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The Changing Social Gradient in Age at Menarche Across Cohorts and Generations in Norway

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Abstract

Declining age at menarche (AAM) – which particularly affects girls growing up in a low socioeconomic position (SEP) – is a concerning development, due to adverse health and social outcomes associated with earlier AAM. Still, it remains unclear whether the social gradient emerges from social causation (socioeconomic resources during childhood influencing pubertal timing) or health selection (maternal AAM influencing the SEP of the next generation). Using data from 122,826 Norwegian women born 1960-2008, we document a declining trend and growing social gradient in AAM. We then analyze 10,896 mother-daughter dyads in the Norwegian Mother, Father and Child Cohort Study and decompose the intergenerational decline in AAM within income quintiles into within-family and between-family components, consistent with the two hypotheses. Mean AAM declined by 0.43 vs. 0.23 years over a generation in the lowest vs. highest quintiles. We show that the decline within families between mothers and daughters is nevertheless of similar size in all income groups, which does not support social causation as a mechanism for the emerging social gradient. However, we find earlier AAM among mothers whose children grow up in a low SEP compared to mothers who themselves had low SEP during childhood, suggesting health selection as a main pathway.

Keywords: menarche, puberty, socioeconomic position, health inequality, Norway, MoBa, HUNT, CONOR

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Introduction

Menarche (the first occurrence of menstruation) is a key pubertal indicator in girls, and age at menarche (AAM) has long-term and broad significance across the life course. Earlier menarche in particular has been associated with worsened health outcomes, both somatic and mental (Askelund et al., 2024; Cheng et al., 2022; Golub et al., 2008), as well as higher mortality (Chen et al., 2019). It has also been associated with lower school performance and educational attainment (Gill et al., 2017; Haapala et al., 2020; Johansson and Ritzén, 2005; Torvik et al., 2021). As an event signifying the maturation of reproductive functions, earlier menarche has been associated with earlier sexual debut and first pregnancy (Lawn et al., 2020; Udry, 1979; Udry and Cliquet, 1982). The wide-ranging implications of AAM have attracted a shared interest from clinical, public health, and social perspectives to understand the variation in AAM and its determinants.

A growing body of evidence suggests that the social gradient in AAM is changing. Childhood growth has become faster with general improvement in health and living conditions, and average AAM has also declined over the last centuries across countries (Eckert-Lind et al., 2020; Leone and Brown, 2020; Parent et al., 2003). Within this trend, while in older cohorts girls from households with lower income and education tended to start menarche later, in more recent cohorts it now appears that the menarche of girls in families characterized by lower socioeconomic position (SEP) is on average earlier than among more affluent peers (Hiatt et al., 2021; Junqueira Do Lago et al., 2003; Krieger et al., 2015; Morris et al., 2011; Veronesi and Gueresi, 1994). This implies that the implications of AAM may have changed, as the context in which AAM affects various life outcomes changed. For example, the expansion of education and its close link with the delay in the timing of births, both of which contribute to the attainment of SEP in adulthood, create a setting in which the association between earlier AAM, poor school performance and earlier childbearing could have more negative implications for later SEP.

The present study fills two important gaps in our current knowledge of the social gradient in AAM. First, while the secular decline in AAM is known, it remains unclear to what extent the decline is a shared experience across socioeconomic strata. If AAM has declined at a faster pace in low SEP groups, then it presents a case of increasing social disparities due to the known negative health and behavioral consequences associated with earlier AAM. However, available evidence is mainly based on cross-sectional comparisons of AAM by indirect or self-reported measures of

SEP (Hiatt et al., 2021; Kim et al., 2023; Krieger et al., 2015; Lyu et al., 2014; Reagan et al., 2012; Veronesi and Gueresi, 1994). This has limited our understanding of how the social gradient in AAM changes during periods with overall increases in education and income.

Second, exactly how the social gradient in AAM emerges remains elusive. It is possible that growing up in low SEP families directly affects AAM. For instance, well-known risk factors for earlier AAM such as higher prepubertal body mass index (BMI) (Bratke et al., 2017; Brix et al., 2020a), lower birth weight (Juul et al., 2017), and maternal smoking during pregnancy (Brix et al., 2019; Chen et al., 2018) (increasingly) tend to be clustered within low SEP families. However, it is also possible that women with younger AAM are more likely to have daughters who grow up in low SEP families, given the known association between early AAM and outcomes predictive of low SEP such as earlier age at childbearing and low school performance (Gill et al., 2017; Lawn et al., 2020). The daughters will then both grow up in low SEP and inherit an early AAM from their mothers, which creates an association. These two reasons are conceptually analogous to social causation and health selection, respectively, which are two hypotheses developed to explain health inequalities (West, 1991; Goldman, 2001). To date, little to no work has explicitly compared the two competing hypotheses to understand how the social gradient in AAM could arise.

To fill these gaps, we use an exceptional opportunity afforded by data from Norway. We linked AAM from multiple health surveys to individual register data, which allows us to compute each respondent's childhood SEP relative within birth cohorts (hereafter, childhood SEP), using the family income and parental education level assessed at the age 7 of each respondent. Determining the origin of the social gradient in AAM is also challenging because other factors, such as altered population composition, can affect the observed gradient. For example, later cohorts are likely to have a higher share of immigrants, and immigrants are likely to be overrepresented in low-SEP families and may have an average AAM that differs from the native population (Gomula and Koziel, 2015; Houghton et al., 2023). One therefore needs comparable prepubertal measures of SEP as well as AAM, preferably in a population that has remained unchanged in its composition across time. Norway is a relatively homogeneous population with small income differences and a generally healthy child population with moderate levels of overweight and obesity.[1] One would thus expect that the socioeconomic differences in AAM would be smaller in Norway than in many other high-income countries, and evidence for any differences in Norway would then imply potentially larger differences in other countries. Restricting

[1] In year 2000, Norway ranked 11th in Europe in under-5 overweight prevalence among girls, at 7% (Institute for Health Metrics and Evaluation, 2020)

our intergenerational analysis to the sample of unique mother-daughter pairs from the Norwegian Mother, Father and Child Cohort Study (MoBa) further ensures the emerging social gradient is unlikely to be caused by changes in population composition.

The aims of this study are to (1) describe the secular trend in mean AAM using data from 193,164 Norwegian girls and women born 1903-2008 and socioeconomic differences therein with data from 122,826 individuals born 1960-2008; and (2) examine to what extent social causation and health selection underlie the intergenerational change in AAM, using data from 10,896 mother-daughter pairs participating in MoBa (Magnus et al., 2006). This latter sample constitutes a balanced panel where each mother-daughter pair is unique (i.e., no same mother with multiple daughters) and contains information on AAM and childhood SEP in both generations. The data allow us to decompose the intergenerational change in AAM into two components. First, we can study whether girls with lower childhood SEP have seen a larger decline in AAM compared to their own mother than their more affluent peers. Differences in this within-family between-generations component would support the social causation hypothesis that the social gradient in AAM emerges because childhood SEP affects AAM. Second, we can study whether girls with lower childhood SEP have mothers whose AAM was younger compared to those mothers who themselves grew up in low SEP. This between-families within-generation component would support the health selection hypothesis that early AAM women are (self-)selected into low-income childbearing. We furthermore explore the extent to which earlier age at childbearing among women with earlier AAM may explain such health selection. Through these analyses, we seek to clarify to what extent the declining AAM is a shared experience across socioeconomic strata, and furthermore, how the social gradient in AAM emerges.

Age at Menarche: Biosocial Mechanisms and Social Gradient

Menarche is a late event in the female pubertal transition, which is regulated by the hypothalamic-pituitary-gonadal (HPG) axis central to reproductive physiology. Both energy balance and psychosocial stress are among the prominent upstream inputs integrated into the axis to initiate and drive pubertal development (Ellison et al., 2012). The secular trend of a decline in AAM has been largely attributed to improvement in nutrition and health (Garenne, 2020; Okasha et al., 2001). Studies from populations in energy-constrained environments or rapidly going through industrialization have shown that AAM is later among girls exposed to famine (Wu et al., 2022) or from less resourceful backgrounds

(Costa et al., 2023; Junqueira Do Lago et al., 2003; Łaska Mierzejewska and Olszewska, 2004; Lyu et al., 2014; Marván et al., 2020; Veronesi and Gueresi, 1994). Some of these studies have also shown that average AAM has declined faster in girls from low SEP (Ong et al., 2006; Parent et al., 2003). However, studies from more recent cohorts (late 1990s and early 2000s) showed not only continued decline in AAM (Morris et al., 2011) but also growing differences in AAM by SEP in a direction that is opposite to that observed in earlier birth cohorts (Kelly et al., 2017; Kim et al., 2023; Sun et al., 2017). That is, recent cohorts show a positive social gradient, in which menarche is earlier in lower SEP groups, based on available studies mostly from high-income countries.

