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Transgenerational health effects of in utero exposure to economic hardship: Evidence from preindustrial Southern Norway

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ABSTRACT

We studied whether *in utero* exposure to economic hardship during a grandmother's pregnancy has a transgenerational effect on her grandchildren's health condition. We used an individual-level three-generation data set covering people born between 1734 and 1840 in the municipality of Rendalen in Norway. We found a culling effect in which grandchildren whose grandmothers gave birth in years of economic hardship lived approximately ten years longer than grandchildren whose mothers were born in years of economic well-being. This impact was only observed among the grandmothers who belong to the lowest social classes. Our results also showed that in higher social classes, economic hardship during a grandmother's pregnancy deteriorated her grandchildren's health by "scarring" the mother's health.

1. Introduction

A large body of economic literature has shown that shocks *in utero* can have a persistent impact on later life outcomes (Almond and Currie, 2011, 2018; Bruckner and Catalano, 2018; Currie, 2020; Lee, 2014; Lindeboom et al., 2010; Menclova and Stillman, 2020; Thompson et al., 2019; Van den Berg et al., 2009a, 2009b). Animal studies suggest that the effect of negative exogenous factors persists across multiple generations (Skinner et al., 2010), but studies spanning more than two generations are still rare in the social sciences (Van Den Berg and Pinger, 2016).

In our paper, we studied whether the grandchildren of women who suffered economic hardship were healthier or less healthy. Fetal vulnerabilities due to shocks are some of the cardinal components of adverse epigenetic[1] inheritance across generations (Franklin and Mansuy, 2010; Skinner et al., 2010). These adverse conditions not only affect prenatal development *in utero* but also remain active in the first year of life through early-life exposures (Barker, 1990). Adverse environmental shocks experienced *in utero* may do more than leave a "scar" (Almond and Currie, 2011). They can also increase fetal and early-life mortality rates. Therefore, those who are exposed to these circumstances *in utero* but survive may also be potentially selected in cases where selection is endogenous to the same adverse event as the scarring effect. As fetal mortality tends to eliminate fetuses that are in poor health, survivors of adverse fetal events are generally positively selected. One of the main issues addressed thus far in this framework is the direction and scale of the transmission of *in utero* exposure to exogenous shocks across generations (Almond and Currie, 2011). According to Almond and Currie (2011), survivors of adverse fetal events are usually positively selected, a process known as culling, because mortality tends to eliminate unhealthy fetuses. For this process to be detected, the positive impact of selection *in utero* among survivors over generations must be strong enough to dominate the negative scarring effects (Almond and Currie, 2011; Blum et al., 2017; Bruckner and Catalano, 2018; Deaton, 2007).

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[1] Skinner et al. (2010) "define epigenetics as 'molecular factors and processes around DNA that are mitotically stable and regulate genome activity independent of DNA sequence".

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Therefore, the net association between shocks *in utero* and the health of children and grandchildren is an empirical issue: it depends on the relative strength of culling and scarring. When the effect of culling dominates, we may observe no scarring because survivors are highly positively selected. When scarring dominates, a negative association between a shock and health is observed.

Only a limited number of studies have addressed how *in utero* exposure to external shock can affect subsequent generations, and their results are mixed. Lee (2014b) demonstrates that women's stress during the Kwangju uprising (1980) in South Korea negatively affected their grandchildren's birth weights. Cook et al. (2019) and Richter and Robling (2013) found that grandmothers' *in utero* exposure to the 1918 influenza pandemic lowered their grandchildren's educational performance. Conversely, Kaati, Bygren and Edvinsson's (2002) study conducted in Överkalix in Sweden found a lower ratio of cardiovascular disease-related deaths in children whose fathers had difficulties obtaining food early in their lives than in children whose fathers did not have such difficulties. Moreover, Van Den Berg and Pinger (2016) show that a grandparent's exposure to famine had a positive effect on their grandchildren's mental health. There are still many unanswered questions that warrant inquiry about whether there are positive or negative influences of *in utero* exposure to external shocks for subsequent generations. To our knowledge, research on the transgenerational effects of *in utero* shocks has not focused on the role of the relative strength of culling and scarring. Our research will help to fill this gap.

Our paper makes several contributions. First, we use rich data from the 18th and 19th centuries to look at the long-term and transgenerational health impacts on individuals. The time period we studied predated the establishment of modern medical infrastructure in Norway (Saunes et al., 2020) as well as the use of the first antibiotics (Zaffiri et al., 2012). Our study uses one of the oldest data sets available for multigenerational studies: the oldest individuals in our data set were born in 1743, and the youngest were born in 1840. The resulting simplicity of the health-related exogenous conditions within this time frame is an advantage of our data.

