The changing social gradient in age at menarche across cohorts and generations in Norway

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Abstract

Age at menarche (AAM; the first occurrence of menstruation) is a critical milestone for women's fertility and health trajectory. While children growing up in wealthier families used to experience menarche relatively early, the pattern now appears to have reversed in some western societies. This observation raises the possibility that AAM demarcates a life course transition through which social inequalities reproduce, as early menarche is associated with adverse health outcomes and lower educational attainment. As yet, it is unclear whether the social gradient in AAM has indeed changed in recent cohorts, and to what extent socioeconomic position is directly related to an inter-generational decline in age at menarche. Here, we use a unique compilation of cohort surveys linked across generations with individual register data in Norway, to track the secular trend of AAM and social gradient therein. From the sample of 99,921 women, we find that AAM has declined by approximately 5 months across cohorts born 1960-2007 and that a social gradient emerged from 1980s. In a balanced sample of 9,435 mother-daughter pairs, we find a three month difference between the highest and lowest income quintile in the daughter generation born 2002-2007, but no social gradient among their mothers born 1960-1990. Using a first difference regression, we find a stronger decline in AAM in daughters compared to their mothers if the mother grew up in household with lower socioeconomic position (0.19 years difference between the top and bottom percentile; CI: 0.06-0.31), and also if the daughter's socioeconomic position is worsened compared to that of the mother during her own childhood (0.16 years if the position drops from the top to the bottom percentile; CI: 0.06-0.26). Using relative income or relative education as indicator of socioeconomic position yielded similar results. We conclude that the earlier AAM in low socioeconomic groups is a novel trend that requires more understanding of underlying mechanisms.

I Introduction

An early age at menarche (the first occurrence of menstruation) is associated with worsened somatic and mental health both during and after adolescence, lower educational attainment, and early pregnancies and family formation (Cheng et al., 2022a; Golub et al., 2008; Udry, 1979; Lawn et al., 2020; Gill et al., 2017; Haapala et al., 2020). Due to the long-term and broad significance, age at menarche and its biosocial determinants have been a shared topic for clinical, public health, and social science research.

Of particular interest is the social gradient in age at menarche. Emerging evidence suggests that, while in older cohorts girls from families with lower socio-economic position (SEP) showed later age at menarche, it may now be that they experience earlier age at menarche than more affluent peers in more recent cohorts (Hiatt et al., 2021; Morris et al., 2011; Krieger et al., 2015). At the same time, average female pubertal timing, in particular ages at menarche and breast development, has declined over the last century across countries (Eckert-Lind et al., 2020; Leone and Brown, 2020; Parent et al., 2015). These observations raise an intriguing possibility that age at menarche, and the timing and pace of pubertal development in general, acts as one axis by which social inequalities reproduce across generations, through the association between childhood SEP and earlier pubertal onset on the one hand, and early age at menarche with relatively poor health and behavioural outcomes on the other hand (Dorn et al., 2019; Hiatt et al., 2017; Houghton, 2021).

As yet, with the current body of evidence largely based on cross-sectional comparisons by SEP, we do not fully understand whether the observed associations between SEP and age at menarche is - at least in part - confounded by factors that affect both the SEP of a household in which a woman grows up in (i.e., childhood SEP) and her age at menarche. Clarifying this point is useful to understand whether directly intervening on SEP, such as family income, could have potential benefits by preventing menarche from starting too early (Deardorff et al., 2014; Dorn et al., 2019). Factors that simultaneously affect childhood SEP and age at menarche could be either genetic or environmental. Age at menarche is a complex trait with the heritability between 0.57 and 0.82 (Dvornyk, 2012). Earlier age at menarche is also related to lower school performance and educational attainment (Gill et al., 2017), which may lead to low SEP. Thus, if a mother inherits the genetic propensity for early menarche, and attains low SEP as adult, then her daughter may start menarche earlier while growing up in a low SEP household. Similar confounding could also arise when considering that age at menarche shares genetic basis with other complex traits that may be associated with low SEP such as obesity (Howe et al., 2020; Kaprio et al., 1995). Another confounding can occur if there is an inter-generationally consistent environmental condition that affects both SEP and age at menarche. If families live in an environment of similar quality across generations, this could be another inter-generationally consistent factor. For example, existing evidence suggests that environmental pollution affects the SEP of a household by increasing income-related health inequality (Liao et al., 2023) as well as the age at menarche (Parent et al., 2015). Taken together, it is possible that genetic correlation between traits or inter-generationally consistent environment confound the association between SEP and age at menarche.