While a substantial body of work highlights factors associated with AAM, few studies have explicitly explored how the social gradient might emerge. Here, we consider two distinct pathways through which the social gradient in AAM could develop between generations (Figure 1).

[Figure 1 about here.]

One pathway is through which SEP, *in utero* and during childhood, affects AAM. Here, the fetal and childhood environment associated with lower SEP enhances various risk factors of earlier AAM and thus creates the social gradient. As more recent cohorts are unlikely to grow up in energetically constrained environments, factors of early AAM considered go beyond resource quantity *per se*. Some of the key factors may relate to dietary quality and energy balance, as higher prepubertal BMI is associated with earlier menarche (Bratke et al., 2017; Brix et al., 2020a). In high-income countries, childhood obesity is more prevalent in low SEP groups (Wang and Lim, 2012), even if population-level childhood overweight and obesity might be leveling off (Koliaki et al., 2023). Furthermore, girls growing up in a low SEP household may be more exposed to endocrine-disrupting chemicals as well as parental smoking during pregnancy and childhood, which may affect the onset of menarche (Averina et al., 2024; Brix et al., 2019; Chen et al., 2018; Parent et al., 2015). Another reason why lower SEP may be associated with earlier AAM is higher levels of psychosocial stress. For instance, there is a well-established association between family disruption and early menarche (Ellis, 2004; Gaml-Sørensen et al., 2021; Webster et al., 2014; Zhang et al., 2019). Given the higher risk of family disruption in low SEP households (Sano et al., 2021), this may form a pathway by which the positive social gradient in AAM has emerged in recent birth cohorts.

The other pathway is through which maternal AAM contributes to differences in SEP between families in the next generation, and is also inherited by the daughters. It rests on notions that AAM is highly heritable, with heritability estimated from family and twin studies between 0.5-0.7 (He and Murabito, 2014), but also acts as a selection mechanism that affects the SEP of families in which their daughters grow up. For instance, earlier AAM is associated with lower school performance and educational attainment (Gill et al., 2017; Haapala et al., 2020; Torvik et al., 2021), which could then affect SEP either directly through the mother's income and education, or indirectly through the tendency of finding partners with similar educational characteristics (Gonggrijp et al., 2023; Torvik et al., 2022). Earlier AAM has also been associated with worsened somatic and mental health both during and after adolescence, including higher prevalence of attention deficit hyperactivity disorder and depression (Askelund et al., 2024; Cheng et al., 2022; Golub et al., 2008), which may affect both income and education attained as adults and thus consequently the offspring's SEP during childhood. Another selection mechanism is through the association between early AAM and earlier childbearing (Lawn et al., 2020; Udry, 1979). The family's income during the daughter's childhood is likely to be lower simply because the parents are younger, and early childbearing may also lead to postponed or reduced education and affect career paths.

The two pathways considered above are conceptually analogous to social causation and health selection, respectively, which have long been recognized as an analytical framework to analyze how health inequalities emerge. While *social causation* implies that a person's available resources affects their health, *health selection* implies that individuals with a certain health condition or health-related trait are more likely to end up in a lower SEP (Goldman, 2001; West, 1991). Empirically, support for each of these pathways can be assessed in a balanced panel where the childhood SEP and AAM are known in two generations. Under the social causation hypothesis, we expect that a deteriorating childhood SEP from mothers to daughters would be associated with larger declines in AAM. Under the health selection hypothesis, we expect the AAM of mothers to differ between those who grew up in low childhood SEP versus those whose daughters grow up in low childhood SEP. Assuming that the heritability of AAM is similar across SEP groups, there should hence not be systematic within-family differences in the intergenerational change in AAM by SEP if the gradient is caused by health selection.

The intergenerational data allow us to clarify the relative contributions of within-family vs. between-family components to an emerging social gradient in AAM, and through that to assess the strength of each of these pathways. Doing so could be useful to hypothesize whether directly intervening on a socioeconomic factor, such as family income or other support during pregnancy and early childhood, can help preventing menarche from starting too early. Alternatively, if the social gradient traces back to selection on maternal AAM, interventions would be more successful if addressing the structural factors through which early menarche influences educational attainment, earnings, and age of childbearing. Taken together, these explanations raise a possibility that AAM could act as one axis by which social inequalities reproduce across generations, through the association between childhood SEP and earlier AAM on the one hand, and early AAM with relatively poor social outcomes on the other hand. Such dynamics would predict a further acceleration of socioeconomic differences in AAM in the future.

Data and Methods

Datasets and Samples

We combine data on AAM from the Cohort of Norway study (CONOR), the Trøndelag Health Study (HUNT), the Young-HUNT study, and MoBa (see Figure 2). In our largest sample, we include 193,164 girls and women born 1903-2008 to display the decline in AAM across 100 years. Our sample with socioeconomic information during childhood consists of a total of 122,826 females (Table 1). This restricts the sample to women born 1960 and later.

[Figure 2 about here.]

CONOR is a research collaboration network, which includes 11 population-based health surveys and screenings conducted 1994-2003 from 173,236 residents from both rural and urban parts of Norway (Næss et al., 2008). The Oslo Immigrant Health Study within CONOR was not included in our sample, because childhood SEP is largely unavailable for the immigrants sample and mean AAM differed substantially from other surveys. We complemented CONOR, which includes wave 2 of HUNT, with HUNT wave 4 from 2017-2019 and four waves of the Young-HUNT study of adolescents aged 13–19 years (Åsvold et al., 2022; Rangul et al., 2024). Lastly, MoBa is a prospective population-based pregnancy cohort with about 95,200 unique mothers who gave birth in 1999-2008 and their approximately 114,500 children (Magnus et al., 2006). We used data from MoBa mothers who reported their AAM in the first questionnaire upon recruitment during week 15 of their pregnancy, and from all MoBa daughters who completed the 14-year-old questionnaire.

[Table 1 about here.]

For the intergenerational analysis, we constructed a balanced panel of 10,896 MoBa mother-daughter pairs for whom we know childhood SEP and menarche in both generations (Table 2). This sample is a share of the 41,014 daughters who were initially invited to participate in the 14-year-old questionnaire, of whom 13,268 responded to the question on AAM. Out of these, the sample was further reduced as we needed information on their mothers, family income, and parental education. The oldest daughter was selected in incidences with more than one responding daughter. Within this balanced panel, the mothers were born 1960-1992 and the daughters 2002-2008.

[Table 2 about here.]

Measures

Age at Menarche

Age at menarche is a self-reported answer to the question ”How old were you when you started menstruating?”. Answers were given in whole years, and values below 7 and above 20 years were excluded as outlying answers. Among MoBa daughters who filled out the 14-year-old questionnaire, 93.9% reported to have experienced menarche. For the 6% who had not had first menstruation, we use multiple imputation with interval regression for partially observed censored variables to compute values. We also impute values for respondents in the Young-HUNT surveys who reported to not have reached menarche. The method imputes values for the censored observations based on an assumption that AAM is normally distributed. The imputed AAM takes a value between the age at survey plus one year, and age 20. It furthermore corrects standard errors for the uncertainty in the regression coefficients that stems from imputation. The analysis is based on 200 imputations. Associations in the balanced sample are similar when using a dummy for early vs. late menarche as outcome, which circumvents the need for imputation (see supplementary material).