Second, with our individual-level data, we are able to identify families according to their social class. Exogenous shocks *in utero* can hit vulnerable groups more heavily by way of selection, while in other groups, they may yield scarred cohorts (Bruckner and Catalano, 2018). The scope for selective fetal mortality (i.e., culling) is generally found to be more prominent in situations where baseline health is poor (Almond and Currie, 2011). Therefore, we focus on the landless as the lowest social class who lived closest to the margin and therefore were not only most vulnerable to economic hardship but also had the lowest possibility of counteracting its negative effects. We thus would expect that short-term economic hardship led to higher selective mortality among this social class.

We also analyzed landowner families, who had relatively more opportunities to counter the negative effects of economic hardship. Children born to this group might suffer from the negative effects of economic hardship for life. The fetal origins hypothesis and selection *in utero* coincide with the scarring effect and similarly assume that *in utero* exposure to maternal stress increases the likelihood of having adverse health conditions later in life (Bruckner and Catalano, 2018). We anticipate that short-term economic hardship resulted in a greater scarring effect among the higher social class.

Instead of examining the direct association of exogenous shocks, health indicators, and other outcomes considered in previous literature, we use more interpretable disaggregated measures. Using mediation analyses, we explore whether the effects of economic challenges faced during pregnancy persist across generations by following the maternal line. We use the health conditions of the mother as a mediator for both high and low social classes. We show that *in utero* exposure to economic hardship plays an important role in the third generation's health condition beyond early life and adulthood. As a result, in addition to the scarring effect that is passed down through generations, we are able to present evidence of the existence of selection.

Our results suggest that the effects of *in utero* exposure to economic hardship during pregnancy persist across multiple generations. The impact of exposure differs according to the social class to which the grandmother belonged: among lower social classes, exposure to economic hardship increases longevity, which may reflect the effects of selective mortality. The most vigorous mothers survived and recovered during their infancy and childhood, leading to positive selection among the surviving grandchildren. As a result, overall negative health conditions later in life dominated the stronger portion of the grandchildren's birth cohort. However, among higher social classes, the grandchildren were scarred, and exposure decreased the longevity of the grandchildren.

This article is organized as follows. Section II provides background on our study area, the municipality of Rendalen. Section III presents the data and discusses the variables we used in the analysis. Section IV provides the methodology. Section V outlines the results. Section VI provides a discussion of our findings. Section VII presents the conclusion.

2. Rendalen

Rendalen is an inland parish in southeastern Norway, close to the Swedish border. Its population was approximately 1000 in 1733 and 2000 in 1840. Throughout the period under examination in our study, it was a vast and sparsely populated parish, with an area of more than 4000 km^2.

The main industries of the region were agriculture, animal husbandry, and forestry. Situated in a highland area with farms located 250–540 m above sea level and summer pastures located up to 940 m above sea level, the harvest seasons were significantly shorter here than further south, which had a more favorable agricultural potential. Additionally, according to the parish priest, who left a note when he finalized the 1801 census of Rendalen's population, enough grain could be cultivated only in the most fertile years. Most of the time, local people had to buy grain and spend endless hours collecting moss, brushwood, and leaves as winter fodder for livestock (Sogner, 1979, p. 260).[2]

As the population increased, farms were divided, and new settlements were built in outlying areas by the so-called *rydningsmenn* (settlers). This resulted in increased social cleavage between family households with taxable land (farmers and *rydningsmenn*) and those who lacked any such property (cotters and lodgers) (Sogner, 1979). Rendalen, according to the 1801 population census, comprised 43% farmers, 7% settlers (*rydningsmenn*), and 35% cotters, lodgers 15% (Sogner, 1979, p. 273), making Rendalen, with its two-class society, an interesting case for further elaboration of plausible mechanisms across generations. Overall, between 1733 and 1828, cotters/lodgers had lower fertility rates than farmers, but the former had a prenuptial birth rate twice as high as the latter.

In the archives of Rendalen, we can find documented examples of how higher prices led to economic hardship. During the struggles of 1742 and 1773, local granaries functioned as banks by lending out grain (Sogner, 1979, p. 433). Apart from the fact that this was necessary for survival, it also shows that the residents of Rendalen depended on cash income to pay off these loans. During both crises, the same number of grain barrels was distributed, but the price of grain was 120% higher during the latter crisis. The list of arrears shows that all loans were paid

[2] During years of hardship, bark (outer covering of a tree) was used as substitute for grain (Östlund et al., 2009). According to medical reports from the beginning of the 19th century, bark bread that contained a mix of bark meal and other types of flour did not have any observed negative consequences for a person's health. However, an unbalanced diet of bark bread made of solely bark meal could result in loss of energy, edema, and "narrow chest," and it could be fatal in some cases.

back only weeks after the 1742 crisis, but the list was still full two years after the 1773 crisis. Obviously, the poor were hit the hardest by economic hardship; 60 households, vast majority of those listed, were occupied by cotters, many of whom were registered as destitute.[3]

