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Socioeconomic background and gene-environment interplay in social stratification across the early life course

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Abstract

To what extent are genetic effects on children's education, occupational standing, and income shaped by their parents' socioeconomic characteristics? Does the impact vary over their children's early life course, and are there differences across the social strata? We studied these research questions with Finnish register-based data on 6,542 pairs of twins born from 1975 to 1986. We applied the classical twin design to estimate the relative importance of genes. As outcomes, we compared education, occupation, and income in early adulthood. We found that shared environment influences were negligible in all cases. Notably, the proportion of genetic effects explained by parental characteristics mattered most for education and for occupation only because they were associated with their children's education—but not for income. We did not find any variation across their early life course; however, we found that genetic influences were stronger among the advantaged families for income and education. Thus, *gene-environment interactions* (*GxE*) operate differently for different status-related characteristics. For the unique environment, the pattern was consistent across outcomes as the effect was greater among the advantaged families. Stratification scholars should therefore emphasize the importance of the unique environment as one of the drivers of the intergenerational transmission of social inequalities.

Keywords: education, occupational status, income, socioeconomic background, genes, shared environment, unique environment, gene-environment interaction, gene-environment correlation

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Introduction

The importance of the socioeconomic rearing environment at specific periods during childhood and youth is well established in the research literature (Duncan et al., 1994; Esping-Andersen, 2002; Heckman, 2006; Burger, 2010). However, empirical evidence suggests that variations in these conditions either by children's age or according to the type of family resources available are of little importance for educational and socioeconomic attainment (Conley and Glauber, 2007; Shanahan et al., 2008; Erola et al., 2016; Lehti and Erola, 2017; see also Adermon et al., 2018; Hällsten and Thaning, 2018).

Why the persistence and perhaps surprisingly low amount of life-course variation? One often ignored explanation is genetic inheritance in that while social environments may change over the early life course, genetic endowments from parents are more or less fixed for life. The associations between parents' socioeconomic resources and child socioeconomic outcomes may simply correlate because the genes we received from our parents had an impact on how well they succeeded in life and therefore have the same effect on us. The importance of family resources could vary only inasmuch as they are not associated with the genes of both parents and children, or because there is interplay between the effects of genes and those of social environment.

In this paper we provide an answer to the research questions that have this far been largely ignored in the previous literature. They are as follows: 1) To what extent are genetic effects on children's education, occupational standing, and income shaped by parents' socioeconomic characteristics?; 2) Does the impact vary over the children's early life course?; and 3) Are there differences across the social strata?

To address these research questions, we built upon established theories on stratification literature and extended the discussion by incorporating findings from behavioral genetics. This acknowledges that the intergenerational transmission of inequalities comprises both social and genetic pathways that are interrelated.

We analyzed high-quality twin data acquired from Finnish administrative registers. Using full population data, we concentrated on the birth cohorts born from 1975 to 1986, which gave us 6,529 twin pairs. For our statistical models, we apply the classical twin design to estimate the relative importance of genes (Plomin et al., 2008). In the absence of zygosity information, the importance of genes was estimated through the comparisons between same-sex and opposite-sex twins. As outcomes, we compared educational attainment at age 28; occupation-based status attainment observed around age 32; and average log income from age 32 to 36. In order to consider the educational and socioeconomic environment of the childhood home, we studied the importance of parental education, occupational standing, and income at different stages of early childhood.

The country context links our findings to the debate on the association between equality of opportunity and genetic inheritance. Previous research indicates that family background matters relatively little in Finland when compared to other countries (Björklund and Jäntti, 2000). However, many believe that stronger equality of opportunity should boost the importance of genes in intergenerational attainment (Guo and Stearns, 2002; Engzell and Tropf, 2019). If that is the case, the importance of genes should be particularly strong in the Finnish context.

Our results provide novel and systematic evidence on how educational and socioeconomic status of the parents contribute to the effect of genes on their children's socioeconomic outcomes. We compared the results across the early life-course and across the three typical socioeconomic outcomes: education, occupational standing, and income. In addition to mapping the importance of genes, our results provide insights on how social differences in family environments may continue to matter over and above the genetic effects even in highly egalitarian institutional settings.

Theoretical background

Social stratification literature often distinguishes two ways how children will benefit from their parents' resources—through *endowments* and *investments* (Becker and Tomes, 1986; Rosenzweig, 1990; Musick and Mare, 2006; Esping-Andersen, 2015; Erola and Kilpi-Jakonen, 2017). Investments refer to parents' efforts to have a positive impact on different children's outcomes, for instance by using their time or money for parenting. Endowments, on the other hand, refer to the resources and assets that are available for children in their rearing environment without intervention from their parents, such as social networks and economic assets. These endowments also include genes transmitted from parents to their children.

Investments and endowments are always interrelated; this also matters when we are interested in the effects of genes. The literature on behavioral genetics refers to these processes as *gene-environment correlations (rGE) and gene-environment interactions (GxE)* (Scarr and McCartney, 1983; Dick, 2014).

Passive rGEs refer to situations in which both parents pass on their genes to their children as well as create, choose, or even just wind up to an environment that fits best their own genetic potential. Because children partially share the same genes, these environments also tend to be beneficial for them. For instance, parents may be skilled in playing musical instruments and also have them in the family home. If a child inherits the same genetic predispositions to musical skills, having instruments available is likely to encourage the development of those skills more than a home environment without any. Much like in the case of investments, *evocative rGEs* refer to a situation in which the parents provide environmental conditions that fit with the skills, talents, abilities, or other characteristics of their children, thereby fulfilling their *genetic potential*. This is shown, for instance, in the way how some parents choose the sporting pursuits for their children. The children may be encouraged to engage in certain sports that their parents assume they might have potential success; the parents may also discourage participation in the sports in which their children do not seem to have much talents. Both in the cases of passive and evocative *rGEs* we should expect the genetic effects to vary according to the parents' resources.

Active *rGEs* refer to situations where the children themselves choose environments that are particularly suitable for their own genetic potential. For example, adult children may find a specific field of study that fits with their own interests and talents and follow that educational pathway—even if their parents never encouraged or supported that choice. Active gene-environment correlations should be less dependent on the parental resources than passive and evocative *rGEs*; it should not matter where the exhausted resources originate from (for instance, through social networks of peers).