Socioeconomic Position

From Norwegian registers, we calculated the family income and highest parental education level of all persons at age 7 relative to their birth cohort (”childhood SEP”). For income percentile, we took the total pensionable income within the family per EU equivalent consumer unit, and ranked income among all children with positive family income within the cohort that year. In an analysis of absolute income, we deflated the family income per consumer unit to Norwegian kroner in 2017, and took the natural logarithm of the amount (see supplementary material). Because the pensionable income data is available 1967-2017, we could assess relative family income at age 7 for those born 1960 onwards. We have education data for all persons encountered in the 1970 census, and all persons yearly from 1974 onwards. We took the highest-ranking education of a living parent of each index person in 1970 for children born 1960-1966, and at age 7 for children born 1967 onwards. For each registered education code, we used the equivalent number of years of education following Statistics Norway's coding standard. Values below 8 correspond to incomplete compulsory education and were set to missing due to low reliability. The relative education measure was calculated by taking the percentile rank of the highest years of education of a living parent within the child birth cohort (see supplementary material).

Statistical Methods

We first conducted a cross-sectional analysis of AAM across 15 surveys, and the social gradient therein. We estimated linear regressions with one-year dummies per birth year as predictors and AAM as outcome in each survey, and then ran a meta-analysis which adjusted for random effects of each health survey to account for that the data stems from different survey samples. In the analysis of MoBa mothers, we adjusted the AAM for age at recruitment since recruitment is contingent on being pregnant in the early 2000s and there is a strong, positive correlation between AAM and age at childbearing (Lawn et al., 2020). The maternal-age-dependent sampling of MoBa mothers would otherwise give incorrect estimates of the secular trend in AAM across birth years. The meta analysis estimated means and standard errors by year of birth for all cohorts available. Next, we estimated survey-specific regressions and conducted meta-analyses for each income quintile in the sample with the SEP information available.

Within the balanced panel, we ran several models to explore how the social gradient in AAM has changed across generations in MoBa. We were first interested in the levels of AAM by SEP during childhood in the two generations of mothers and daughters. We estimated the equation:

$$AAM_{ig} = \beta_{q,g} * I_{q,g} + e_{ig} \tag{1}$$

Where AAM_{ig} is the age at menarche of a person in family i in generation $g = (1,2)$ where 1 and 2 refer to mother and daughter generations, respectively. $\beta_{q,g}$ are the coefficients of interest and $I_{q,g}$ are income quintiles in each generation.

Having established how the intergenerational decline in AAM differs by childhood SEP, it becomes compelling to investigate the sources of this difference. To this end, we conducted a decomposition of the intergenerational change in AAM within each income quintile. This analysis is conducted to estimate the importance of between-family versus within-family factors for the observed intergenerational decline in AAM. Concretely, we decomposed the intergenerational decline within each quintile in the following way:

$$\overline{AAM_1(I_{q,1})} - \overline{AAM_2(I_{q,2})} = \left[\overline{AAM_1(I_{q,1})} - \overline{AAM_1(I_{q,2})}\right] + \left[\overline{AAM_1(I_{q,2})} - \overline{AAM_2(I_{q,2})}\right] \tag{2}$$

Where $\overline{AAM_1(I_{q,1})} - \overline{AAM_2(I_{q,2})}$ is the difference between the AAM of Generation 1 by their childhood income quintile q and the AAM of Generation 2 by their childhood income quintile. This intergenerational difference in AAM is decomposed into the between-family effect $\left[\overline{AAM_1(I_{q,1})} - \overline{AAM_1(I_{q,2})}\right]$ which is the difference between the AAM of Generation 1 by Generation 1's own childhood income quintile and the AAM of Generation 1 by Generation 2's childhood income quintile; and the within-family effect $\left[\overline{AAM_1(I_{q,2})} - \overline{AAM_2(I_{q,2})}\right]$ which is the difference between the AAM of Generation 1 by Generation 2's childhood income quintile and the AAM of Generation 2 by Generation 2's income quintile. The between-family component was then further decomposed using a Blinder-Oaxaca decomposition (Blinder, 1973; Oaxaca, 1973), to estimate the contribution of age at childbearing to the between-family component. As an alternative to the decomposition method, we have used more formal regression methods to estimate within-family and between-family effects (see supplementary material). All analyses were conducted using Stata version 18 (Statacorp, Texas).

Results

Secular Changes in Age at Menarche by Socioeconomic Position

Figure 3 shows the secular trend in average AAM across cohorts born 1903-2008 in Norway. We observe that average AAM declined from 14.13 years for females born in 1903 (95% confidence interval [CI]: 13.19, 15.07) to 12.44 years for females born in 2008 (95% CI: 12.28, 12.60). The decline is evident in the entire period, and was particularly sharp for cohorts born in the 1930s. Unlike the trend in means, we do not find that the variance in AAM is monotonically changing (see supplementary material).

[Figure 3 about here.]

On a sample whose childhood SEP is known through the Norwegian register, the secular decline in AAM was steeper in low SEP groups. Figure 4 shows that the predicted AAM for the lowest income quintile declined from 13.14 years for females born 1960 (95% CI: 13.10, 13.17) to 12.63 for those born in 2008 (95% CI: 12.58, 12.69). For the highest income quintile, AAM was at the similar level as the lowest quintile in 1960 (13.12 years, 95% CI: 13.09, 13.15) but declined less to 12.79 for those born in 2008 (95% CI: 12.75, 12.84). The results were similar if SEP was measured as parental education.

[Figure 4 about here.]

Intergenerational Change in Age at Menarche

In the balanced panel, we find that a positive social gradient in AAM emerges among the daughters, both when SEP is measured as relative income and highest parental education (Figure 5). There is no clear evidence of a social gradient in the AAM of MoBa mothers. For MoBa daughters, we observe that not only has AAM declined compared to the maternal generation in all SEP strata, but there is also a social gradient. Among the daughters in the bottom income quintile, AAM occurs about 5.2 months (-0.43 years, 95% CI: -0.54 – -0.32) earlier than the mothers who grew up in the same bottom income quintile, whereas the difference is about 2.7 months (-0.23 years, 95% CI: -0.29, -0.16) between daughters from the top income quintile group and mothers in that same top quintile. Similarly, AAM in the MoBa daughters whose parents had a lower secondary education or less is about 6.5 months (-0.54 years, 95% CI: -0.75

– -0.32) earlier than the mothers whose parents had lower secondary education or less. The intergenerational difference is reduced to 3.7 months (-0.31 years, 95% CI: -0.39 – -0.22) when comparing MoBa daugthers whose parents had higher tertiary education with MoBa mothers with the highest educated parents.

[Figure 5 about here.]

Figure 6 shows the decomposition of intergenerational change in AAM in each income quintile. The solid black lines are the observed mean AAM among the mothers, by income quintile when they were 7 years old. The dashed black lines are the observed mean AAM among the mothers by their *daughter's* family income quintile. The difference shown in green reflects the between-family contribution to the intergenerational change, which varies from -.15 years (CI: -0.27 – -0.03) in the lowest quintile to +0.09 years (CI: 0.02 – 0.16) in the highest quintile. The dark green area represents the part of this contribution attributable to mother's age at childbearing, which amounts to -0.02 years (CI: -0.04 – -0.01) in the poorest quintile, or 17% of the between-family component. In the highest quintile, the age composition can explain 0.01 years (CI: 0.01 – 0.02) of the difference in AAM, which is 12% of the between-family component.

In figure 6, the red lines represent the AAM of the daughters, and when comparing it to their mother's AAM represented by the dashed black lines, we get the within-family component of the intergenerational change shown in yellow. This component is negative in all quintiles, displaying intergenerational decline in AAM in all quintile groups, and amounts to -0.29 years (CI: -0.40 – -0.19) in the lowest quintile and -0.34 years (CI: -0.39 – -0.29) in the highest quintile.

[Figure 6 about here.]

In the supplementary material, we arrive at the same conclusions using linear regression analyses on the whole sample with continuous measures of SEP. These show no association between intergenerational changes in SEP and AAM (i.e., no within-family effect), and that the child's income position is as closely associated with maternal AAM as it is with the child's AAM (i.e., a large between-family effect).