The present study uses a unique compilation of multiple cohorts data from Norway, to better understand the social gradient in age at menarche across generations. The data harbor information on recalled age at menarche from long time breadth (birth cohorts 1907-2007), and importantly, is linked through Norwegian register data to household income during childhood and parental education (birth cohorts 1960-2007). With the data, we complement existing evidence that either does not cover birth cohorts across a long stretch of time or relies on indirect or self-reported measurements of SEP. Furthermore, our data include balanced sample of 9,435 mother-daughter pairs. We use a first difference identification strategy that examines inter-generational change in SEP and age at menarche, while differencing out family-specific genetic or environmental effects that remain constant across generations and may affect both SEP and age at menarche.

Our inter-generational analysis provides an additional opportunity to answer some remaining questions regarding the current trends in age at menarche. It is currently unclear to what extent the decline in age at menarche is a shared experience across the social gradient. If the decline is more pronounced in certain social groups, then this would suggest the selection in the trend of declining age at menarche, and would occur if biological and social factors associated with earlier age at menarche tend to concentrate in certain groups. Another remaining question is whether a change in age at menarche is larger if the SEP during childhood deteriorates from the parent to the child generation. Such an association is consistent with a causal effect of SEP on age at menarche, albeit still associational. A possible causal effect could operate through increased psycho-social stress, worsened nutritional quality, smoking or other health and lifestyle behaviours associated with lower SEP. Finally, it may be the case that it is not the parental SEP that influences age at menarche of daughters, but rather that certain social groups have experienced more rapid inter-generational declines than others, and that the root causes of an earlier age at menarche can be traced back to the parents' own family background or beyond.

Several mechanisms underlying the variation in age at menarche have been proposed. The secular trend of declining age at menarche has been largely attributed to the improvement in nutrition availability. The physiological mechanism underlying pubertal development is responsive to environmental signals related to energy availability (Ellison et al., 2012). Consistent with this notion, studies from populations in energetically constrained environments have shown that age at menarche is later among girls exposed to famine (Wu et al., 2022) or from less resourceful backgrounds (Veronesi and Gueresi, 1994; Junqueira Do Lago et al., 2003; Łaska Mierzejewska and Olszewska, 2004; Lyu et al., 2014). The same studies have also shown that average age at menarche declines faster in groups with poorer nutrition. This may suggest that the social gradient in age at menarche is at least narrowing, in countries where living conditions further improve or as the secular decline slows down (Ong et al., 2006; Parent et al., 2003)

However, studies from more recent cohorts (born in late 90s and early 2000) suggest persisting differences in age at menarche by SEP, in a direction that may be 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. As more recent cohorts are unlikely to grow up in energetically constrained environments, mechanisms considered so far go beyond nutrition per se and include dietary quality, endocrine disrupting factors, maternal smoking during pregnancy, body-mass index, and family dynamics with associated early life stress (Cheng et al., 2022b). These factors often vary by SEP and thus likely form downstream mechanisms by which the positive social gradient in age at menarche emerges in recent birth cohorts. Having a comprehensive population-level assessment of the social gradient in age at menarche is a necessary step before deciphering the underlying mechanisms.

