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Did social change strengthen genetic associations? Gendered educational attainment before and after German reunification

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ABSTRACT

Recent research on post-socialist societies demonstrates that as institutional barriers decline, the genetic associations with educational attainment become more pronounced. However, existing studies have only partially considered the role of gender in this process. To address this gap in the literature, this study examines gendered genetic associations with educational attainment in Germany before and after reunification. Using Gene-SOEP data (N = 1573) and stepwise OLS regression, we analyze polygenic scores across cohorts (1943–1992) in East Germany (German Democratic Republic, GDR) and West Germany (Federal Republic of Germany, FRG). Our findings reveal that genetic associations with educational attainment increased over time, thereby reducing gender-based educational inequality in both regions. However, this positive trend began at lower levels of gender inequality and exhibited an earlier erosion of these differences in the FRG. Despite promoting gender equality, the GDR's policies alone were insufficient to eliminate gender-based differences in genetic educational attainment.

1. Introduction

Modern nation-states have long sought to reduce social inequalities, often focusing on expanding access to education as a key mechanism for fostering greater equality (Blanden & MacMillan, 2016; Buchholz et al., 2016). Early in the 20th century, access to education and career opportunities were largely shaped by traditional norms and structural barriers (Leopold, Skopek, & Schulz, 2018; Von Oertzen & Rietzschel, 1997). The expansion of educational opportunities in the 1960s and 1970s marked a significant shift, as policies promoting greater access began challenging entrenched educational inequalities (Fernández, 2013; Schofer & Meyer, 2005). Gender-based disparities in particular came under increasing scrutiny, leading to efforts aimed at reducing the barriers that had long limited women's educational and professional opportunities (Bailey & Graves, 2016; Jackson & Holzman, 2020; Ronsijn, 2014). By the 1980s, these policies had contributed to reversing educational gender inequality in many Western societies. Women were increasingly surpassing men in higher upper secondary school and university graduation rates (Becker, 2014; DiPrete & Buchmann, 2013; Hadjar & Buchmann, 2016).

Recent genetically sensitive studies have provided new insights into how institutional and other forms of social change influence inequalities. These studies have highlighting that genetic associations become more apparent as institutional and normative constraints on individual choices diminish (Herd et al., 2019; Engzell & Tropf, 2019; Lahtinen, Korhonen, Martikainen & Morris, 2023; Rimfeld et al. 2018). Genetic associations capture the relationship between specific genetic variants and an outcome, as identified through large genome-wide association studies. In this literature, genetic associations serve as proxy indicators of equality of opportunity. They reflect the extent to which differences in individuals' ability to attain social positions, such as educational attainment are shaped by genetic variation rather than by family background or ascribed characteristics such as gender or race (Branigan et al., 2013; Baier, Eilertsen, Ystrom & Lyngstad, 2022a,Baier et al.; 2022b; Engzell & Tropf, 2019).

A few studies have examined the effects of rapid social transformations following the collapse of the Soviet Union on equality of opportunity. Studies of Estonia (Rimfeld et al., 2018), Hungary (Ujma et al., 2022), and, notably, the former German Democratic Republic (GDR; Fraemke et al., 2025), report increased genetic associations with

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educational attainment after regime change. The authors argue that, following the fall of the Soviet Union, political privilege—previously a key driver of social mobility in socialist systems—was replaced by more meritocratic structures. Consequently, genetic associations with educational attainment became more pronounced, indicating a transition toward greater equality of opportunity.

Recent studies have highlighted the increased genetic influence on educational attainment following institutional change. However, much less is known about how these dynamics vary by gender. Herd et al. (2019) were the first to examine this phenomenon in the United States during the latter half of the 20th century. They found stronger genetic associations for women in later cohorts. Historically, institutional barriers and gender norms limited women's participation in the labor force, reducing their incentive to pursue higher education. Consequently, earlier cohorts of women exhibited a weaker association between genetic factors and educational attainment compared to men. Over time, social and normative changes gradually reduced these gender disparities. In the youngest cohorts, genetic associations with educational success now favor women, reflecting broader trends of higher educational attainment among females (Buchmann, DiPrete & McDaniel, 2008). Since then, others have provided corroborating evidence of the erosion of gender differences in the genetic associations with educational attainment in Scandinavian countries such as Finland (Lahtinen et al. 2023) and Norway (Røgeberg, Harden & Lyngstad 2024). However, no study has yet examined whether these gendered patterns persist in contexts outside the US or highly egalitarian, post-industrial welfare states.

In this article, we use a genetically informed research strategy to examine the effects of social transformations on gender inequality in educational attainment since the mid-20th century. By focusing on Germany, we aim to contribute to the expaning body of research on social change and gender inequality in education. Examining Germany's context is particularly relevant because institutional differences likely influenced the pace at which the gender gap in genetic associations with educational attainment narrowed. Germany's institutional configuration represents a missing conservative-corporatist archetype, alongside the liberal United States and social-democratic Scandinavian countries (Esping-Andersen, 1990). Furthermore, we expand upon previous research by analyzing gender differences in genetic associations with education in Germany during and after its division into the socialist GDR in the east and the liberal, democratically oriented Federal Republic of Germany (FRG) in the west. Historically, (West) Germany's institutional arrangements have supported traditional family structures and reduced incentives for female labor force participation. This has potentially limited the perceived returns on prior educational investments for women (Orloff, 1996; Rosenfeld, Trappe, & Gornick 2004; Mandel & Semyonov, 2006). In contrast, the more liberal United States experienced earlier shifts toward female labor market participation and higher educational attainment. These developments were driven by a weaker welfare system that provided fewer incentives for traditional family structures to persist (Esping-Andersen, 1990; Hook & Paek, 2020). Although Scandinavia is characterized by its extensive welfare state and a strong focus on gender equality and women's roles as independent contributors, this contrasts with Germany's emphasis on traditional family structures. Based on these institutional differences, we expect that gender disparities in genetic associations with educational attainment may have eroded more slowly in Germany than in Scandinavia, and more slowly still than in the United States. While not an empirical test per se, deriving expectations from institutional differences and comparing them with the observed empirical patterns can provide tentative evidence for the plausibility of theoretical accounts.

Beyond this international comparison, Germany offers a unique opportunity to examine how social transformations have shaped gender inequality in educational attainment over time. This examination utilizes an institutional setting that is often described as a "natural experiment". Building on prior research, we compare gender gaps in genetic associations with education within two distinct political systems during the division of Germany. Throughout the second half of the 20th century, both the FRG and GDR shaped post-war educational policies, social policy goals, and normative changes in their own ways. Specifically, the GDR is a unique case in that its institutional structures actively sought to reduce class and gender inequalities in education and labor markets, which contrasts sharply with the FRG. Although the GDR's social stratification and gender parity policies aimed to reduce educational inequalities, the regime's emphasis on political loyalty and prioritizing individuals from working-class background over merit constrained the overall strength of genetic association with educational attainment (Bukodi & Goldthorpe, 2010; Fraemke et al., 2025). Moreover, the GDR's emphasis on promoting educational participation primarily for economic development in industry and production, alongside persistent gender inequalities in pedagogical concepts and paid and unpaid work, suggests that gender disparities in genetic associations with educational attainment likely persisted. This unique combination of progressive and restrictive policies makes the East-West comparison particularly valuable for understanding how different institutional contexts shape the genetic association with educational attainment by gender. Based on its specific institutional and policy profile, the GDR's patterns of gender inequality should more closely resemble those of the social-democratic Scandinavian countries. Thus, the GDR should thus show a faster erosion of gender differences in the genetic association with educational attainment than in the FRG.