Discussion

From almost 200,000 Norwegian females born more than 100 years apart, we document a continued decline in AAM from above 14 to less than 13 years of age. Among those whose childhood SEP could be assessed through register data, we find that the decline in AAM has been faster for girls who grew up in lower income groups, with the socioeconomic difference becoming apparent from cohorts born in the 1980s and continuing to grow. For cohorts born 1960-2008, the decline in AAM has been more than 50% faster in the lowest income quintile than in the highest quintile (6.1 months vs. 4 months), resulting in a clear positive social gradient. Furthermore, in almost 11,000 unique mother-daughter pairs, we find that mothers of different AAM are selected into childbearing in households with different SEPs. This, in turn, would underlie the emergence of a social gradient in AAM among daughters, providing evidence for the health selection hypothesis.

To the literature concerned with the emerging social gradient in AAM, we contribute novel evidence in support of the health selection hypothesis. We find much lower AAM among mothers who raise children in low-income families than among mothers who themselves grew up in low-income households. The impact of maternal AAM on the childhood SEP in daughters could operate through weaker school performance and lower educational attainment by mothers with earlier AAM (Torvik et al., 2021; Gill et al., 2017), worse health (Lee et al., 2022) or earlier childbearing (Lawn et al., 2020). Our findings furthermore suggest that the selection began in the generation of the MoBa mothers. If early AAM also selected mothers into low-income childbearing in the grandmother generation, we would have seen a social gradient in AAM by childhood SEP already in the MoBa mother generation. One reason why such selective forces started to operate recently could be that the association between AAM and outcomes related to SEP, such as school performance (Torvik et al., 2021; Gill et al., 2017), became more important for the family's income position, as women increasingly attained higher education and entered the labor market, contributing with an increasing share of the family's income. In Norway, socioeconomic selection for childbearing in women has changed from negative to positive since the late 1960 birth cohorts (Jalovaara et al., 2019). If men with a high SEP increasingly find partners with higher education and/or income potential, such a change could also explain why health selection is implicated in the emerging social gradient in more recent birth cohorts born after 1980 in Norway. When we further examine age at childbearing as a separate mechanism for larger differences in AAM by the child's than by the mother's own childhood SEP, we find a statistically significant although relatively modest contribution, amounting to 1/6 of the health selection in the lowest income quintile. The finding thus urges more research on how AAM affects various behavioral outcomes over the life course and comprises a selection mechanism, through which AAM potentially becomes more different between socioeconomic groups.

The little support for the social causation hypothesis is perhaps surprising, given that some of the well-known risk factors for earlier AAM tend to exhibit clear socioeconomic differences. This finding may have at least three potential explanations. One possibility is that some of the risk factors for an earlier AAM may be fairly evenly distributed among socioeconomic groups. For example, maternal smoking during pregnancy is associated with younger AAM (Brix et al., 2019), but it is fairly evenly distributed between income groups among MoBa mothers (Cupul-Uicab et al., 2011). This may be altered due to the changing social gradient in smoking, which has been documented in Norway and also in other countries (Grøtvedt et al., 2017; Keyes et al., 2013). Maternal smoking may thus be a factor that in the past has contributed to declining AAM in *all* income groups but not to the emerging social gradient. Other risk factors such as childhood BMI show significant socioeconomic differences in means (Michel et al., 2023; Frederick et al., 2014; Broadbent et al., 2024), also in MoBa children (Mekonnen et al., 2021). However, these studies also show that the BMI distributions by socioeconomic status largely overlap, and few children have BMI levels that are pathological.[2] Secondly, environmental risk factors for early AAM might not have sufficiently strong effects. Some effects of childhood conditions on early AAM may have been exaggerated, which in particular applies to studies that have not taken maternal AAM and other selection mechanisms into account. One such example is the association between father absence and AAM (Sear et al., 2019). The effect size in these studies is often small, and there are mixed findings on whether the phenomenon can be fully or partially explained by genetic confounding (Barbaro et al., 2017; Gaml-Sørensen et al., 2021; Gaydosh et al., 2018; Schlomer and Marceau, 2022). The third possibility is that there is some social causation that is not captured in our model due to other counteracting factors. A particularly plausible explanation is regression-to-the-mean effects (Galton, 1886; Barnett et al., 2005). Mothers with an early menarche are less likely to see an even earlier menarche in their daughters due to such mechanisms, while the contrary holds for mothers with late menarche. This opens up the possibility that mothers with early menarche are first selected into low-income childbearing and then the daughter's AAM is further reduced through effects of an adverse childhood

[2]Mekonnen et al. (2021) find a 0.08 point difference in BMI between 7-year-old MoBa children with paternal income above vs. below the mean, which amounts to a Cohen's d of approximately 0.01, implying 99.4% overlap between the distributions. 9.79% are overweight or obese at this age, suggesting 3-4% prevalence of pathological obesity.

environment, but that the decline in AAM is not larger for low-income groups given the limited scope for menarche to occur much earlier than their mother's early AAM. In any case, such effects hinge on there also being a large health selection component.

An early menarche in contemporary Norway is thus associated with selection into low-income childbearing, and the mother's early AAM is inherited by daughters growing up in low-income households. Daughters are additionally subject to a large secular decline in AAM which is shared among socioeconomic groups. If early AAM continues to be a factor selecting mothers into childbearing in low SEP, it may indeed be a mechanism that increases social inequalities across generations. If the associations remain, we may expect continued increases in socioeconomic differences in AAM in future generations. To mitigate this increasing social gradient, policies should primarily focus on breaking the association between early menarche and low-income childbearing in adulthood.

The present study has two main limitations. First, our collection of AAM from surveys does not capture the whole Norwegian population nor a representative sample of it. CONOR is based on regional surveys and low-income respondents are over-represented. The sample is also subject to survival bias, as respondents were born 1903-1972 and interviewed in 1994-2003. The MoBa mothers are selected on having a pregnancy and conditioned upon a 41% participation rate, while the MoBa daughters include those who will likely remain childless in the future. In addition, MoBa daughters who provided information on AAM tend to come from slightly higher SEPs than their mothers, and participation in both generations is higher in groups with high childhood SEP (Table 2). The participation rate among the MoBa daughters was relatively low at 33%, which could give an inaccurate estimate of mean AAM both in the population as a whole and in sub-groups, although a study has not found pubertal timing to be correlated with participation in a similar Danish cohort study (Brix et al., 2020b). Due to sampling criteria and selective attrition, both MoBa mothers and daughters may not capture the distribution of AAM that is fully representative of the general population in Norway. Although this could potentially pose a challenge in estimating average AAM, it is not implausible that the relationship between the intergenerational changes in SEP and AAM is similar in our sample and the general population, especially given that large sample size allows us to capture both mothers and daughters across SEP strata. Second, the reliance on self-reported AAM is prone to recall bias. Follow-up studies find relatively high correlation (r = 0.6-0.8) between AAMs reported by same individuals across time (Must et al., 2002; Siegel et al., 2021). Although it is still possible that recall is less reliable especially for older cohorts given the longer lag of recall (Koo and Rohan, 1997), we believe that systematic differences in the direction of recall bias, and consequent bias in the estimated intergenerational decline in AAM, are less likely.

Conclusion

This study provides a comprehensive population-level assessment of the secular trend and social gradient in AAM, a necessary step before deciphering their underlying mechanisms. It establishes the emergence of a positive social gradient in AAM in Norway during a period of continued decline in AAM. We find evidence supporting that the emerging social gradient is attributed to the increased selection of mothers with early menarche into low-income childbearing. The study does not find evidence for a secondary explanation, namely that a resource-poor childhood environment may cause an earlier AAM. To what extent the emerging social gradient in AAM is evident in other populations remains an important question for future research. Possible underlying mechanisms are showing a similar pattern of change between countries (e.g., see Van Bavel et al. (2018) on educational expansion and mating preferences). We might also expect possible moderations by the degree of health disparities and the strength of social welfare. More research is also warranted on the mechanisms through which women with earlier menarche are selected into low-income childbearing. Doing so will benefit from taking a life course approach to examine the impact of pubertal timing on health, educational attainment, income, and patterns of family formation. Lastly, future research should also investigate how the combination of growing up in low childhood SEP and early menarche affects human capital formation and future SEP, as that combination is becoming increasingly common.