The aim of this study is to 1) examine the changes over time in age at menarche by SEP, and 2) to study the extent to which levels of and inter-generational changes in SEP can explain inter-generational change in age at menarche. First, to assess the secular trend of age at menarche by parental SEP, we combine data on age at menarche from the Cohort of Norway study (CONOR), the Trøndelag Health Study (HUNT), the Young-HUNT study, and the Norwegian Mother, Father and Child Cohort Study (MoBa), and link individuals to the register data on parental income and education available for those born after the second half of 20th century. Second, our inter-generational analysis is based on a subset of MoBa mothers and daughters for which age at menarche is available, linked to register data where we calculate SEP during childhood for both generations.

II Data and methods

A) Datasets and Samples

Our sample consisted of a total of 99,921 females in CONOR, HUNT, Young-HUNT, and MoBa, for whom age at menarche is known from surveys and SEP could be assessed through the Norwegian register.[1] 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 most of the immigrants sample. Furthermore, we have complemented CONOR which includes wave 2 of the Trøndelag Health Study (HUNT) with wave 4 from 2017-2019, and four waves of the Young-HUNT study of adolescents aged 13–19 years (Rangul et al., 2024). Lastly, MoBa is a prospective population-based pregnancy cohort with about 95,000 mothers who gave birth in 1999-2009 and their children (Magnus et al., 2006). We used data from MoBa mothers who filled out their age at menarche as the first question asked in the first questionnaire upon recruitment in week 15 of their pregnancy, and MoBa daughters who completed the 14-year-old questionnaire. For the MoBa mothers, we restricted to those who were recruited at age 25-34 years to avoid over-sampling of women whose age at delivery was either very young or old at the tails of the birth cohort distribution. For example, a mother born in 1965 would only be sampled if giving birth at the age between 34-44 during 1999-2009 when MoBa children were born. Since there is a positive correlation between age at menarche and age at childbearing (Lawn et al., 2020; Udry, 1979), the sampling would give incorrect estimates of the cohort average age at menarche in the population. We used data from all MoBa daughters who had completed

[1] This restricts the sample to women born 1960 and later.

the 14-year-old questionnaire by 2022, and these participants were born 2002-2007. For the inter-generational analysis, we constructed a balanced panel of 9,435 MoBa mother-daughter pairs for whom we know childhood SEP and age at menarche in both generations.

Survey	N	Age at Menarche	Birth Year	Year of Survey	Age at Survey
Tromsø IV	2,941	13.05 (1.34)	1960-1969	1994-1995	25-35
Hunt II	8,090	13.04 (1.32)	1960-1977	1995-1997	20-37
Hubro	3,898	13.03 (1.40)	1960-1970	2000-2001	30-41
Opphed	2,433	13.05 (1.37)	1960-1970	2000-2001	30-41
Tromsø V	352	12.92 (1.28)	1961-1971	2001	30-40
Trofinn - Troms	493	12.92 (1.31)	1962-1972	2002	30-40
Trofinn - Finnmark	287	13.05 (1.31)	1960-1972	2002	30-42
MoRo II	161	13.02 (1.57)	1961-1969	2003	34-42
MoBa mothers	52,016	13.02 (1.36)	1965-1984	1999-2009	25-34
MoBa daughters	11,341	12.74 (1.24)	2002-2007	2016-2022	14-16
Young-Hunt I	1,870	12.86 (1.34)	1976-1984	1995-1997	12-20
Young-Hunt II	762	12.91 (1.36)	1980-1983	2000-2001	16-21
Young-Hunt III	2,435	12.79 (1.39)	1986-1994	2007-2008	12-20
Young-Hunt IV	3,607	12.84 (1.36)	1996-2006	2017-2019	12-21
Hunt IV	9,173	12.97 (1.43)	1960-1999	2017-2019	19-59

Table 1: Summary of Survey Statistics

B) Measures of 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. We excluded values below 7 and above 20 years as unlikely answers. For MoBa daughters, age at menarche was asked as part of the 14-year questionnaire. Among those who filled out the questionnaire, 93.9% reported to have experienced menarche. For the 6% who had not had first menstruation at the time of filling out the questionnaire, we used multiple imputation with interval regression for censored variables. We also imputed values for respondents in the Young-HUNT surveys who had not reached menarche. The method imputes values for the censored observations based on an assumption that age at menarche is normally distributed. It furthermore corrects standard errors for the uncertainty in the regression coefficients that stems from imputation. The analysis is based on 200 imputations.