Building on these contributions, we address the following research questions: (I) How have gender differences in genetic associations with educational attainment evolved over time in Germany, and how do these trends compare to those in the United States and Scandinavia? (II) How have institutional differences and policy changes in East and West Germany influenced the gender differences in genetic associations with educational attainment over time? To answer these questions, we use data from the Gene-SOEP, which provides polygenic risk scores based on genetic data in the context of the German Socio-Economic Panel (SOEP) study (Koellinger et al., 2023). The SOEP is Germany's largest and longest-running panel study. Started in 1984, it covers around 20,000 households and surveys participants' detailed educational and labor market histories. The Gene-SOEP provides the first genotyped sample that is representative of the entire German population, including 2600 participants. Crucially, the Gene-SOEP covers the latest polygenic risk score for educational attainment (Okbay et al., 2022) which provides the basis for cohort analyses investigating changes in the gender gap of genetic associations with educational attainment in East and West Germany. Specifically, the Gene-SOEP enables us to study birth cohorts from 1943–1992, covering those who attended school in the newly divided Germany and those who completed their education in a reunified Germany.

2. Studying equality of opportunity: sociological and behavior genetics approaches

The assessment of a society's equality of opportunity has a long sociological tradition. One method is to study intergenerational social mobility (Blanden et al., 2023; Ganzeboom, Treiman & Ultee, 1991; Van de Werfhorst & Mijs, 2010). Accordingly, a weaker `social gradient` suggests that family background plays a smaller role, leaving less room for ascribed characteristics based on inherited social positions to influence attainment. However, this approach has come under scrutiny because the family-based measure 'social background/origin' measure is broad and may be genetically confounded. Parental education is, at least partly, influenced by genetic associations, which are, at least partly, inherited by their children and contribute to their educational success (Freese, 2008; Marks & O'Connell 2023). Thus, this broad measure of "social background/origin" may obscure the relative contributions of genetic and environmental factors to status attainment. Genetic confounding seriously hampers the interpretation of these correlations as purely social pathways to inheriting privilege and makes it difficult to disentangle the influence of genetic inheritance from other factors. At the very least, these correlations represent a combination of genetic and environmental contributions. Therefore, many genetically sensitive studies do suggest that intergenerational correlations in educational attainment (e.g., Baier et al., 2022a,2022b; Eifler & Riemann, 2022; Marks & O'Connell, 2023) and attitudes and personality traits (e.g., Hatemi et al., 2010; Spörlein, Kristen & Schmidt, 2024), are largely driven by genetic factors.

Genetically sensitive studies approach the question of equality of opportunity from a related yet distinct perspective. First, twin studies decompose individual differences into genetic (i.e., heritability of an outcome) and environmental components (i.e., the shared and non-shared environment; Harden 2021a). In this framework, the extent to which educational attainment is heritable (i.e., due to genetic differences) serves as an indicator of equality of opportunity. As the proportion of a characteristic's differences explained by genes increases, the proportion attributable to environmental factors – including the shared family environment, where social background effects are subsumed –necessarily decreases. Engzell and Tropf (2019) demonstrate that genetic endowment matters more in societies with higher equality of opportunity, which are characterized by lower intergenerational correlation. In these societies, shared family environmental differences are less consequential. Furthermore, these general patterns are also evident over time: as equality of opportunity increases, heritability estimates rise. In Norway for example, the heritability of lifetime income doubled during the 20th century, while the influence of shared environmental factors disappeared (Isungset, Baier & Lyngstad, 2025). However, the same study also highlights persistent gender disparities. Although heritability increased for both men and women across cohorts, women's genetic influence on lifetime income lags behind men's. This suggests that environmental barriers to full equality of opportunity persist.

The second approach to genetically sensitive studies of social inequalities involves directly genotyping individuals rather than inferring genetic contributions through family relationships. These genotyped data are combined with results from large genome-wide association studies (GWAS) to generate polygenic risk scores (Mills & Tropf, 2020). GWAS analyze genetic data from thousands to millions of individuals to estimate the correlations between genetic variants and various outcomes. Regarding educational attainment, the most recent GWAS identified approximately 4000 genetic variants, each of which has a minor influence on the likelihood of attaining higher education (Okbay et al., 2022). The identified genetic variants, and their estimated correlations are then used to construct polygenic indexes (PGIs), which serve as out-of-sample predictors of genetic associations with educational attainment.

Research using PGI from genotyping individuals examines equality of opportunity by analyzing how the relationship between genetic associations and realized educational attainment varies across social groups and contexts. Differences in this statistical relationship imply that certain groups encounter more obstacles in reaping the benefits from genetic associations. This concept follows a similar logic to that of twin studies: the stronger the genetic associations with an outcome, the greater the equality of opportunity in their attainment. However, it is important to note that PGIs provide a probabilistic or correlational estimate. While having many genetic variants positively associated with education increases the likelihood of higher attainment, it does not determine the outcome.

The PGI paradigm has been used to study changes in equality of opportunity following major societal transformations, particularly after the fall of the Soviet Union. Since genetic influences require a supportive environment to manifest, having many genetic variants that are beneficial for high educational attainment may be inconsequential when social and familial conditions are restrictive (Kitcher, 2001; Harden 2021b). Studies of Estonia (Rimfeld et al., 2018), Hungary (Ujma et al., 2022) and the former GDR (Fraemke et al. 2025) suggest that genetic associations were suppressed under Soviet-era policies that restricted access to higher education based on political loyalty rather than ability (Filtzer, 2013). Following the transition to market economies in the early 1990s, genetic associations with educational attainment strengthened. This indicates that removing (social) environmental barriers allowed genetic associations to play a larger role, reflecting greater equality of opportunity. This line of research therefore highlights so-called *gene-environment interactions,* in which the social and institutional environment can either facilitate or suppress the association between genes and behavior (Seabrook & Avison, 2010; Knopik, Neiderhiser, DeFries & Plomin, 2017; Mills & Tropf, 2020). Thus, the strength of genetic associations depends on historical, institutional, and social conditions, making PGI a valuable tool for studying the interplay between genetics and social inequality.

Several studies have investigated how genetic associations with specific outcomes vary across social groups such as by gender, exemplifying gene-environment interactions. Herd et al. (2019) provide evidence from the U.S. that genetic associations with educational attainment were initially weaker for women, likely due to the limited returns to education under restrictive gender norms. However, as barriers to education and career opportunities eroded and gender norms shifted, women's genetic associations with educational attainment strengthened. This gradually closed the gender gap by the 1980s. By the 2000s, this pattern had reversed, with stronger genetic associations among women born in the 1980s. Lahtinen et al. (2023) report a similar trend in Finland, where a male advantage among older cohorts was largely eroded beginning with the birth cohorts of the 1950s. However, in contrast to the US findings, a reversal of the gender gap with a stronger female association is absent in younger birth cohorts. Finally, Røgeberg et al. (2025) provide indirect twin-based evidence from Norway that replicates a consistent male advantage in genetic contribution to educational attainment until the 1960 birth cohorts. By the 1980s birth cohort, gender differences in heritability had effectively disappeared. Overall, these three country case studies demonstrate the erosion of the gender gap in genetic associations with educational attainment over the course of the 20th century. While all contexts report a female advantage in measured educational attainment among recent cohorts, only the U.S. data show a clear reversal of gender inequality in genetic associations. However, it remains largely unexplored whether and to what extent similar patterns exist in other contexts, particularly in the former Cold War partition and post-Soviet regions.