3. Data

The original Rendalen database covers individual life trajectories that are recorded over the generations from 1733 to 1900. Its main sources are baptism, marriage, and burial entries from church books, and individuals have been manually linked across different sources in accordance with Louis Henry's family reconstitution method (Henry, 1970). In addition to the main sources, information about confirmations, smallpox vaccinations, stillbirths, inbound and outbound migration and decennial nominative population censuses and cadastral registers were included. The construction of the database took place in several stages. First, handwritten family reconstitution cards, which were gathered and carefully stored in shoeboxes by Sølvi Sogner, formed the basis of her doctoral dissertation in 1979 (Sogner, 1979). The database was digitalized and documented in approximately 2000 in a funded project led by Sogner (Gjeldseth, 2000), and it was expanded with data for the period after 1900 by the Norwegian Historical Data Centre in approximately 2010. Today, the Rendalen database is a part of the Norwegian Historical Population Register (Norwegian Historical Data Centre and the National Archive of Norway, 2019).

To understand the association between economic hardship during pregnancy and grandchildren's health condition, we formed a unique dataset of three generations that includes 2070 children, their mothers, and grandmothers (see Fig. 1). We limited our analysis to individuals born before 1840, as the exact ages at death of the individuals who were born later are not known. The ages at death fell dramatically after 1840, as shown in Fig. 1. Consequently, the sample used for the analysis contains 798 grandchildren, 271 mothers, and 170 grandmothers, all of whom were born and died in Rendalen.

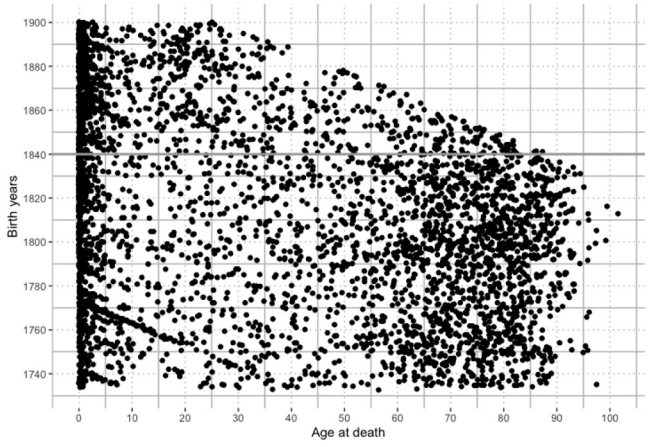

Fig. 1. Birth years and ages at death of three generations. Note: The area under the gray horizontal line displays the individuals in the sample; their ages are between 0 and 103 years, and their birth years were between 1733 and 1840. Our dataset includes 1239 individuals, of whom 798 were grandchildren, 271 were mothers, and 170 were grandmothers.

[3] More specifically, we are talking about three farmers, three settlers, 43 cotters (including five widows), and three lodgers. The likelihood of collecting on the loans was considered slim: 4 of the recipients were dead, 21 of them were described as having a moderate condition, eight were poor, and 23 o were extremely poor (Sogner, 1979, p. 434).

To determine the level of economic hardship faced during the pregnancies of the grandmothers and mothers,[4] we used the annual inflation rates between 1734 and 1840 taken from Grytten's (2018) comprehensive consumer price index (CPI) study for Norway. His study is the most recent publicly available source of data on the Norwegian historical CPI. For the period between 1736 and 1816, his main sources were the Proviant Office, price currents, merchant archives and Wedervang Archive records. Some of these sources were also located near Rendalen (see Appendix A). To establish the price index, he constructed subindices in the structure of commodity and expenditure group series. He weighted[5] commodity and expenditure groups, and 70% of this weighting was food prices (see Appendix A). Therefore, the annual inflation rates were used as an indicator of economic hardship during the period under examination.

3.1. Variables

Our data consist of three generations along the maternal line. The first generation, *grandmothers,* gave birth to at least one daughter who survived into adulthood to give birth to the second generation (*mothers*) and had at least one *grandchild* (third generation).

Rendalen was a rural two-class society in the 18th and late 19th centuries (Bull, 2005; Sogner, 1979). To understand whether the effect of *in utero* exposure to economic hardship during the grandmother's pregnancy on the health of her grandchildren differed by social class, we used the HISCLASS[6] scheme to divide our sample group into two main categories: lower and higher grandparental social class. The lower grandparental social class included mainly lower-skilled and unskilled farmworkers and cotters/lodgers. Farmer grandparents who owned land and other members of the upper classes are classified as part of the higher social class (see Appendix B).