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

Variable		Mean	S.D.	Min.	Max.	N
Age at menarche	Mothers	13.02	1.37	7	20	10,141
	Daughters (imputed)	12.73	1.25	7	17.72	10,141
	Inter-generational change	-0.30	1.57	-8	6.30	10,141
Share reached menarche	Daughters	0.94	0.24	0	1	10,141
Age at survey	Mothers	30.44	4.42	17	47	10,141
	Daughters	14.41	0.51	14	16	10,141
Birth order	Mothers	1.77	0.88	1	16	10,141
	Daughters	1.89	1.08	1	14	9,693
	Inter-generational change	-0.12	1.34	-13	13	9,693
Maternal age at birth	Mothers	26.18	5.15	14	47	9,693
	Daughters	30.73	4.37	16	47	10,141
	Inter-generational change	4.48	6.36	-21	28	9,693
Parental income percentile	Mothers	0.55	0.28	0.01	1	9,435
	Daughters	0.62	0.25	0.01	1	10,088
	Inter-generational change	0.08	0.34	-0.97	0.98	9,391
Parental education percentile	Mothers	0.51	0.31	0.01	1	9,597
	Daughters	0.56	0.27	0.01	1	10,099
	Inter-generational change	0.06	0.33	-0.93	0.99	9,565
Log family income	Mothers	12.54	0.64	5.30	15.69	9,435
	Daughters	13.12	0.45	7.66	15.58	10,088
	Inter-generational change	0.59	0.72	-4.38	8.04	9,391
Parental years of education	Mothers	13.20	2.78	8	21	9,597
	Daughters	16.26	2.13	10	22	10,099
	Inter-generational change	3.06	2.83	-7	14	9,565

C) Measures of income and education

From the Norwegian register, we calculated the parental income and highest parental education level of all index 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. Because the pensionable income data is available 1967-2017, we could assess relative family income at age 7 for those born 1960 onwards.[2] We have education data for all persons encountered in the 1970 census and 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 any parent within the child birth cohort.

D) Statistical methods

We first conducted a cross-sectional analysis of the social gradient in age at menarche across 15 surveys. We applied a linear panel regression with age at menarche as outcome, and separate intercepts and linear birth cohort trends for each income quintile. The model furthermore adjusts for random effects for each health survey, to account for that the data stems from different samples.

Within the balanced sample, we run several statistical models to explore how the social gradient in age at menarche has changed across generations in MoBa. We were first interested in the levels of age at menarche by SEP during childhood in the two generations of mothers and daughters. We estimate the equation:

$$AaM_{i,g} = \beta_{1-5,g} * I_{p1-p5,g} + e_{i,g}$$

[2] In a supplementary analysis, we examined age at menarche by SEP for those born before 1960, using ranks of average income from the years when each index person was aged 30-60 ("adult SEP"). This was done for the subset of our samples who were aged 30-60 during 1967-2017.

Where $AaM_{i,g}$ 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. $\beta_{1-5,g}$ are the coefficients of interest and $I_{p1-p5,g}$ are income quintiles in each generation.