3. Trends in gender inequality and educational attainment in east and west Germany

As in the Western societies, norms and structural constraints regarding female educational participation changed substantially in Germany during the second half of the 20th century. However, the German context, however, was characterized by its own historical idiosyncrasies, not least due to its division into two ideologically distinct states after WWII. In what follows, we interpret historical policy periods (e.g., the early years of the GDR, the post-1968 reforms in the FRG) through the lens of birth cohorts. These cohorts provide a meaningful window into how individuals were socialized and exposed to institutional conditions during their formative educational years. This cohort-based approach also aligns with our empirical strategy, which uses cohort comparisons to track changes in gender-based genetic associations over time.

3.1. The birth cohorts of 1943–1952 participating in the educational system of the 1950s and 1960s

The GDR differed markedly from the FRG in its official commitment to reducing social inequality, particularly in education and the labor market. From its early years, the socialist government implemented large-scale programs designed to promote social mobility and achieve parity in educational access. Access to higher education was therefore not based solely on merit, but rather was tightly regulated, particularly during the 1950s and 1960s, with a strong emphasis placed on family background and political loyalty. Students could qualify for university either through secondary-level education (Polytechnische Oberschule POS) or the combined vocational training and Abitur program (Berufsausbildung mit Abitur BmA). According to data from the 1981 GDR census, educational expansion is evident in the growing proportion of students who completed the 10th grade, increasing from approximately 50–66 % across the 1943–1952 cohorts (Köhler, Rochow, & Schulze 2001). However, despite the state's emphasis on equality and education, the percentage of students who obtain the German high school diploma (Abitur), remained low for these cohorts due to deliberately limited opportunities in the "state of works and peasants". Completion rates increased gradually over cohorts and peaked around the less populated post-war and 1953–1954 cohorts. This was followed by a decline most likely mirroring central planning targets of lower university enrollment beginning in 1971 (Köhler et al., 2001). On average, Abitur attainment remained capped at approximately 10 % per cohort. An additional 5 % followed the combined vocational track, which was subject to slightly fewer political oversight in admissions (Geißler, 2014). These restrictions also limited the modest increase in university degree attainment (6–7 %), which was subject to centrally defined capacities (Köhler et al., 2001). Despite these constraints, approximately 50 % of university students in the GDR came from working-class families by the late 1950s – a striking difference in equality of opportunity compared to the FRG, where the corresponding number was less than 10 % (Geißler, 2014). This difference highlights the GDR's efforts to restructure social hierarchies by prioritizing university access for working-class students, while simultaneously maintaining strict control over educational pathways.

In its early years, the GDR prioritized social class and regional differences over gender in education policies. This left decisions about higher education pathways for working-class boys and girls largely to parents. During the 1950s and early 1960s, traiditional gender roles persisted, and GDR's support for families and women – particularly parental leave and childcare policies – was far less developed than it would be by the mid-1970s (Drasch, 2012). As male preference in educational investment behavior is common in resource-limited families (Powell & Steelman, 1990), (working-class) parents may have been more inclined to invest in their sons' education to foster upward mobility and labor market prospects. Therefore, educational trajectories therefore strongly gendered also in the GDR as well, with higher Abitur attainment among men (11–13 %) than women (6–8 %) in the 1943–1952 cohorts (Köhler et al., 2001). Similarly, men (6–9 %) were more likely than women (3–5 %) to attain a university degree. Conversely, technical college (Fachschule) degrees, particularly in the fields of pedagogical and medicine, offered women a more accessible alternative for women, often directly after completing the 10th grade without an Abitur.

Taken together, these patterns, which persisted over time suggest that educational opportunities and outcomes remained shaped by persistent gendered norms, despite socialist policies to reduce class-based inequality in the GDR and the absence of class or gender-based policies in the FRG. This situation potentially constrained the genetic association for women's educational attainment and maintained a male advantage in genetic associations in both the GDR and the FRG the 1950s and early 1960s.

3.2. The birth cohorts of 1953–1972 participating in the educational system of the late 1960s and 1970s

Lower birth rates and economic demands during this period shifted the GDR's policy agenda from addressing primarily class inequality to also promoting gender equality in education and the labor market. This shift coincided with a significant increase in educational attainment during the 1960s. Among the 1953–1972 birth cohorts, completion of the 10th grade (POS) steadily increased from approximately 65 % to over 85 %, and gender disparities largely disappeared (Köhler et al., 2001). In contrast, Abitur attainment remained capped, peaking at around 18 % for men in the late 1960s (mid 1950s cohorts). Among women, however, a substantial increase occurred, leading to gender convergence by the 1957–1962 cohorts, where Abitur attainment rates for both sexes reached approximately 16–18 %.

However, for cohorts born after the early 1960s, the attainment of an Abitur and a university degree sharply declined, particularly among women. This was likely due to reduced study capacity in the early 1970s (Köhler et al., 2001). Many women were instead channeled into Fachschulen instead (18 % compared to 5–15 % among male cohorts), particularly in feminized fields such as education and healthcare. These schools provided formal qualifications, but they offered limited academic prestige and reduced career advancement opportunities compared to university degrees. Nevertheless, the temporary expansion of higher education led to a historic increase in female university enrollment. By the mid-1970s, when university enrollment peaked, women had nearly achieved – a milestone that West Germany did not reach until the 2000s (Geißler, 2014).

Despite these progressive policies and an ideological commitment to gender equality, as well as a significant reduction in gendered educational gaps, gender disparities persisted across societal, educational, and labor market structures. These disparities likely influenced the gendered genetic associations with educational attainment. The GDR's full employment mandate (Article 24) supported centralized education and workforce planning, requiring both men and women to participate in the labor market as a constitutional obligation to counter labor shortages caused by technological underdevelopment and emigration to West Germany. Consequently, women were actively encouraged and supported to participate in the workforce. Supportive family policies, such as maternity and parental leave (introduced in 1976), and an increased provision of free public childcare, including after-school care and holiday programs for older children (Drasch, 2012), enabled women to pursue higher education and comparable careers to those of men (Lane, 1983; Rueschemeyer, 1993; Miethe, Soremski, Suderland, Dierckx & Kleber, 2015; Jessen, 2022). By the late 1980s, female employment rates in the GDR were therefore among the highest in the world, nearly equal to those of men (Rosenfeld et al., 2004). However, due to limited resources, persistent technological lag, and the goal of controlling ideological conformity, the GDR prioritized training skilled workers and technicians, as well as loyalty-based selection over expanding higher education, particularly after 1971.

Apart from legal norms and institutional frameworks, in the GDR gender norms regarding work and family in the GDR began to diverge from those in the FRG (Zoch, 2021) and other Western societies (Fernández, 2013; Goldin, 1990). Rooted in the ideal of the "workers' and peasant state", the GDR promoted the image of working mothers as the norm. This idea was reinforced through education, the media, children's literature, and songs. Maternal employment and institutional childcare, even when of low quality, were portrayed positively and were widely accepted. Full-time work for women was not an exception, but a normative expectation. This expectation was further supported by policies such as free access to contraceptives (since 1965) and legal abortion (since 1972), which granted women greater autonomy over their reproductive and professional lives. On the surface, societal norms regarding the role of women in general or female labor force participation specifically as well as the structural conditions that discouraged gendered labor market participation, created an environment in which women's investment in educational attainment was bound to yield returns comparable to those of men. This would presumably reduce the gender gap in genetic associations with educational attainment in sharp contrast to the FRG.