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Table 1: Characteristics of sample with socioeconomic information

Survey name	**Obs.** no.	**Imputed** no. (share)	**Age at menarche** mean (S.D.)	**Birth year** interval	**Survey year** interval	**Age at survey** interval
Tromsø IV	2,941	0	13.05 (1.34)	1960-1969	1994-1995	25-35
Hunt II	8,090	0	13.04 (1.32)	1960-1977	1995-1997	20-37
Hubro	3,898	0	13.03 (1.40)	1960-1970	2000-2001	30-41
Opphed	2,433	0	13.05 (1.37)	1960-1970	2000-2001	30-41
Tromsø V	352	0	12.92 (1.28)	1961-1971	2001	30-40
Trofinn - Troms	493	0	12.92 (1.31)	1962-1972	2002	30-40
Trofinn - Finnmark	287	0	13.06 (1.29)	1960-1972	2002	30-42
MoRo II	161	0	13.02 (1.57)	1961-1969	2003	34-42
MoBa mothers	73,371	0	13.01 (1.36)	1960-1992	1999-2009	16-47
MoBa daughters	12,953	760 (5.9%)	12.72 (1.24)	2002-2008	2016-2023	14-16
Young-Hunt I	1,870	95 (5.4%)	12.86 (1.35)	1976-1984	1995-1997	12-20
Young-Hunt II	762	<5 ($<.7\%$)	12.93 (1.35)	1980-1983	2000-2001	16-21
Young-Hunt III	2,435	235 (9.7%)	12.79 (1.39)	1986-1994	2007-2008	12-20
Young-Hunt IV	3,607	266 (7.4%)	12.85 (1.35)	1996-2006	2017-2019	12-21
Hunt IV	9,173	0	12.97 (1.41)	1960-1999	2017-2019	19-59

Table 2: Characteristics of the balanced panel of MoBa mothers and daughters

Variable		Mean	S.D.	Min.	Max.	N
Age at menarche	Mothers	13.02	1.35	8	20	10,896
	Daughters (incl. imputed)	12.72	1.23	7	17.63	10,896
	Intergenerational change	-0.29	1.56	-8	6.31	10,896
Share reached menarche	Daughters	0.94	0.23	0	1	10,896
Age at survey	Mothers	30.49	4.36	17	45	10,896
	Daughters	14.41	0.51	14	16	10,896
Birth order	Mothers	1.91	1.09	1	14	10,894
	Daughters	1.78	0.87	1	11	10,896
	Intergenerational change	-0.13	1.34	-13	7	10,894
Maternal age at birth	Mothers	26.25	5.14	14	47	10,894
	Daughters	30.79	4.31	16	45	10,896
	Intergenerational change	4.54	6.35	-21	24	10,894
Parental income percentile	Mothers	0.55	0.28	0.01	1	10,896
	Daughters	0.63	0.25	0.01	1	10,896
	Intergenerational change	0.08	0.34	-0.97	0.98	10,896
Parental education percentile	Mothers	0.51	0.31	0.01	1	10,846
	Daughters	0.56	0.27	0.01	1	10,896
	Intergenerational change	0.06	0.33	-0.93	0.99	10,846
Log family income	Mothers	12.54	0.64	5.30	15.69	10,896
	Daughters	13.13	0.44	8.19	15.58	10,896
	Intergenerational change	0.59	0.72	-4.38	8.04	10,896
Parental years of education	Mothers	13.22	2.78	8	21	10,846
	Daughters	16.29	2.09	10	22	10,896
	Intergenerational change	3.07	2.84	-7	14	10,846

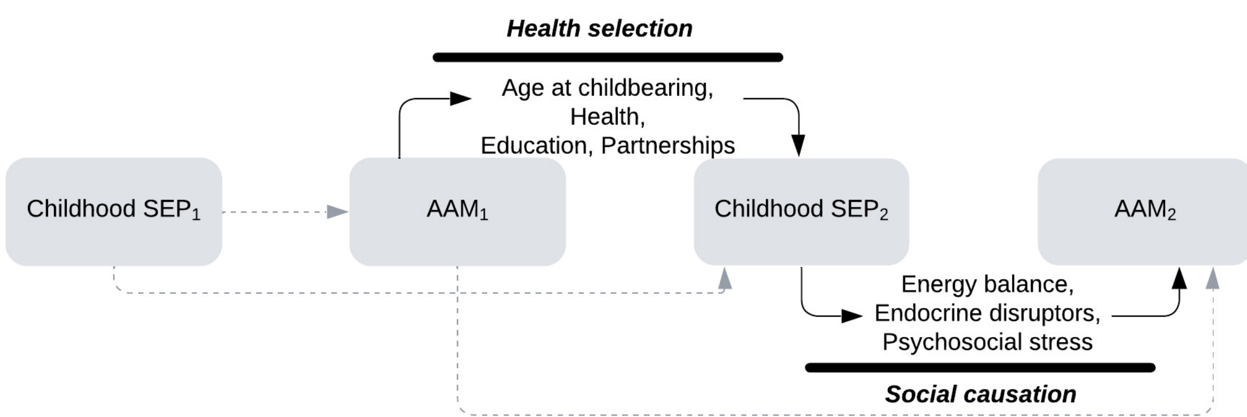

Figure 1: Conceptual framework. SEP_1 and SEP_2 refer to childhood socioeconomic position in the parent and child generations. AAM_1 and AAM_2 refer to their respective age at menarche.

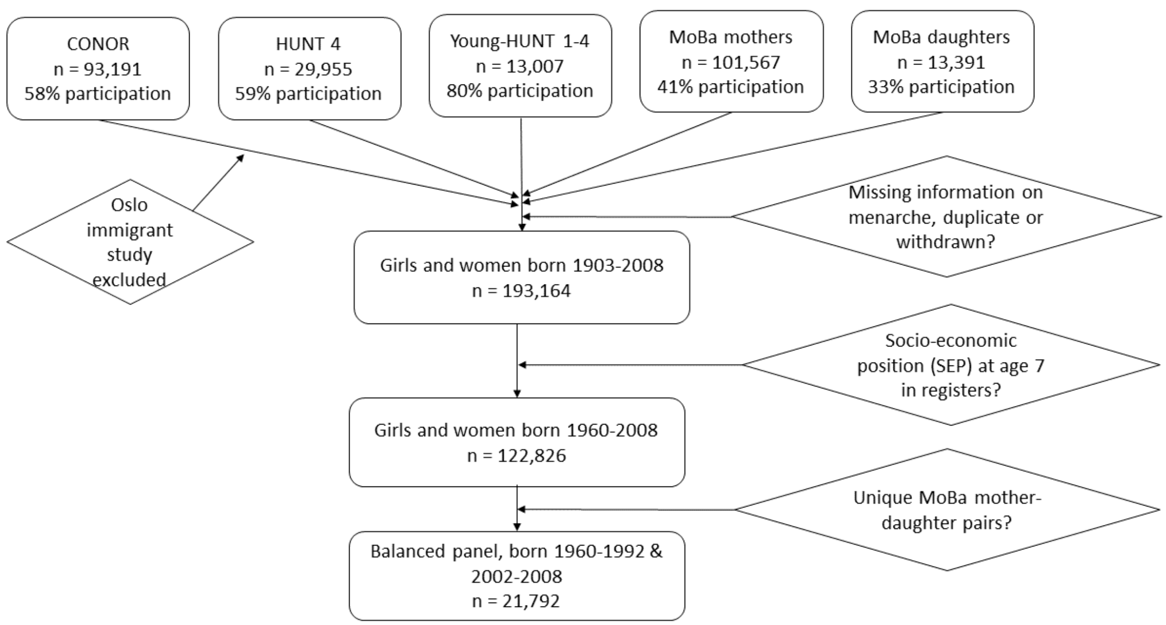

Figure 2: Flowchart of sample selection process.