We were furthermore interested in the role of SEP in the *change* in age at menarche across generations. We used a first-difference estimator, which differences out any common factors between the mother and the daughter that may affect age at menarche. In Model 1, we estimate whether the change in age at menarche is associated with the change in SEP between the generations, and with the SEP of the mother during her childhood (lagged SEP). Due to regression-to-the-mean effects, we control for the mother's age at menarche in all equations. In Model 2, we additionally control for the change and lagged birth order and maternal age at birth, to address potential confounding by reproductive timing. We estimate the equation:

$$\Delta AaM_{i,2} = \Delta\alpha_{i,2} + \beta\Delta I_{i,2} + \gamma I_{i,1} + AaM_{i,1} + \Delta X_{i,2} + X_{i,1} + \Delta e_{i,2}$$

Where $\Delta AaM_{i,2} = AaM_{i,2} - AaM_{i,1}$, i.e., the change in age at menarche across generations. The constant, $\Delta\alpha_{i,2}$ reflects a secular change in age at menarche. $\Delta I_{i,2}$ is the change in SEP in generation 2 compared to generation 1, $I_{i,1}$ is SEP in generation 1 (lagged SEP), $AaM_{i,1}$ is a control for mother's age at menarche. In Model 2, $\Delta X_{i,2}$ and $X_{i,1}$ are changes in and lagged birth order and maternal age at birth. The analysis is carried out first with relative income (percentile rank) and then with relative years of parental education as indicator of SEP. All analyses were conducted using Stata version 18 (Statacorp, Texas).

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III Results

A) Secular changes in age at menarche by socioeconomic position

On a sample whose childhood SEP is known through the Norwegian register, Figure 1 shows that the predicted age at menarche for the poorest quintile declined from 13.1 years in the 1960 to 12.6 in 2007. For the richest quintile, age at menarche was at similar levels in 1960 but had only declined to 12.8 by 2007.