In Table 1, we present the list of variables with their descriptive statistics.[7]

3.1.1. Dependent variable: grandchild's health

We used the age at death as a proxy for the health condition of the mothers and grandchildren: a higher age at death represents a healthier person, and a lower age indicates poor health. This measure is widely used in the literature as an indicator of quality of health (for example, see Kaati et al., 2002 and Lundborg and Majlesi, 2018). We calculated the individuals' ages by subtracting their birth dates from their death dates.

[4] Missing dates and age heaping are well-known challenges when working with historical population data. Therefore, we focused on the year of birth and called that year "during pregnancy." Approximately 10% of the mothers and grandchildren in our sample group were born in January.

[5] The figures regarding commodity and expenditure groups cover the years between 1736 and 1816, and they are presented here as percentage values in parentheses: Grain (12%); flour and bread (14%); vegetables, fruits and berries (5%); dairy products (7%); meat (13%); fish (14%); beverages and tobacco (6%); colonial goods (salt) (5%); clothing and footwear (16%); and fuel and lighting (8%).

[6] "HISCLASS is an international historical class scheme, created for the purpose of making comparisons across different periods, countries and languages". *Maas, I., & van Leeuwen, M. (n.d.). HISCLASS. Retrieved December 12, 2019, from* http://www.hisma.org/HISMA/HISCLASS.html.

[7] We examined correlation indexes to determine the correlations between all of the variables and to detect whether they are all insignificant. We have a multigenerational set of variables, which can pose the risk of multicollinearity. To be on the safe side, we conducted variance inflation factor (VIF) analysis for all models to check the probability of multicollinearity risk in our study. The results of the VIF analysis ranged from 1.016 to 2.491. As a result, we concluded that multicollinearity is not a risk factor in our analysis since the results are close to the smallest possible value for VIF (Purkayastha, 2018).

Table 1
Variable descriptions and summary statistics.

	Lower grandparental social slass					Higher grandparental social class				
	N	Mean	Standard deviation	Min	Max	*N*	Mean	Standard deviation	Min	Max
Health										
Grandchild's health	408	48.6	33.08	0	95.89	390	48.09	32.39	0	101.51
Mother's health	408	70.55	14.57	27.25	96.09	390	70.07	15.42	18.08	93.24
Grandmother's health	408	72.52	13.13	33.65	97.47	390	72.01	15.21	32.75	95.82
Macrolevel variables	*N*	%				*N*	%			
Economic hardship during grandmother's pregnancy										
No (ref)	218	53.4				192	49.2			
Yes	190	46.6				198	50.2			
Economic hardship during mother's pregnancy										
Low annual inflation (ref)	115	28.2				137	35.1			
High annual inflation	293	71.8				253	64.9			
Local-level variables										
Disease environment during grandmother's pregnancy	408	2.97	3.06	0.28	21.2	390	2.88	2.87	0.28	21.2
Disease environment during mother's pregnancy	408	2.14	0.84	0.84	5.29	390	2.11	0.86	0.84	5.29
Individual-level variables										
Parental social class										
High (ref)	122	29.9				325	83.3			
Low	286	70.1				65	16.7			
Illegitimacy of mother										
No (ref)	387	94.9				377	96.7			
Yes	21	5.1				13	0.3			
Illegitimacy of grandchild										
No (ref)	352	86.3				339	86.9			
Yes	56	13.7				51	13.1			
Vaccinated grandchild (smallpox)										
No (ref)	224	54.9				207	53.1			
Yes	184	45.1				183	46.9			
Grandchild's gender										
Male (ref)	215	52.7				212	54.4			
Female	193	47.3				178	45.6			

Note: We divided our sample group based on the grandparent's social class, as defined by HISCLASS. Those whose occupational classification was between 1 and 8 were included in the higher social class, and all others were grouped into the lower social class (see Appendix B.1.). We determined economic hardship by dividing the annual inflation rates between 1736 and 1840 into quartiles; years above and below the upper and lower quartile rates were designated as economic hardship years. The variable of child mortality rate only covers the births and deaths of children between 0 and 9 years old in Rendalen. Vaccination refers to smallpox and indicates the grandchildren who were vaccinated during their life span.

3.1.2. *Independent variables*

Our study focuses on determining whether *in utero* exposure to economic hardship during a grandmother's pregnancy has either a positive culling effect or a transgenerational negative scarring effect on her grandchildren's health conditions. Similar to Van den Berg et al. (2009a, 2009b), we used the annual inflation rates from 1734 to 1840 from Grytten's (2018) study as a primary explanatory variable for understanding the transgenerational mechanism of exogenous shocks from the grandmother to her grandchild as our proxy for economic hardship. We used annual inflation rates outside the interquartile range to determine the years of economic hardship during our time frame. We defined economic hardship as an annual inflation rate above the 3rd quartile (6.9%) or below the 1st quartile (−3.4%) (see Fig. 2 and Appendix A).