Contrary to the more progressive norms regarding the division of paid work, household labor remained gendered. This was reinforced by policies such as the 'household day,' which granted working mothers a monthly day off for domestic responsibilities, as well as financial incentives for married couples. These policies perpetuated traditional gender roles and influenced career trajectories. For example, educational materials and societal norms often steered women toward teaching or care-related professions (Baader, Koch & Neumann, 2023; Ritter & Ritter, 2016). Although women were expected to participate in the labor market alongside men, educational pathways often conveyed conflicting messages that reinforced gendered career choices requiring lower educational investment. For instance, the combined vocational track (BmA), which provided access to university education, was predominantly pursued by men, presumably because of its focus on technical and scientific subjects (Correll, 2004; Gambaro, Wilhelm & Schober, 2023). Similarly, the advanced secondary education track (EOS; comparable to the Gymnasium in the FRG) emphasized science and technology from the 5th grade onwards, which may have further contributed to gendered educational sorting. Finally, one-quarter of EOS class slots were reserved for army officer candidates, effectively excluding women from this higher education pathway. The first female officer in the GDR was not appointed until the mid-1980s (Waterkamp, 1987).

Although political loyalty was a key factor in educational and career advancement in the GDR, systematic gender differences in loyalty likely did not play a significant role. Parents of one gender were not inherently more or less aligned with the regime. However, other mechanisms may have favored boys over girls when it came to accessing higher education and career opportunities. Political loyalty was often demonstrated through active membership in state-organized youth groups such as the Thälmann Pioneers (ages 6–14) and the Free German Youth (FDJ, ages 14 and up). These organizations were structured hierarchically with a strong focus on discipline, physical training, and ties to the National People's Army. They may have been more appealing to boys, which reinforced their pathways into leadership roles and higher-paying professions. Taken together, these structural barriers channeled men into fields with higher economic and professional returns while limiting women's access to certain occupations. This reinforced traditional gender roles and stereotypes. This dynamic likely constrained genetic associations with education for women.

In the FRG, large-scale policy initiatives to reduce gender inequalities were either largely absent or driven by social movements, such as counterculture of the late 1960s, rather than a coordinated state agenda (Miethe et al., 2015). Thus, efforts to reduce gendered educational inequalities lagged behind those in the GDR, gaining momentum only after 1968. However, these effects fell short of achieving gender parity in university enrollment, for example, even a decade after reunification (Geißler, 2014). Although norms surrounding female higher education shifted after 1968, policies and gender ideologies remained rooted in the "male breadwinner" model (Zoch, 2021). Sparse parental leave policies (14 weeks compared to 12 months in the GDR in the mid-1970s), tax breaks for married couples and a lack of public childcare made full-time employment difficult to achieve (Drasch, 2012; Rosenfeld et al., 2004). These constraints likely suppressed genetic associations with educational attainment for women in the FRG during this period by pushing women toward family roles.

However, the counterculture of the late 1960s, initiated substantial social changes, particularly regarding gender roles and education. Reforms in pedagogical and didactic approaches, such as shifting towards child-centered education and incorporating non-cognitive criteria in educational achievement, were one vehicle of social change (Noelle-Neumann & Petersen, 2001; Pahl 2022). Systematic gender differences in certain non-cognitive skills, such as self-regulation, social competencies and classroom behavior, have been shown to contribute to girl's higher success in the educational system (Ogden, Olseth, Sørlie & Hukkelberg, 2023; Weis, Heikamp, & Trommsdorff 2013). This normative shift and the evolving education system increased women's opportunities and incentives to pursue higher education, gradually closing the gender gap in educational attainment. Consequently, genetic associations with educational attainment for men and women in the FRG should have likely converged during this period.

3.3. The birth cohorts of 1973–1992 participating in the educational system of the 1980s and post-reunification

Following the reunification of Germany in 1990, its distinct political systems merged into the Western model of the FRG. The trajectories of normative change in gender roles and their consequences for the educational systems in terms of pedagogical approaches and curricular content remained essentially unchanged for West Germany. However, East Germany implemented West Germany's tiered educational system (Hauptschule, Realschule and Gymnasium), which was associated with substantial structural changes that systematically restructured pathways to higher secondary and tertiary education. Previous avenues favoring boys, such as slots reserved for officer candidates or prioritizing MINT graduates coupled with gendered role expectations conveyed in schoolbooks, were now largely blocked (Baader, Koch & Neumann, 2023; Ritter & Ritter, 2016). Similarly, political loyalty to the GDR system, which was previously a criterion for access to higher education lost relevance. This increased the general relationship between genetic associations and educational attainment post-reunification (Fraemke et al., 2025), as has been observed in other post-Socialist countries (Rimfeld et al., 2018; Ujma et al., 2022).

Overall, the implementation of the FRG's educational system in East Germany likely had led to patterns of gender differences in genetic associations with educational attainment similar to those in West Germany. In the West, however, this trajectory was already moving towards the erosion of gender differences in genetic associations with education, presumably due to ongoing normative changes and improving labor market prospects.

In summary, each historical episode can be characterized by mechanisms that increase or reduce gender-specific genetic associations with educational attainment. Table 1 summarizes the context-specific expectations related to these mechanisms. The respective signs indicate the expected effect on equality of opportunity, i.e., a reduction in the gender gap in genetic associations with educational attainment. Differentiating empirically between those varied, rarely instantaneous, and moreover ambiguous social changes as explanations for the development of gender inequality in genetic associations is a challenge that few studies can overcome. For this reason and because it is unlikely that each explanation contributes equally to gender-specific genetic associations, we do not provide a summary expectation.

4. Data and methods

We draw on the data from the Gene-SOEP, an innovation sample from the German Socio-Economic Panel study (SOEP; Koellinger et al., 2023) from 2019. Based on a random sample of households, the Gene-SOEP is currently the only German data source that includes both genotyped individuals and detailed information on demographics, work and employment, health, education, attitudes and personality, and family-related characteristics covering an extensive age range. Overall, the Gene-SOEP covers nearly half of the information collected for the Core SOEP (Goebel et al., 2019). Of the original sample of 4283 individuals, 2598 individuals donated valid genetic samples (ages 0–96).[1] Compared to characteristics of individuals sampled in the Core SOEP, genotyped Gene-SOEP individuals tend to be socioeconomically

[1] Saliva samples were collected using Isohelix IS SK-1S buccal swabs and genotyped using Illumina Infinium Global Screening Array-24 v3.0 BeadChips. Missing genetic data was imputed using the Haplotype Reference Consortium reference panel (r1.1; Koellinger et al., 2023: 9).

Table 1
Summary of period and context-specific patterns of gendered equality of opportunity in genetic associations with educational attainment.

	GDR			FRG/unified Germany		
	1950s	1960s-1970s	1980s-reunification	1950s	1960s-1970s	1980s-post reunification
Structural expansion of educational system	+	0		+	+	+
Policies aimed at reducing social inequality	-					
Policies aimed at reducing gender inequality		+	+			
Egalitarian gender norms	-	+	+	-	+	+
Curricular content	-	-	-	-	+	+
Pathways connected with political loyalty to the system	-	-	-			

Note: + = increases equality of opportunity, - = reduces equality of opportunity, 0 = process was halted in the denoted period.

somewhat better off (see Koellinger et al., 2023: Table 1).

The Gene-SOEP data provides 36 precalculated polygenic risk scores that summarize genetic associations for various traits, including body mass index, life satisfaction, propensity to read, cognitive abilities and crucially for our study, educational attainment. Polygenic indexes are generated in a two-step process. First, secondary information is gathered from independent large-scale genome-wide association studies (GWAS). GWAS rely on genotyped data from thousands to millions of individuals, correlating genetic information with attributes and behavioral outcomes of individuals. In the second step, genetic variants (or more specifically single-nucleotide polymorphisms [SNPs]) whose coefficients are statistically significantly related to the studied outcome are collected for out-of-sample prediction of polygenic indexes. For educational attainment, a GWAS of three million individuals identified 3952 SNPs, each with a tiny effect, which together account for nearly half of the genetic associations with differences in educational attainment (Okbay et al., 2022). Therefore, polygenic indexes do not cover all genetic associations with the outcome for various reasons. Instead, GWAS tend to focus on common SNPs thereby missing the effects of rare variants (Young, 2022). Furthermore, polygenic indexes capture not only genetic associations but can also be environmentally or socially confounded ("social genetic effects", Burt, 2024). This confounding generates indirect genetic associations whereby individual outcomes are influenced by the behaviors of others, which possess a genetic component themselves. Previous studies have suggested that between a quarter to a third of genetic associations with educational attainment captured by polygenic indexes are confounded in this manner (Domingue & Fletcher, 2020; Wang et al., 2021). Because our research design does not allow us to apply procedures that reduce social confounding (e.g., a trio design that relies on data from the child and both parents), we should interpret polygenic indexes as imperfect approximations of genetic associations.

