An Anatomy of the Intergenerational Correlation of Educational Attainment

-Learning from the Educational Attainments of Norwegian Twins and their Children

Tina Baier[1)], Espen Moen Eilertsen[2)], Eivind Ystrom[2)], Imac M. Zambrana[3)], Torkild H. Lyngstad[1)]

[1)] Department of Sociology and Human Geography, University of Oslo,
[2)] Department of Mental Disorders, Norwegian Institute of Public Health
[3)] Department of Special Needs Education, University of Oslo

Corresponding author
Tina Baier
Email: tina.baier@sosgeo.uio.no
Address: University of Oslo, Department of Sociology and Human Geography, Postboks 1096, Blindern, 0317 Oslo, Norway
Phone: + 49178394783

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ABSTRACT

Research on the intergenerational correlation of educational attainment (ICE) has long attempted to identify the impact of family background, specifically parent's education. However, previous research has largely ignored genetic inheritance. We address this shortcoming by adopting a Multiple-Children-of-Twin design and decompose the ICE into its environmental and genetic transmission mechanisms. This decomposition reveals to what extent the impact of parents' education operates through the rearing context and/or genetic factors. We use a register-based dataset from Norway, a context with egalitarian access to education. Our results show that the direct impact of parents' education is negligible once genetic factors are accounted for. While genetic factors represent the main driver of the ICE, the genetic variants that mattered for educational attainment in the parent generation overlap only partially with those that mattered for their offspring's attainment. Together, our findings complement common sociological narratives on how parent's education affects offspring's education by emphasizing the role of genetic transmission. Furthermore, our study challenges current research practices in genetics that overlook the importance of parallel changes in social structures and gene-expression over generations.

Keywords: Intergenerational transmission, Education, Multiple-Children-of-Twins design, Norway, Genetics

1. INTRODUCTION

The association between an individual's family of origin and an individual's position in social hierarchies is typically conceptualized as a summary indicator of the openness of the social structure. A strong origin-destination association would indicate fewer opportunities for mobility and greater system closure. Conversely, a weaker origin-destination association would indicate more opportunities for mobility. An established line of research has used the intergenerational association as a reverse indicator of the openness of a society and its social stratification system (e.g., Beller & Hout, 2006; Breen & Jonsson, 2005; Ganzeboom et al., 1991; Pfeffer & Hertel, 2015). A commonly studied relationship is the intergenerational correlation in educational attainment (ICE). This measure is also thought of as representing a well-established empirical regularity: Children of highly educated parents have, on average, more education compared to children whose parents are less educated. Several explanations have been offered for this correlation. Much sociological research has highlighted the importance of various kinds of resources that parents provide for their children to enhance their chances for educational success (e.g., Jackson, 2013; Teachman, 1987). One pathway typically argued for in this literature is the direct effect of parent's education: By using their own education-related resources, highly educated parents support offspring's educational careers and maintain their social status.

Most studies on the ICE, however, overlook that parents transmit not only their educational resources to their children but also genetic factors that affect offspring's education as well (e.g., Lee et al., 2018; Nielsen, 2006; Nielsen & Roos, 2015). Consequently, the impact of parent's education on children's education can run through either of these transmission mechanisms, or a combination of both. The concept of gene-environment correlation (rGE) reflects that genetic influences and environments often co-occur (Plomin et al., 1977). The transmission of education, actually, serves as prime example for a so-called passive rGE: Highly educated parents transmit certain genetic factors that shape offspring's educational success and are also more likely to expose their children to a more stimulating home-environment. Thus, due to the presence of genetic transmission, the impact of parental education may either be genetically confounded or even spurious.

Over the last decades, studies on the ICE began to control for genetics, but typically engaged with genetics in an indirect way by treating genetic influences as part of unobserved heterogeneity or confounding. These studies frequently focus on the causal impact of parental education, and exploit natural experiments (for reviews: Björklund & Salvanes, 2011; Holmlund et al., 2011). With increasing availability of molecular data, an emerging scholarship started to analyze direct measures of genetic influences on education, and some have explicitly addressed the ICE (Conley et al., 2015; Domingue et al., 2015; Isunget et al., 2021; Liu, 2018). A common conclusion based on these studies is that the direct impact of parental education attenuates once genetic influences are accounted for.

The present study builds on previous genetically informative studies on the ICE and uses an advanced twin based modelling approach. Specifically, we dissect the ICE into the underlying genetic-, and environmental (i.e., social) transmission mechanisms. To this end, we adopt a Multiple-Children-of-Twin design (MCoT) (McAdams et al., 2018). The MCoT represents an extension of the Classical Twin Design (CTD) which is a widely applied approach in quantitative genetics to differentiate between social and genetic sources of individual variation (e.g., Plomin et al., 2008). Broadly speaking, the CTD infers the relative importance of genetic and environmental influences by comparing monozygotic (identical) and dizygotic (fraternal) twins. The MCoT design includes not only twins but also their children, and provides such a genetically sensitive variance decomposition for each generation. We furthermore integrate twins' partners to correct for assortative mating in education which is a well-established phenomenon in Western countries (Blossfeld, 2009; Kalmijn, 1998; Mare, 1991). Importantly, analyzing information from two generations allows us to investigate how genetic influences contribute to education across generations, and to scrutinize the direct impact of parental education while accounting for passive rGE. Thus, this decomposition method reveals to what extent the direct impact of parents' education operates through the (family) environment and parental efforts and/or through shared genetics.

The empirical analysis are based on a large twin register-based dataset from Norway covering twin birth cohorts from 1940 to 1960, their partners and their children. We specify MCoT models for educational attainment measured in years of education by means of structural equation modeling (McAdams et al., 2018; Silberg et al., 2010).

Our results shed light on the underlying mechanisms accounting for the intergenerational transmission from parents to children and inform current debates on the equality of opportunity. Most sociological perspectives on the ICE do not explicitly acknowledge the role of genetic transmission. A positive parent-child correlation in education is treated as the result of parental efforts, inputs and resources related to their social background. Differences in education due to ascribed characteristics clearly speak against the equality of opportunity as they indicate social closure. Yet, the interpretation of a positive parent-child correlation may change, if we account for genetic factors that are shared across generations. As some scholars argue, to the extent that genetic influences on education represent merit or talent, the importance of genetic influences on education can be treated as an indicator for the openness of a society (e.g., Guo & Stearns, 2002; Nielsen, 2006). Thus, knowledge about the specific sources of the parent-child correlation in education may change how we evaluate a society's opportunity structure.

Norway represents a particularly interesting study context in this regard, as it is arguably one of the contexts where the state has gone to the greatest length in ensuring equality of opportunity in terms of access and affordability of education. Since some scholars argue that genetic influences on education unfold better in societies where social barriers to education are low (e.g., Guo & Stearns, 2002; Nielsen, 2006), we expect the direct impact of parent's education to be comparatively small once genetic transmission is taken into account, and relatedly that genetic influences represent the main pathway of the intergenerational transmission of education.

Together, our study contributes to the literature on the ICE by explicitly accounting for genetic transmission, which is still largely ignored in most sociological studies, despite the mounting evidence for genetic influences on education (e.g., Branigan et al., 2013; Lee et al., 2018; Nielsen, 2006). In addition, we make use of methodological advances in twin based approaches and apply for the first time a MCoT design to the study of the ICE. This design allows us to account for passive rGE and to correct for assortative mating thereby addressing two of the major limitations of basic twin modeling.

2. PATHWAYS CONTRIBUTING TO THE INTERGENERATIONAL CORRELATION IN EDUCATIONAL ATTAINMENT (ICE)

Stratification scholars traditionally conceive the correlation between family of origin and their children's educational attainment as being socially transmitted (Eckland, 1967; Pinker, 2003). Most theories in the social sciences argue that the positive zero-order association between individual's and parent's education can be largely attributed to various kinds of material and non-material resources that are more prevalent among socially advantaged families (e.g., Boudon, 1974; Teachman, 1987; Shavit & Blossfeld, 1993). The narratives put forward in that literature mainly circle around the financial means to cover the direct and indirect costs of education, the presence of positive role models, institutional knowledge, cultural resources and preferences, and relevant network ties (e.g., De Graaf et al., 2000; Erikson & Jonsson, 1996; Lareau & Weininger, 2003). These mechanisms are not mutually exclusive and potentially contribute to the social transmission of education.

Even though the linkage between genetics and education was already acknowledged decades ago (Carter, 1932; Eckland, 1967; Jencks, 1980), stratification scholars have mainly ignored genetic transmission mechanisms in their theories on the ICE. Obviously, there is no single gene that accounts for individuals' success or failure in the educational system. Instead, genetic influences that affect education directly are mediated through the body and run through so-called embodied characteristics (Freese, 2008). Kraphol and colleagues (2014), for instance, show that genetic influences on education stem from IQ, self-efficacy, motivation, personality and problem behaviors. Next to direct genetic influences, genetics can also contribute indirectly to the ICE as many aspects of the rearing environment are genetically confounded (cf McAdams et al. 2014). Parenting behavior, parental interests or even parent-child relationships, for instance, are all significantly influenced by genetic influences (e.g., Avinun & Knafo, 2014; Elkins et al., 1997; Kandler et al., 2011; Klahr & Burt, 2014; Narusyte et al., 2011; Neiderhiser et al., 2007). The concept of passive rGE acknowledges such confounding: Parents' genetics shape children's outcomes, but they can also affect how parents tailor the rearing environment. Children are "passive recipients" of both the genetic material and the corresponding rearing environment. To the extent that children's education is associated with those features of the family environment, any correlation may be genetically confounded.