We controlled for the disease environment in Rendalen during grandmothers' and mothers' pregnancies (Borrescio-Higa et al., 2019; Quintana-Domeque et al., 2011) using the annual childhood mortality rate[8] (CMR). We also controlled for other individual-level factors known in the literature to affect health and life span, such as parental social class (Currie and Vogl, 2013), illegitimacy[9] of the mother and grandchild (Edvinsson et al., 2008; Lust, 2020; Modin et al., 2008), whether the grandchildren had received a smallpox vaccine[10] (Steckel, 2009; Van den Berg et al., 2009a, 2009b; van Dijk, 2019), and gender (Classen, 2010; Classen and Thompson, 2016). We used baptism records to determine the mother's and grandchildren's illegitimacy and used confirmation records to determine the grandchildren's smallpox vaccination status.

4. Methods

In our study, we hypothesized that there are two main mechanisms by which economic hardship during the grandmother's pregnancy with her daughter can be associated with a grandchild's life span: a positive culling effect and a negative scarring effect through the mother's health condition. Hence, we used mediation analysis (Gunzler et al., 2013; Imai et al., 2010; Thompson et al., 2019). We followed Thompson et al.'s (2019) method and employed the structural equation model (SEM)

[8] Appendix C presents the annual CMR calculation, and Appendix C.1 shows the CMR fluctuations between 1741 and 1900.

[9] Illegitimate: "not recognized as lawful offspring" *The Merriam-Webster.com Dictionary, Merriam-Webster Inc.,* https://www.merriam-webster.com/dictionary/illegitimate. *Accessed December 12, 2019.*

[10] In 1810–11, the smallpox vaccine was mandated by law, and no one could get married or be confirmed in church or attend school unless they had a certificate of vaccination or had contracted smallpox naturally (Jensen, 2009). The church kept confirmation records after children turned 15; therefore, we do not know precisely when the children were vaccinated. Due to uncertainty regarding the children's ages at vaccination, we used the smallpox vaccination variable in our model only for those aged 15 years and older (see Appendix D).