Importantly, for the current study, passive and evocative *rGEs* should differ from active by the age of the children when these types are particularly influential. It may be expected that parental characteristics shape the genetic effects stronger during earlier than in the later stages of their offspring's life course. During the early childhood children rely almost exclusively on the family as parents usually provide the environmental conditions and stimuli under which they develop. As the children grow older, they will also become more and more capable of exhausting the resources provided by others than from their parents. Because of the *age-specific exposure to a socioeconomic growth environment*, we arrive at our first hypothesis:

> *H1: The younger their children, the influence of parents' education and socioeconomic resources on genetic effects on status relevant outcomes are generally stronger.*

Following similar reasoning, we may expect differences across the socioeconomic outcomes. Educational careers begin very early in childhood and their maturity also tends to be achieved earlier (before age 30) than in the case of other socioeconomic outcomes (cf. OECD, 2014). This is in contrast with occupation as the occupational careers usually begin the earliest at around age 20 and maturity is reached at around age 35 (Härkönen et al., 2016). Regarding income, maturity is achieved even later (after age 40) with substantial country variation, which is around age 40 in the US and after age 50 in Finland (Cheng and Song, 2019; Karonen and Niemelä, 2019). This indicates that parents' influence may also vary in a similar manner according to outcomes. Because many decisive educational choices are made at an age when children are still living with their parents, the passive or evocative influences of genes should be strongest in the case of education. Therefore, in a similar manner, they should matter least for income. Thereby, our second hypothesis (*H2*) is as follows:

H2: The influence of parents' education and socioeconomic resources on genetic effects on status relevant outcomes is stronger the earlier the maturity in an outcome has been reached.

It was assumed above that if the passive and evocative *rGEs* mattered for the studied outcomes, we should expect the genetic effects to vary according to the parents' resources. Explaining why such variance occurs requires that we also consider *GxE* (Guo and Stearns, 2002; Turkheimer et al., 2003; Shanahan and Hofer, 2005; Belsky et al., 2018).

Two types of *GxE* would lead us to expect stronger genetic effects among the advantaged families and weaker ones among the disadvantaged families. The first of these is *enhancement*, which is the positive multiplicative processes between genes and environment where specific aspects of the environment further the realization of favorable genetic dispositions. For example, the findings of Baier and Lang (2019) for Germany are as follows: the higher the education of the parents, the stronger the impact of genes in education. This kind of *GxE* is also referred to as the Scarr-Rowe effect (Scarr-Salapatek, 1971). The second type of *GxE* that is relevant here is *social control* where norms or values shared in social environment constrain behavior and choices and thereby lead to the cancellation or at least reduction in genetic expressions (Shanahan and Hofer, 2005). This would be the case if social expectations about schooling or occupational career choices are shared in families but stem from a broader socioeconomic context.

Thus, we have our third hypothesis (*H3*) which is related to *GxE*:

H3: Genetic effects on status relevant outcomes are weaker among children from disadvantaged families compared to children from advantaged families.

Institutional context

We study the hypotheses using register data from Finland. Traditionally, the country has been considered as a society with a high level of equality of opportunity, meaning that parental socioeconomic status determines children's adult socioeconomic outcomes relatively weakly. This has been found out to be true for various socioeconomic outcomes—including education, occupational status, and income (Björklund and Jäntti, 2000; Jäntti et al., 2006; Pfeffer, 2008; Erola, 2009; Grätz et al., 2019). The reasons for openness are subject to debate, but often cited explanations which include high-quality early childcare (Karhula et al., 2017; Hiilamo et al., 2018), high-quality and a free of charge educational system (Pekkarinen et al., 2006; OECD, 2008) and strong public support for the egalitarian welfare state (Forma, 2012).

A relatively high level of equality of opportunity makes Finland a particularly interesting institutional context to study our topic. It has been argued in the literature (Guo and Stearns, 2002; Nielsen, 2006) that heritability in socioeconomic attainment should be considered as a measurement of the equality of opportunity. According to the authors supporting this point of view, the extent to which individuals can realize their genetic potential is seen as an indicator of the openness of a society. As a consequence, we should expect that when the effects of social origin are weak, genetic inheritance would be strong. Recent empirical evidence provides support for this assumption. Engzell and Tropf (2019) studied children born starting from the 1940s and up to the 1980s in 10 countries and showed that the heritability rises as educational mobility increases. Similarly, if there is a link between high level of mobility and high heritability, we should expect the importance of genes to be fairly strong and the importance of social origin to be weak in Finland.

Yet, heritability is not necessarily closely associated with equality of opportunity. High heritability can also reflect genetic influences of ascribed characteristics such as skin color, attractiveness, height, and sex—all of which clearly violated the equal opportunity assumption (Diewald et al., 2015). Furthermore, the "gene lottery" of not being able to pick one's own genetic background but being forced to inherit them from parents is often considered as unfair and against the principles of equal opportunities (Rawls, 1971). Therefore, in the Finnish case where social institutions aim at reducing the importance of some ascribed characteristics and increasing fairness, it could be that the importance of neither genes nor social origin is particularly strong.

The heritability of education and income has also been previously studied in Finland. It has been shown that the lifetime earnings strongly depend on the genetic variance that explains around 40% of the variance in women's and over half of the variance in men's labor earnings in the birth cohorts from the 1950s (Hyytinen et al., 2019). Furthermore, in these cohorts the contribution of the shared environment was negligible (Hyytinen et al., 2019). In the case of the education of Finnish birth cohorts born from 1936 to 1955, Silventoinen et al. (2004) found the genetic variance to explain around 48% of the variation for men and a little less for women. The shared environment accounted for around 40% for both (Silventoinen et al., 2004). In line with these estimates, Nisen et al. (2013) found that the additive genetic component accounted for 42% and 41% for men and women respectively in birth cohorts from the 1950s. Larger differences were found in the common environmental factors that accounted for 37% and 54% for men and women respectively; this differed somewhat from the estimate of 42% for women in the study by Silventoinen et al. (2004).

The Finnish findings can be compared to the results from a similar institutional setting of Norway. Lyngstad et al. (2017) discovered—much in line with the Finnish results—that the share of variance in educational attainment attributable to the additive genetic variance is around 45%. In contrast to the Finnish studies, they found that the shared family background accounts for only 19% of the variance. A key difference between the studies is that Lyngstad et al. (2017) studied cohorts who born from 1967 to 1979, whereas Silventoinen et al. (2004) and Nisen et al. (2013) studied cohorts born from the 1930s until the 1950s. Earlier research on Norwegian men indicated that the shared family background mattered less for cohorts born after 1940 than for those born earlier (Heath et al., 1985).

Data and research methods

We tested our hypotheses by using high-quality twin data acquired from Finnish administrative registers. The data cover the entire Finnish population and thereby all of the twins who were alive during the years 1987 to 2016. In this study we focused on those who were born from 1975 to 1986.

