children was measured when they were aged 26 or older and was averaged over all such years for which it was observed (an average of ten years). Parents' income was averaged over all observed years in which the child lived with the parents (an average of 9.4 years).
Source: From PSID data, Hertz (2002). The 10 × 10 transition matrix on which this figure is based is available at ⟨http://www-unix.oit.umass.edu/~gintis⟩.

that a certain fraction of the intergenerational correlation is accounted for by the genetic inheritance of IQ or by the fact that the children of rich parents are also wealthy.

It is a remarkable fact about correlation coefficients that this can be done. Moreover, the technique we use does not require that we introduce variables in any particular order. Suppose that parents' income (measured by its logarithm, y_p) and offspring education (s) affect offspring income (also measured by its logarithm, y). Like any correlation coefficient, this intergenerational correlation $r_{y_p y}$ can be expressed as the sum of the normalized regression coefficients of measures of parental income $(\beta_{y_p y})$ and offspring education (β_{ys}) in a multiple regression predicting y, each multiplied by the correlation between y_p and the regressor (which, of course, for parental income itself is just 1). A normalized regression coefficient is the change in the dependent variable, in standard deviation units, associated with a one standard deviation change in the independent variable. The *direct effect* of parental income is the normalized regression coefficient of parental income from this regression. The education component of this decomposition of

Figure 2
Representing a Correlation as the Sum of Direct and Indirect Effects



the intergenerational correlation is called an *indirect effect.*[2] Figure 2 illustrates this breakdown, which gives

$$r_{yy_p} = \beta_{y_p y} + r_{y_p s}\beta_{ys}$$

intergenerational correlation = direct effect + indirect effect.

As long as the multiple regression coefficients are unbiased, the decomposition is valid whatever the relationship among the variables. Specifically, it does not require that the regressors be uncorrelated. This decomposition allows us to be more precise about our "black box" claim in the introduction. We mean that the direct parental effect is a substantial fraction of the intergenerational correlation in a number of studies allowing this comparison (Bowles, 1972; Bowles and Nelson, 1974; Atkinson, Maynard and Trinder, 1983; Mulligan, 1999).

Our strategy is to estimate the size of these direct and indirect effects. Note that the decomposition uses correlations between parental incomes and other variables—schooling in the example—thought to be causally related to the income-generating process. These correlations with parental income need not reflect causal relationships, of course. But the above decomposition can be repeated for the correlations between parental income and the causes of offspring income, in some cases permitting causal interpretations. For example, a study of the role of wealth in the transmission process could ask why parental income and offspring wealth are correlated. Is it bequests and inter vivos transfers or the cultural transmission of savings behaviors that account for this correlation? Or do we simply not know why parent and offspring wealth is correlated and as a result should avoid giving the data a causal interpretation? Similarly, parent-offspring similarity in human capital may be due to genetic or cultural inheritance of whatever it takes to persist in schooling and to acquire skills and behaviors that are rewarded in the labor market. Unlike the models of parental and child behavior accounting for persistence pioneered by Becker and presented in this issue by Grawe and

[2] This decomposition can be found in Blalock (1964) and is described in the Appendix to this paper. Goldberger (1991) describes the standard regression model with normalized (mean zero, unit standard deviation) variables on which it is based.

Mulligan, our approach is more diagnostic, not giving an adequate causal account of the transmission process, but indicating where to look to find the causes. The next sections of this paper will explore such decompositions.

The Role of Genetic Inheritance of Cognitive Skill

One of the transmission channels deserves special attention not only because of its prima facie plausibility, but also because of the extraordinary attention given to it in popular discussions of the subject. This is the genetic inheritance of cognitive skill. The similarity of parents' and offsprings' scores on cognitive tests is well documented. Correlations of IQ between parents and offspring range from 0.42 to 0.72, where the higher figure refers to measures of average parental and average offspring IQ (Bouchard and McGue, 1981; Plomin et al., 2000). The contribution of cognitive functioning to earnings both directly and *via* schooling attainment has also been established in a variety of studies that estimate determinants of earnings using IQ (and related) test scores. The direct effect of IQ on earnings is estimated from multiple regression studies that typically use the logarithm of earnings as a dependent variable and estimate the regression coefficients of a variety of explanatory variables, including performance on a cognitive test, years (and perhaps other measures) of schooling, a measure of parental economic and/or social status, work experience, race and sex. The indirect effect of IQ operating through its contribution to higher levels of educational attainment is estimated using measures of childhood IQ (along with other variables) to predict the level of schooling obtained.

We have located 65 estimates of the normalized regression coefficient of a test score in an earnings equation in 24 different studies of U.S. data over a period of three decades. Our meta-analysis of these studies is presented in Bowles, Gintis and Osborne (2002). The mean of these estimates is 0.15, indicating that a standard deviation change in the cognitive score, holding constant the remaining variables (including schooling), changes the natural logarithm of earnings by about one-seventh of a standard deviation. By contrast, the mean value of the normalized regression coefficient of years of schooling in the same equation predicting the natural log of earnings in these studies is 0.22, suggesting a somewhat larger independent effect of schooling. We checked to see if these results were dependent on the weight of overrepresented authors, the type of cognitive test used, at what age the test was taken and other differences among the studies and found no significant effects. An estimate of the causal impact of childhood IQ on years of schooling (also normalized) is 0.53 (Winship and Korenman, 1999). A rough estimate of the direct and indirect effect of IQ on earnings, call it b, is then $b = 0.15 + (0.53)(0.22) = 0.266$.

Do these two facts—parent-child similarity in IQ and an important direct and indirect causal role for IQ in generating earnings—imply a major role for genetic inheritance of cognitive ability in the transmission of intergenerational economic status? One way to formulate this question is to ask how similar would parental and offspring IQ be if the sole source of the similarity were genetic transmission. Also, how similar would the incomes of parents and offspring be if there were no other transmission channel?