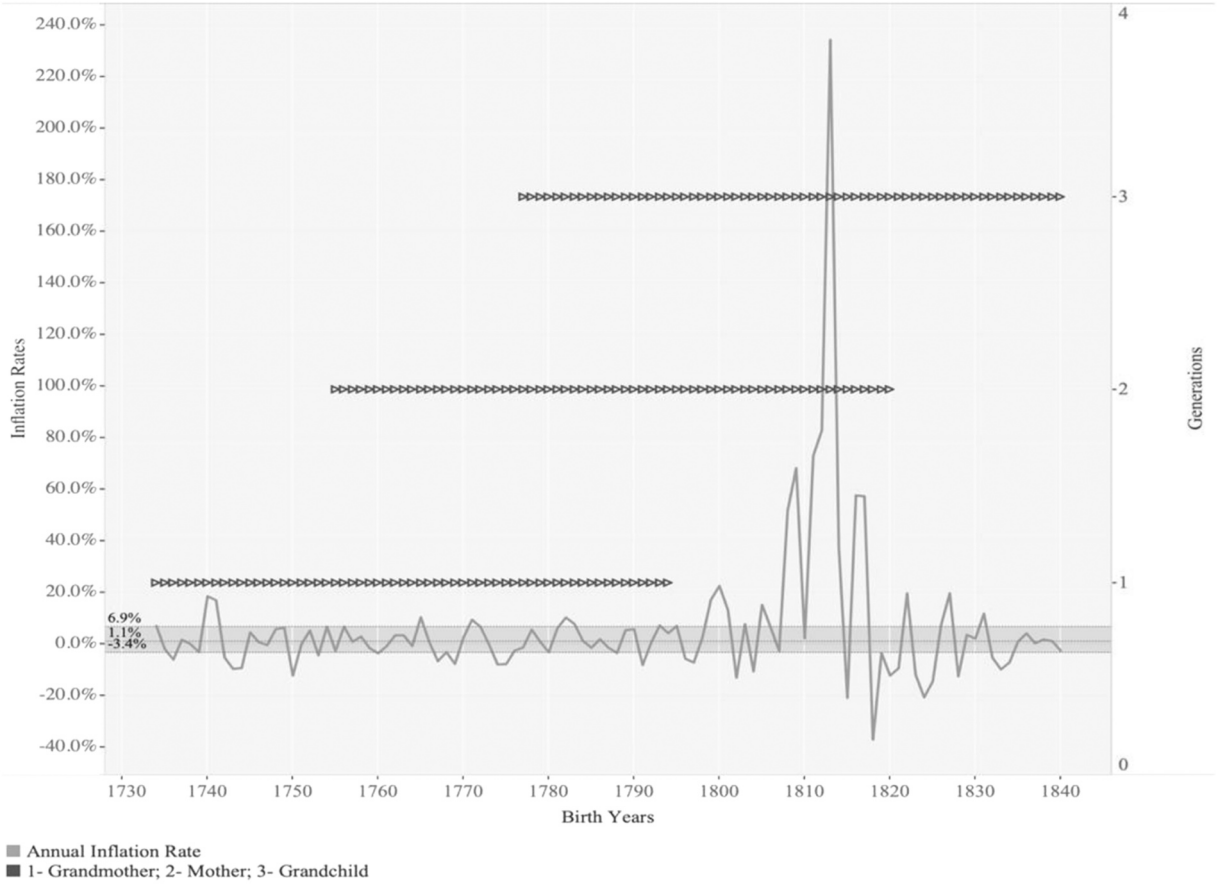

Fig. 2. Annual inflation rate and generations, from 1734 to 1840. Note: Triangles represent the birth years of the generations; 1 shows grandmothers born between 1734 and 1794, 2 shows mothers born between 1755 and 1820, and 3 shows grandchildren born between 1777 and 1840. The line graph shows the annual inflation rates over the years covered by this study. These inflation rates were calculated by the CPI data taken from Grytten's (2018) research. We divided the annual inflation rates into quartiles: the 1st quartile was − 3.4%, the 3rd quartile was 6.9%, and the median annual inflation rate was 1.1%. We used annual inflation rates outside of these quartiles, namely, below the 1st quartile and above the 3rd quartile, to determine the years of economic hardship.

approach under the sequential ignorability assumption.[11] As Gunzler et al. (2013) highlight, SEM is a conceptual model for capturing the complex and dynamic relationships within the network of observed and unobserved variables. The logic of the model is to use a path diagram and a system of linked regression-style equations. As a result, SEM simplifies the testing of transgenerational transmission of economic hardship because it is designed to test more complicated mediation models in a single analysis (Gunzler et al., 2013).

We examined the influence of the mother's health condition on the grandchild's health by separating the total effect of *in utero* exposure to economic hardship during the grandmother's pregnancy on the grandchild's health condition into two determinants: the culling effect, reflected by the average direct effect, and the scarring effect, expressed by the average mediation effect in the SEM. Thus, we fitted two models: a first ordinary least squares regression model that regressed the mother's health condition on economic hardship during the grandmother's pregnancy (*a*-path) and a second ordinary least squares regression model that regressed the grandchild's health condition on economic hardship during the grandmother's pregnancy (c'-path) and the mother's health condition (*b*-path). The models are presented below:

$$Y = i_1 + cX + e_1 \quad (1)$$

$$Y = i_2 + c'X + bM + e_2 \quad (2)$$

$$M = i_3 + aX + e_3 \quad (3)$$

$$Y = (i_2 + bi_3) + (c' + ab)X + (e_2 + be_3) \quad (4)$$

The basic conceptual framework of a mediation process is illustrated in Fig. 3. The outcome variable, *Y*, denotes the grandchild's health condition; the explanatory variable, *X*, represents economic hardship during the grandmother's pregnancy; and the mediator variable, *M*, represents the mother's health condition. In the Eqs. (1)–(3), the intercepts are denoted by $i_1, i_2,$ and i_3. *c* indicates the coefficient between *X*

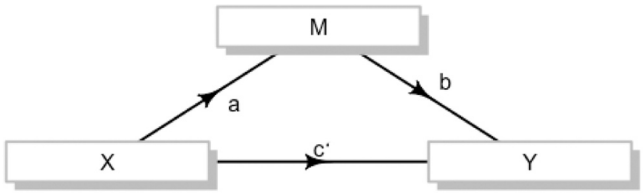

Fig. 3. The conceptual mediation model path diagram. Note: X denotes an explanatory variable, economic hardship during grandmother's pregnancy; M represents the mediator, the mother's health condition; and Y represents the outcome, the grandchild's health condition. c′ is for a direct impact on the coefficient between X and Y, fitted for M. a indicates the coefficient between X and M. b represents the effect of M for the explanatory variable on the adjuster, Y.

[11] "The treatment is firstly assumed to be ignorable given the pre-treatment covariates, and then the mediator variable is assumed to be ignorable given the observed value of the treatment as well as the pre-treatment covariates" (Imai et al., 2010).

and Y, and the total effect, $c^{'}$, indicates the average direct effect on the coefficient linkage of X on Y, fitted for M. a indicates the coefficient between X and M. b represents the effect of M for the explanatory variable on the adjuster Y. According to the sequential ignorability assumption, residuals ($e_1, e_2,$ and e_3) are not correlated with the variables, and they are independent of one another (*the results of the sensitivity analysis also support this; see Appendix E*) (Imai et al., 2010; Zhang et al., 2016). M is a subset of Y, and to obtain the mediation analysis equation in Eq. (4), we replaced M in Eq. (2) with Eq. (3). In Eq. (4), the product coefficient of ab is a denotation of an average mediation effect. We calculated the total effect by multiplying the a-path coefficient by the b-path coefficient and adding the $c^{'}$-path coefficient ($c^{'} + ab$). Like Thompson et al. (2019), we used 5000-simulation bootstrapping to increase estimation accuracy at 95% confidence intervals since the average mediation effects tend to be skewed.