We compared results across three outcomes: highest level of education measured in years by age 28; occupation-based socioeconomic status at age 30 utilizing the International Socio-Economic Index of Occupational Status (ISEI); and logged mean annual income at age 32 to 36. Income includes all individual annual earnings, capital income, and income transfers after taxation. When controlling for the characteristics of the parents, we used similar outcomes recorded to the registers at the five stages of the early life course of the children. These stages are: age 0 to 5 (pre-school); age 6 to 10 (early elementary school); age 11 to 15 (late elementary school); age 16 to 20 (secondary education); and age 21 to 25 (after secondary education). For the parents' education and the ISEI we used the dominance principle and took into account the highest value for each one among the biological parents. In the case of the parents, we differentiated the level of education instead of measuring it in years: 1) basic or less, 2) vocational secondary, 3) general secondary, 4) post-secondary/lowest tertiary, 5) bachelor's degree, and 6) master's or higher degree. For income, we took into account the incomes of both parents.

After omitting the cases with missing information on occupation (7%), income (3%), and parent's information on either (additional 2%), our final analytical sample included 6,529 twin pairs.

We used the classical twin design (CTD, Plomin et al., 2008) to estimate the relative importance of genes. Twins are born at the same time, and while dizygotic (DZ) twins share on average 50% of their DNA, monozygotic (MZ) twins are genetically identical. These distinct features of twins allow researchers to decompose the total variance of an outcome into a component associated with additive genetic influences (A), shared environmental influences (C), and unique environmental influences (E)—the last of these (E) also includes the error term of the variance decomposition.

The identification of genes and environmental influences is based on additional assumptions (Plomin et al., 2008). First, ACE-models identify additive genetic effects; it is assumed that genetic effects on phenotypes do not interact with each other (no epistasis). However, for complex traits such as education, occupation, and income, non-additive genetic effects play only a minor role. The second assumption is the equal-environment assumption (EEA) (Scarr and Carter-Saltzman, 1979). It states that MZ and DZ twins are similarly treated by their environment (e.g., parents, peers or friends). If the EEA is violated, heritability estimates tend to be inflated because the similarity of MZ twins is then driven by more comparable treatment of their surroundings and not due to their genes. However, MZ twins are often treated more similarly than DZ twins, partly because they are genetically identical. To date, the EEA has been tested for several mostly psychological characteristics traits and the results show that more similar treatment does not bias heritability estimates (for IQ, see Derks et al., 2006).

The third assumption is that there are neither gene-environment interactions nor gene-environment correlations in the population for the specific trait. We address this assumption by studying a) ACE models for certain life stages of the children's childhood and b) by estimating ACE models separately for socially-defined groups. This analytical strategy is known as nonparametric *GxE* analysis (Guo and Wang, 2002). This means we relax the assumption by allowing genetic and environmental influences on our outcomes to vary by life stage and by social background.

Finally, it is assumed that there is no assortative mating among spouses. Random mating justifies the assumption that DZ twins (or siblings) share on average 50% of their DNA. If spouses are more similar according to the characteristics relevant for the trait under study, the genetic similarity of DZ twins or siblings is higher. As a consequence, genetic influences are overestimated and shared environmental influences underestimated. Since assortative mating by education and ISEI is a well-established phenomenon in industrialized countries (Kalmijn, 1994; Blossfeld, 2009) we correct our analyses as suggested by Loehlin and collaborators (2009). Specifically, we adjust the genetic correlation of DZ twins as follows: $0.5 + 0.5 * h_0^2 * r_p$, where h_0^2 stands for the heritability estimate without the correction for assortative mating and r_p is the correlation of spouses (here: education and ISEI). In our data spousal correlation in education is 0.44 (0.42 for ISEI), leading to a genetic correlation for DZ twins of 0.59 for education and 0.58 for ISEI, respectively. Note that we did not adjust our estimations for income since shared environmental influences were absent.

Typically to the registers, our data sources do not include information on zygosity (i.e., whether a twin is a MZ or DZ twin). Based on the assumption that about half of the same-sex (*ss*) twins were MZ twins and the fact that all of the opposite-sex (*os*) twins are DZ twins we corrected for the genetic similarity of the *ss* twins (Figlio et al., 2017) as follows: (*ss*-*os*)/*ss* + 0.5* *ss*/*os*. Applying this correction yields a genetic similarity of *ss* twins in the Finnish data of about 0.76. The previous comparisons suggest that this correction provides ACE components that are comparable to those acquired using information on zygosity (de Zeeuw and Boomsma, 2017).

In addition, we standardized our outcomes by gender to account for a higher similarity of *ss* twins that might be induced by having the same sex (Figlio et al., 2017). The comparison of intraclass correlation coefficients (ICCs) of the *ss*- and os twins to those of ss- and os non-twin siblings (i.e., sibling correlations) are reported in the Appendix (Figure A1). They show that the similarity of twins is higher compared to non-twin siblings, indicating the role of genes. In addition, there a no substantial differences among same-sex female and same-sex male dyads.

In order to estimate the importance of the observed parental characteristics at the different stages of the offspring's early life course, we fitted ACE models to retrieve the genetic influences on the chosen outcomes (Rabe-Hesketh et al., 2008), and compared the components before and after controlling for parental observed socioeconomic characteristics (Boomsma et al., 2002). A problem for identifying such differences are the correlations between education, occupation, and income. Luckily the relationships between the outcomes of interest are likely to be one-directional; income is not likely to have an impact on occupation and occupation not on education (Erola et al., 2016; Lahtinen et al., 2019). This is also reflected in the previous findings of Marks (2017) for Australia, indicating that the effects of genes run through education and occupational standing. Thus, when testing the hypothesis on occupational standing, we need to control for education, and when on income, we need to take into account both education and occupation. All of the models were estimated using the acelong package in Stata (Lang, 2017).

Results

Figure 1 reports the results for our three outcomes of interest; the left side shows the unadjusted baseline models and the right side presents them adjusting for assortative mating by parents' education. The bars show the relative importance of the components, while the absolute values and standard errors can be found from the Appendix (Table A1). In the unadjusted models, we find that for education the relative importance of genetic influences (*A%*) is about the same as the importance of unique environmental influences (*E%*). In the case of ISEI and income, genetic influences are less pronounced than those for unique environment. The relative importance of shared environmental influences (*C%*), however, is small for education and ISEI; it is even absent for income. This is in contrast with the previous findings on education which studied older birth cohorts (Branigan et al., 2013; for Finland, see Silventoinen et al., 2004; Nisen et al., 2013). After adjusting for assortative mating by parents' education, *C* is substantially smaller and no longer statistically significant neither for education nor for ISEI (see Appendix, Table A1). The results suggest that in Finland families and the social institutions faced by the relatively recent birth cohorts provide rather equal rearing environments.