Acknowledging the presence of genetic confounders, some scholars have tried to recast the problem as the more limited question of identifying a causal effect of parent's education on their children's education (for reviews: Björklund & Salvanes, 2011; Holmlund et al., 2011). In these studies, genetic influences are addressed as part of the unobserved heterogeneity. This reformulation reduces complexity in the sense that if one can provide evidence of a causal effect of growing up with highly educated parents, then this bolsters the argument for a causal interpretation of the intergenerational correlation. Using different types of quasi-experimental designs, social scientists have circumvented the issue of genetic confounding by using exogenous variation resulting from quasi-random events, or by analyzing identical twins or adoptees. Overall, this body of literature shows that the impact of parental education is reduced once unobserved (genetic) heterogeneity is accounted for, meaning that genetic transmission mechanisms contribute to the ICE. However, the findings on the impact of parental education remain mixed as some studies find a direct, i.e. socially transmitted, effect of parent's education, while others fail to find one, and this discrepancy appears even in similar populations (Björklund & Salvanes, 2011; Holmlund et al., 2011). In addition, the different approaches do not necessarily estimate the same causal effect of parental education, as adopted children for instance are predominantly placed in better off families while exogenous variation in compulsory schools is associated with an increase of education among low educated families (Holmlund et al. 2011). Together, this strand of literature remains inconclusive about whether and/or to what extent the impact of education runs through genetic transmission mechanisms.

2.1 DISSECTING THE INTERGENERATIONAL CORRELATION IN EDUCATIONAL ATTAINMENT (ICE)

Genetically sensitive data provide an opportunity to specify genetic and social transmission mechanisms, and thus to illuminate the processes leading to the emergence of the ICE. The behavioral genetics literature explicitly considers genetic influences as a source of individual variation. Consequently, these studies inform not only about the role of genetics for individual differences but also about the role of environmental influences, which represent "purely" social transmission mechanisms - net of genes. Specifically, the latter is of interest for stratification scholars who seek to understand how parent's social background and associated resources shape children's attainments (see also Diewald et al., 2015).

Numerous studies in this research tradition have analyzed twins, mostly using the CTD (Polderman et al., 2015; Turkheimer, 2000). In this set-up neither genetic nor environmental influences are measured directly, but inferred through the knowledge of genetic relatedness and common upbringing. In its core, these studies differentiate between genetic-, shared environmental-, and non-shared environmental influences. Shared environmental influences are those that lead to the similarity among siblings/twins, while non-shared environmental influences lead to differences among them. It is important to note that shared and non-shared environmental influences are defined based on their impact (i.e., whether they lead to similarity or dissimilarity between siblings/twins). Parental divorce, for instance, is an event that is experienced by all children from one family. However, children can strongly differ in their individual responses (Turkheimer & Waldron, 2000). The notion of "objective" and "effective" environments reflects that difference, while the latter acknowledges that similar circumstances can lead to different individual reactions (Turkheimer & Waldron, 2000). This means that every difference among monozygotic twins is due to non-shared environmental influences. However, as dizygotic twins and siblings only share half of their genome, the non-shared half contributes to differences as well. Shared environmental influences are of great interest for stratification scholars as they represent a summative measure for all social transmission that are associated with the proximate and more distal family context and have therefore been equated with social origin effects (e.g., Nielsen, 2006).

Most studies using the CTD have not been concerned with the ICE but rather genetic influences on education per se and their variation across social contexts (e.g., Baier & Lang, 2019; Branigan et al., 2013; Erola et al., 2021; Heath et al., 1985; Silventoinen et al., 2020). These studies consistently demonstrate that genetics represent an important transmission mechanism. According to an international meta-analysis genetic factors explain about 40% of differences in education while shared environmental influences explain about 30% (Branigan et al., 2013). Interestingly, shared environmental influences on education are much larger compared to most other individual characteristics, including those that are highly predictive for education such as cognitive and non-cognitive skills (Freese & Jao, 2015). One explanation refers to social ascription mechanism as an individual's educational attainment is not only determined by innate talents but also stratified schooling choices and the motivation to maintain social status (e.g., Breen & Goldthorpe, 1997). The comparatively large shared environmental component clearly points to the pivotal role of parental education on offspring's education. However, next to direct social transmission effect from parents' education to their children, other family related influences such as siblings or neighborhood characteristics, schools or organizations in which children take part, as well as peer and kinship networks possibly account for the comparatively strong impact of the shared environment on education (Freese & Jao, 2015).

One study for Germany analyzed the impact of parental education on twins' education using the CTD and found a positive impact, which mainly operates through the shared environment (Baier & Lang, 2019). However, the CTD cannot control for rGE since twins grow up in the same family, and hence share the same family background including genes and a corresponding rearing environment. Thus, we cannot rule out that the direct impact of parental education is at least partially genetically confounded. Extended twin designs that include in addition to twins other family members provide more accurate estimations of environmental and genetic transmission mechanisms and make it possible to examine to what extent the impact of parental education operates through genetics and/or the rearing environment (e.g., Coventry & Keller, 2005;

McAdams et al., 2014, 2018). As of now adaptations of extended twin designs to the study of the impact of parental education are missing from the literature.

In light of the increasing availability of molecular genetic data, scholars have started to analyze direct measures of individuals' genotypes in their models of educational attainment. Using polygenic scores (PGS) researchers have examined several aspects of the ICE. In general terms, education PGS represent the cumulative impact of measured genetic variants on educational outcomes. PGSs are based on large scale genome wide association studies (GWAS) and are weighted sum scores of genetic variants (i.e. single-nucleotide polymorphisms (SNPs)) that are common in the population (i.e. >1% prevalence).

Studies for the United States based on an early GWAS of educational attainment showed that parent's education remained significant after accounting for children's education PGS, which supports a direct impact of parental education - net of genes (Conley et al., 2015). In addition, genetic transmission mechanisms explained only about one sixth of the mother-child correlation in education (Conley et al., 2015). With increasing sample sizes, the predictive power of PGS have already increased from about 3 to 15%. Recent research using PGS based on newer GWAS show that the direct impact of parental education is reduced by about a fifth while still being significant (Liu, 2018; Isungset et al., 2021).

There is an advantage of using direct measures for genetic influences for both parents and children because one can study the genetic component of the ICE directly and account for rGE. However, even with remarkable advances made in the molecular genetics literature, current studies may still obscure genetic influences as PGS are based on GWAS studies that are not able to pick up rare genetic variants leading to an underestimation of genetic influences. At the same time, by way of construction, current PGS capture not only genetic but also environmental influences (Demange et al., 2020; Hart et al., 2021; Lee et al., 2018). Together, these early results based on molecular genetic data may change, as better-powered studies are undertaken and new molecular-genetic tools will be developed.

In light of these shortcomings, there is still added value in using quantitative, twin based, approaches for elucidating the relationship between the educational attainments of parents and children. Specifically for the purpose of the study, which seeks to analyze the types of transmission mechanisms and how they relate to each other, extended twin designs, are well suited. We use a Multiple-Children-of-Twin design (MCoT) design, which is a new adaptation of the Children-of-Twin design (CoT) and a powerful tool to investigate the processes that drive parent-child correlations (McAdams et al. 2018).

2.1.1 THE CHILDREN-OF-TWINS (CoT) DESIGN

The CoT design is an extended twin family design (for an overview: Keller et al., 2010). The CoT analyzes one child, and the MCoT more than one child per twin parent. Yet, the underlying assumptions are the same. We illustrate the logic of the CoT design in this section to provide a basic understanding and elaborate on the nuances of the MCoT below (see Analytical strategy).

The CoT design shares the same intuition as the CTD. Broadly speaking, the CTD compares the similarity of monozygotic (MZ) and dizygotic (DZ) twins and relies on Mendelian rules of inheritance. Twins are born and raised at the same time and grow up under most similar family circumstances. MZ twins are genetically identical (1.0), while DZ twins share on average half of their genes (0.5). These features enable us to decompose the total variation in an outcome in additive genetic (A), shared environmental (C), and non-shared environmental influences (E). Non-shared environmental influences (E) include also the error term of the variance decomposition. This decomposition method is commonly referred to as the ACE model. The related path diagram is displayed in Figure 1. A, C, and E represent latent factors while the related path coefficients are indicated with small letters a, c, and e.