For this we need some genetics (the details are in the Appendix and in Bowles and Gintis, 2001) and a few terms—phenotype, genotype, heritability and the genetic correlation—unfamiliar to many economists. A person's IQ—meaning, a test score—is a *phenotypic* trait, while the genes influencing IQ are the person's *genotypic* IQ. *Heritability* is the relationship between the two. Suppose that, for a given environment, a standard deviation difference in genotype is associated with a fraction h of a standard deviation difference in IQ. Then h^2 is the heritability of IQ. Estimates of h^2 are based on the degree of similarity of IQ among twins, siblings, cousins and others with differing degrees of genetic relatedness. The value cannot be higher than 1, and most recent estimates are substantially lower, possibly more like a half or less (Devlin, Daniels and Roeder, 1997; Feldman, Otto and Christiansen, 2000; Plomin, 1999). The *genetic correlation* is the degree of statistical association between genotypes of parents and children, which is 0.5 if the parents' genotypes are uncorrelated ("random mating"). But couples tend to be more similar in IQ than would occur by random mate choice ("assortative mating"), and this similarity is associated with an unknown correlation m of their genotypes. The effect is to raise the genetic correlation of parent and offspring to $(1 + m)/2$.

Using the method of decomposition introduced in the previous section, the correlation γ between parental and offspring IQ that is attributable to genetic inheritance of IQ alone is the heritability of IQ times the genetic correlation. Thus, we have $\gamma = h^2(1 + m)/2$. The correlation between parent and offspring income that is attributable to genetic inheritance of IQ is this correlation times the normalized (direct and indirect) effect of IQ on the income of parents, times the analogous effect for the offspring, or γb^2. Another way to see this is to note that the correlation between parental income and offspring IQ that we would observe were the genetic inheritance of IQ the only channel at work is γb, and this times the effect of offspring IQ on earnings, which is b, gives the same result.

Using the values estimated above, we see that the contribution of genetic inheritance of IQ to the intergenerational transmission of income is

$$(h^2(1 + m)/2)(0.266)^2 = .035(1 + m)h^2.$$

If the heritability of IQ were 0.5 and the degree of assortation, m, were 0.2 (both reasonable, if only ballpark estimates) and the genetic inheritance of IQ were the only mechanism accounting for intergenerational income transmission, then the intergenerational correlation would be 0.01, or roughly 2 percent the observed intergenerational correlation. Note the conclusion that the contribution of genetic inheritance of IQ is negligible is not the result of any assumptions concerning assortative mating or the heritability of IQ: the IQ genotype of parents could be perfectly correlated and the heritability of IQ 100 percent without appreciably changing the qualitative conclusions. The estimate results from the fact that IQ is just not an important enough determinant of economic success.

Might the small contribution of genetic inheritance of IQ to parent-offspring similarity of incomes be the result of measurement error in the cognitive measures? There are two issues here. First, what is the *reliability* of the test: whatever the test measures, does it measure well? Second, what is the *validity* of the test: does the test measure the right thing? The concern that the tests are a very noisy measure is misplaced. In fact, the tests are among the more reliable variables used in standard earnings equations, where reliability is measured by the correlation between tests and retests, between odd and even numbered items on the tests, and by more sophisticated methods. For the commonly used Armed Forces Qualification Test (AFQT), for example—a test used to predict vocational success that is often used as a measure of cognitive skills—the correlation between two test scores taken on successive days by the same person is likely to be higher than the correlation between the same person's reported years of schooling or income on two successive days.

The second concern, that the tests measure the wrong thing, is weightier and less easy to address with any certainty. Could it be that cognitive skills not measured on existing test instruments are both highly heritable and have a major impact on earnings, thereby possibly explaining a more substantial fraction of the transmission process? The search for general cognitive measures that are substantially uncorrelated with IQ and predictive of success in adult roles began with Edward Thorndike's (1919) paper on "social intelligence." Some alternative test instruments, such as Robert Sternberg and collaborators' "practical intelligence" predict economic success in particular occupations (Sternberg et al., 1995; Williams and Sternberg, 1995). But despite the substantial fame and fortune that would have accrued to success in this area, the quest that Thorndike launched three generations ago has yielded no robust alternative to IQ, let alone one that is highly heritable. Thus, the possible existence of economically important but as yet unmeasured heritable general cognitive skills cannot be excluded, but should at this stage be treated as speculation.

Indeed, we are inclined to think that available estimates *overstate* the importance of general cognitive skill as a determinant of earnings, since in many respects taking a test is like doing a job. Successful performance in either case results from a combination of ability and motivation, including the disposition to follow instructions, persistence, work ethic and other traits likely to contribute independently to one's earnings. This is the reason we eschew the common label of a test score as "cognitive skill," but rather use the more descriptive term "cognitive performance." Eysenck (1994, p. 9), a leading student of cognitive testing, writes: "Low problem solving in an IQ test is a measure of performance; personality may influence performance rather than abstract intellect, with measurable effects on the IQ. An IQ test lasts for up to 1 hour or more, and considerations of fatigue, vigilance, arousal, etc. may very well play a part." Thus, some of the explanatory power of the cognitive measure in predicting earnings does not reflect cognitive skill, but rather other individual attributes contributing to the successful performance of tasks.

Genetic and Environmental Inheritance

Although the genetic inheritance of IQ explains little of the intergenerational transmission process, this says nothing about the possible importance of other genetically transmitted traits. Indeed, the remarkable income similarity of identical twins compared to fraternal twins suggests that genetic effects may be important. We will use the similarity of twins to estimate the genetic heritability of income as well as the environmental component of intergenerational transmission.