We expected that the influence of the parents' education and socioeconomic resources on genetic effects on status relevant outcomes is stronger overall when their children are younger (*H1*). Figure 2 shows our findings for the relative variance components, controlling for parental socioeconomic characteristics observed at different ages of the children. Appendix Table A2 additionally reports the absolute variance components and all standard errors. The findings did not support *H1*. The differences in the variances explained (R^2) across the controlled models are substantially negligible. For education, R^2 ranges from 12.4% at age 0 to 5; and 13.6% at age 16 to 20. Similarly, for ISEI, it ranges from 13.0% from age 0 to 5; to 14.0% at age 11 to 20. For income, the total variance explained is much smaller and varies again only a little over the children's life course (i.e., from 1.8% at age 0 to 5 and 2.7% at age 16 to 20). For all outcomes we found that controlling for parents' characteristics reduces variance only in genetic components.

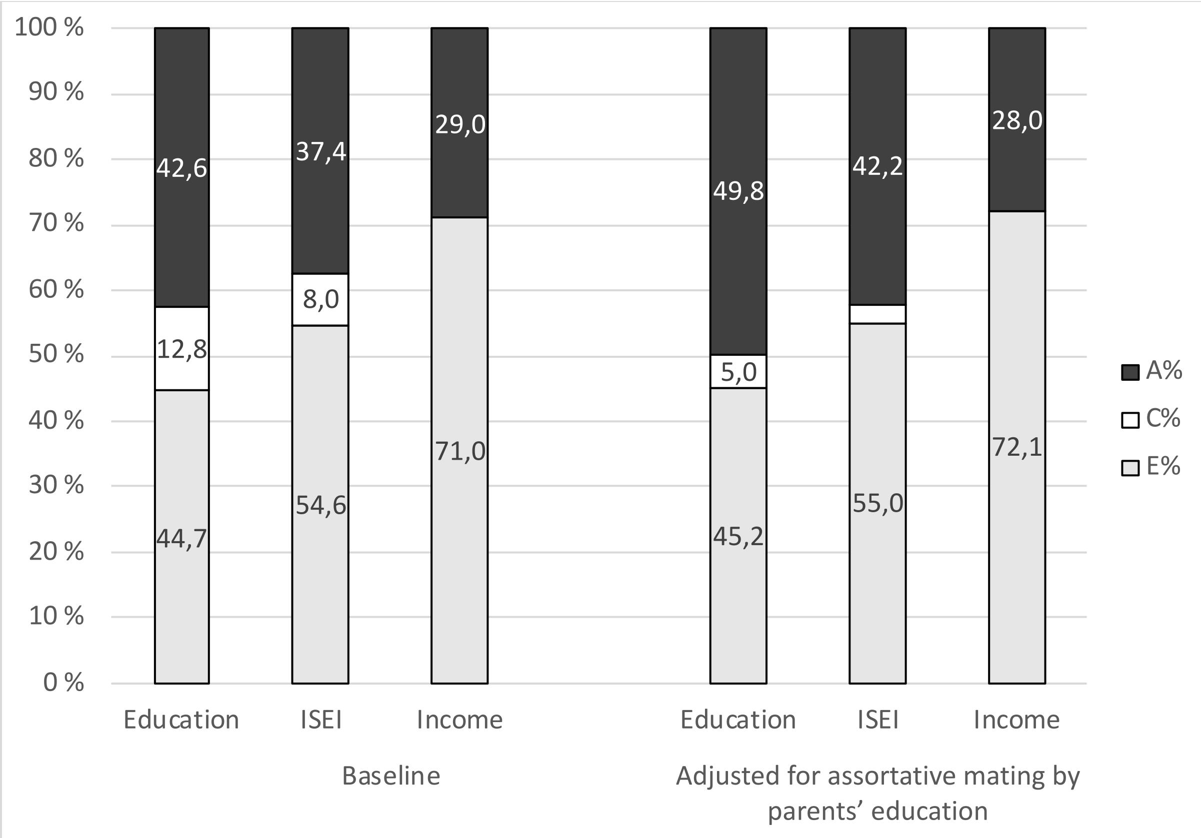


Figure 1. ACE components across different outcomes.

Because shared environmental influences are basically absent once assortative mating is taken into account, in our subsequent analyses we estimated AE models instead of ACE models.

We next considered *H2*, expecting that when the earlier maturity in a socioeconomic outcome is reached, the greater is the contribution of parents' education and socioeconomic resources on genetic effects. Thus, the variance explained with these factors should be the greatest in the case of education and then weakest in the case of income.

Figure 2 shows that the proportion explained by parental characteristics is smallest for income, thus supporting the hypothesis. However, the differences in the variance explained between education and ISEI are negligible, which is what we would not expect according to the hypothesis. As discussed above, this may, nevertheless, follow from the strong association between the children's education and occupational standing. The variance components reported in Figure 2 do not necessarily reflect the role of genes and shared environment for ISEI, but rather their role in education that is just shown in consequent occupational attainment.

Because of this, we conducted a set of additional analyses. For ISEI, we controlled for parent-observed characteristics after accounting for their children's own education. In this case we controlled first for education and then additionally for occupational attainment. These models are reported in Figure 3 (absolute and relative components and their standard errors can be found from Appendix Table A3). The findings suggest that in the case of ISEI, over two-thirds of genetic influences are mediated by children's own education (*Baseline*: 46.1% vs. *Education controlled*: 12.5%). More so, the contribution of parental characteristics on genetic influences seems to be almost entirely mediated by education. The genetic component barely changes when, in addition to children's own education, we also control for parental characteristics (*Education controlled:* 1.5% vs. *Education and parents controlled:* 11.4%). Thus, parents' resources are mainly associated with genetic influences relevant for education. This can follow from at least two different mechanisms: the genes that influence parents' attainment have a similar effect on children, or the parents' resources facilitate genetic expressions on these outcomes—or both.

Interestingly, in the case of income, only less than one-fourth of A is mediated through children's own education and ISEI (*Baseline:* 30% vs. *Education and ISEI controlled:* 22.8%). Controlling additionally for parental characteristics does not change with regard to *A*. On the whole, the estimations provide further evidence to support *H2*, but with the important specification on how parental socioeconomic characteristics affect genetic influences on children's socioeconomic outcomes. In the case of ISEI and income, these associations are found only because they are mediated by children's educational attainment, which is a process that is already beginning in early childhood. The results also indicate that genes relevant for education and ISEI are not that important for income.