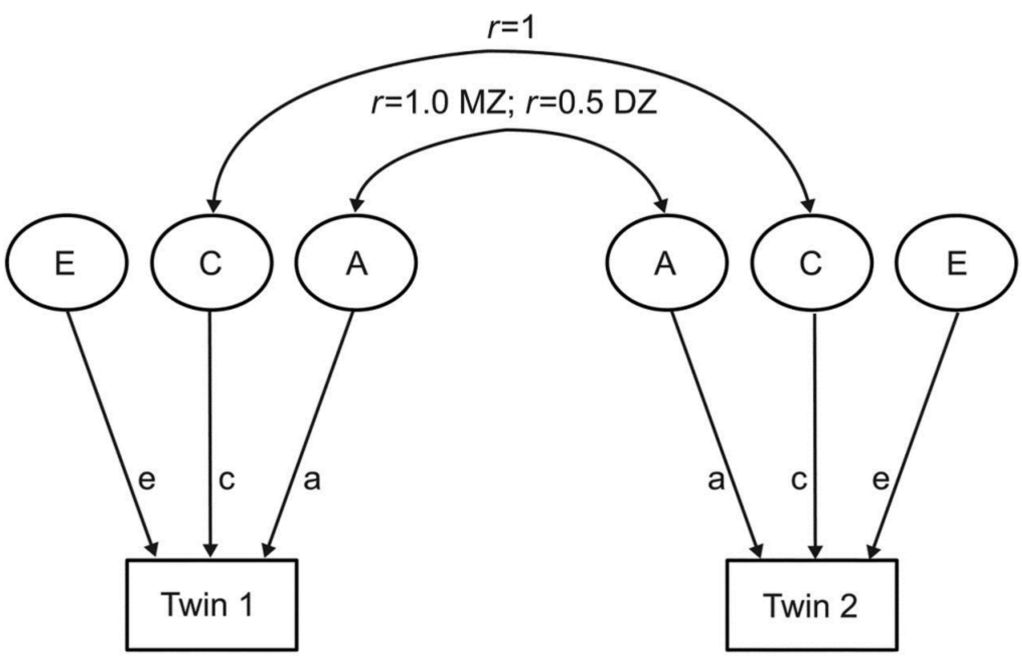


Figure 1. Path Diagram for the Classical Twin Design (CTD).

CoT designs expand these considerations to two generations and analyze in addition to MZ and DZ twins also their children. Key to any specification of the CoT design is that children of MZ twins are as related to their parents as to their uncles/aunts (0.5). In addition, the children of each MZ twin parent share twice as much of their genes compared to children of DZ twin parents (0.25 vs 0.125). Thus, while children of each MZ twin parent are cousins, they share as much of their genes as half siblings. Figure 2 visualizes the underlying assumptions and logic of the CoT design.

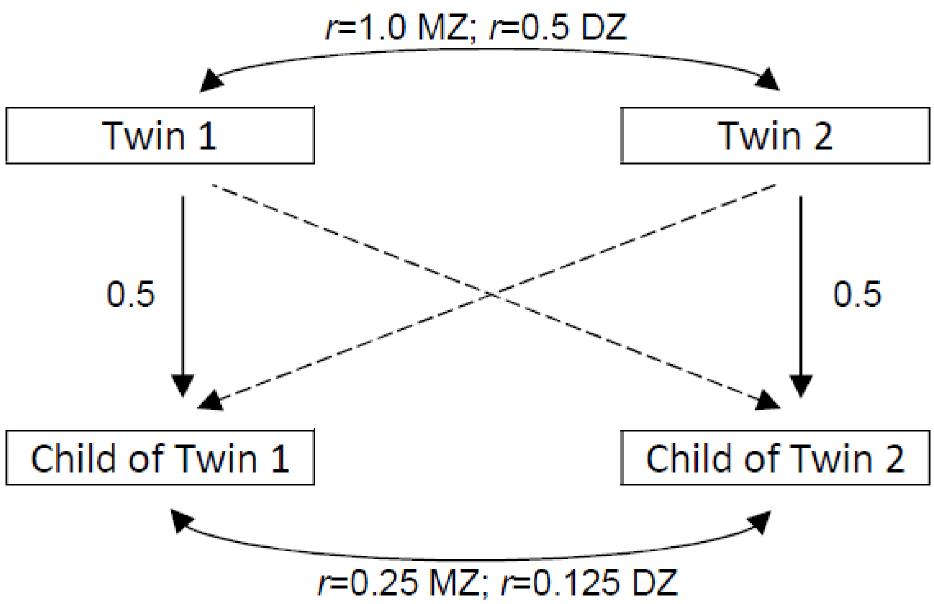


Figure 2. Basic intuition of the Children-of-Twin design (CoT). Adapted figure from Ahmadzadeh et al. (2019).

These differences in genetic relatedness allow for the following conclusions about the role of environmental and genetic influences (Silberg et al., 2010): Comparing MZ and DZ twin similarity reveals how environmental and genetics shape education in the *parental generation*. As in the CTD, higher MZ correlations than DZ correlations indicate the importance of genetic transmission mechanisms (Plomin et al. 2008). Comparing the similarity of children with their aunt/uncle in MZ and DZ families reveals how these influences operate *across generations* as children of a MZ twin parent share more genes with their aunt/uncle (co-twin) than children of DZ twins. The comparison of the MZ parent-child correlation with the avuncular correlation (child-aunt/uncle) is used to scrutinize the *direct impact of parents' phenotype* (education) on children's phenotype (education). If children from MZ twin parents resemble their parents more than their aunts/uncles, then parental education has a direct impact on children's education. Lastly, the comparison of cousins of MZ and DZ twins informs how genetic and environmental influences contribute to variability in the offspring generation independently of the parental generation. Together, the CoT design allows us not only to account for passive rGE which the CTD is not capable of. It also allows for genetic influences on education to differ across generations, which is important since genetic influences on education are sensitive to social change (e.g., Heath et al., 1985; Lin, 2020; Liu, 2018).

The CoT design relies on further assumptions. First, it is assumed that parents mate randomly with respect to phenotype under study (here: education). This justifies the assumption that siblings (and hence, DZs) share on average half of their genes. If spouses choose their partners based on characteristics that are related to the phenotype, then the genetic similarity of twins/siblings is increased leading to an underestimation of genetic-, and an overestimation of shared environmental influences. We relax this assumption in our analyses by including twins' spouses and the information about their education.

Second, the CoT is based on an extended version of the equal environment assumption (EEA). The EEA states that MZ twins are not more similarly treated by their surroundings than DZ twins. A more similar treatment of MZs can increase their similarity leading to an overestimation of genetic influences, and an under-estimation of shared environmental influences. Applied to the CoT this also means that MZ and DZ twin family members have similar relationships (in terms of frequency of contact and/or closeness for instance). Yet, to be a threat to the design, an increased level of contact or closeness must have an impact on the trait under study. Studies that explicitly test the EEA applied to the CoT design are scarce. However, a large body of literature, including outcomes relevant for this study (e.g., cognitive ability, school grades, and educational attainment) demonstrates that a violation of the EEA in its original version (i.e., referring to the CTD) does not lead to an overestimation of genetic influences (Conley et al., 2013; Derks et al., 2006; Mönkediek, 2021). Additionally, one study found that while MZ twins are indeed more in contact with their co-twin, this did not bias their findings on genetic influences on children's externalizing problems (Koenig et al., 2010).

Third, the CoT identifies additive genetic influences and precludes dominant genetic effects or epistasis. If there are any non-additive genetic effects, we would overestimate shared environmental influences. However, such bias seems unlikely since our outcome of interest, educational attainment, is a complex trait and research demonstrated that genetic influences on complex traits are mainly additive (Mills et al., 2020; Polderman et al., 2015).

3. THE NORWEGIAN CONTEXT AND EMPIRICAL EXPECTATIONS

Our study context refers to Norway, a wealthy Scandinavian welfare state with a long history of active policies towards levelling social disparities broadly conceived and a comprehensive social safety net aiming to expand opportunity structures of all social groups of the society (e.g., Esping-Andersen, 2014). Compared to many other western industrialized countries the ICE in Norway is comparatively low at 0.35 while it is for instance for the United States, a country with a liberal welfare state characterized by low state intervention, at 0.46 (Björklund & Salvanes, 2011; Hertz et al., 2008).

The comparatively low ICE in Norway can partially be explained by institutional features of the educational system: In general, the educational systems in the Nordic countries are marked by comparatively egalitarian access coupled with high and homogenous quality. Lower secondary education is compulsory, and children are not tracked until upper secondary education, around the age of 16. Thus, compared to many other western industrialized countries, the sorting of children appears at a relatively late stage of the educational career which is associated with lower social background influences (e.g., Breen & Jonsson, 2005; Pfeffer, 2008; Van de Werfhorst & Mijs, 2010). The schooling system is highly standardized across the country, and school characteristics do not explain much of adult educational attainment (Hermansen et al., 2020). A standard high school diploma, i.e., graduation from upper secondary education (either vocational or general), qualifies individuals for admission to university or university college programs ("studiekompetanse" comparable to the Higher Education Entrance Qualification). There are degree-granting tertiary institutions spread across the country. Contemporary Norway belongs to the few western industrialized countries in which tertiary education is easily accessible due to a rather universal access and the lack of tuition fees. Figure A1 in the Appendix provides an overview about the Norwegian educational system.