From the original sample of 2598 individuals, we restricted it to those with valid genetic information that passed quality control (approximately 90 percent), those who provided valid information on all relevant measures, and those born within the study cohort window (1943–1992, see below). Thus, our analytical sample thus consisted of 1573 individuals, 373 of whom (24 percent) completed their education in the GDR or in East Germany after reunification. We classified individuals into GDR and FRG subsamples based on their place of residence in 1989. For individuals born after 1989, we relied on information regarding their place of residence. Given the overall sample size, statistical power – especially for the GDR subsample – may be limited.

Our key dependent and independent variables were years of education (7–18 years) measuring educational attainment, gender (0 =males and 1 =females), and the biologically informed measure of genetic influences on education, the polygenic index (PGI; for descriptive statistics see Table 1). For each individual i, the PGI is formally defined as the sum of the number of alleles X_m for each SNP m weighted by their respective coefficient β_m.

$$PGI_i = \sum_{m=1}^{M} \beta_m X_{mi}$$

β_m represents the association between SNP_m and educational attainment from the most recent GWAS study (Okbay et al., 2022). The number of alleles X_m can be 0 (no alleles inherited), 1 (one allele inherited from one parent) or 2 (one allele inherited from each parent; Burt, 2024). When standardized, polygenic indexes summarize an individual's position in the risk distribution of the studied population. A polygenic index score (EA-PGI) of 0 indicates average genetic variants associated with high educational attainment. In contrast, a score of 1 or −1 indicates that an individual possesses genetic variants that are one standard deviation above or below the sample average, respectively. It is important to emphasize that this measure summarizes an association and is therefore probabilistic. Whether and to what extent this association manifests as higher or lower educational attainment is fundamentally a function of the social environment. The Gene-SOEP provides polygenic indexes precalculated and we residualized this measure for the first 20 principal components of genetic ancestry. Genetic ancestry is a common control variable included in these types of analyses to account for population stratification which can lead to spurious associations if populations of different ancestries differ in the frequency of genetic variants as well as in outcomes (Mills, Barban & Tropf, 2020).[2] Note that, since GWAS are largely based on samples with European ancestry, it is common practice to restrict samples to this ancestry group because out-of-sample predictions for other ancestry groups tend to perform considerably worse (Lee et al., 2018). Therefore, the Gene-SOEP scientific use-file does not include PGI scores for individuals of non-European descent. An additional drawback of using PGIs in cohort studies is differential mortality (Domingue et al., 2017). Our results may suffer from attenuation bias because education and mortality are correlated, and we rely on data from individuals born as early as 1943. We provide simulation results and a more detailed discussion of this issue in Appendix 1. In short, our findings may be conservative, as they potentially underestimate the extent of gender differences in genetic associations. However, they may be too optimistic regarding the speed of the erosion.

To examine descriptive trends over time, we use birth years as a reference point. We chose 1943 as the lower limit because children would typically enter school at age 6, which coincides with the establishment of the GDR and the FRG in 1949. The upper limit of 1992 was chosen to minimize the issue of individuals who are still in education artificially lowering the educational attainment scores of the youngest cohorts. In the multivariate analyses, we use on a moving-window approach to address statistical power limitations by grouping individuals into overlapping twenty-year birth cohort windows. Thus, we estimate results for the following cohorts: 1943–1962, 1944–1963, 1945–1964, and so on up to the final cohort of 1973–1992. This produces a series of continuous, overlapping cohort estimates. Since each estimate is based on overlapping groups of birth years rather than fixed, non-overlapping decade-long cohorts, we can track gradual changes over time more smoothly. Since all cohorts within the full range are

[2] Results including the first 20 principal components of genetic ancestry as well as all interactions with cohort, gender, the PGI as per the Keller (2014) approach can be found in the replication repository: https://osf.io/3mkqg/. Our conclusions are robust to these additional controls.

successively included and covered, the cutoffs chosen for descriptive interpretation are not decisive in multivariate analyses. For certain analyses, we use a twenty-year categorization of birth year (e.g. for data description and when controlling for birth cohort in multivariate analyses), and we provide robustness checks with ten-year categorizations in the online appendix.

Table 2 provides descriptive information for the analytical samples.

4.1. Analytical approach

To examine gender differences in the genetic associations (EA-PGI) with educational attainment, we estimated linear regression models. First, we regressed years of education on gender, birth cohort, and the EA-PGI for the combined German data. Then, we regressed years of education on gender, birth cohort, and the EA-PGI for the GDR and FRG samples separately. We estimated stepwise regression models, including a two-way interaction between gender and the EA-PGI. To assess how gendered associations evolved across cohorts, we re-estimated the two-way interaction models using twenty-year moving-windows, focusing on marginal effects to facilitate model interpretation. The moving-window approach reduces power issues and circumvents the need to define arbitrary cohort boundaries. Due to low statistical power, the findings should be considered tentative; therefore, our focus will be on effect sizes rather than statistical significance.[3] Alternative German data sources including genotyped individuals such as the TwinLife study (Diewald et al., 2025) are too limited in their age range (i.e. covering birth cohorts starting in the late 1960s in meaningful numbers) or provide insufficient information to identify where individuals resided or completed education before reunification to present a meaningful alternative or to enable in independent replication of our results.

Table 2
Descriptive statistics of the analytical sample, combined and separately for GDR and FRG samples (n = 1573).

		Full sample		GDR sample		FRG sample	
	Range	Mean	SD	Mean	SD	Mean	SD
Years of education	7–18	12.63	2.72	12.73	2.45	12.60	2.80
Polygenic index for educational attainment (EA-PGI)	−3.83 – 3.41	−0.01	1.00	−0.05	0.97	−0.00	1.00
Female	0–1	0.55		0.57		0.55	
Living in GDR 1989	0–1	0.24					
Cohorts							
1943–1962	0–1	0.48		0.53		0.47	
1963–1982	0–1	0.37		0.32		0.38	
1983–1992	0–1	0.15		0.15		0.16	

Note: Cohort descriptive shown for reference.

5. Results

To determine whether environmental conditions (e.g., norms or educational structures) and changes therein can be associated with gender differences in genetic associations, we first present descriptive findings that whether the EA-PGI varies systematically between genders, contexts and over time. Fig. 1 presents corresponding density plots of the polygenic index for educational attainment. All three subgraphs show a strong overlap in their respective distributions. For each comparison, the means deviate by no more than 0.02 (gender, Panel A), 0.04 (context, Panel B) and 0.20 (cohort comparison, Panel C) standard deviations from the overall sample mean. Although cohort deviations are larger than those for gender and context, the ordering of deviations (strongest for the fourth cohort, followed by first, fifth, third and second cohort) does not suggest a systematic pattern. That is, deviations do not covary with cohort membership. Therefore, these descriptive findings provide substantial evidence that differences in the gender-specific relationship between genetic associations with educational attainment are not due to systematic and substantial differences in the EA-PGI between men and women, living in the GDR or FRG and individuals of different birth cohorts.