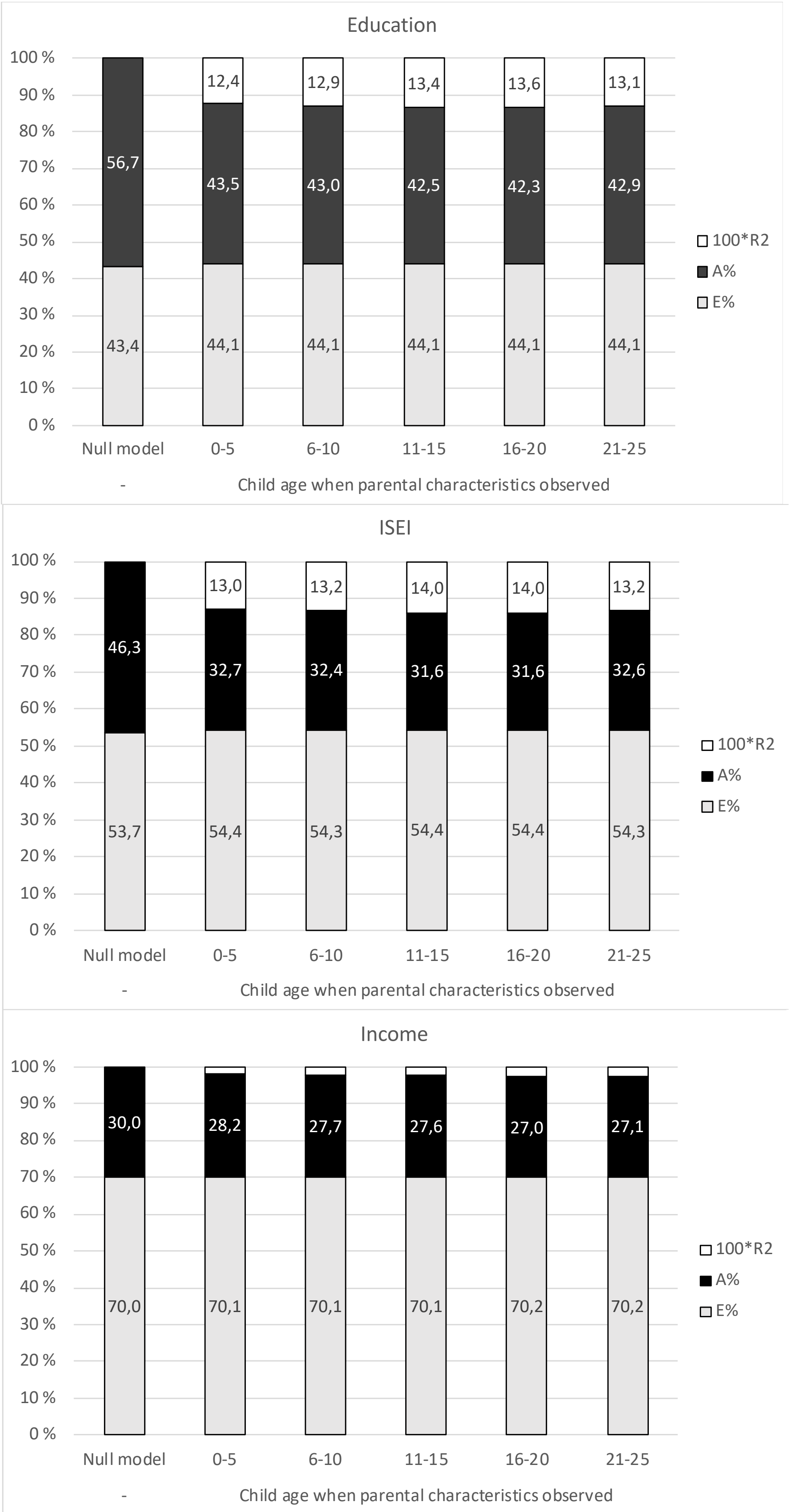
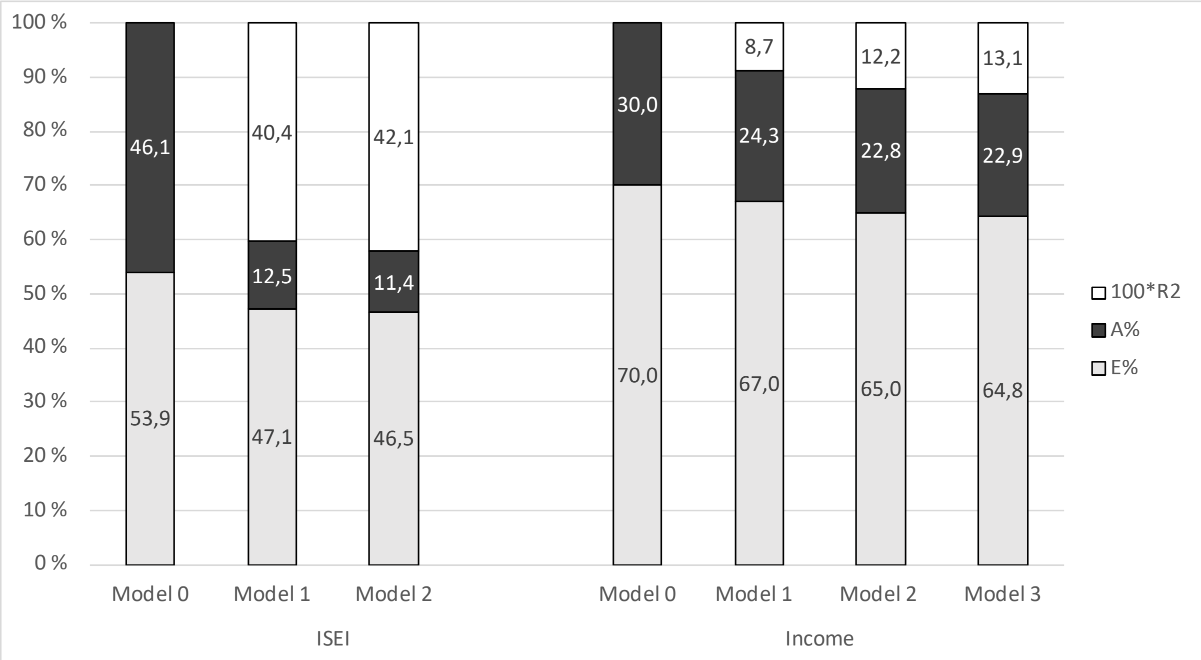


Figure 2. A and E components for education, ISEI and income before and after controlling for parental socioeconomic characteristics at different phases of childhood and youth.