But two words of caution are in order. First, as we will demonstrate, our estimates are quite sensitive to variations in unobserved parameters. Second, it is sometimes mistakenly supposed that if the heritability of a trait is substantial, then the trait cannot be affected much by changing the environment. The fallacy of this view is dramatized by the case of stature. The heritability of height estimated from U.S. twin samples is substantial—about 0.90 (Plomin et al., 2000). Moreover, there are significant height differences among the peoples of the world: Dinka men in the Sudan average 5 feet and 11 inches—a bit taller than Norwegian and U.S. military servicemen and a whopping 8 inches taller than the Hadza hunter-gatherers in southern Africa (Floud, Wachter and Gregory, 1990). But the fact that Norwegian recruits in 1761 were *shorter* than today's Hadza shows that even quite heritable traits are sensitive to environments. What *can* be concluded from a finding that a small fraction of the variance of a trait is due to environmental variance is that policies to alter the trait through changed environments will require nonstandard environments that differ from the environments on which the estimates are based.

Consider the case of South Africa, where in 1993 (the year before Nelson Mandela became president), roughly two-thirds of the intergenerational transmission of earnings was attributable to the fact that fathers and sons are of the same race, and race is a strong predictor of earnings (Hertz, 2001). That is, adding race to an equation predicting sons' earnings reduces the estimated effect of fathers' earnings by over two-thirds. Because the traits designated by "race" are highly heritable and interracial parenting uncommon, we thus find a substantial role of genetic inheritance in the intergenerational transmission of economic status. Yet, it is especially clear in the case of South Africa under apartheid that the economic importance of the genetic inheritance of physical traits derived from environmental influences. What made the genetic inheritance of skin color and other racial markers central to the transmission process were matters of public policy, not human nature, including the very definition of races, racial patterns in marriage and the discrimination suffered by nonwhites. Thus, the determination of the genetic component in a transmission process says little by itself about the extent to which public policy can or should level a playing field.

Estimates of heritability use data on pairs of individuals with varying degrees of shared genes and environments. For example, identical and fraternal twins are exposed to similar environments during their upbringing, but fraternal twins are less closely related genetically than identical twins. Under quite strong simplifying assumptions (explained in the Appendix) one can exploit the variation in genetic and environmental similarities among pairs of relatives to estimate heritability of a trait such as income, years of schooling or other standard economic variables. Taubman (1976) was the first economist to use this method. The model underlying the following calculations assumes that genes and environment affect human capital, which produces earnings, as the equation below indicates, but the effects of wealth and other contributions to income are unaffected by genes and environment and will be introduced subsequently.

Here are the assumptions. First, genes and environments have additive effects—genes and environment may be correlated, but the direct effect of "good genes" on earnings (its regression coefficient) is independent of the quality of the environment and conversely. Thus, an individual's earnings can be written

$$\text{earnings} = h(\text{genes}) + \beta(\text{environment}) + \text{idiosyncratic effects}.$$

Second, within-pair genetic differences (for the fraternals) are uncorrelated with within-pair environmental differences (for example, the good-looking twin does not get more loving attention). Third, the environments affecting individual development are as similar for members of fraternal pairs of twins as for the identical twins pairs. Fourth, the earnings genotypes of the two parents are uncorrelated ("random mating"). Given these assumptions, we show in the Appendix that the heritability (h^2) of earnings is twice the difference between the earnings correlations of identical and fraternal twins. As the difference between these two correlations is 0.2 in best data sets available—the Swedish Twin Registry studied by Björklund, Jäntti and Solon (forthcoming) and a smaller U.S. Twinsburg data set studied by Ashenfelter and Krueger (1994)—these assumptions give an estimate of h^2 equal to 0.4.

Because, due to the assumption of random mating, the correlation of genes for the fraternal twins is 0.5, the implied correlation of fraternal twins' earnings because of genetic factors is $h^2/2$. The fact that the observed correlation of twins' earnings exceeds this estimate is explained by the fact that twins share similar environments. Thus, once we know h^2, we can use information about the degree of similarity of these environments to estimate how large the environmental effects would have to be to generate the observed earnings correlations.

The assumptions concerning random mating and common environments are unrealistic and can be relaxed. First, we need an estimate of m_y, the correlation of parents' earnings genotypes. The relevant measure is the earnings *potential* (the correlation of actual earnings would understate the degree of assortation, because many women do not work full time). The degree of assortation on phenotype is likely to be considerably larger than on genotype for the simple reason that the basis of the assortation is the phenotype, not the genotype (which is unobservable), and the two are not very closely related for the case of earnings, as we will see. Assuming that the genotype for potential earnings of parents is half as similar as are the actual incomes of brothers, the correlation would be about 0.2.

Second, note that because it was assumed that the environments experienced by the two identical twins are not, on the average, more similar to the environments of the two fraternal twins, the fact that within-twin-pair earnings differences are less for the identical twins must be explained entirely by their genetic similarity. But if the identical twins experience more similar environments (because they look alike, for example) than the fraternals, the estimate will overstate the degree of heritability.

It is likely that identical twins share more similar environments than fraternal twins and other siblings (Loehlin and Nichols, 1976; Feldman, Otto and Christiansen, 2000; Cloninger, Rice and Reich, 1979; Rao et al., 1982). Estimates of the extent to which the environments of identical twins are more similar than those of fraternal twins are quite imprecise, and we can do no better than to indicate the effects of using plausible alternative assumptions. Just how sensitive the estimates are to reasonable variations in the assumptions concerning differences in the correlations of twins' environments can be estimated by assuming some degree of statistical association of genes and environment, with the correlated but not identical genes of the fraternal twins giving them less correlated environments than the identical twins.

Table 1 presents estimates based on various magnitudes of this genes-environment effect. As the assumed correlation between genes and environment increases, the correlation of the environments of the identical twins rises, and because this then explains some of the earnings similarity of the identical twins, the resulting estimate of heritability falls.[3] We take the third numerical column of Table 1 as the most reasonable set of estimates. On this basis, two striking conclusions follow. First, the heritability of earnings appears substantial. Second, the environmental effects are also large. The normalized regression coefficient of environment on earnings is $\beta_e = 0.38$, which may be compared with the normalized regression coefficient for a measure of years of schooling in an earnings equation, from our earlier meta-analysis, which is 0.22. Thus, while educational attainment captures important aspects of the relevant environments, it is far from exhaustive.