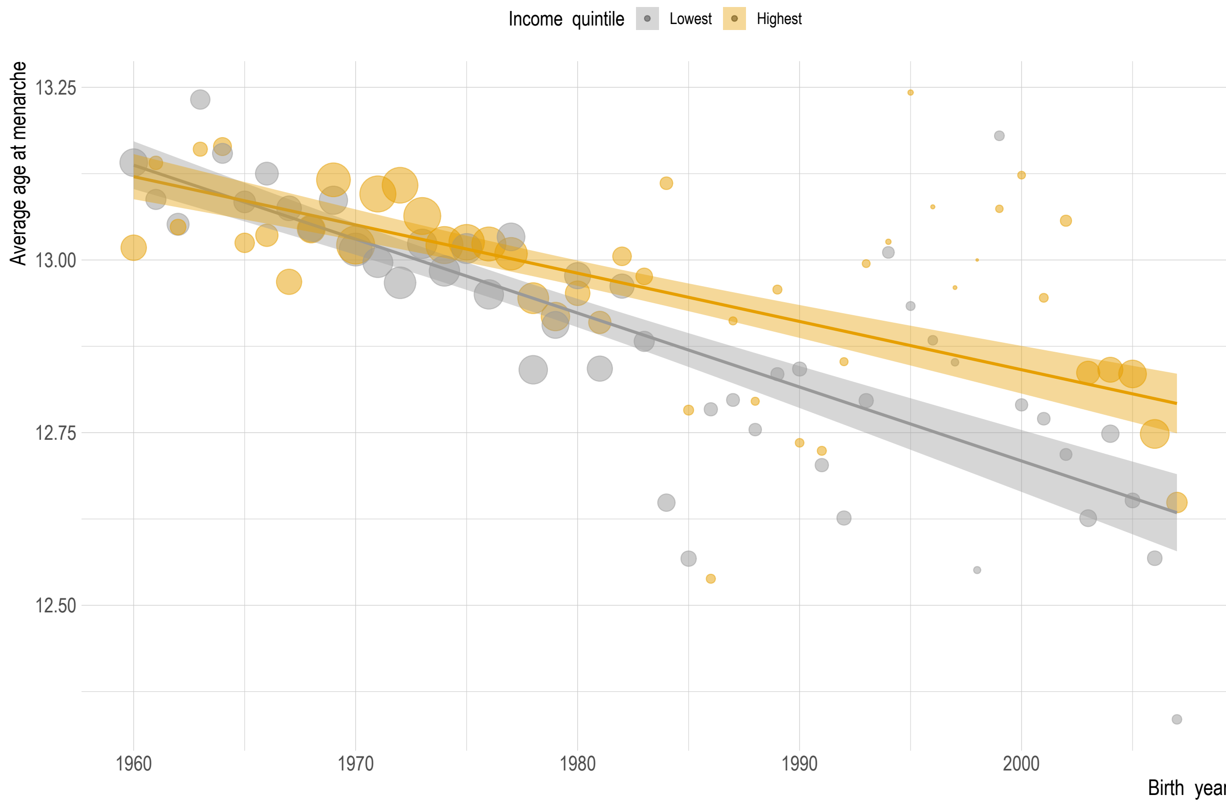

Figure 1: Age at menarche in poorest vs. richest quintile of parental income distribution at age 7

B) Inter-generational change in age at menarche

In the balanced panel of MoBa mothers and daughters, we find the emergence of a gradient in age at menarche by SEP groups from the daughters generation (Figure 2), both when SEP is measured as relative income (Figure 2, top) and education years (Figure 2, bottom). There is no clear evidence of a social gradient in the age at menarche for the mothers. For the MoBa daughters, not only has age at menarche declined compared to the mother generation in all SEP groups, but also a social gradient has emerged. Among the daughters in the bottom income quintile, age at menarche occurs about 4.8 months (-0.41 years, 95% CI: -0.53, -0.30) earlier than the mothers who grew up in the same bottom income quintile, whereas such difference is about 2.4 months (-0.20 years, 95% CI: -0.28, -0.12) for the top income quintile. Similarly, age at menarche in the MoBa daughters whose parents have lower secondary education or less is about 7.2 months (-0.62 years, 95% CI: -0.83, -0.42) earlier than the mothers whose parents have lower secondary education or less, but the difference reduces to 3 months (-0.25 years, 95% CI: -0.31, -0.20) if parents have higher tertiary education.