Notes:

For ISEI as an outcome:

Baseline: no controls -Model 0

Educ. controlled: adjust for own education -Model 1

Educ. + parents controlled: adjust for children's education and parental education, ISEI, and income -Model 2

For income as an outcome:

Baseline: no controls -Model 0

Educ. controlled: adjust for own education -Model 1

Educ. + ISEI controlled: adjust for children's education and ISEI, and parental education, ISEI, and income – Model 2

Figure 3. *A and E components for ISEI and income, controlling for own education and parental characteristics at the ages 11 to 15.*

Finally, we tested our third hypothesis (*H3*) which proposed that genetic influences on the three outcomes are less pronounced among children from disadvantaged families. Specifically, we looked at the differences in education, ISEI, and income by parents' education. We contrasted children from low-educated parents (basic education or less) to the children of the highly-educated parents (tertiary degrees), omitting the children with secondary educated parents (2792 twin pairs).

These findings are reported in Table 1. The lower part reports the relative shares of *A* and *E* of the total variance according to the groups of parents, similarly to Figures 1 through 3. For all outcomes, standard errors of the shares of the genetic components are so large that their share should be considered as being equal in both groups by parental education—thus providing no support for *H3*.

However, the table reveals a greater heterogeneity among the children from more advantaged family backgrounds; the total variance is higher among the children of those with higher education. This variance is in a more pronounced manner in the case of education and income than in the case of ISEI. This kind of pattern in the socioeconomic outcomes is often observed when children of the advantaged and disadvantaged groups are being compared (Oettinger, 1999; Goldstein and Warren, 2000; Heflin and Pattillo, 2006). This in its turn indicates that in order for the shares of A and E to remain roughly the same, both of the A and E components need to be bigger in absolute terms among the children of the highly-educated parents. When this is the case, a comparison based on the relative shares alone can hide substantial differences and similarities across the outcomes and the groups by parental education.

This is confirmed by a comparison of the absolute variance components. In the case of education, the genetic component is somewhat bigger among the children of the highly-educated parents than among the children of the low-educated parents (education: 0.53 vs. 0.43). Notably, there are no significant differences in the case of ISEI. However, in the case of income, the contrast is greatest (0.40 vs. 0.22). Finding no gene-environment interaction in ISEI is in line with the results reported in Figure 3. They suggest that a large proportion of the genetic component in ISEI was mediated by education, and over and above that, the parents' socioeconomic characteristics mattered only a little for genetic influences. Findings on income, on the other hand, provided further evidence that different genes are important for income rather than for the other two outcomes. All in all, the comparison of the absolute sizes of the genetic components in the groups by parental education provides some support to our hypothesis in the case of education. Nevertheless, this does not seem to be the case with regard to ISEI and income.

Nonetheless, perhaps what is even more interesting are the differences in the absolute size of effects of unique environment. For all outcomes, E components are clearly greater among the children of the highly-educated parents. Furthermore, it seems that the effects of unique environment are stronger for the outcomes where maturity is reached later. The differences between the groups by parental education are relatively consistent; they are around one-third higher among the children of the highly-educated parents than among the children of the low-educated parents (education: 0.55 vs. 0.40; ISEI: 0.63 vs. 0.48; income 0.88 vs. 0.60). So far, unique environmental influences have not received much attention neither in the behavioral genetics or social stratification literatures.

Table 1. *A and E components for education, ISEI and income among the children of the low and high educated parents.*

	Education		ISEI		Income	
	Low parental education	High parental education	Low parental education	High parental education	Low parental education	High parental education
a^2	0.43	0.53	0.42	0.40	0.22	0.40
s.e.	*0.04*	*0.02*	*0.04*	*0.02*	*0.04*	*0.05*
e^2	0.40	0.55	0.48	0.63	0.60	0.88
s.e.	*0.03*	*0.02*	*0.03*	*0.02*	*0.08*	*0.10*
Total	0.83	1.08	0.90	1.03	0.82	1.28
s.e.	0.03	0.02	0.03	0.02	0.08	0.12
A%	51.54	49.18	46.64	38.47	26.86	31.00
s.e.	*4.78*	*2.24*	*4.47*	*2.24*	*4.50*	*4.13*
E%	48.46	50.82	53.36	61.53	73.14	69.00
s.e.	*3.28*	*1.76*	*3.31*	*1.94*	*9.24*	*7.81*
N pairs	926	2771	926	2771	926	2771
N	1852	5542	1852	5542	1852	5542

Conclusions

In this paper we have presented our study of the gene-environment interplay over the early life course in education, occupational standing, and income. Despite the enthusiasm, there is little research on how this interplay changes over childhood and youth—especially in the case of socioeconomic outcomes. For this, we have analyzed a high-quality register based data from Finland—focusing on twins born from 1975 to 1986—that allowed us to observe children's educational and socioeconomic attainment in adulthood. We applied the classical twin design by exhausting the same/opposite-sex twin approach and decomposed variances in outcomes into genetic (A), shared environment (C), and unique environment (E) components. Our main measured approximates for the childhood rearing environment were the socioeconomic characteristics of the parents (parental education, ISEI, and income) observed at different ages of childhood and youth.

In summary our study highlights five findings. First, our baseline findings for education, occupational status, and income show that the relative importance of shared environmental influences was negligible. This is especially in contrast with the established findings in the literature on education, which usually provides evidence for the substantial influence of the shared environment (Branigan et al., 2013). The results also differ from the studies on older twin cohorts in Finland finding a stronger effect of the shared environment (Silventoinen et al., 2004; Nisén et al., 2013), but are closer to the findings on more recent cohorts in Norway with similar institutional settings (Lyngstad et al., 2017). The result is in line with previous Finnish studies on income (Hyytinen et al., 2019) and socioeconomic attainment (Karhula et al., 2019).

Second, in contrast to our first hypothesis, the proportion of the genetic effects explained by parental educational and socioeconomic characteristics does not depend on children's age. This finding is in line with the previous research on the importance of family background that does not differentiate between genes and shared environment (Erola et al., 2016). Parental characteristics observed at different stages of the early life course explain more or less the same amount of variance of children's socioeconomic outcomes independently of children's life stage. For future research, the results suggest that information on parental educational and socioeconomic characteristics can be acquired from any period of childhood and youth without a fear of substantial bias in the results.