What is the intergenerational correlation of earnings implied by our estimate of β_e and h? To answer this question, in addition to h and β_e, we require the correlation of parents' earnings with genes (which is already implied by our estimates) and the correlation of parents' earnings with environment. The first

[3] The Swedish Twin Registry data set assembled by Björklund, Jäntti and Solon (forthcoming) has data not just on twins, but on many pairs with varying degrees of relatedness (half-siblings, for example) and may allow more robust estimates using the methods developed by Cloninger, Rice and Reich (1979), Rao et al. (1982) and Feldman, Otto and Christiansen (2000).

Table 1
Estimating the Heritability of Earnings

Assumed Correlation of Genes and Environment	0.00	0.50	0.70	0.80
Heritability of Earnings (h^2)	0.50	0.29	0.19	0.13
Normalized Regression Coefficient:				
Genes on Earnings (h)	0.71	0.54	0.44	0.36
Environment on Earnings (β)	0.29	0.33	0.38	0.44
Correlation of Environments:				
Fraternal Twins	0.70	0.70	0.70	0.70
Identical Twins	0.70	0.80	0.90	0.97

Notes: The association of genes with environment is represented by the normalized regression coefficient of genes on environment. This table assumes that parental earnings-determining genes are correlated 0.2, and the correlation of fraternal twins' environment is 0.7. We use the correlations of income for identical twins of 0.56 and of fraternal twins of 0.36, taken from the U.S. Twinsburg Study, and assume that these are also the correlations of earnings.

column in Table 2 gives our estimates. The genetic contribution is simply h times the correlation between parental earnings and offspring genotype, or $h^2(1 + m)/2$. The environmental contribution, similarly, is β_e times a correlation of parents' earnings and environment (namely 0.74) selected to yield a total intergenerational earnings correlation of 0.4.

The estimate that genetic inheritance may account for almost one-third of the intergenerational correlation is somewhat unexpected, in light of our negative findings concerning the inheritance of IQ. The surprising importance of both environment and genes point to a puzzle. If the genetic contribution is not strongly related to IQ and if the environmental contribution is much larger than the contribution of years of schooling, what are the mechanisms accounting for persistence of income over the generations? We shall return to this puzzle, but will turn to data other than twins studies first to show that the same puzzle arises.

Human Capital

Because schooling attainment is persistent across generations and has clear links to skills and perhaps other traits that are rewarded in labor markets, an account of the transmission of intergenerational status based on human capital has strong prima facie plausibility. The data already introduced allow a calculation of the portion of the intergenerational income correlation accounted for by the fact that offspring of high-income parents get more schooling (measured in years). This is the correlation of parent income and offspring schooling (about 0.45) multiplied by the normalized regression coefficient of schooling in an earnings equation (0.22 from our meta-analysis), or 0.10. This correlation is substantial, particularly in the light of the fact that it is restricted to the effects of years of schooling operating independently of IQ (because our estimate of 0.22 is from earnings functions in

Table 2
Contribution of Environmental, Genetic and Wealth Effects to Intergenerational Transmission

	Earnings	*Income*
Environmental	0.28	0.20
Genetic	0.12	0.09
Wealth		0.12
Intergenerational correlation	0.40	0.41

Notes: The income column and the estimated contribution of wealth are discussed below. The environmental versus genetic breakdown assumes the figures in the third numerical column in Table 1.

which the regressors include the AFQT test or a similar instrument). The full contribution, including the effect of schooling on IQ and its effect on earnings as well as the direct effect of schooling on earnings holding constant IQ is 0.12.

It used to be commonly assumed that once adequate measures of schooling quality were developed, the only effects of parental economic status on offspring earnings would operate through effects on cognitive functioning and schooling, with the direct effect of parental status on offspring earnings vanishing. But even as the measurement of school quality has improved over the years, the estimated direct effect of parental incomes (or earnings) on offspring earnings has turned out to be remarkably robust. For example, Mulligan (1999), using early 1990s data from the (U.S.) National Longitudinal Study of Youth, first estimated the effect of a change in the logarithm of parental earnings on offspring's logarithm of earnings without controlling for any other factors and then controlled for a number of measures of school quality, as well as the AFQT and standard educational and demographic variables. He found that between two-fifths and one-half of the gross (unconditional) statistical relationship of parental and offspring earnings remains even after controlling for the other factors. These results just reaffirm the black box puzzle using entirely different data and methods: more than two-fifths of the intergenerational transmission coefficient is unaccounted for.[4]

Taking account of the fact that the children of the well-to-do are much healthier than poor children (Case, Lubotsky and Paxson, 2001) along with the fact that poor health has substantial effects on incomes later in life (Smith, 1999) would probably account for a substantial part of the intergenerational transmission process. The role of health in the process is particularly striking because parental incomes appear to have strong impacts on child health that are not accounted for by either the health status of the parents nor by the genetic similarity between parents and children.

[4] It is also true that we *can* typically statistically account for less than half of the variance of the earnings or income using the conventional variables described above. But this fact does not explain our limited success in accounting for the intergenerational correlation, as this correlation measures only that part of the variation of earnings that we can explain statistically by parental economic status.

Wealth Effects

Economic success can be passed on in a family through the inheritance of wealth as well as inter vivos wealth transfers to children. Remarkably little scholarly attention has been given to this mechanism, in part because no representative panel data set with adequate measures of other earnings determinants exists for which the second generation has reached the age at which the inheritance of wealth typically has been completed. The only study of which we are aware that addresses this problem by following the second generation to their deaths estimates a much higher intergenerational wealth correlation than those reported by Mulligan, above (Menchik, 1979). But while inheritances of wealth clearly matter for the top of the income distribution, we doubt whether such transfers play an important role for most families. Very few individuals receive inheritances of significant magnitude. Mulligan (1997) estimates that estates passing on sufficient wealth to be subject to inheritance tax in the United States constituted between 2 and 4 percent of deaths over the years 1960–1995. Even though this figure leaves out some quite substantial inheritances, as well as transfers that occur during life, it seems unlikely that for most of the population a substantial degree of economic status is transmitted directly by the intergenerational transfer of property or financial wealth.