Studies that systematically link distinct features of the educational system with the importance of genetic influences on education are missing from the literature. To date, there are two twin based internationally comparative meta-analyses which provide conflicting evidence with respect to cross-country differences in genetic influences on education as well as their variation over time (Branigan et al, 2013; Silventoinen et al. 2020). Another study that used that same country sample as the meta-analysis from Branigan et al. (2013) found that genetic influences on education matter more in egalitarian countries with higher levels of social mobility and less social inequality (Engzell & Tropf, 2019). However, this findings was recently challenged as methodological choices may have driven these conclusions (Morris, 2020).

Research for the Norwegian context, however, mainly supports the notion that egalitarian educational policies that shape the opportunity structures for individuals' educational careers affect individuals' chances to realize their genetic potential for education. Early studies showed that the relative importance of genetic influences on education increased over the twentieth century (Heath et al., 1985; Tambs et al., 1989), and that the relative importance of genetic factors exceeded the relative importance of shared environmental influences for men born after 1940 but not for women (Heath et al., 1985). Ørstavik and colleagues (2014) found this pattern to be reversed for younger birth cohorts born between 1967 to 1979 as genetics explained about 40% of differences in education for men and about 55% for women. Yet, previous research has used the standard twin methodology, i.e., analyzed only twins, and did not, for instance, correct for assortative mating. In light of the well-established similarity of spouses with respect to their education (Blossfeld, 2009; Kalmijn, 1998; Mare, 1991), it is likely that the genetic component is underestimated in these studies.

Putting our expectations on the different transmission mechanisms driving the ICE in context, we propose that the direct effect of parental education is weak once common genetic factors are accounted for. Relatedly, genetic influences should be more important for educational differences than shared environmental influences, which are often equated with social origin effects.

4. DATA AND METHODS

Data and Sample

Our data combines information from twins included in the Norwegian Twin Register (NTR) and administrative register data on educational attainment. The NTR was established in 2009 by the Norwegian Institute of Public Health and represents a largescale high quality twin register including twins born between 1895 and 1969, and between 196 and 1979 (Harris et al., 2006; Nilsen et al., 2013, 2016; Tambs et al., 2009). Consent to be included in the twin register was granted by each twin individually via a completed questionnaire or specific consent form. The number of twins that provided consent to participate in the NTR varies across birth cohorts but is quite high for the birth cohorts we study (Nilsen et al. 2013; 2016). Twins' zygosity, i.e., whether a twin is mono- or dizygotic, was determined through similarity reports. In Norway, each individual has a unique personal identification number (PIN). This PIN system allowed us to link the information from the NTR with the administrative register data. The resulting data set includes basic demographic variables of twins, their spouses, and their children, as well as their educational attainment.

Our analytical sample uses information of same-sex twins and their partners born between 1940 and 1960, and their children, mostly born between 1972 and 1983 (IQR = 1972-1983). We restricted the data set to twin pairs born 1940-1960 and their children because a) covering a longer range of cohorts would increase the likelihood of bias from processes of broader social change, and b) the NTR has a gap in the period 1961-1966. We furthermore excluded twins in which only one twin consented to be part of the NTR or where we lack information about any of the variables included in the models as well as individual twins without children. The family units we analyze are composed of two nuclear families where one parent in each family is a twin of one parent in the other family (either MZ or DZ). Each nuclear family contributes either one or two children to the analyses (on average 1.8 per nuclear family). Note that twins do not have to be married to their partners in order to identify their children. Because the inclusion of two children per nuclear family identifies all relevant parameters and very few families had more than two children, we included two siblings selected at random from these families. A complete unit therefore includes educational measurements from up to eight individuals, two mothers, two fathers and up to four children.

Variables

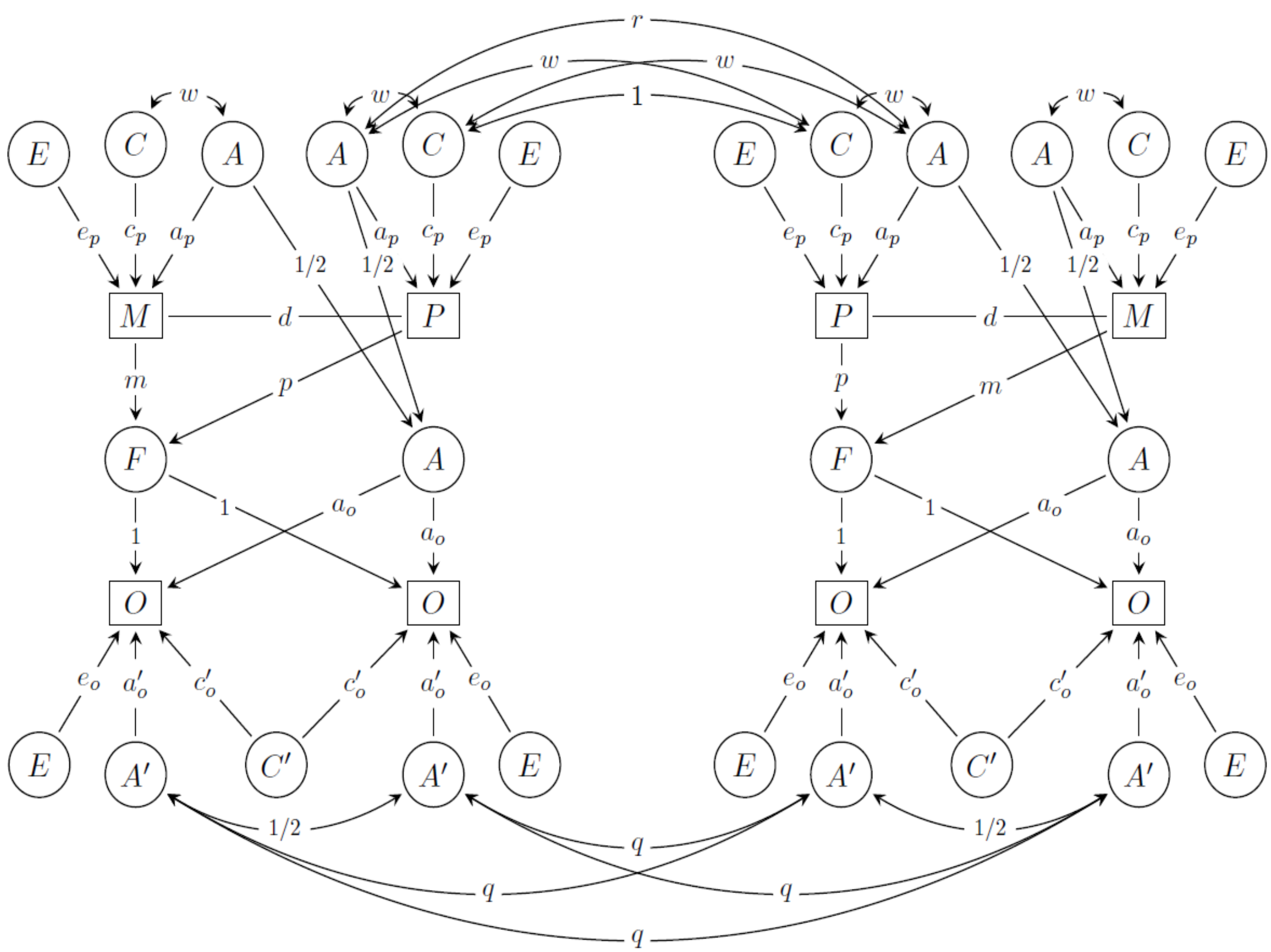
Our outcome of interest refers to educational attainment indicated with years of education. Educational attainment was measured as close to age 30 as possible for all individuals on the 9-level NUS2000 scale, ranging from no education (0) to doctoral level degree (8). There is also a separate missing category (9). We transformed the nine educational levels to the corresponding years of education (see Appendix TableA2 for the NUS2000-scale and the corresponding years of education). Our linear measure *years of education* reflects not the actual time spent in the educational system, but the highest educational certificate. We chose to measure education around the age 30 because the information about individuals' education was available for the years 1970, and 1980-2018. Thus, for some parents (typically those born before 1950), we will not get their educational level when they are precisely 30 years old. The same holds for the youngest child cohorts (e.g., born in 1980). In these cases, we selected the measurement closest in time to the year when the person was 30 years old. Thus, by focusing at education at age 30 we balanced the needs for getting as close to the same age for all cohorts as possible, and the restrictions in our education time series.