Third, in line with our third hypothesis, we found that the contribution of the observed parental characteristics on genetic effects is stronger the earlier the maturity of an outcome is reached. More specifically, parental characteristics matter only for the genetic effects of education, and for the subsequent socioeconomic outcomes of the children only because they are mediated by their children's education. Notably, in the case of income, the parental characteristics did not explain the genetic effect even before the effects of their children's own education was considered. This finding is striking as it suggests that nearly all of the aspects that have made the parents succeed (or fail) in terms of their observed socioeconomic outcomes cannot *on average* explain too much how their children have succeeded economically by age 32 to 36.

Fourth, supporting our third hypothesis, when comparing the absolute components, we find that genetic influences are stronger in high educated families when compared to low educated families. These differences are most pronounced for income, but a similar pattern can also be observed with regard to education. These findings suggest that either enhancement increases the chances of the children of the higher educated families to reach their genetic potential or that social controls restrict the same chances among the children of the low-educated parents.

Finally, the results showed that unique environmental influences were more important for the children of the highly-educated parents. This result was consistent across the three outcomes. Also, earlier studies have reported greater variance in socioeconomic outcomes among the children of the advantaged families (Goldstein and Warren, 2000; Heflin and Pattillo, 2006). Yet, these studies have not considered the different roles of genes and social environment which lead to that result.

A possible explanation can be borrowed from the literature on stratified parenting (Lareau, 2011; Kalil et al., 2012). This particular research presents that higher social status parents are able to make more child-specific investments based on their individual differences or particular weaknesses which accentuates differences among their children. (Baier, 2019). However, similar findings could also result from the multiplicative processes if advantaged parents or the children themselves prefer differential treatment. For example, the same genetic skills in math could lead to different educational and career pathways and could encourage careers in either business or in academia. This could be intended by either parents or the children themselves.

Our results also contribute to the broader discussion on equality of opportunity. Some of the researchers (Guo and Stearns, 2002; Nielsen, 2006) have argued that the strength of heritability should be considered as an indicator for the equality of opportunity.

Because comparative research has shown that family background matters relatively little in Finland, this argument would lead one to expect that the genetic component in attainment should also be particularly strong. To some extent, the results are in line with the following: the shared environment alone matters very little if compared to the results on the older birth cohorts in Finland or in other Nordic countries (Silventoinen et al., 2004; Branigan et al., 2013; Nisén et al., 2013). Still, the comparison of outcomes shows that a deniable impact of shared environmental influences does not mean that only the effect of genes would automatically become stronger; it can also change the differences due to unique environment. To date, changes in the unique environment influences are barely discussed in the literature considering genetic effects in social status relevant attainment. These channels nonetheless appear to be relevant for intergenerational socioeconomic transmission processes.

The caveat of the data is that we could not follow income quite as long as would have been preferable (until over age 40); we only looked at average log-income from the ages of 32 to 36. It may be that the stronger role of genes for incomes of the highly-educated parents we observe now exactly reflects their children's improved chances to fulfill their own genetic potential, rather than the parents' investments for their children. Furthermore, immediate family is not the only environment we are exposed to during childhood and youth. Our results cannot say much about the importance of extended families, schools, or neighborhoods which could have also contributed to the gene-environment interplay. Moreover, a detailed analysis on gender differences was beyond the scope of our study.

In sum, the results underline the value of studying gene-environment interplay for the better understanding the intergenerational inequalities. Clearly genetic inheritance plays a key role in this and should find a stronger integration in stratification research. Importantly, the results show that our theoretical assumptions about the relationship between social inequalities, genes, as well as shared and unique environments are still relatively underdeveloped—especially in regard to the importance and the role of the unique environment. In the future, one of the key tasks of research of intergenerational social mobility and attainment should be the development of better theories on the relationship between gene-environment interplay and its implications for equality of opportunity. The latter goal calls for comparisons of results applying similar research designs across multiple nations.

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Appendix. Intraclass correlation coefficients among same and opposite sex twins and same-sex siblings

Figure A1 reports the intraclass correlation coefficients (ICCs) of same-sex (*ss*) and opposite-sex (*os*) twins and *ss* siblings. To increase comparability, sibling correlations are computed based on families with no more than two children. If differential treatment of twins should bias our results, *ss* siblings should have lower ICCs than other combinations of twins. This does not seem to be the case in our data, for both education and International Socio-Economic Index of Occupational Status (ISEI), the ICCs are at the same level as in the case of *ss* siblings.

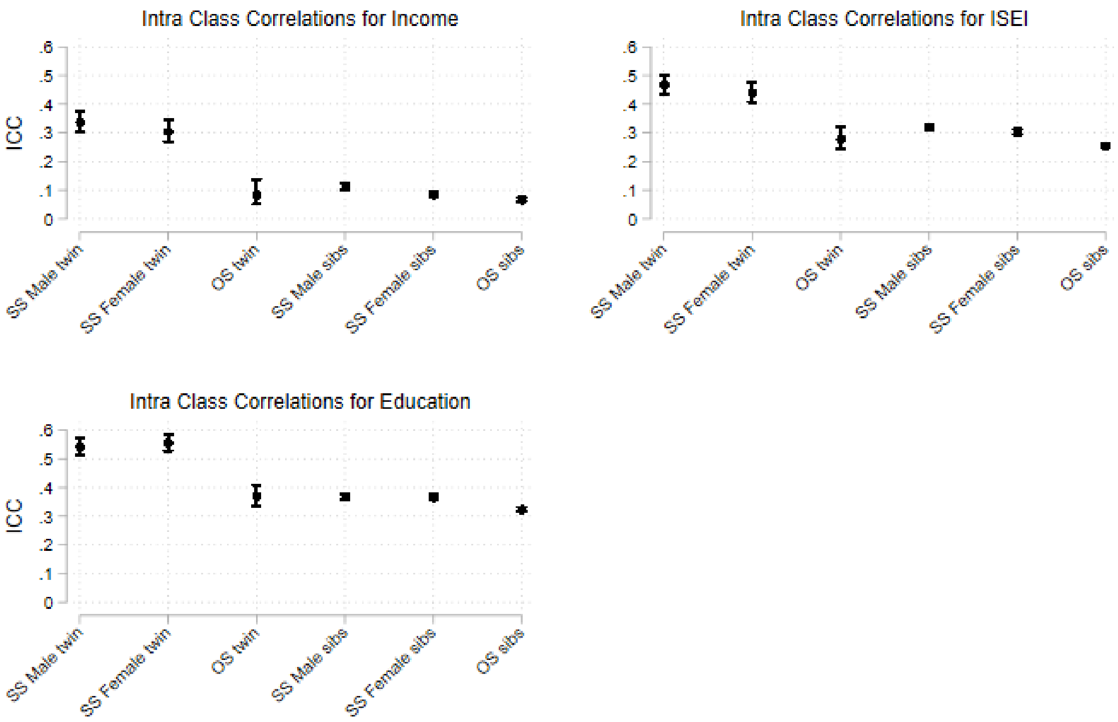

Figure A1. Inter-class correlations (ICCs) in different outcomes for same- and opposite-sex twins and same-sex siblings.