With this approach, we tested the existence of a mediation effect that fits the three linear regressions separately and tests the null hypothesis; $a = 0$, $b = 0$, $c = 0$ and $c^{'} = 0$ (Imai et al., 2010). To conclude that the transgenerational effect of economic hardship during a grandmother's pregnancy affects consecutive generations as a culling effect, we must determine that the c'-path p-value is significant and that the coefficient is greater than zero. Conversely, to determine the transgenerational scarring effect through the mediating effect of the mother's health, the model must meet the following criteria: First, the confidence interval for the scarring effect should not contain zero; second, the p-values of the a-path and b-path must be significant; and third, the p-value of the c'-path must be insignificant (Thompson et al., 2019).

5. Results

As a result of the mediation analyses, we found evidence of both the positive culling effect in the lower social class and the negative scarring effect in the higher social class. As shown in Fig. 4(A), the average life span of grandchildren whose mothers were in the lower social class and were born in years of economic hardship was 10.2 years longer than that of grandchildren in the lower social class whose mothers were born in economically better-off years. Notably, in our model, we found a significant result on the c'-path, but not a significant effect on the a-path or the b-path. Hence, we see that the effect of economic hardship during the grandmother's pregnancy "skipped" the mother's generation, which provides evidence in support of the culling effect.

However, first, we need to state that unlike in Fig. 4(A), Fig. 4(B) shows a negative and significant relationship between economic hardship during the grandmother's pregnancy and the grandchild's health condition for the higher social class. For the higher social class, the average life span of a grandchild whose grandmother endured economic hardship during her pregnancy was 1.3 years shorter than that of a grandchild whose grandmother was not pregnant during an economically challenging year. Second, we see that economic hardship during the grandmother's pregnancy had a significant and negative impact on her daughter's life span, shortening it by 4.2 years. Third, we found that a one-unit increase in the mother's health condition could result in a 0.3-year increase in the life span of her child. A sensitivity analysis yielded similar results (see Appendix E). As a result, the criteria for the transgenerational scarring effect were met by significant a-path and b-path and a nonsignificant c'-path. This result shows a transgenerational negative scarring effect of economic hardship *in utero* for the grandchild of a grandmother from the higher social class.

We also obtained some other expected results from regression models (see Table 2). We found that within the higher social class, a worse disease environment during the grandmother's pregnancy resulted in a decrease of the grandchild's average life span by 1.1 years, while greater *in utero* exposure to disease environment during the mother's pregnancy resulted in a decrease of the grandchild's average life span by 5.3 years. In addition, being born out of wedlock had a significantly negative impact on grandchildren's life span, regardless of their grandmother's social class. Additionally, the impact of being a woman born into a lower social class was statistically significant; their average life span was 6.5 years longer than that of men.

6. Discussion

In our study, we used rich 18^{th-} and 19th-century individual-level data from the municipality of Rendalen in Norway, one of the oldest data sets used in transgenerational studies in the social sciences. We were able to identify families' social classes using individual-level data that includes three generations, and we investigated the transgenerational effect of *in utero* exposure to economic hardship as an exogenous shock during the grandmothers' pregnancy. Our study provides evidence to support the hypothesis that economic hardships during a grandmother's pregnancy have a transgenerational impact on her grandchildren's health condition by focusing on the role of the relative strength of culling and scarring.

Our results indicate that for a grandchildren born to a family in the lower social class, there is a positive and significant relationship between economic hardship during the grandmother's pregnancy and the grandchild's health. To test the robustness of our finding, we reduced our sample size by age at death, based on the work of Lindeboom and van Ewijk (2015) (see Appendix D). In conclusion, considering our findings in conjunction with the results of parallel testing of subsets of samples, it appears unlikely that the culling effect occurred solely by chance.