Our observation period is quite long as our design covers two generations. To avoid bias related, for instance, to the expansion of educational opportunities across generations, we standardized educational attainment within birth cohort and sex using data on the full population of Norway (see Appendix, A3, for an overview on differences in educational attainment by gender over time). Analyses without standardization as well as analyses based on an alternative generation-based standardization yielded similar results and lead to the same conclusion. These results are shown in the Appendix, A4a and A4b.

There are only a few missings for educational attainment (<1%) in our data. Families in which not all members have valid information on their education still enter the analysis. Our analytical sample includes 4424 extended nuclear families and we analyze 33432 educational measurements in total (i.e. educational attainments from those families). Table A5 in the Appendix displays summary statistics for the sample.

Analytical Strategy

We specify MCoT models by means of structural equation modelling (McAdams et al., 2018). Figure 3 visualizes the related path diagram for one twin pair and their nuclear families.



<u>Observed Variables</u>
M Maternal Education
P Paternal Education
O Offsprings' Education
<u>Latent Variables</u>
A Additive Genetic Effects (Parents)
A' Additive Genetic Effects (Offspring)
C Shared Env. Effects (Parents)
C' Shared Env. Effects (Offspring)
E Non-Shared Env. Effects
F Parents' Education
<u>Path Coefficients</u>
a_p, c_p, e_p Effect of A, C, and E (Parents)
a_o, a'_o, c'_o, e_o Effect of A, C, and E (Offspring)
m Effect of Maternal Education
p Effect of Paternal Education
<u>Covariances</u>
r Genetic Relatedness among Twins
q Genetic Relatedness among Cousins
w Passive rGE
d Assortative Mating

Figure 3. Path diagram for the MCoT design.

In figure 3, the father of the family to the left and the father of the family to the right are twins, their genetic relatedness is indicated with *r* (1.0 MZ/0.5 DZ). The genetic relatedness of the children of each twin family, i.e. cousins, are indicated with *q* (0.25 Children of MZ twin parents/ 0.125 children of DZ twin parents). Educational attainment from mothers, fathers and children are depicted by rectangles labeled M, P and O, respectively. Latent variables are in circles.

We describe educational attainment in the *parental generation* as a function of additive genetic effects (A), shared environmental effects (C), and environmental effects unique to one individual (E). The strength of these influences is estimated from the corresponding path coefficients. The covariance between maternal and paternal education is estimated with the parameter d. Assortative mating based on the phenotype education induces correlations of genetic and environmental effects between partners. These implications are represented with the horizontal line between maternal and paternal levels of education. We have also specified a model where we do not account for assortative mating (d=0). As expected genetic influences are smaller when we assume random mating of spouses. The results are provided in the appendix (A6). In light of substantial assortative mating in our data (spousal correlation in education was at 0.51), models which account for assortative mating represent the more realistic scenario.

With respect to the *offspring generation*, we split the additive genetic effect into two components, one component shared with parental education (A) and the other one being specific to offspring's educational attainment (A'). This allows that different genetic factors are expressed across generations. For example, if the same genetic factors contribute to education in both generations, the coefficient from A' is expected to be zero. On the other hand, if completely different genes are expressed across generations, the coefficient from A is expected to be zero. We also split the shared environmental effect into one component directly attributable to parental education (F) and one component due to other shared environmental influences (C'). We allow that mothers and fathers to contribute differently to the shared environment due to their education (F) with separate coefficients *m* and *p*. If the only source of shared environmental influences is due to parental education, then the coefficient from C' is expected to be zero. Vice versa, if shared environmental influences are unrelated to parental education, then m and p are expected to be zero.

Lastly, if education is transmitted because of common genetic influences and directly from parental education, genetic and environmental effects influencing offspring's education will be correlated. This can be seen in figure 3: The same genetic factors affecting parental education (A) are transmitted to the offspring, which would induce a correlation between the environment (F) and offspring genetic factors (A), because they share the same cause. This is a form of passive rGE because the parents provide both genes and environments for their children. We assume that rGE has been ongoing in both generations, represented by the correlation *w* between shared environmental and additive genetic effects in the parent generation. Because we do not have educational data on the previous generation, the correlation *w*, is set to be equal to the total correlation between genetic and common environmental effects in the children generation, w= Corr(A+A',F+C').

For identification, all latent factors in the model are scaled to have a total variance of one, except for F where the residual variability is set to zero. This parameterization of F is equivalent to specifying paths directly from the observed education of parents to their children, but makes clear that this implies an environmental component that is shared among siblings. We estimated structural equation models with R/OpenMx software package.

5. RESULTS

Table 1 displays the raw correlations in educational attainment among extended family members.

Table 1: Correlation in educational attainment by kinship

	Similarity in educational attainment	SE
Within Generations		
Parental generation		
MZ twin – MZ twin	0.77	0.01
DZ twin – DZ twin	0.56	0.01
MZ twin – partner	0.50	0.01
DZ twin – partner	0.44	0.01
Offspring generation		
MZ children (cousins)	0.26	0.02
DZ children (cousins)	0.20	0.02
MZ children (siblings)	0.41	0.01
DZ children (siblings)	0.41	0.01
Across Generations		
Parent-offspring		
MZ parent – child1	0.38	0.01
MZ parent – child2	0.35	0.02
DZ parent child1	0.35	0.01
DZ parent – child2	0.34	0.01
Aunt/uncle-child		
MZ parent – child1	0.36	0.01
MZ parent – child2	0.35	0.02
DZ parent – child1	0.26	0.01
DZ parent – child2	0.25	0.01

Source: Norwegian Registers, own calculations.

Both, the similarity of MZ and DZ twins and cousins in MZ and DZ twin families indicate that genetic factors play an important role for educational differences as the similarity is higher in MZ families (0.77 vs 0.56 (parental generation), 0.26 vs 0.20 respectively (offspring generation).

Considering the correlations across generations (parent-offspring and avuncular relationships) we see that the children of MZ twin parents resemble their MZ twin parent almost as much as their aunt/uncle (co-twin). Additionally, avuncular correlations are lower in DZ families which is suggestive of genetic transmission. Together, this indicates that the impact of parents' education runs mainly through genetic factors and not through the shared family environment. In conclusion, the correlations provide descriptive support for our expectations regarding the direct impact of parental education and the importance of genetic influences for the ICE.

Next, we present the results from MCoT model fitting. We first evaluate the findings for the direct effect of parental education (p and m, see table 2), and present then how genetic and environmental influences contribute to the ICE (table 3 and figure 4).

To test for a direct effect of parental education on offsprings' own education we specify three alternative models underlying the ICE: Model I "full", Model II "genetic", and Model III "environmental". The "genetic" model assumes that the impact of parental education runs entirely through genes, therefore the effect of parent's education is set to zero ($p = m = 0$). The "environmental" model, by contrast, assumes that the impact of parental education runs solely through environmental pathways and hence requires that genetic effects are zero ($a_o = 0$). Lastly, the "full" model allows for both transmission pathways and estimates parameters for the direct impact of parental education as well as genetic transmission.

Table 2:Parameter estimates and standard errors for the fitted models.

	Model I Full		Model II Genetic		Model III Environmental	
	b	**SE**	b	SE	b	SE
Parents						
Additive Genetic Effects (*a*¿¿ *p*)¿	0,76	0,04	0,76	0,04	0,72	0,04
Shared Env. Effects (*c*¿¿ *p*)¿	0,39	0,07	0,38	0,08	0,45	0,06
Non-Shared Env. Effects (*e*¿¿ *p*)¿	0,47	0,01	0,47	0,01	0,47	0,01
Assortative mating (d)	0,48	0,01	0,48	0,01	0,48	0,01
Parental Education						
Maternal Education (m)	-0,04	0,03	0,00	---	0,21	0,01
Paternal Education (p)	0,00	0,03	0,00	---	0,26	0,01
Offspring						
Additive Genetic Effects (a_o)	0,63	0,09	0,58	0,03	0,00	---
Additive Genetic Effects–Offspring-Specific (*a*¿¿*o*')¿	0,47	0,08	0,49	0,06	0,58	0,04
Shared Env. Effects–Offspring-Specific (*c*¿¿*o*')¿	0,14	0,08	0,14	0,07	0,21	0,05
Non-Shared Env. Effects(*e*¿¿*o*)¿	0,58	0,02	0,59	0,02	0,64	0,02

Model-Comparison

base	comparison	-2LL	df	AIC	Δ-2LL	Δdf	p
Model I Full	NA	84253.23	33418	17417.23	-	-	-
Model I Full	Model II Genetic	84261.46	33420	17421.46	8.22	2	0.016
Model I Full	Model III Environmental	84332.24	33419	17494.94	79.00	1	0.000

Notes: $N_{extended\ family\ units}$ = 4424, $N_{measurements}$ = 33432. Best fitting model in bold. -2LL = - 2 log likelihood; df = degrees of freedom; AIC = Akaike information criterion. Source: Norwegian Registers, own calculations.