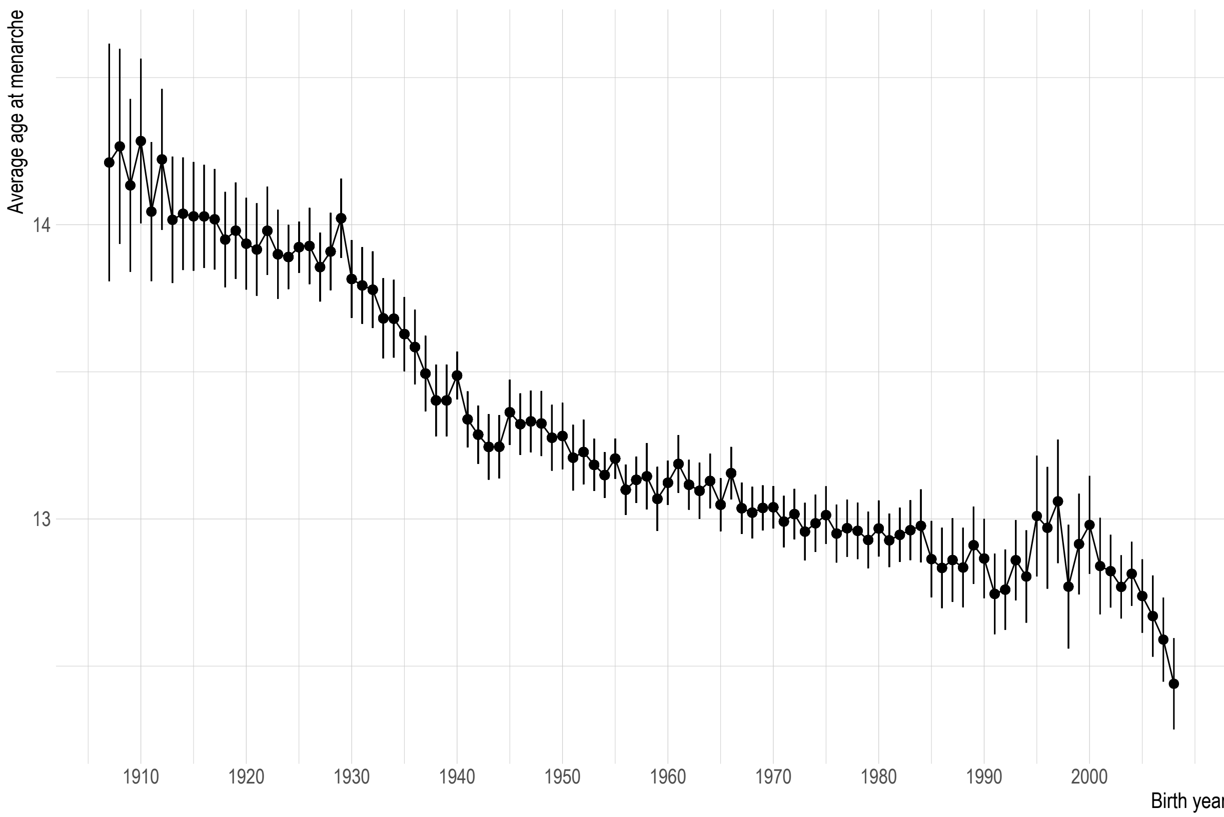

Figure 3: Mean age at menarche with 95% confidence intervals for each birth cohort in Norway, estimated with survey-specific random effects.

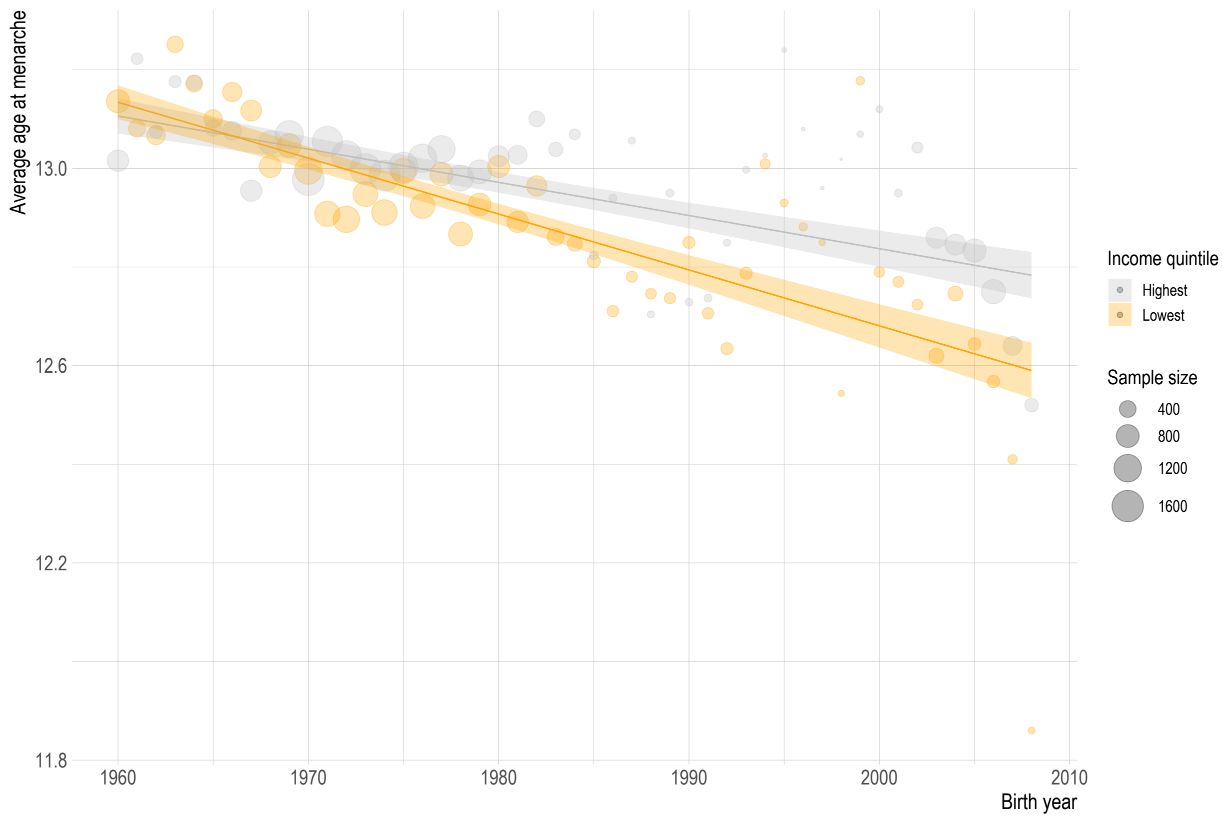

Figure 4: Age at menarche by childhood socioeconomic position, which is shown here as the lowest (orange) vs. highest (grey) quintile of family income distribution at age 7. Lines and shaded areas are estimated means and 95% confidence intervals from linear regression models with random effects by survey. Dots represent yearly estimates with the size of the dot representing the available number of observations.