It thus seems likely that the intergenerational persistence of wealth reflects, at least in part, parent-offspring similarities in traits influencing wealth accumulation, such as orientation toward the future, sense of personal efficacy, work ethic, schooling attainment and risk taking. Some of these traits covary with the level of wealth: for example, less well-off people may be more likely to be risk averse, to discount the future and have a low sense of efficacy. Because of this correlation of wealth with the traits conducive to wealth accumulation, parent-offspring similarity in wealth may arise from sources independent of any bequests or transfers.

Whatever their source, for families with significant income from wealth, parent-offspring wealth similarities can contribute a substantial fraction to the intergenerational persistence of incomes. Using the same decomposition methods as above, this contribution is the correlation of parent income and child wealth times the normalized regression coefficient of wealth in an income equation. We use data from the Panel Study of Income Dynamics analyzed by Charles and Hurst (2002). The correlation between parent income and child wealth (both in natural logarithms) in this data set is 0.24. The average age of the children is only 37 years, so this correlation does not capture inheritance of wealth at death of the parents. To get a rough idea of the normalized regression coefficient, one way to proceed is by starting with the percentage change in income associated with a 1 percent change in wealth; this elasticity will range from virtually zero (for those with little or no wealth) to one (for those with no source of income other than wealth). A plausible mean value (based on average factor income shares) for the U.S. population is 0.20. We convert this to a normalized regression coefficient by multiplying by the ratio of the standard deviation of log wealth to the standard deviation of log income, also from the PSID data set provided by Charles and Hurst (2002). This calculation suggests that the fact that higher income parents have wealthier children contributes 0.12 to the intergenerational correlation of incomes.

This figure, while substantial, may be an underestimate, as it is based on data that, for the reasons mentioned above, do not capture a key transmission process, namely inheritance of wealth upon the death of one's parents. Moreover, the estimate should be adjusted upward to take account of the fact that those with greater wealth tend to have higher average returns to their wealth (Bardhan, Bowles and Gintis, 2000; Yitzhaki, 1987). Greater parental or own wealth may also raise the rate of return to schooling and other human investments, but we have no way of taking account of this empirically. For a sample of very rich parents, the contribution of wealth to the intergenerational correlation would be much higher, of course. For a sample of families with very limited wealth, the contribution would be nearly zero. The difference in the contribution of wealth effects across the income distribution is a reflection of the heterogeneous nature of the transmission process mentioned earlier. Because of the very skewed distribution of wealth, the family with the mean level of wealth (to which our estimates apply) is considerably wealthier than the median family.

Group Membership and Personality

Thus far, we have followed the production function approach, which underpins most economic approaches to intergenerational transmission, seeking to determine the contribution of parent-child similarity in ownership of factors of production. We have complemented the usual choice-based approach by including the influence of genetic inheritance. But other traits are persistent across generations and are arguably as important—for example, race, first language, number of children, number of siblings and others. For example, obesity is a predictor of low earnings for women, while height predicts high earnings for men. Good looks predict high earnings for both men and women, the latter independently of whether they hold jobs interacting with the public (Hammermesh and Biddle, 1993). Bowles, Gintis and Osborne (2002) provide a survey of empirical evidence concerning these and many other nonskill determinants of economic success.

Two such variables illustrate the potential importance of nonskill factors in the intergenerational transmission of economic status: group membership and personality.

Suppose that economic success is influenced not only by a person's traits, but also by characteristics of the group of individuals with whom the person typically interacts. Groups may differ in a variety of dimensions: average level of schooling, economic success, cognitive functioning and wealth level. Groups may be residential neighborhoods, ethnic or racial groups, linguistic groups, citizens of a nation or any other set of individuals who typically interact with one another. Group effects on economic success are well documented and may arise for a number of reasons, including discrimination, conformist effects on behavior, differential access to information and complementarities in production (Cooper, Durlauf, and Johnson, 1994; Durlauf, 2001; Borjas, 1995).

Race apparently plays a significant role in the intergenerational transmission of economic success. This is suggested by the fact that for the United States, the correlation among brothers' earnings estimated by Björklund et al. (2002), namely 0.43, falls by 0.10 when the sample is restricted to whites. Apparently, what brothers almost always have in common, namely race, accounts for much of their similarity of income. The same is true of parents and their children. In the data set underlying Figure 1, the elasticity of offspring family income with respect to parents' family income is 0.54, but the same elasticity for whites only is 0.43 and for blacks only is 0.41 (Hertz, 2002). Parent-offspring similarity in income is explained in important measure by the fact that "race" is transmitted across generations. Using Hertz's estimates, we find that race (that is, the correlation of parents income with offspring race) contributes 0.07 to the intergenerational correlation. While this estimate is a bit lower that those suggested by the above data, it may nonetheless be an overestimate, as it is based on an income equation with the standard regressors, but without a measure of cognitive performance, the inclusion of which would probably lower the race coefficient somewhat.

A second example of traits not found in a conventional production function but that contribute to intergenerational status transmission are dispositions such as a sense of personal efficacy, work ethic or a rate of time discount (present orientation). The importance of these aspects of personality stems from the fact that in a large class of exchanges, including the hiring of labor, borrowing and lending, or the exchange of goods of uncertain quality, it is impossible to specify all relevant aspects of the exchange in a contract enforceable by the courts. Where this is the case, the actual terms of the exchange are influenced by the degree of trust, honesty, hard work and other dispositions of the parties to the exchange. For example, a very present-oriented employee will not value the employer's promise of continued employment in the future, conditional on hard work now. Instead, such an employee will require a higher wage to motivate hard work in the present and, therefore, is less likely to be employed. As another example, fatalistic workers who believe that the probability of job termination is unaffected by their own actions will be costly to motivate under this type of labor contract (Bowles, Gintis and Osborne, 2002). The empirical importance of these traits is suggested in a number of studies (Duncan and Dunifon, 1998; Heckman and Rubinstein, 2001; Kuhn and Weinberger, 2001; Heckman, forthcoming).