Results of the “environmental” model which estimates only social transmission mechanisms show that both maternal and paternal education have a strong and statistically significant impact on children's education. The impact of father's education is larger than mother's education (b=0.26, 0.21 respectively). In the "full" model which accounts for common genes across generations and social transmission mechanisms, we find that the impact of parental education vanishes substantially: father's education hast zero impact (b=0.00), and mother's education is small in magnitude and tends to be negative (b=-0.04). Neither mother's nor father's education is statistically significant at conventional significance levels. Thus, the "full" model comes to almost the same conclusions as the genetic model, which assumes that the impact of parental education runs solely through genetic transmission.

To conclude about the magnitude of the direct impact of parental education we compare the model fit which provides further support for genetic confounding: Considering AIC statistics we find that both models, the "full" and the "genetic", have a better model fit than the "environmental" model that ignores genetic transmission. In addition, AIC statistics slightly favor the full model compared to the genetic model. Using a 5% significance level, there is a significant loss in fit by omitting the environmental transmission. However, from a more substantive point of view and by examining the substantive size of the coefficients, we find that the direct impact of parents' education, that is the environmental transmission pathway, is, if anything, very small. In addition, neither of the coefficients is statistically significant in isolation. Thus, the slight preference for the "full" model should not be over-interpreted as the relevant difference across the models refers to the contrast between the "environmental" model vs the other two ("full" and "genetic") models.

In conclusion, the data strongly supports the relevance of genetic transmission for education while there is overall weak support for an environmentally transmitted impact of parental education. In line with our expectations, the direct transmission from parental education to children's education mostly runs through common genetic factors.

Finally, we examine how environmental and genetic transmission mechanisms contribute to educational attainment across generations by looking at the related variance components (table 3). Figure 4 visualizes the findings for the relative variance components from the "full" model. Note that we present here the results from the "full" model due to the best fit statistics, while the results for the variance components based on the "genetic" model reveal the same pattern.

Table 3 shows that additive genetic influences, A and A', are the main driver for educational differences in both generations as they account for more than 60% of the differences in educational attainment, i.e., 61% in the parental generation, and 65% in the offspring generation (42%+23%). Interestingly, the results show that the genetic factors that account for differences in education in each generation overlap only partially: 42% of the variance in offspring's education can be attributed to the genetic factors that mattered also for educational differences in the parental generation, while 23% of the variance relate to genetic factors specific to the offspring's generation. This corresponds to a genetic correlation of 0.69 across generations. Thus, genes have been a major source of differences in education across generations, but the kind of genetic factors that contribute to education differs across generations.

Table 3: Absolute and Relative Variance Components (full model).

Source	Absolute	Relative Variance (%)
Parents		
Additive Genetic Influences (A)	0,58	0,61
Shared Env. Influences (C)	0,15	0,16
Passive rGE $(A, C$¿	-0,01	-0,01
Non-Shared Env. Influences (E)	0,22	0,23
Total	0,94	1
Offspring		
Additive Genetic Influences (A)	0,40	0,42
Additive Genetic Influences – Offspring-Specific (A')	0,22	0,23
Parental Education (F)	0,00	0,00
Shared Env. Influences – Offspring-Specific (C')	0,02	0,02
Passive rGE $(A, F$¿	-0,02	-0,03
Non-Shared Env. Influences (E)	0,33	0,36
Total	0,94	1

Source: Norwegian Registers, own calculations.

Shared environmental influences, C', are negligible as they account for only 2% of the variation in education in the children's generation. Again, shared environmental influences are unrelated to parental education as indicated by the almost zero impact of A,F (the covariance of genes and parental education), and the almost zero impact of parental education once genetics are accounted for (see Model I "full" Model). For the parental generation, shared environmental influences are larger as they account for about 16% of the differences in education. Findings for both generations confirm our expectation that genetic factors play a stronger role for education than shared environmental influences in the Norwegian context. Lastly, non-shared environmental influences, those that lead to differences among individuals within a family, explained a substantial part of the variation in education in both generations: About a fourth for the parent's, and more than a third for the offspring's generation. Thus, in both generations non-shared environmental influences represent the dominant environmental pathway.

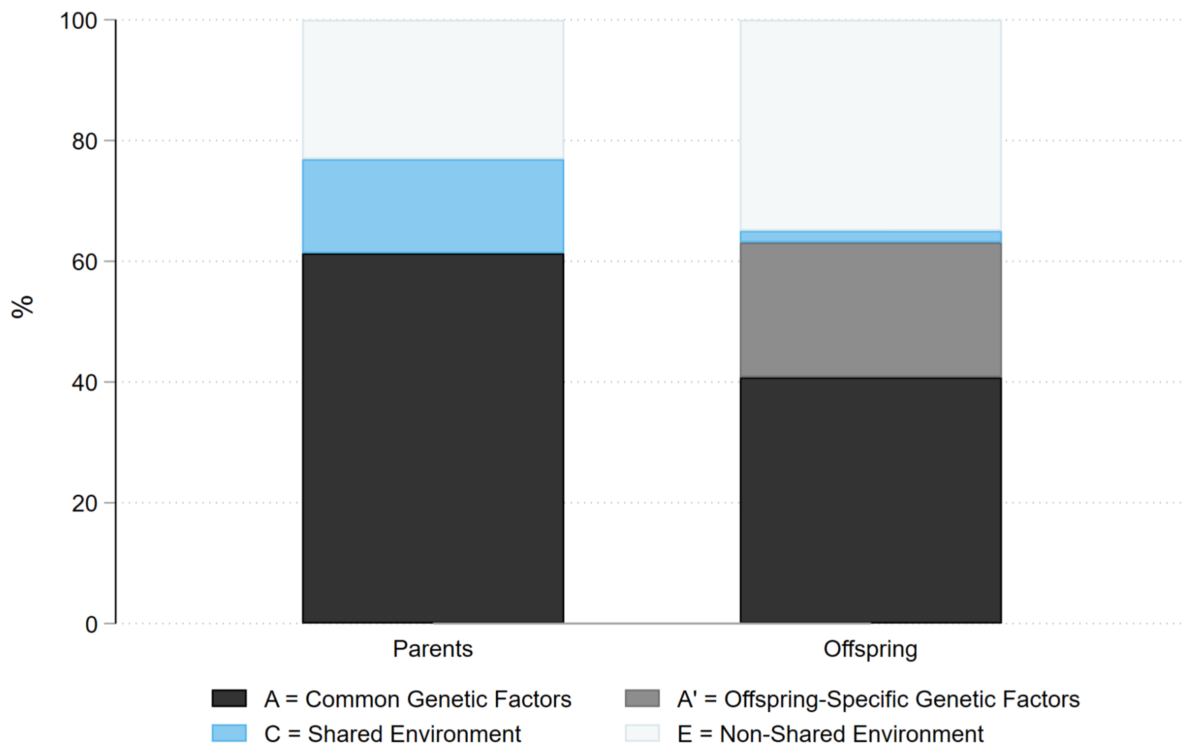


Figure 4: Variance decomposition for parents and their children (variances in %). Note: Relative variances that are smaller than 1% are not displayed.

We have also examined whether our findings are driven by birth-order effects, which is important in light of previous findings that show that first-borns tend to have higher levels of education than later-borns (Black et al., 2005; Härkönen, 2014; Kristensen & Bjerkedal, 2010). As shown in the appendix, A7, the relative fit of these models is consistent with the main analyses and the parameter estimates are similar while standard errors are slightly larger for some parameters likely to be due to fewer measurements. Together, the findings do not substantively differ and demonstrate the robustness of our results with respect to birth-order effects.

6. FINAL DISSECTION: WHAT FACTORS MATTER FOR THE INTERGENERATIONAL CORRELATION IN EDUCATIONAL ATTAINMENT (ICE) IN NORWAY?

In this paper we studied the ICE while accounting for both social and genetic pathways. Specifically, we adapted a MCoT design and exploited information from twins, their partners and children. Central to our efforts was to estimate the postulated direct effect of parents' education on their offspring's education, in the context of the relatively open and accessible Norwegian educational system.

Our study has three important findings: First, the direct transmission pathway from parents to children's education is indeed negligible once we account for genetic inheritance. Thus, our results are partly in line with previous genetically sensitive studies on the ICE that demonstrated genetic confounding. Yet, we find that the impact is spurious, as the impact of parents' education runs entirely through genetic factors. In addition, we find that genetic influences capture the lion's share of differences in educational attainment. This pattern is consistent for both the parental and the offspring generation, covering birth-cohorts from 1940 to the mid-eighties. Both the limited direct impact of parent's education and the strong contribution of genetic influences support the expectation that genetics can unfold better in a more egalitarian country context. Thus, our results demonstrate the pivotal role of environmental conditions for the realization of genetic potential for education as genetic factors represent the main driver for differences in education in Norway which is known for its equal access to education and low levels of social inequality.