Table A1. ACE components across different outcomes

	Baseline			Adjusted for assortative mating		
	Education	ISEI	Income	Education	ISEI	Income
A	0.44	0.39	0.3	0.52	0.44	0.29
s.e.	*0.05*	*0.05*	*0.02*	*0.07*	*0.06*	*0.02*
C	0.13	0.08	0	0.05	0.03	0
s.e.	*0.04*	*0.04*	*0*	*0.06*	*0.05*	*0*
E	0.46	0.56	0.73	0.47	0.47	0.74
s.e.	*0.01*	*0.01*	*0.06*	*0.01*	*0.01*	*0.06*
Total variance	1.04	1.03	1.02	1.05	1.04	1.02
s.e.	*0.01*	*0.01*	*0.07*	*0.01*	*0.01*	*0.07*
A%	42.57	37.44	28.96	49.81	42.22	27.95
s.e.	*5.25*	*5.16*	*2.41*	*6.44*	*5.99*	*2.32*
C%	12.76	7.96	0	4.96	2.74	0
s.e.	*4.24*	*4.24*	*0*	*5.32*	*5.03*	*0*
E%	44.67	54.6	71.04	45.23	55.04	72.05
s.e.	*1.10*	*1.20*	*5.73*	*1.09*	*1.18*	*5.73*
N pairs	6529	6529	6529	6529	6529	6529
N	13058	13058	13058	13058	13058	13058

Table A2. A and E components for education, ISEI and income before and after controlling for parental socioeconomic characteristics at different phases of childhood and youth.

		Child age when parental characteristics observed				
Education	*Null model*	*0-5*	*6-10*	*11-15*	*16-20*	*21-25*
a^2	0.60	0.46	0.45	0.45	0.45	0.45
s.e.	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*
e^2	0.46	0.47	0.47	0.47	0.47	0.47
s.e.	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*
Total variance	1.06	0.92	0.92	0.91	0.91	0.92
s.e.	0.01	0.01	0.01	0.01	0.01	0.01
A%	56.65	43.50	43.03	42.50	42.31	42.85
s.e.	*1.48*	*1.39*	*1.38*	*1.38*	*1.38*	*1.38*
E%	43.35	44.08	44.08	44.14	44.14	44.07
s.e.	*1.05*	*1.05*	*1.05*	*1.05*	*1.05*	*1.05*
100*R^2		12.42	12.89	13.36	13.55	13.08
		Child age when parental characteristics observed				
ISEI	*Null model*	*0-5*	*6-10*	*11-15*	*16-20*	*21-25*
a^2	0.48	0.34	0.34	0.33	0.33	0.34
s.e.	*0.02*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*
e^2	0.56	0.57	0.57	0.57	0.57	0.57
s.e.	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*	*0.01*
Total	1.04	0.91	0.91	0.90	0.90	0.91
	0.01	0.01	0.01	0.01	0.01	0.01
A%	46.31	32.70	32.44	31.58	31.55	32.56
s.e.	*1.47*	*1.34*	*1.33*	*1.33*	*1.33*	*1.33*
E%	53.69	54.35	54.31	54.41	54.44	54.29
s.e.	*1.16*	*1.15*	*1.15*	*1.15*	*1.15*	*1.15*
100*R^2		12.96	13.24	14.01	14.01	13.15
		Child age when parental characteristics observed				
Income	*Null model*	*0-5*	*6-10*	*11-15*	*16-20*	*21-25*
a^2	0.31	0.29	0.28	0.28	0.28	0.28
s.e.	*0.03*	*0.03*	*0.03*	*0.02*	*0.02*	*0.02*
e^2	0.72	0.72	0.72	0.72	0.72	0.72
s.e.	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*	*0.06*
Total variance	1.03	1.01	1.00	1.00	1.00	1.00
	0.06	0.06	0.06	0.06	0.06	0.06
A%	29.99	28.17	27.65	27.56	27.01	27.12
s.e.	*2.48*	*2.48*	*2.42*	*2.33*	*2.31*	*2.31*
E%	70.02	70.07	70.11	70.10	70.16	70.15
s.e.	*5.40*	*5.40*	*5.40*	*5.39*	*5.39*	*5.40*
100*R^2		1.75	2.24	2.34	2.83	2.73

N pairs: 6529

N: 13058

Table A3. A and E components for ISEI and income controlling for own education and parental characteristics at age 11 to 15.

	ISEI			Income			
	Model 0	Model 1	Model 2	Model 0	Model 1	Model 2	Model 3
a^2	0.48	0.13	0.12	0.31	0.25	0.23	0.23
s.e.	*0.02*	*0.01*	*0.01*	*0.03*	*0.02*	*0.02*	*0.02*
e^2	0.56	0.49	0.48	0.72	0.69	0.67	0.67
s.e.	*0.01*	*0.01*	*0.01*	*0.06*	*0.06*	*0.06*	*0.05*
Total	1.04	0.62	0.6	1.03	0.94	0.90	0.89
s.e.	*0.01*	*0.01*	*0.01*	*0.06*	*0.06*	*0.06*	*0.06*
A%	46.06	12.5	11.41	29.98	24.27	22.81	22.90
s.e.	*1.15*	*1.63*	*1.60*	*2.48*	*2.48*	*2.50*	*2.437*
E%	53.94	47.10	46.50	70.02	66.99	65.02	64.75
s.e.	*1.16*	*1.58*	*1.65*	*5.40*	*5.99*	*6.00*	*6.128*
$100*R^2$		40.38	42.13		8.74	12.17	13.05
N pairs	6529	6529	6529	6529	6529	6529	6529
N	13058	13058	13058	13058	13058	13058	13058

Notes:

For ISEI as an outcome:

Baseline: no controls -Model 0

Educ. controlled: adjust for own education -Model 1

Educ. + parents controlled: adjust for children's education and parental education, ISEI, and income -Model 2

For income as an outcome:

Baseline: no controls -Model 0

Educ. controlled: adjust for own education -Model 1

Educ. + ISEI controlled: adjust for children's education and ISEI, and parental education, ISEI, and income – Model 2