Fig. 2 presents descriptive findings on the development of years of education by gender and region, using twenty-year moving averages. The upper part of Fig. 2, which depicts cohort-specific means shows similar yet distinct trends in gender-specific education in West and East Germany. On average, women spent more time in the education system than men, gaining between 1 (FRG) and 0.5 (GDR) additional years. This upward trend is consistent for all birth cohorts of men and women in West Germany. In contrast, in the GDR, both women and men born before the 1960s, initially reduced their time in the education system. This resulted in persistently lower average years of education for women than for men. This negative trend reversed only for female cohorts born in the early 1960s (i.e., those entering the education system by the end of the 1960s). From that point on, women's educational attainment began to rise more sharply, while men continued their decreasing pathway. This overall pattern may be the result of the educational system essentially halting expansion at the beginning of the 1970s, combined with a strong focus on technical, non-tertiary education which required fewer years of schooling.

The lower panel of Fig. 2 shows the difference between in years of education between women and men, with positive values indicating an advantage for women. While both contexts display similar trends, the GDR shows a more pronounced decline in women's educational disadvantage, resulting in a stronger reversal of the gender gap than the FRG's more gradual erosion. For cohorts born before the late 1960s, educational attainment trends in both regions moved closely in parallel in both regions, with relatively small, though noticeable gender gaps favoring men. However, a substantial divergence in trends between East and West emerges in the late 1960s. In West Germany, the gender gap favoring men gradually closed, approaching parity. In East Germany, however, the shift was more dramatic, with women surpassing men by over half a year for cohorts born in the 1980s. A more thorough examination of the GDR results indicates that the narrowing of the gender gap in educational attainment post-1960s appears to be driven to a greater extent by declining male attainment than by sustained gains among women. This phenomenon stands in stark contrast sharply to the FRG, where convergence is attributable to rising female attainment. This phenomenon, while unexpected in light of the GDR's declared commitment to gender equality, finds its rationale in the constraints imposed by the institutional framework. These constraints encompass, but are not limited to, the overall decline in Abitur quotas and the reservation of EOS slots for male army candidates. The analysis indicates that both increased selectivity and possibly growing tension between

[3] We conducted post-hoc power analyses using several approaches. The results are inconclusive in that sufficient power (80 %) to detect statistically significant associations was suggested in the FRG but not the GDR sample by the analytical method discussed in Beauchamp, Schmitz, McGue, and Lee (2023), but the opposite was found using the incremental R^2 approach discussed by Ghirardi, Gil-Hernández, Bernardi, van Bergen, and Demange (2024). Moreover, simulations by Von Stumm, Nancarrow (2024) suggest a sample size of more than 10,000 participants to detect statistically significant associations for interaction effects like the one reported here. It should be noted that detecting statistically significant associations is not necessarily the goal of this study. Based on prior studies and on our findings, the gender gap is expected to vary across cohorts with older cohorts showing larger differences which are expected to erode and possible reverse for younger cohorts. Assuming that the reversal is relatively benign given the cohort profile of our study, we would not even expect a statistically significant difference for a considerable number of cohorts.

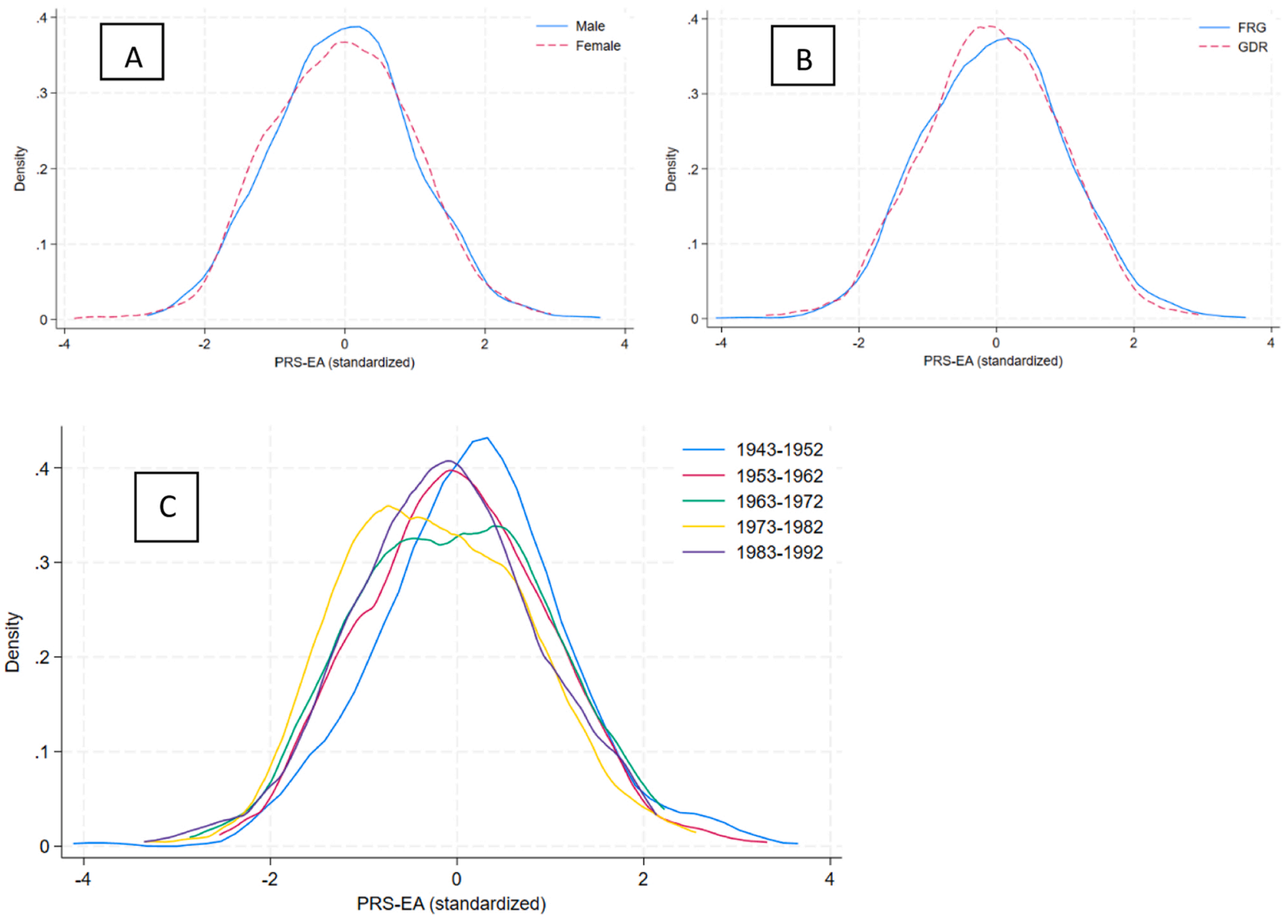

Fig. 1. No substantial difference in the polygenic index for educational attainment across gender, context and categorized birth cohort. Note: SOEP-G, N = 1.573, own calculation.

ideological commitment to equality and practical concerns due to capacity limits in higher education, political loyalty, or labor market needs in the less industrialized GDR are evident. Consequently, access to higher education became increasingly restricted over time, thereby also limiting access for males, particularly for those not pursuing the military track. Concurrently, women experienced an enhancement in their access to childcare and a shift in gender norms, underscoring the asymmetric impact of policy on educational opportunities.