Integrating the finding that social origin effects are comparatively strong in countries that have an early tracking systems (e.g., Breen and Jonsson, 2005; Jackson, 2013; Van de Werfhorst and Mijs, 2010), one would expect that genetic factors play a less important role in countries that have socially stratified educational systems that select children early in their life, such as Germany or the Netherlands. In these countries, access to education is strongly linked to parents' socio-economic standing and the realization of genetic factors is likely to be constrained. Judging from our results, it seems that policymakers would do well in imitating Norwegian educational policy in providing easy access and financing if equalization of educational opportunity is the desired goal. However, future international comparative research is needed to assess the external validity of these findings and their relevance for policy in other contexts.

Second, genetic factors that contribute to differences in educational attainment have changed over generations, as genetic factors of both generations correlated by about 0.7. Thus, the genetic architecture of education is -at least in the Norwegian context- measurably different for the two generations. Substantively this means that because genetic influences affect educational attainment through embodied characteristics such as non-cognitive and cognitive skills (Freese 2008), their contribution to education must have changed across generations otherwise the genetics factors would correlate by 1. There might be several reasons for this, of which some lie with the educational system. Over the last few decades, access to education has become increasingly more inclusive, both with regards socio-economic background and gender, in which a right for students to develop their skills is embedded in the educational system. In addition, it has become easier to transfer credits from one institution to another, enter, combine and shift between educational programs (except for a few elite programs), alongside the universal financing that offers free education for all. This trend has been gradual, and as such differences due to genetic factors might only be expected to be seen when looking at their contribution across generations. One may theorize that the educational system in the earlier period was more oriented towards rote learning and basic skills, and in the later period instructional modes moved more towards non-cognitive skills. Outside of the educational system, there have of course also been other social changes that directly and indirectly affect how individuals attain educations (and thus the selection into and out of educational programs), and therefore also change what genetic dispositions can explain such outcomes.

This finding has also major implications for molecular genetic studies of educational outcomes, as it means that effects of specific genetic variants may differ over birth cohorts. To date, most studies using molecular genetic data are based on results from GWAS, and therefore derived PGS, which implicitly assume that the association between each genetic variant and the educational outcome is constant over birth cohorts or other social contexts. Current research in genetics often overlooks social and institutional change. Our results highlight that future efforts in genetically informed social science must consider social-structural changes.

Third, shared environmental influences have almost no impact on differences in education. Indeed, only 2% of the variation in education could be attributed to shared environmental influences in the children’s generation, and 16% in the parental generations. The differences in the importance of shared environmental influences over generations could indicate that social constraints -possibly gender related norms- played a larger role for educational attainment in the parents' generation. Alternatively, this finding could indicate that environmental influences affect siblings only in similar fashion, if siblings are close in age as parents are twins while their children are not. Importantly, our findings on the small to almost non-existent impact of shared environmental influences do not mean that the family context is not important. One pathway through which family influences may affect children's education is through non-shared influences. In line with recent results from Finland (Erola et al. 2021) we found a substantial impact of the non-shared environment. This highlights that non-shared environmental influences represent a relevant environmental pathway through which (dis-)advantage is reproduced across generations, and should receive greater attention in the stratification literature.

On that note, using the MCoT, we cannot rule out that parental education may as well operate through the non-shared environment. For instance, highly educated parents may be more sensitive to child-specific needs and foster children's talents more individually (Baier, 2019). Child-specific parental behaviors then may eventually lead to different educational careers. Selective parenting would lead to an underestimation of the impact of parental education and an overestimation of the role of genetics in our analyses. However, based on the sibling correlation literature it seems unlikely that differential investments represents the dominant parenting strategy as parents may only allocate their resources selectively, if resources are scares. Thus, if there are any non-shared environmental influences associated with parent's education, we expect that their importance is rather small. Nonetheless, future research that also considers differences across the social strata is needed to examine this claim.

It is furthermore important to keep in mind that the MCoT design relies, as any other extension of the CTD, on the assumption that genes and environment do not interact with each other. Any kind of gene-environment interaction would bias our results to an unknown extent. In the context of genetic influences on education, previous studies have predominantly examined whether genetic influences differ along the social spectrum (e.g., Baier & Lang, 2019; Erola et al. 2021; Conley et al. 2015; Lin, 2020). While results remain overall inconclusive and differ by country, previous research for Norway shows that there is no systematic variation in the importance of genetic influences on education by parental social background (Isungset et al., 2021).

Lastly, the generalizability of our twin based findings needs to be discussed. It is well-documented that twins are often born premature and have low birth weight (e.g., Gielen et al., 2010). Both is negatively associated with cognitive development, possibly leading to lower educational attainment among twins compared to non-twins. However, previous findings show that differences between twins and non-twins in cognitive skills and educational achievement vanish already during childhood (de Zeeuw et al. 2015; Webbink et al. 2008). Relatedly, previous studies showed that twins and non-twins do not substantially differ in their personality traits (Johnson et al., 2002), and that twins do not receive different parenting than non-twins (Mönkediek et al. 2020). Together, these findings allow the conclusion that twins are actually not too different from non-twins with respect to characteristics that are predictive for educational success. Yet, the question remains whether our findings can be applied to one child families. From a theoretical point of view, there is no reason to believe that the importance of genetic transmission should be different, if there is only one child. It could be that parents' educational resources play a stronger role if there is only one child. However, this would increase the importance of non-shared environmental influences but not change the importance of genetics factors. Nevertheless, the question to what extent our findings are transferable to one child families, remains ultimately an empirical question.

In sum, our results add to leading sociological narratives of educational inequalities. Stratification scholars often highlight the pivotal role of social mechanisms flowing from parents' own education. Our results for Norway point to other mechanisms, notably genetically influenced traits, as being more important for the parent-offspring association in educational attainment and demonstrate how important environmental conditions can be for the realization of genetic potential for education. We also found that the genetic factors contributing to educational attainment are different in the parent- and offspring generation. This is important for research based on education GWAS results, as these to date have not allowed cohort-specific genetics effects. Changes in the genetic architecture for education across cohorts will likely affect the validity of intergenerational studies of polygenic prediction of education. It remains an interdisciplinary challenge to better understand how features of the environment shape how individuals, with their specific genetic dispositions and environmental exposures, move through the educational system.

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Appendix

A1. Overview of the Norwegian Educational System

Age	Educational Program		Years
	Higher Education (PhD)		21 20 19
	Higher Education (Master)		18 17
	Higher Education (Bachelor)		16 15 14
18 to 19 17 16	Upper Secondary School (High school)	Vocational Education* High School	13 12 11
15 14 13	Lower Secondary School (Middle School)		10 9 8
12 11 10 9 8 7 6	Primary School		7 6 5 4 3 2 1
3 to 5	Kindergarten/Preschool in childcare centers		

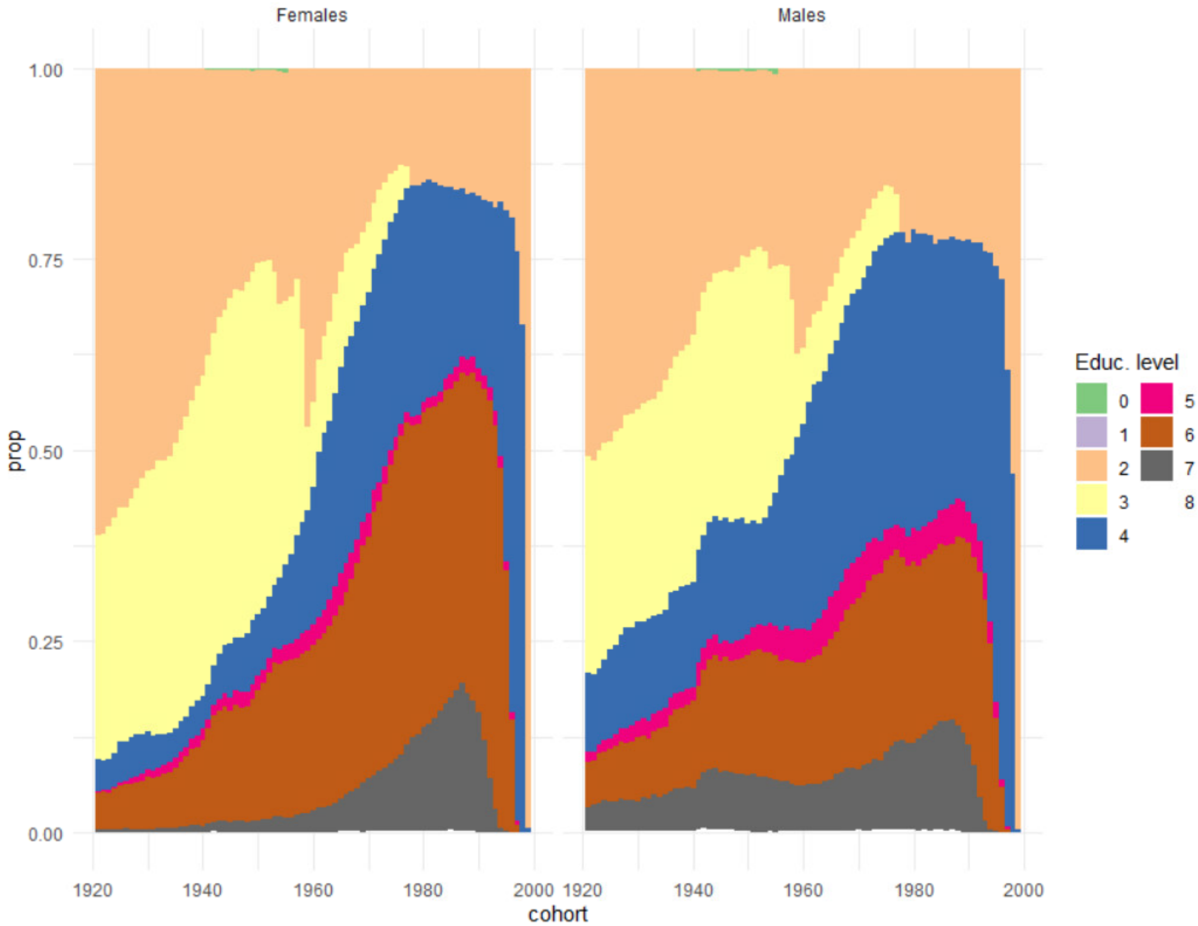
Note: *Vocational Education can encompass 1 or 2 years.