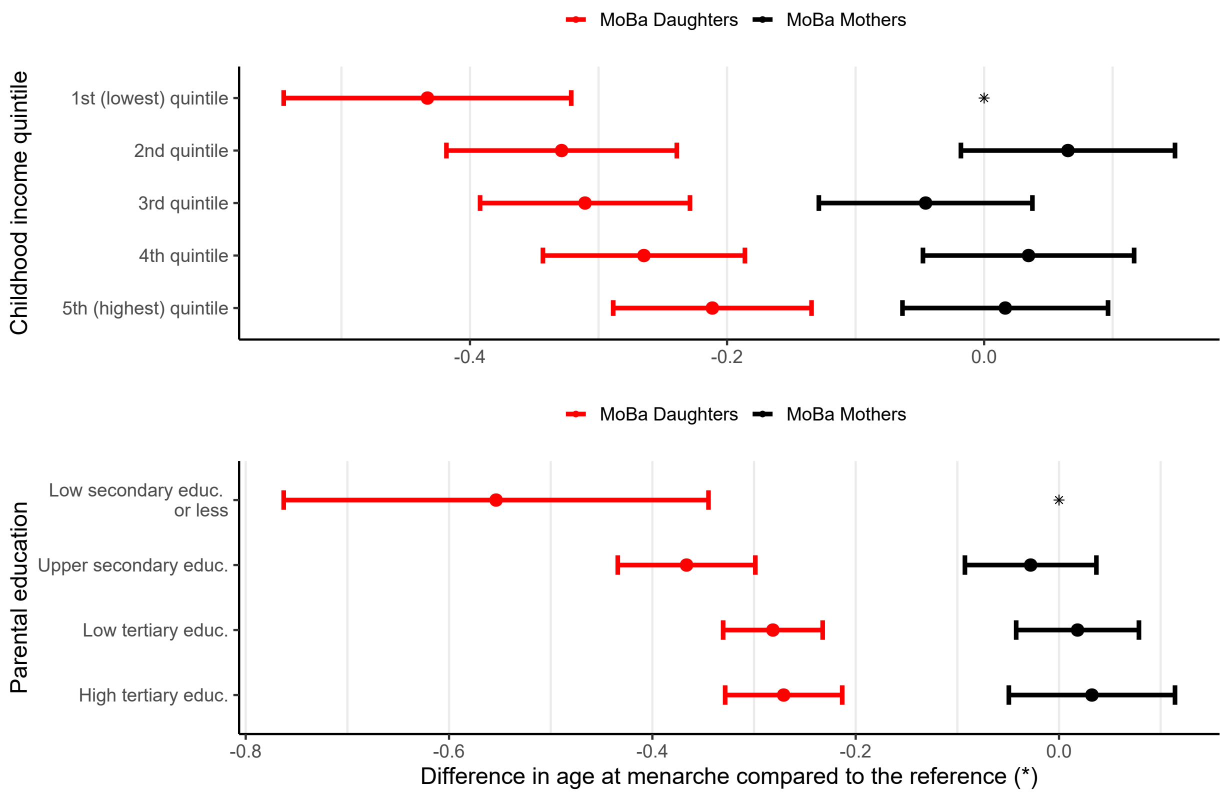

Figure 5: Regression coefficients with 95% confidence intervals, estimating the difference in age at menarche among MoBa mothers (black) and MoBa daughters (red) by quintiles of family income at age 7 according to the equation 1. The reference group (*) is the lowest quintile of MoBa mothers.

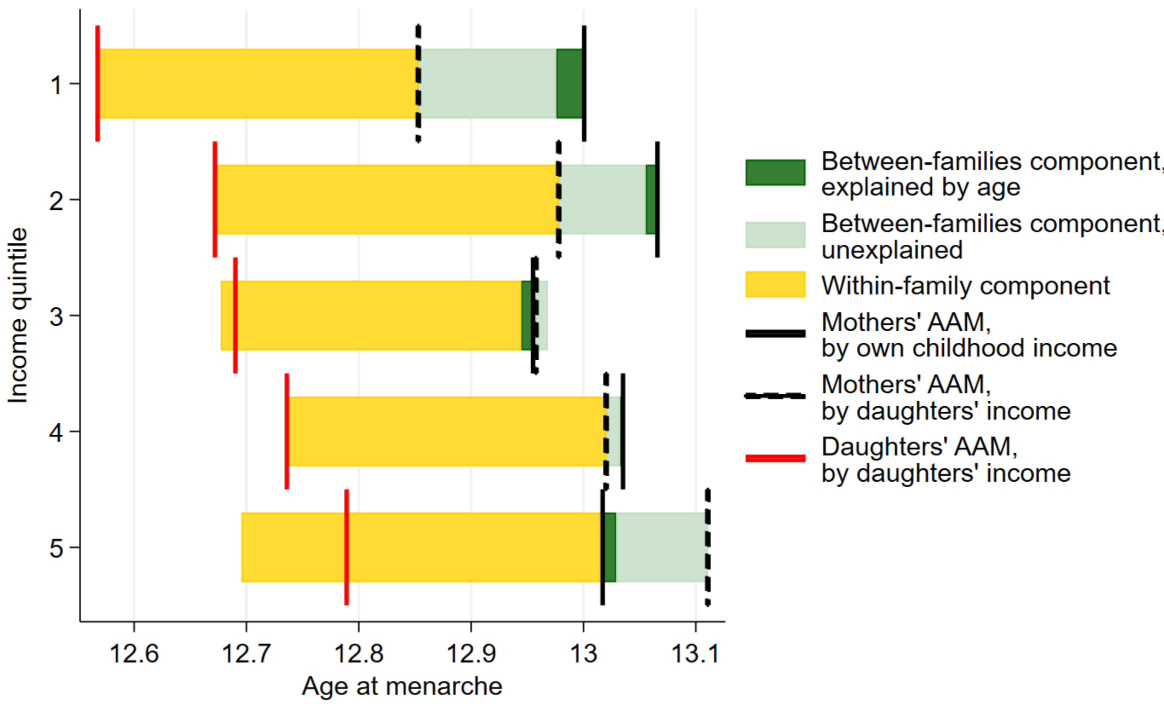

Figure 6: Decomposition of observed change in age at menarche (AAM) between generations, within each income quintile group. Lines represent AAM of mothers by own childhood income (black), AAM of mothers by daughters' income (blue) and AAM of daughters by own childhood income quintile (red). Colored areas represent decomposed parts of the intergenerational change in AAM.

Appendix

A) Formal regression analysis results

We conducted separate regression analyses, each of which is conceptually analogous to each step of the decomposition. While the overall conclusion drawn from these separate analyses is not different from that from the decomposition, the separate analyses give more detailed information on how the intergenerational decline in AAM differs by SEP. Below, we show results from these analyses using a continuous SEP.

Table A1 below shows differences in AAM by income position (defined as a 0-1 continuum) in the mothers and daughters generation in MoBa, first without controls and then controlling for birth order and their mother's age at birth using singular dummies. It shows that there is no gradient in the 1st generation and a .24 years difference between the lowest and highest SEP in the second generation, with all controls.

[Table 3 about here.]

Table A2 below shows results from a within-family analysis, where we control for a shared fixed effect in each mother-daughter pair. This is analogous to first differences, and results can therefore be interpreted as the impact of a difference in childhood SEP on the difference in AAM between mothers and daughters. The results show that there is no effect of childhood income position once accounting for shared family effects, or that a change in childhood SEP from mothers to daughters is not associated with the pace of intergenerational decline in AAM.

[Table 4 about here.]

Table A3 below shows results from between-family analyses, on the sample of MoBa mothers. The explanatory variables in these models are both the mother's own SEP, and the SEP of her child. The results show a .31 years difference in mothers' AAM between those with the lowest and highest SEP of the child, after controlling for own childhood SEP, their mother's age, and birth order. This is somewhat reduced to .22 years when controlling for own age at childbearing in the last column. The difference in the mother's AAM by the child's SEP and the child's AAM by the same measure is thus of similar size (the point estimate is actually a bit larger for the mothers).

[Table 5 about here.]

B) Results with absolute and relative income and education variables

In Table A4, we have used logged absolute income per consumption equivalent, in Norwegian kroner and deflated for price increases. The mean value across both generations is 12.83 with a standard deviation of 0.62, which corresponds to 374,973 2017-NOK. Adding one standard deviation increases the income to 698,260 2017-NOK, an increase of 323,287. This increase of one standard deviation which almost doubles the income is associated with an insignificant change in AAM in the first generation and an increase of 0.09 years in AAM in the second generation, when controls are included.

[Table 6 about here.]

Tables A5 and A6 show the associations between age at menarche and parental education, using both absolute and relative measures. One additional year for the parent with highest education is associated with 0.014 years increase in age at menarche in the second generation, when all controls are included. In the first generation, there is no assocation between parental education and AAM. The mean years of parental education across the generations is 14.76 with a standard deviation of 2.90, and a standard deviation increase thus corresponds to 0.04 years higher AAM, a weaker assocation than with income. For the relative analysis, there is a marginally insignificant association between the ranked parental education and AAM of 0.077 in the first generation including controls. In the second generation, the association is significant and larger, although not statistically different from the first generation. The difference between the lowest and highest percentile is 0.119 years of AAM when controls are included, which is about half the size of the association with income percentile (see Table A1).

[Table 7 about here.]

[Table 8 about here.]

C) Results without imputation

In the main analysis of this paper, AAM is imputed for girls who had not yet reached menarche at the time of survey. An alternative approach is to use a dummy of early vs. late AAM which can be obtained for the whole sample without the need to impute values. We set this dummy equal 1 if menarche was reached at age 13 or later, and 0 if it was reached at age 12 or earlier. Table A1 can then be replicated using this dummy variable as outcome.