Osborne (forthcoming) has studied the economic importance and intergenerational persistence of fatalism, as measured by the Rotter Scale, a common measure of the degree to which individuals believe that important events in their lives are caused by external events rather than by their own actions. Her study of a sample of U.S men and their parents found that the score on the Rotter Scale measured before entry to the labor market has a statistically significant and large influence on earnings. Moreover, the Rotter score is persistent from parents to offspring. The normalized influence of the Rotter Scale on earnings in Osborne's study is somewhat larger (in absolute value, namely −0.2) than the average influence of IQ in our meta-analysis of 65 studies discussed earlier. The estimated correlation of parental income with child fatalism is −0.14. The contribution of the fatalism channel to the intergenerational correlation is the correlation of parent income to child fatalism multiplied by the correlation from child fatalism to subsequent income, 0.028—that is, (−0.2)(−0.14).

Osborne (forthcoming) also studied a sample of women in England and found that measures of social maladjustment taken at age eleven (the Bristol Social Adjustment Scale), such as aggression and withdrawal, are strong predictors of earnings at age 33. The normalized influence of personality traits of aggression and withdrawal on earnings is considerably larger than the influence of IQ. There are no measures of intergenerational persistence of personality traits in the Osborne's English data set, but other studies suggest that parent-child similarity in measures of social maladjustment may be quite high. For example, Duncan et al. (forthcoming) found that deviant forms of behaviors of U.S. mothers were strong predictors of the same behaviors in daughters, including drug use, violent behaviors, early sex, suspension from school and criminal convictions. Osborne's work thus suggests that the intergenerational transmission of personality traits (whether genetic or cultural) may be an important channel explaining the intergenerational persistence of income.

We know relatively little about the workings of the intergenerational transmission process for personality traits relevant to economic success, other than cognitive functioning. However, Kohn's (1969) study of child rearing values of parents suggests that at least for some traits, parents' experiences in the workplace are generalized and passed on to children. Kohn categorizes his parent sample by the degree of self-determination that each experiences on the job, ranging from those who are relatively unsupervised to those who are closely directed by superiors. Kohn found that parents with high levels of what he termed "occupational self-direction" emphasize curiosity, self-control, happiness and independence as values for their children. Those who are closely monitored by supervisors at work emphasize conformity to external authority. Kohn concluded: "Whether consciously or not, parents tend to impart to their children the lessons derived from their own social class and thus help prepare their children for a similar class position." The work by Osborne suggests that the degree of self-direction has significant effects on earnings later in life. Other work by Yeung, Hill and Duncan (2000) shows that parental behavior, including church attendance, membership in social organizations and such precautionary behavior as seat belt usage have significant impacts on their children's earnings.

Conclusion

Recent evidence points to a much higher level of intergenerational transmission of economic position than was previously thought to be the case. America may

Table 3
The Main Causal Channels of Intergenerational Status Transmission in the U.S.

Channel	*Earnings*	*Income*
IQ, conditioned on schooling	0.05	0.04
Schooling, conditioned on IQ	0.10	0.07
Wealth		0.12
Personality (fatalism)	0.03	0.02
Race	0.07	0.07
Total Intergenerational Correlation Accounted For	0.25	0.32

Notes: For each channel, the entry is the correlation of parent income with the indicated predictor of offspring income, multiplied by its normalized regression coefficient in an earnings or income equation. The total is the intergenerational correlation resulting from these channels, in the absence of a direct effect of parents' status on offspring status.
Source: Calculations described in text and Bowles and Gintis (2001).

still be the land of opportunity by some measures, but parental income and wealth are strong predictors of the likely economic status of the next generation.

Our main objective has been to assess the extent of intergenerational transmission and the mechanisms accounting for it. Table 3 summarizes our best estimates of the relative importance of the main causal channels we have been able to identify. The only entry not previously explained is the first, which is an estimate of the correlation between parental income and child IQ multiplied by our estimate of the normalized effect of IQ on earnings, conditioned on, among other things, years of schooling. The estimates for IQ, schooling and personality in the income column are simply those in the earnings column adjusted to take account of the effect of earnings differences on income differences, suitably normalized as described in Bowles and Gintis (2001). Thus, we do not take account of the way that these earnings determinants may affect the rate of return to one's wealth. By contrast, we assume that the race effect is of the same magnitude in determining the returns to both human capital and conventional wealth (if the race effect on incomes worked solely via an effect on earnings, its contribution to the intergenerational earnings correlation would be significantly greater).

While the estimates in Table 3 are quite imprecise, the qualitative results are not likely to be affected by reasonable alternative methods. The results are somewhat surprising: wealth, race and schooling are important to the inheritance of economic status, but IQ is not a major contributor, and, as we have seen above, the genetic transmission of IQ is even less important.

A policymaker seeking to level the playing field might use these results to design interventions that would loosen the connection between the economic success of parents and the economic prospects of their children. But does a level playing field entail *no* correlation between parental and child incomes (Swift, forthcoming)? There are important values of family life and privacy that would be compromised by any serious attempt to disconnect the fortunes of parents and children completely. Rather than pursuing an abstract (and to our minds unattractive) objective of zero intergenerational correlation, a better approach might be to ask which mechanisms of intergenerational transmission seem unfair, and to direct policies accordingly. The role of race in transmitting status from generation to generation is clearly unfair. Many people regard the strong correlation between parental income and child health as morally suspect, and many feel the same way about high levels of wealth inheritance. Large majorities favor policies to compensate for inherited disabilities. Other mechanisms of persistence—the genetic inheritance of good looks, for example—strike most people as unobjectionable and not an appropriate target for compensatory policy interventions. Even if some consensus could be formed on which of these mechanisms are morally suspect, the policy implications would be far from clear. For example, the possible incentive effects on parental behaviors of reduced parental influence on child success would have to be estimated and considered.