Table 3 shows the results of the linear regression models that estimate the relationship between the polygenic index for educational attainment and years of education – for the entire sample as well as for the FRG and GDR groups separately. According to findings of Model 1, a one-standard deviation increase in the polygenic index is associated with a roughly one-year increase in educational attainment. This association is similar in West and East Germany (0.96 and 1.04, respectively). Model 2 allows the genetic associations to vary by gender. In the full sample as well as in both East and West Germany, the interaction is negative suggesting an overall smaller genetic association for women across all birth cohorts.

To explore trends in gendered genetic associations between the 1950s and early 2000s, we calculate cohort-specific average marginal effect differences using a twenty-year rolling window approach.[4] Fig. 3 plots the average marginal effects of gender differences in genetic associations with educational attainment for the full sample (left panel) and again separately for the FRG and the GDR (right panel). Positive values indicate a female advantage. As expected, early cohorts show a clear male advantage in genetic associations. In the full sample, the trend line remains below zero until the early-1980s cohort. The initial male advantage in average marginal effects of around 0.3 gradually erodes only in the latest birth cohorts with a reversal to a female advantage merely implied in the final uptick.

The right panel of Fig. 3 breaks down the general pattern into an east-west comparison. The GDR pattern differs from the FRG pattern in two important aspects: First, the GDR shows a more pronounced initial male advantage, which remains at half a year's worth of educational attainment consistently until the mid-1970s birth cohorts. After the mid-1970s cohorts, the erosion process quickly reverses the female disadvantage, creating a slight advantage for females in the 1980s birth cohorts. Surprisingly, for the FRG, the erosion of the gender gap in genetic associations begins considerably earlier, completing for the mid-1960s birth

[4] Appendix Table 1 reports the gender-specific marginal effects using the categorized twenty-year birth cohorts. Although these boundaries are essentially arbitrary, the results suggest that genetic associations tend to increase across cohorts. While the average association was approximately one additional year for each one-standard deviation increase in the PGI, the later cohorts exhibited considerably larger associations in both contexts (e.g., between 1.09 and 1.65 for the 1983–1992 cohort). Furthermore, consistent with the more robust moving window analyses, gender differences diminish over time.

Fig. 2. Trends in realized educational attainment of men and women Note: SOEP-G, N = 1.573, own calculation; Upper panel: Average years of education with means based on twenty-year rolling cohort windows, Lower panel: Gender differences, in realised education, with positive values indicating female advantage.

Table 3
Model estimates (n_{Total}=1573, n_{FRG}=1200, n_{GDR}=373).

	Full sample				Federal Republic of Germany				German Democratic Republic			
	Model 1		Model 2		Model 1		Model 2		Model 1		Model 2	
	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.	Coef.	s.e.
Constant	12.51*	0.12	12.69*	0.14	12.41*	0.14	12.56*	0.16	12.78*	0.21	13.10*	0.24
EA-PGI	0.99*	0.06	1.16*	0.14	0.96*	0.08	1.15*	0.17	1.04*	0.12	1.17*	0.26
Female	−0.29*	0.13	−0.61*	0.18	−0.36*	0.15	−0.63*	0.22	−0.09	0.23	−0.59	0.32
Birth cohort (ref: 1943–1962)												
1963–1982	0.48*	0.14	0.21	0.21	0.64*	0.16	0.40	0.25	0.00	0.26	−0.29	0.40
1983–1992	0.89*	0.19	0.37	0.27	1.09*	0.22	0.73*	0.31	0.29	0.35	−0.84	0.49
EA-PGI*Female			−0.34	0.19			−0.32	0.22			−0.48	0.35
Adjusted R^2	0.14		0.14		0.13		0.13		0.16		0.18	

Note: * = $p < 0.05$, own calculation, Gene-SOEP. Model 2 additionally controlled for Cohort-Female and Cohort-PGI interactions as per GxE guidelines (Keller, 2014).

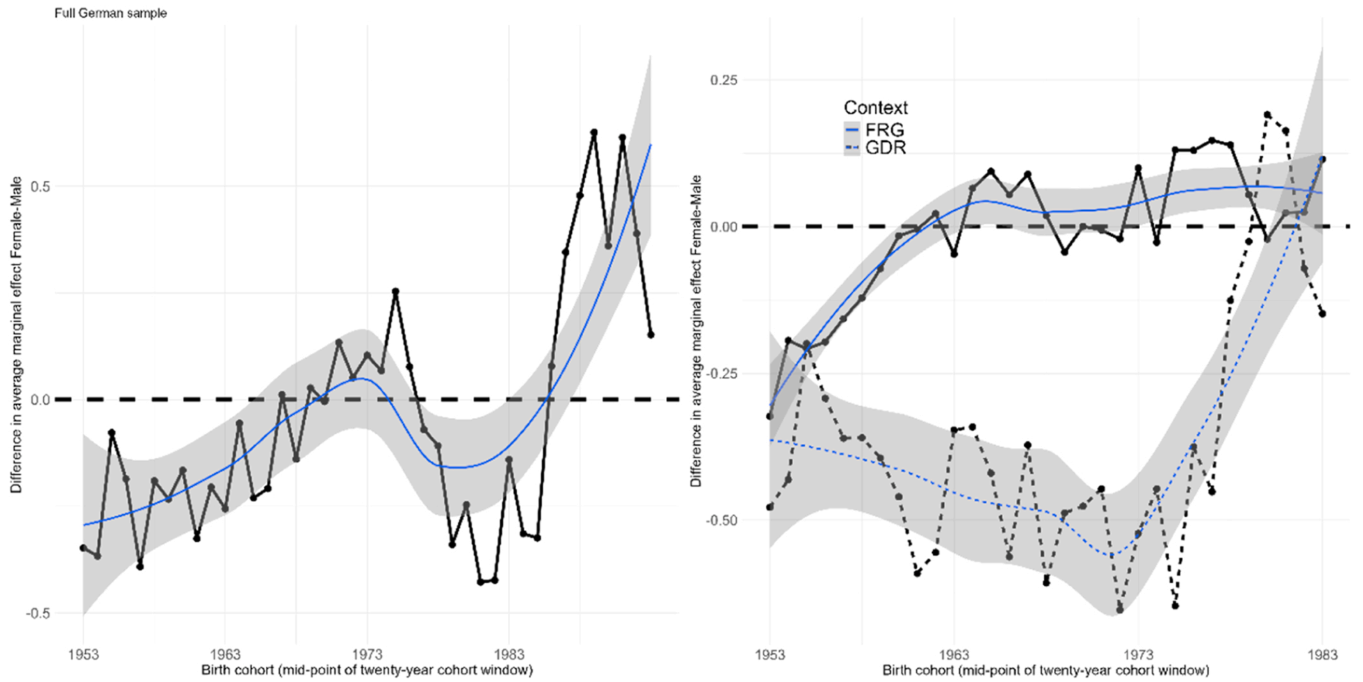

Fig. 3. Gender differences in average marginal effects of polygenic index on years of education, full sample (left) and separately for GDR and FRG (right), Note: SOEP-G, N = 1.573, own calculation, estimates based on twenty-year rolling cohort windows of marginal effect difference. Grey band does not represent confidence level but merely a smoothing of the trend trajectory.

cohorts (i.e., those individuals who started attending school in the late 1960s and graduating in the late 1970s and early 1980s). Thus, gendered genetic associations were not only more severe and persisted longer in the GDR, suggesting that progress towards equality of opportunity was slower in the East. Despite the GDR's strong policy emphasis on reducing gender inequality across various life domains, our findings provide tentative evidence that the erosion of the gender gap began earlier and more pronouncedly in West Germany.