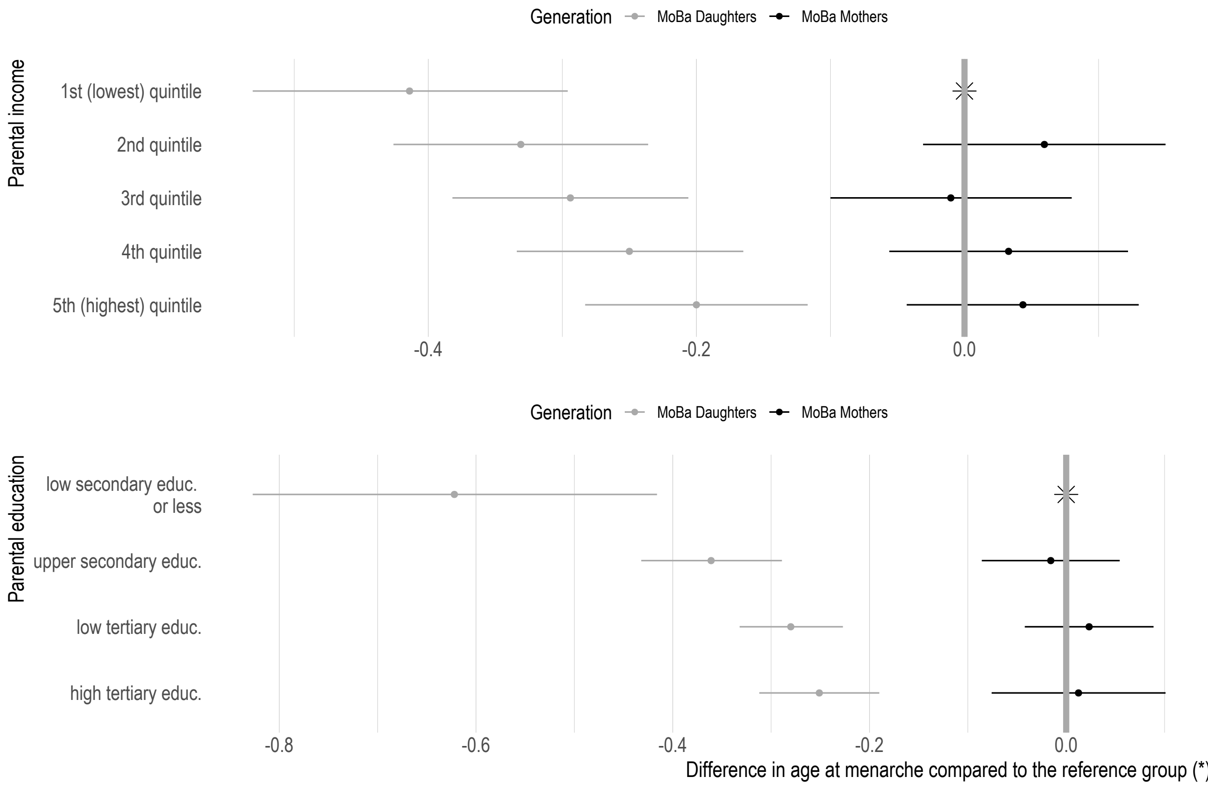

Figure 2: Regression coefficients of age at menarche among MoBa mothers (blue) and MoBa daughters (red), by quintiles of family income at age 7, compared to the lowest quintile of MoBa mothers, with 95% confidence intervals.

Next, we examined the inter-generational change *within* mother-daughter pairs. The first-difference results (Figure 3, top) show that age at menarche has decreased on average by 0.4 years (95% CI: 0.32, 0.48) in daughters, if their mothers grew up in households at the bottom of the income distribution and the relative economic situation did not improve in the daughter generation. Higher income only partially moderated this secular trend of declining age at menarche. The inter-generational decline is smaller by 0.16 (95% CI, 0.06, 0.25) for mother-daughter pairs whose relative SEP increases from the bottom to the top percentile across generations. If a mother grew up in households at the top income quintile, this also has a similar 'protective' effect against the declining age at menarche of 0.19 years (95% CI: 0.07, 0.31).

We find very similar patterns (Figure 3, bottom) if relative SEP is measured as the rank in parents' highest number of years of education. Mothers whose parents are in the top percentile in terms of years of schooling experienced a

0.13 years (95% CI: 0.02, 0.24) smaller decline in age at menarche in the next generation compared to mothers with parents in the bottom percentile. A change in parental education from being in the bottom to the top percentile was associated with a 0.11 years (95% CI: 0.02, 0.21) reduction in the decline.

The coefficient estimates remain largely unchanged if mother's age at birth and daughter's birth order are added (Model 2, Figure 3, dotted lines). Overall, these findings are consistent with both an emerging causal effect of household income on age at menarche and a larger decline in households with lower SEP causing the increasing social gradient.