Appendix
Decomposing Correlation Coefficients and Estimating Heritability

Suppose parental earnings y_p directly affects offspring earnings y, but offspring earnings is also affected by two variables, v_1 and v_2, that are correlated with parental earnings.[5] Then, if $r_{y_pv_1}$ and $r_{y_pv_2}$ are the correlations of parental earnings with v_1 and v_2, respectively, and if the normalized regression coefficients of y_p, v_1, and v_2 predicting y are given by β_{y_py}, β_{v_1y} and β_{v_2y} respectively, we have

$$(1) \qquad r_{y_py} = \beta_{y_py} + r_{y_pv_1}\beta_{v_1y} + r_{y_pv_2}\beta_{v_2y}.$$

This is the correlation between parental and offspring earnings, decomposed into its direct effect (the first term), the effect *via* variable v_1 (the second term) and the effect *via* variable v_2 (the third term). To derive this equation, we write

$$(2) \qquad y = \beta_{y_py}y_p + \beta_{v_1y}v_1 + \beta_{v_2y}v_2 + \varepsilon_y,$$

where all variables are normalized to have zero mean and unit variance, and ε_y is uncorrelated with the independent variables. Then, substituting the above expression for y into the expectation $\mathbf{E}[y_py]$, and noting that if two variables (e.g., y and y_p) have zero mean and unit variance, the correlation between these variables is the expected value of their product, we get

[5] For previous treatments of this material, see Rao, Morton and Yee (1976), Cloninger, Rice and Reich (1979), Rao et al. (1982) and Otto, Feldman and Christiansen (1994).

$$(3) \qquad r_{y_p p} = \mathrm{E}[y_p y] = \mathrm{E}[y_p y_p]\beta_{y_p y} + \mathrm{E}[v_1 y]\beta_{v_1 y} + \mathrm{E}[v_2 y]\beta_{v_2 y}.$$

Since, given our normalization, $\mathbf{E}[y_p y_p] = 1$, $\mathbf{E}[v_1 y] = rv_1 y$, and $\mathbf{E}[v_2 y] = r_{v_2 y}$, we arrive at equation 1.[6]

We now apply this method to estimating heritability using data on similarity of identical and fraternal twins. A more general treatment, using pairs of varying degrees of relatedness, is developed in Feldman, Otto and Christiansen (2000). Suppose a family has two sons whose earnings, y_1 and y_2, depend additively on their genotypes, g_1 and g_2, and their environments, e_1 and e_2. Thus,

$$(4) \qquad y_i = \beta_e e_i + hg_i + \varepsilon_{y_i} \qquad \text{for } i = 1, 2,$$

where ε_{y_i} is uncorrelated with the independent variables in the model and is chosen such that the variance of y_i is unity. The variances of e_i and g_i are also normalized to unity. Note that the normalized regression coefficient of genotype is then h, the square root of the heritability of earnings. We assume the environment e_i of brother i depends both on his genotype g_i and the common family environment E. We thus have

$$(5) \qquad e_i = \beta_E E + \beta_{ge} g_i + \varepsilon_{e_i} \qquad \text{for } i = 1, 2,$$

where ε_{e_i} is uncorrelated with the independent variables in the model and is chosen such that the variance of e_i is unity. We interpret E as including the effect of parental earnings, education and any other environmental factor that affects offspring earnings and is shared by brothers. For simplicity, we include the full effect of genes on environment in the coefficient β_{ge}, so g_i is uncorrelated with E. Finally, the genotype g_i of brother i is determined by the genotypes of the parents, given by

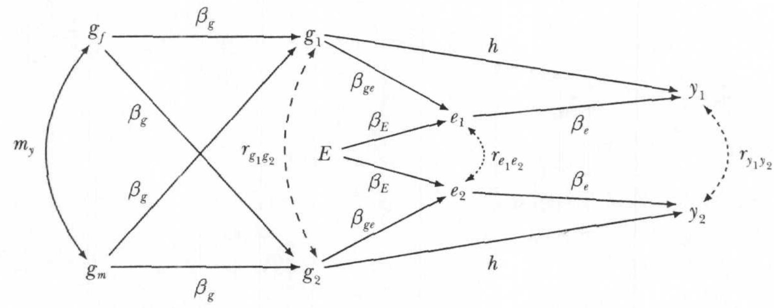
$$(6) \qquad g_i = \beta_g g_f + \beta_g g_m,$$

where g_f and g_m are the genotypes of father and mother, and β_g is the normalized regression coefficient (*path*) of father's (or mother's) genotype predicting son's genotype. The structure of this model is illustrated in Figure 3.

To show that β_g is 1/2, suppose m_y is the correlation of maternal and paternal genes. Since we are assuming additivity (meaning that the total effect of the genome is the sum of the effects of each gene), we can derive β_g for a single locus. We label each possible gene at this locus with the amount x it contributes to earnings. We normalized x so that $\mathbf{E}[x] = 0$ and $\mathbf{E}[x^2] = 2$. By basic genetics, a son

[6] Note that the same argument holds if we replace the expectations, which refer to population values, with the sample means, variances and covariances. In this case, the statistical independence of the error terms and the independent variables is assured by construction, whereas on the population level this independence is assumed.