Setting aside the GDR, the results for the FRG largely replicate the patterns observed in the United States and Finland (Herd et al., 2019; Lahtinen et al., 2023): positive genetic associations were present in all contexts. However, the relationship between genetic associations and educational attainment is slightly stronger on average in West Germany (0.97) than in the U.S. (ranging from 0.75 to 0.9) and Finland (0.74). Early birth cohorts in West Germany (until the mid-1960s) exhibit a male advantage in genetic associations. However, with the structural expansion of the educational system during the 1950s and 1960s and the acceleration of normative changes post-1968 began to erode this gender gap in genetic associations. Similarly, comparing the FRG to Norwegian patterns suggest only minor differences (Røgeberg et al., 2024). Nevertheless, in all countries studied, the gender gap in genetic associations had largely disappeared by the early 1980s birth cohorts in all countries studied. Notably, however, the erosion process started somewhat later in West Germany than in the U.S and Finland. Despite similar and mostly concurrent social and cultural shifts, West Germany's legal and institutional framework – particularly the aspects that reinforced traditional family arrangements –likely prolonged the reduced genetic associations with educational attainment for women compared to other contexts. Among all previously studied societies, the GDR shows the largest gender differences and experienced the latest erosion.

6. Summary and conclusion

This study examines changes in genetic associations with educational attainment within the context of Germany's rapid social and institutional transformations, particularly focusing on gender inequalities before and after reunification. Efforts to reduce social inequalities have often centered on educational reforms aimed at expanding access and fostering greater equality of opportunity. Using a genetically sensitive framework and using the novel Gene-SOEP dataset, this study is among the first to investigate how institutional and normative changes have shaped gender differences in genetic associations with educational attainment in Germany. Specifically, we examine how the contrasting policy environments in East and West Germany influenced the observed patterns. The GDR explicitly focused on reducing class and gender inequalities, while the FRG slowly adapted gender equality in education. By contributing to the growing body of research on gendered genetic patterns in the United States (Herd et al., 2019) and other European societies (Lahtinen et al., 2023; Røgeberg et al., 2024), our study sheds light on how policy environments and structural contexts modulate the interplay between genetic associations and social outcomes.

Our findings reveal three key insights: first, the results show a strong and consistent positive relationship between genetic associations with educational attainment, regardless of region or subgroup. In the German case, a difference in polygenic index scores of one standard deviation is associated with a one-year difference in years of education. This finding aligns with a growing number of studies that rely on polygenic indexes from other Western countries (Belsky et al., 2018; Herd et al., 2019; Lahtinen et al., 2023) as well as from selected post-Soviet societies (Rimfeld et al., 2018; Ujma et al., 2022). Second, our findings reveal that, in post-war Germany, there was considerable male advantage in genetic associations with education showed, which narrowed substantially across the studied cohorts until it resolves in birth cohorts since the early-to-mid-1980s in united Germany. By comparing our findings with those from the United States, Finland and Norway (Herd et al., 2019; Lahtinen et al., 2023; Røgeberg et al., 2024), we observe broadly similar trends in the erosion of gender disparities in genetic associations with educational attainment.

Thirdly, the findings of this study indicate the presence of contextual differences; however, these differences manifested to a greater extent in the context of within-Germany comparisons as opposed to cross-national comparisons. The findings indicate that gender disparities in genetic associations manifested not only in the GDR but also persisted throughout the 20th century, with the erosion of these disparities not occurring until the early 1980s birth cohorts, who were likely to have completed their education in the unified German educational system. Consequently, the findings of this study do not corroborate the hypothesis that the GDR's pronounced policy emphasis on curbing social and gender disparity resulted in the emergence of more sophisticated or systematic patterns in comparison to those observed in the FRG. This finding is particularly noteworthy in light of the GDR's comprehensive state-led initiatives and propaganda efforts aimed at promoting gender quality, including universal childcare and full employment policies. However, the parallel erosion of gender gaps in both contexts suggests that broader societal factors, such as normative shifts, may have exerted a more substantial influence than state policies alone. Furthermore, it is imperative to acknowledge the potential impact of structural inequalities embedded within the educational policies of the GDR on the observed genetic associations. Despite formal commitments to equality, the GDR was marked by limited personal freedoms, restricted access to diverse educational and occupational pathways, and a rigid, state-controlled allocation of educational and professional opportunities, which often benefited men. These factors may have suppressed the extent to which genetic differences could influence educational attainment, thereby muting the potential impact of gender-specific policies. This discrepancy could be attributed to the fact that, despite its emphasis on gender equality, the GDR did not demonstrate more favorable patterns compared to the FRG, where individual choice exerted a more significant influence on educational trajectories. However, the FRG exhibited a delayed pattern by approximately a decade compared to other Western countries. This finding aligns with the expectation that the FRGs' stronger and longer adherence to traditional family arrangements may have reduced female incentives for educational attainment and thereby likely suppressed genetic associations.

It is imperative to reiterate that the constrained statistical power of our dataset engenders limitations in the robustness of our conclusions. The study's low statistical power and the general research design are inadequate to provide unambiguous evidence for one explanation (e.g., social policy) over another (e.g., institutionally blocked pathways for women). Consequently, the findings should be considered descriptive. We endeavored to ameliorate this issue by employing a rolling window approach; however, any attempts to statistically identify specific social drivers of the observed results are not feasible with the Gene-SOEP. Given the scope of historical idiosyncrasies that transpired over a relatively brief period in a formerly unified social context, the undertaking of more in-depth studies could yield valuable insights for comparative research. However, identifying the precise mechanisms underlying these shifts will remain challenging not only due to the complex interplay of genetic and environmental factors but more fundamentally due to the lack of data enabling direct disentanglement of these influences. A further constraint of the specific cohort design, which is predicated on birth cohorts dating back to 1943, pertains to attenuation due to mortality bias. The correlation between mortality and educational attainment may result in a selective sample of individuals "surviving" until surveyed in the recent past. This phenomenon potentially attenuates the relationship between the PGI and educational attainment (Domingue et al., 2017). This mechanism suggests that our findings may be conservative, as the true extent of gender differences in genetic associations is attenuated due to gender-specific mortality patterns. Conversely, this process may be overly optimistic with respect to the rate of erosion.

Although genetic data is fixed at birth so data collection efforts do not depend on historical luck to cover specific study periods, the predictive power of PGI may vary over cohorts (Lahtinen et al., 2023). Consequently, some authors have proposed the utilization of twin data to circumvent this issue (Isungset et al., 2025). The findings on gender inequality in educational attainment are largely consistent with the results presented here (Røgeberg et al., 2024). However, the twin data required to replicate these findings at the scale necessary for Germany is not available. In this regard, the Gene-SOEP signifies a significant yet underpowered advancement, and both this study and previous research underscore the potential of integrating a genetically informed perspective into comparative research. Nevertheless, the necessity for additional, large-scale, high-quality datasets from non-English-speaking contexts remains paramount to fully capitalize on the potential inherent in genetically sensitive studies.

Within the broader field of gender inequality and comparative research, the present study underscores the significance of the institutional and normative context in shaping genetic associations with educational attainment as a pivotal factor in determining an individual's life chances and trajectories. The findings of this study underscore the value of integrating a genetically sensitive perspective with historical and institutional analyses to illuminate the pathways through which broad social changes may influence educational outcomes. By examining gendered genetic associations with educational attainment, we offer a novel and more comprehensive perspective on the evolution of equality of opportunity.

CRediT authorship contribution statement

Gundula Zoch: Writing – review & editing, Writing – original draft, Validation, Investigation, Conceptualization. **Schlueter Elmar:** Writing – review & editing, Writing – original draft, Conceptualization. **Christoph Spörlein:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

We the authors declare no conflict of interest for the manuscript entitled "Did Social Change Strengthen Genetic Effects? Gendered Educational Attainment Before and After German Reunification"

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.rssm.2025.101091.

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