A2. The Norwegian Standard Classification of Education

Tripartition of Levels	Levels	Level name	Corresponding years of education
	0	No education and pre-school education	0
Compulsory education	1	Primary education	7
	2	Lower secondary education	9
Intermediate education	3	Upper secondary. basic	11
	4	Upper secondary. final year	13
	5	Post-secondary not higher education	14
Higher education	6	First stage of higher education. undergraduate level	17
	7	First stage of higher education. graduate level	19
	8	Second stage of higher education (postgraduate education)	21
	9	Unspecified	Missing

Adapted overview from Statistics Norway (2017).

A3: Distribution of Educational Attainment by Birth Cohort and Gender



A4. Sensitivity Analyses: Standardization of Years of Education

A4a. Years of education – unstandardized. Parameter estimates and standard errors

Parameter	**Full**		Genetic		Environmental	
	Est.	**SE**	Est.	SE	Est.	SE
Parents						
	2.46	**0.13**	2.45	0.13	2.32	0.13
	1.06	**0.31**	1.13	0.27	1.38	0.22
	1.46	**0.02**	1.46	0.02	1.47	0.02
d	**4.80**	**0.12**	4.80	0.12	4.80	0.12
Children						
m	**-0.02**	**0.03**	0.00		0.22	0.01
p	**0.03**	**0.03**	0.00		0.27	0.01
	1.83	**0.25**	1.93	0.11	0.00	
	1.82	**0.19**	1.77	0.19	2.01	0.12
	0.58	**0.20**	0.58	0.21	0.75	0.16
	1.86	**0.08**	1.84	0.07	2.05	0.06
Modelfit						
-2LL	**-81390.03**		-81394.60		-81426.136	
AIC	**162810.07**		162813.19		162878.271	

Note: $N_{extended\ family\ units}$ = 4424. $N_{measurements}$ = 33432. Best fitting model in bold. -2LL = - 2 log likelihood; AIC = Akaike information criterion. Source: Norwegian Registers. own calculations.

Relative variance components under the full model.

Source	Absolute	Relative
Parents		
A	6.06	0.64
C	1.12	0.12
$A.C$	0.12	0.01
E	2.15	0.23
Total	9.45	1.00
Children		
A	3.34	0.32
A'	3.32	0.31
F	0.01	0.00
C'	0.34	0.03
$A.F$	0.12	0.01
E	0.36	0.33
Total	0.36	1.00

A4b. Years of education – generation-specific standardization within the sample. Parameter estimates and standard errors.

Parameter	**Full**		Genetic		Environmental	
	Est.	**SE**	Est.	SE	Est.	SE
Parents						
	0.80	**0.04**	0.80	0.04	0.75	0.04
	0.37	**0.09**	0.37	0.09	0.45	0.07
	0.47	**0.01**	0.48	0.01	0.48	0.01
d	**0.51**	**0.01**	0.51	0.01	0.51	0.01
Children						
m	**-0.03**	**0.03**	0.00	---	0.21	0.01
p	**0.01**	**0.03**	0.00	---	0.26	0.01
	0.61	**0.09**	0.59	0.03	0.00	---
	0.53	**0.07**	0.54	0.06	0.61	0.04
	0.18	**0.06**	0.18	0.06	0.23	0.05
	0.56	**0.03**	0.56	0.02	0.62	0.02
Modelfit						
-2LL		**-42749.54**		-42754.09		-42785.63
AIC		**85529.07**		85532.19		85597.27

Note: $N_{\text{extended family units}}$ = 4424. $N_{\text{measurements}}$ = 33432. Best fitting model in bold. -2LL = - 2 log likelihood; AIC = Akaike information criterion. Source: Norwegian Registers. own calculations.

Relative variance components under the full model.

Source	Absolute	Relative
Parents		
A	0.64	0.64
C	0.14	0.14
$A.C$	-0.01	-0.01
E	0.23	0.23
Total	0.99	1.00
Children		
A	0.37	0.38
A'	0.28	0.29
F	0.00	0.00
C'	0.03	0.03
$A.F$	-0.01	-0.01
E	0.31	0.32
Total	0.98	1.00

A5. Descriptives by Zygosity

	MZ					DZ				
Variable	Mean	Std	Min	Max.	Miss.	Mean	Std	Min.	Max.	Miss.
Twins as Parents										
Fathers										
Education	12.44	3.20	9	21	27	12.39	3.18	0	21	46
Birth-cohort	1948.76	6.23	1908	1972	0	1949.09	6.01	1912	1967	0
Mothers										
Education	11.76	2.92	0	19	23	11.74	2.91	0	21	32
Birth cohort	1951.66	6.04	1934	1981	0	1951.98	5.87	1930	1983	0
Children of Twins										
Education	14.23	3.30	9	21	133	14.28	3.26	9	21	183
Birth-cohort	1977.30	8.09	1958	2013	0	1977.81	7.99	1959	2015	0
Female	0.49	0.50	0	1	0	0.48	0.50	0	1	0

Source: Norwegian registers. Own calculations. N_{Pairs_MZ} = 1912; N_{Pairs_DZ} = 2512.

A6. Random mating

Parameter estimates and standard errors

Parameter	Est.	SE
Parents		
a_p	0.64	0.02
c_p	0.55	0.02
e_p	0.47	0.01
d	0.00	-
Children		
m	0.00	0.03
p	0.05	0.03
a_o	0.61	0.09
$a_o^{'}$	0.40	0.09
$c_o^{'}$	0.16	0.07
e_o	0.56	0.03
Modelfit		
Logl		-43428.98
AIC		86885.96

Note: $N_{extended\ family\ units}$ = 4424. $N_{measurements}$ = 33432.
Best fitting model in bold. -2LL = - 2 log likelihood;
AIC = Akaike information criterion.
Source: Norwegian Registers. own calculations.

Relative variance components.

Source	Absolute	Relative
Parents		
A	0.41	0.44
C	0.30	0.32
$A.C$	0.01	0.01
E	0.22	0.24
Total	0.94	1.00
Children		
A	0.37	0.42
A'	0.16	0.18
F	0.00	0.00
C'	0.03	0.03
$A.F$	0.02	0.02
E	0.32	0.36
Total	0.89	1.00

A7: Sensitivity Analyses for Birth order

To examine the role of birth order effects one would ideally consider only first-borns. However, then we would not be able to estimate a C component (recall that C represents environmental influences contributing to the similarity among siblings). Consequently, we would not be able to draw meaningful conclusions based on the comparison of both models. A feasible alternative was to run a model in which we set second-born children to missing. The results are presented below.

Parameter estimates and standard errors.

Parameter	Full		Genetic		Environmental	
	Est.	SE	Est.	SE	Est.	SE
Parents						
	0.75	0.04	0.75	0.04	0.72	0.04
	0.39	0.08	0.40	0.07	0.45	0.06
	0.47	0.01	0.47	0.01	0.47	0.01
d	0.48	0.01	0.48	0.01	0.48	0.01
Children						
m	-0.02	0.04	0.00	-	0.21	0.01
p	0.04	0.04	0.00	-	0.27	0.01
	0.58	0.10	0.60	0.04	0.00	-
	0.59	0.08	0.58	0.07	0.66	0.05
	0.51	0.06	0.51	0.06	0.59	0.05

Model-Comparison

base	comparison	-2LL	df	AIC	Δ-2LL	Δdf	p
Full	-	66073.28	26204	13665.28	-	-	-
Full	Genetic	66081.08	26206	13669.08	7.80	2	0.02
Full	Environmental	66117.54	26205	13707.54	44.26	1	0.00

Note: $N_{\text{extended family units}}$ = 4424. $N_{\text{measurements}}$ = 26218. Best fitting model in bold. -2LL = - 2 log likelihood; df = degrees of freedom; AIC = Akaike information criterion. Source: Norwegian Registers. own calculations.