Figure 3
The Earnings of Brothers



Notes: In this diagram, g_f and g_m are the genotypes of father and mother, g_1 and g_2 are the genotypes of brothers, E is the common environment of brothers, e_1 and e_2 are the total environment of brothers and y_1 and y_2 are the earnings of brothers. Here, m_y is the genetic relatedness of parents based on assortative mating and as explained below, $\beta_g = 1/2$, while h^2 is the heritability of earnings. The path labeled β_{ge} represents the tendency of genes to affect the environments ($\beta_{ge} > 0$ means that identical twins experience more similar environments than fraternal twins).

inherits one copy of the gene at the locus from each parent, say x_f from the father and x_m from the mother. The value of genes at this locus for a son is then $(x_f + x_m)/2$, assuming that both genes have equal expected effect on economic success, which we do here and throughout.[7] In addition to x_f, the father has another gene with value z_f at this locus, with the same mean 0 and variance 2. The corresponding value for the father is then $(x_f + z_f)/2$, where x_f and z_f are uncorrelated. The corresponding value for the mother is $(x_m + z_m)/2$, where z_m is the mother's other gene at this locus, and x_m and z_m are uncorrelated. Because of assortative mating, each gene of the father x_f, z_f, is correlated m_y with each gene of the mother x_m, z_m. The variance of the parents' genetic value at this locus is $\mathbf{E}[(x_m + z_m)^2/4] = \mathbf{E}[(x_f + z_f)^2/4] = 1$, and the covariance of father and son is $\mathbf{E}[(x_f + z_f)(x_f + x_m)/4] = (1 + m_y)/2$. Therefore, the correlation of father's and son's genetic value at this locus is the quotient of the previous two expressions, or

$$r_{g_f g_i} = \beta_{ge} + \beta_{ge} m_y = \frac{1}{2} + \frac{m_y}{2}. \tag{7}$$

The first term in this expression represents the direct path from father's genome to son's, and the second is the correlation of father's and mother's genetic value at the locus, m_y, multiplied by the direct path from mother to son at that locus. To see this, recall that the least squares estimator of b_1 in the regression equation

[7] The actual value of a pair of genes at a locus can be higher or lower than their average value, of course, as when one gene is dominant or recessive.

$y = b_1x_1 + b_2x_2 + \varepsilon$, where x_1, x_2 and y are normalized to mean zero and variance unity, and where ε is uncorrelated with x_1 and x_2, is given by (Goldberger, 1991):

$$b_1 = \frac{r_{x_1y} - r_{x_1x_2}r_{x_2y}}{1 - r_{x_1x_2}}. \tag{8}$$

In our case, $b_1 = \beta_g$, $r_{x_1y} = r_{x_2y} = (1 + m_y)/2$, and $r_{x_1x_2} = m_y$. Substituting in the above expression, we get $\beta_g = 1/2$.

To determine the correlation of fraternal twins' genotypes, we multiply the right sides of (6) for $i = 1, 2$, and take expectations, giving

$$r^{fr}_{g_1g_2} = E[g_1g_2] = (1/2)^2E[g_f^2] + (1/2)^2E[g_m^2] + 2(1/2)^2E[g_mg_f]$$

$$= (1/2)^2(2 + 2m_y) = (1 + m_y)/2,$$

which, consulting (7), confirms the standard result in genetics that fathers and sons on the one hand and nonidentical brothers with the same parents on the other are equally related. To determine the correlation of environments of fraternal twins, we multiply the right sides of (5) for $i = 1, 2$ and take expectations, giving

$$r^{fr}_{e_1e_2} = \beta_E^2 + r^{fr}_{g_1g_2}\beta_{ge}^2 = \beta_E^2 + (1 + m_y)\beta_{ge}^2/2.$$

Finally, multiplying the right sides of (4) for $i = 1, 2$ and taking expectations, we get

$$r^{fr}_{y_1y_2} = \beta_e^2r^{fr}_{e_1e_2} + h^2r^{fr}_{g_1g_2} + 2\beta_ehr_{g_1g_2}\beta_{ge},$$

which expands to

$$r^{fr}_{y_1y_2} = \beta_e^2(\beta_E^2 + (1 + m_y)\beta_{ge}^2/2) + h^2(1 + m_y)/2 + (1 + m_y)\beta_e\beta_{ge}h. \tag{8}$$

In the case of identical twins, the same figure is relevant, but now the correlation of genotypes of brothers is $r^{id}_{g_1g_2} = 1$. We then

$$r^{id}_{e_1e_2} = \beta_E^2 + r^{id}_{g_1g_2}\beta_e^2 = \beta_E^2 + \beta_{ge}^2,$$

and

$$r^{id}_{y_1y_2} = \beta_e^2r^{id}_{e_1e_2} + h^2r^{id}_{g_1g_2} + \beta_ehr^{id}_{e_1g_2} + \beta_ehr^{id}_{e_2g_1},$$

which becomes

$$r^{id}_{y_1y_2} = \beta_E^2(\beta_E^2 + \beta_{ge}^2) + h^2 + 2\beta_e\beta_{ge}h. \tag{9}$$

In the text, we assume $r^{id}_{e_1e_2} = 0.9$ for identical twins (although our results are not very sensitive to this assumption), so $\beta_e = \sqrt{0.9 - \beta_g^2}$. The two equations for the correlations of brother earnings, (8) and (9), together with the observed values of these correlations, allow us to determine h and β_e for various values of β_g.

Equations (8) and (9) imply that the difference between the correlations of earnings of identical and fraternal twins is given by

$$r^{id}_{y_1y_2} - r^{fr}_{y_1y_2} = (1 - m_y)(h + \beta_e\beta_{ge})^2/2. \tag{10}$$

Note that assuming greater assortative mating raises the estimate of h^2, while assuming a stronger tendency for genes to effect environment (raising β_{ge}) has the opposite effect, as one would expect. In the literature, it is often assumed that $m_y = 0$ and $\beta_{ge} = 0$, in which case we get the standard equation for estimating heritability:

$$h^2 = 2(r^{id}_{y_1y_2} - r^{fr}_{y_1y_2}). \tag{11}$$

If this is the case, we can estimate h^2 directly from this equation and then use this estimate of h^2, together with (8), to estimate β_e.

■ *We would like to thank Jere Behrman, Anders Björklund, Kerwin Kofi Charles, Bradford De Long, Williams Dickens, Marcus Feldman, James Heckman, Tom Hertz, Erik Hurst, Arjun Jayadev, Christopher Jencks, Alan Krueger, John Loehlin, Casey Mulligan, Suresh Naidu, Robert Plomin, Cecelia Rouse, Michael Waldman and Elisabeth Wood for their contributions to this paper, Bridget Longridge and Bae Smith for research assistance and the John D. and Catherine T. MacArthur Foundation for financial support.*

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