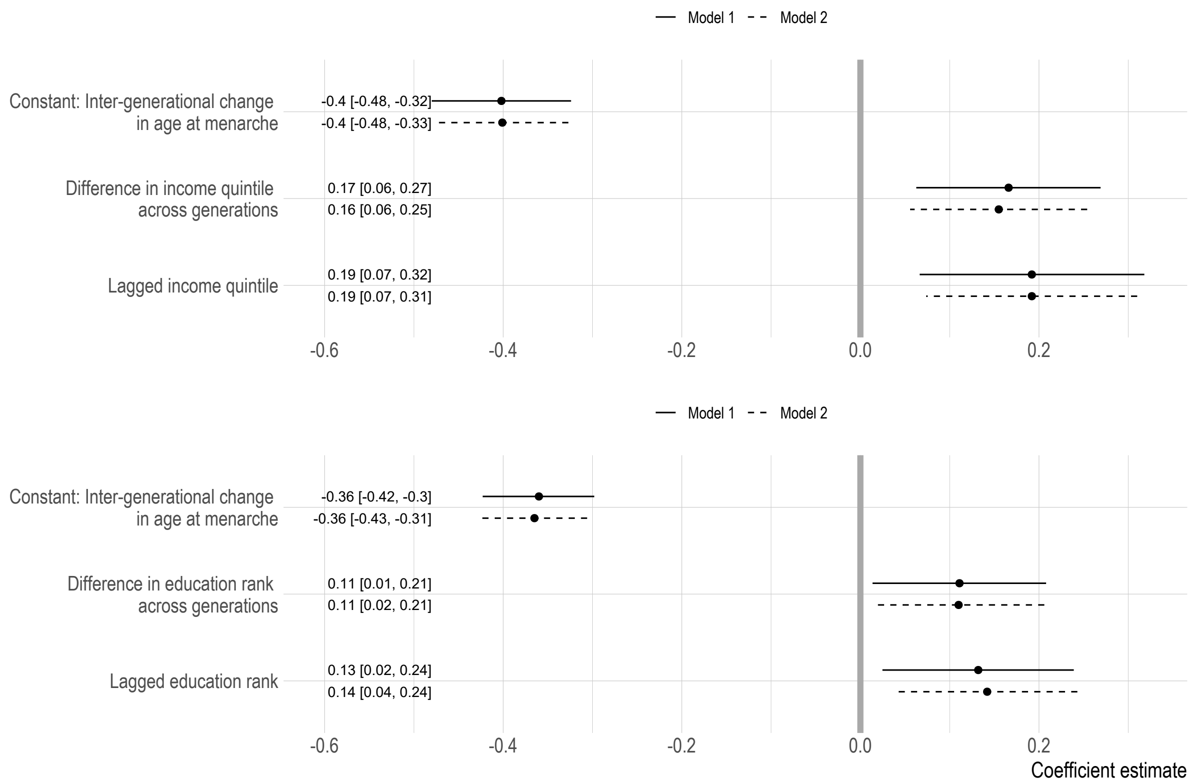

Figure 3: Regression coefficients on changes in age at menarche between mothers and daughters. Model 1 controls for mother's age at menarche only, Model 2 also controls for changes in and lagged birth order and maternal age at birth. Constants are estimated margins when the SEP ranks are set to 0 and other variables are at means.

IV Discussion

This study has shown an emerging social gradient in the age at menarche in Norway. We show that differences in age at menarche by household income quintile at age 7 starts to diverge between the lowest and highest groups from the

1980s, and that this difference continues to develop in more recent birth cohorts. Based on the balanced sample of mother and daughter pairs, we have also shown social gradient in the inter-generational decline in age at menarche. That is, age at menarche has declined across all strata of SEP but more so if a mother grew up in lower SEP household or if the income position deteriorated between the generations.

The present study has some limitations in that it is based on several surveys with varying degrees and selectivity in attrition, and that age at menarche is self-reported. A major shortcoming is that, although we used the first-difference estimation to get closer to the direct association between SEP and age at menarche, we are not able to establish causality, nor the mechanisms through which SEP is associated with age at menarche.

This study contributes to the literature in two main ways. We establish the emergence of a social gradient in age at menarche in Norway. This new social-biological phenomenon calls for further research into how early puberty in children from low socio-economic backgrounds affect their life trajectories, including impacts on their health, educational attainment, and patterns of family formation. Secondly, we show that changes in income position across generations is associated with changes in age at menarche. This is consistent with a causal effect of income on age at menarche, although causality cannot be fully established. Parental resources may affect children's BMI, their exposure to endocrine disruptors, and childhood stress, which are known risk factors for early menarche. Further research is warranted on the mechanisms through which parental income and education associates with pubertal timing.

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