The share who reached menarche at age 13 or later was reduced from 63% among MoBa mothers to 57% among MoBa daughters. We see from Table A7 that childhood income position is not associated with late AAM in the 1st generation of MoBa. However in the 2nd generation, there is a clear association in both models, with 9.1 percentage points higher likelihood of a late AAM in the top vs. bottom income percentile in the controlled case (95% CI: 5.1-13.0).

[Table 9 about here.]

D) Variance in age at menarche across time

We also estimated the standard deviation of age at menarche for each birth year, using the same meta-analysis method as described for the means. We see a slight tendency of increasing standard deviation which peaks around 1984, and then declined. It is only among cohorts born after 2000 that we see significant lower standard deviations than some of the previous birth cohorts. The estimates from females born in the 1980s and onwards include data that is imputed for individuals who had not reached menarche at the time of survey. The imputation assumes a normal distribution, and hence it is the variation among those who enter puberty early that determine the standard deviation. We are unable to ascertain whether the development in variance in this time period is due to the imputation or an actual decline in the variation in AAM.

[Figure 7 about here.]

Table A1: Formal regression analysis of social gradient in age at menarche

Dependent variable: Age at menarche	1st gen.	1st gen.	2nd gen.	2nd gen.
Childhood income position	-0.002	-0.058	0.258***	0.237***
	(0.046)	(0.048)	(0.047)	(0.050)
Constant	13.02***	14.48***	12.56***	11.94***
	(0.028)	(1.451)	(0.032)	(1.233)
Birth order controls	no	yes	no	yes
Mother's age controls	no	yes	no	yes
Observations	10,896	10,894	10,896	10,896

Note: Numbers in parentheses are standard errors.
†$p<.10$, * $p<.05$, **$p<.01$, ***$p<.001$

Table A2: Within-family analysis

Dependent variable: Age at menarche	all	all
Childhood income position	-0.065	-0.048
	(0.044)	(0.045)
2nd generation	-0.290***	-0.238***
	(0.015)	(0.021)
Constant	13.05***	14.70***
	(0.026)	(1.555)
Family fixed effects	yes	yes
Birth order controls	no	yes
Mother's age controls	no	yes
Observations	21,792	21,788

Note: Numbers in parentheses are standard errors.
†p<.10, * p<.05, **p<.01, ***p<.001

Table A3: Between-family analysis

Dependent variable: Age at menarche	1st gen.	1st gen.	1st gen.
Child's income position	0.304***	0.305***	0.217***
	(0.053)	(0.053)	(0.049)
Own childhood income position	-0.055	-0.061	-0.088*
	(0.046)	(0.048)	(0.049)
Constant	12.86***	14.87***	14.48***
	(0.039)	(1.345)	(1.450)
Birth order controls	no	yes	yes
Mother's age controls	no	yes	yes
Age at childbearing control	no	no	yes
Observations	10,896	10,894	10,894

Note: Numbers in parentheses are standard errors.
†$p<.10$, * $p<.05$, ** $p<.01$, *** $p<.001$

Table A4: Regression analysis of logged income on age at menarche

Dependent variable: Age at menarche	1st gen.	1st gen.	2nd gen.	2nd gen.
Childhood log income	-0.017	-0.022	0.151***	0.138***
	(0.020)	(0.020	(0.027)	(0.028)
Constant	13.23***	15.28***	10.74***	10.25***
	(0.255)	(1.371)	(0.352)	(1.284)
Birth order controls	no	yes	no	yes
Mother's age controls	no	yes	no	yes
Observations	10,896	10,894	10,896	10,896

Note: Numbers in parentheses are standard errors.
†$p<.10$, * $p<.05$, **$p<.01$, ***$p<.001$

Table A5: Regression analysis of maximum parental years of education on age at menarche

Dependent variable: Age at menarche	1st gen.	1st gen.	2nd gen.	2nd gen.
Parental years of education	0.004	0.004	0.018**	0.014*
	(0.005)	(0.005)	(0.006)	(0.006)
Constant	12.96***	14.96***	12.43***	11.79***
	(0.063)	(1.348)	(0.093)	(1.237)
Birth order controls	no	yes	no	yes
Mother's age controls	no	yes	no	yes
Observations	10,846	10,844	10,846	10,846

Note: Numbers in parentheses are standard errors.
†$p<.10$, * $p<.05$, **$p<.01$, ***$p<.001$

Table A6: Regression analysis of relative parental education on age at menarche

Dependent variable: Age at menarche	1st gen.	1st gen.	2nd gen.	2nd gen.
Childhood parental education percentile	0.078†	0.077†	0.148***	0.119**
	(0.041)	(0.044)	(0.044)	(0.046)
Constant	12.98***	14.99***	12.64***	11.95***
	(0.025)	(1.347)	(0.028)	(1.234)
Birth order controls	no	yes	no	yes
Mother's age controls	no	yes	no	yes
Observations	10,846	10,844	10,846	10,846

Note: Numbers in parentheses are standard errors.
†$p<.10$, * $p<.05$, **$p<.01$, ***$p<.001$

Table A7: Regression analysis of social gradient in early vs. late menarche

Dependent variable: Menarche $\geq$ 13	1st gen.	1st gen.	2nd gen.	2nd gen.
Childhood income position	-0.008	-0.008	0.095***	0.091***
	(0.016)	(0.017)	(0.019)	(0.020)
Constant	0.638***	1.003*	0.515***	-0.024
	(0.010)	(0.482)	(0.013)	(0.494)
Birth order controls	no	yes	no	yes
Mother's age controls	no	yes	no	yes
Observations	10,896	10,894	10,896	10,896

Note: Numbers in parentheses are standard errors.
†p<.10, * p<.05, **p<.01, ***p<.001

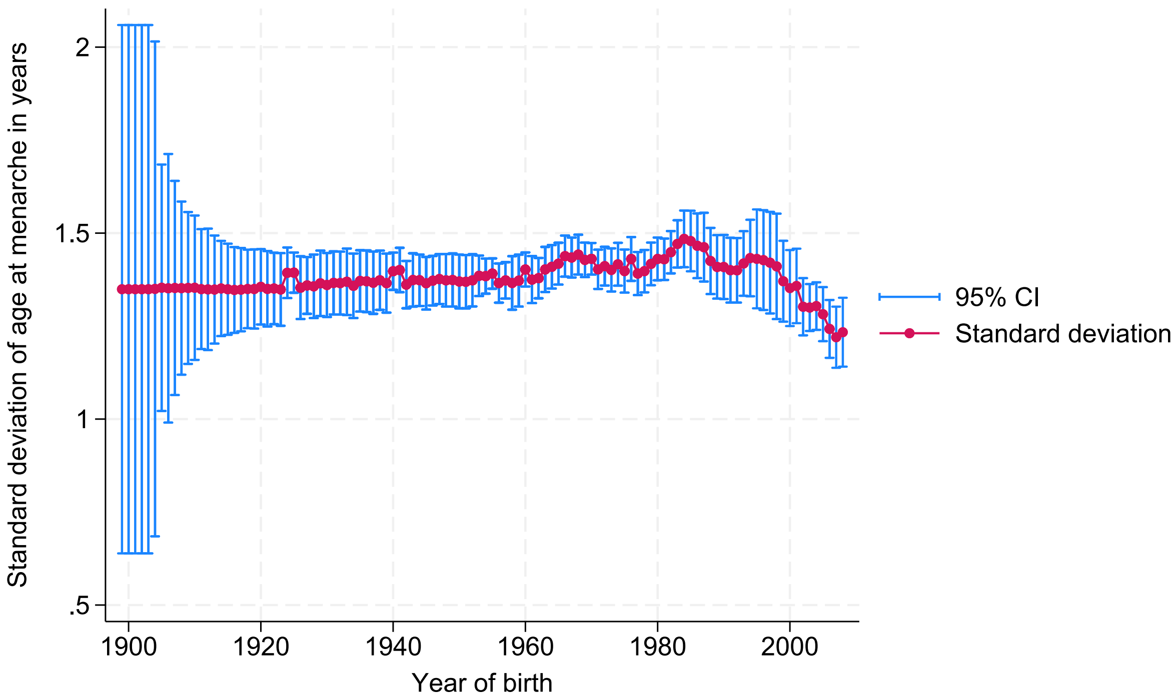

Figure A1: Predicted standard deviations of age at menarche, females born 1903-2008