The question is as follows: when a mother is born in a year marked by economic hardship, why did low-status grandmothers' grandchildren live longer? In the literature, the results of most intergenerational studies (e.g., Lee, 2014b; Cook et al., 2019) show the consecutive effects of exogenous influences across generations. Additionally, as Van Den Berg and Pinger (2016) stated, it is crucial to distinguish this transgenerational influence from parental effects. Following this, one plausible explanation is that the observed economic hardship resulted in a positive selection among grandmother births in the lower social class,

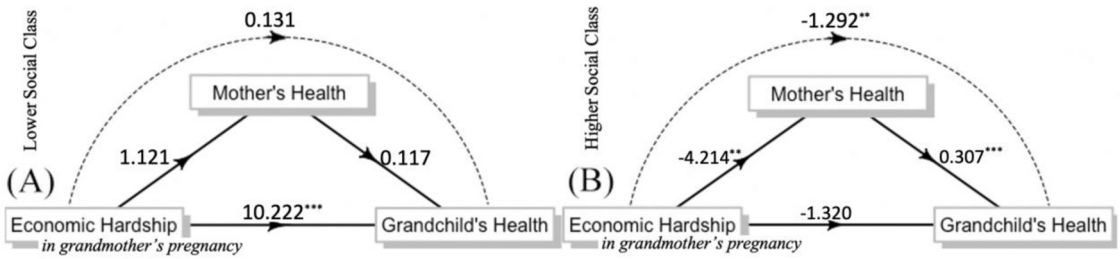

Fig. 4. The results of the mediation analysis for all ages presented in the models. Note: (A) presents a positive culling effect of economic hardship during the grandmother's pregnancy on the grandchildren's health condition for the grandmothers in the lower social class; (B) illustrates the transgenerational scarring effect of economic hardship during the grandmother's pregnancy in the higher social class. Dashed lines demonstrate the result of multiplying the a-path coefficient by the b-path coefficient. *p < 0.1; * *p < 0.05; * **p < 0.01.

Table 2
The intergenerational effect of *in utero* exposure on health conditions.

	Dependent variable: Grandchild's health		*Dependent variable: Mother's health*	
	Lower social class (1)	Higher social class (2)	Lower social class (3)	Higher social class (4)
Grandmother → Grandchild				
Economic hardship	10.221***	-1.320		
	(3.935)	(3.648)		
Grandmother's health	0.099	-0.075		
	(0.125)	(0.114)		
Disease environment	-0.288	-1.072*		
	(0.536)	(0.585)		
Parental social class	-0.460	-0.976		
	(3.506)	(4.301)		
Illegitimacy of the mother	-1.097	-12.642		
	(7.198)	(8.901)		
Birth year time trend	0.505*	-0.022		
	(0.284)	(0.278)		
Mother → Grandchild				
Economic hardship	-1.807	-0.654		
	(3.618)	(3.526)		
Mother's health	0.117	0.307***		
	(0.109)	(0.105)		
Disease environment	0.814	-5.265***		
	(2.015)	(1.927)		
Illegitimacy of the grandchild	-25.965***	-18.723***		
	(4.817)	(4.911)		
Female	6.517**	-2.948		
	(3.161)	(3.185)		
Birth year time trend	-0.823***	-0.353		
	(0.281)	(0.284)		
Grandmother → Mother				
Economic hardship			1.121	-4.214**
			(1.774)	(1.782)
Grandmother's health			0.181***	0.080
			(0.056)	(0.055)
Disease environment			0.356	-0.376
			(0.242)	(0.287)
Illegitimacy of the mother			2.068	-4.918
			(3.249)	(4.365)
Birth year time trend			-0.118**	0.048
			(0.058)	(0.061)
Constant	73.938***	82.739***	62.440***	64.236***
	(19.658)	(18.178)	(4.968)	(4.849)
Observations	408	390	408	390
R^2	0.128	0.114	0.037	0.029
Adjusted R^2	0.102	0.086	0.025	0.017
Residual std. error	31.350 (df = 395)	30.970 (df = 377)	14.387 (df = 402)	15.290 (df = 384)
F statistic	4.839*** (df = 12; 395)	4.034*** (df = 12; 377)	3.112*** (df = 5; 402)	2.310*** (df = 5; 384)

Note: We examined two different sets of models based on the differences in dependent variables; one was the grandchild's health condition, and the other was the mother's health condition. According to the grandparents' social class, we divided the sample groups into higher and lower classes. Grandmother's health, mother's health, and disease environment were continuous variables. We used the smallpox vaccination variable in our model only for those aged 15 years and over (see Appendix D). Standard errors are presented in parentheses;

* $p < 0.1$;

** $p < 0.05$;

*** $p < 0.01$.

where the subsequent birth-cohort outcomes (mothers) were improved by eliminating the weakest individuals. According to Almond and Currie (2011), survivors of adverse fetal events are generally positively selected because mortality tends to remove those in poor health, and the positive culling effect among survivors was strong enough to dominate the negative effect of scarring. Another potential explanation for the transgenerational effect in the lower social class is that the grandmother's exposure to economic hardship during pregnancy has nonbiological consequences, such as effects on behaviors toward offspring, education within the household, and the model of upbringing adopted (Van Den Berg and Pinger, 2016). However, it is challenging to conclude that this transmission from grandmother to grandchild is due to biological or cultural inheritance.

For the higher social class, economic hardship during the grandmother's pregnancy had a significant and negative effect on the grandchild's health condition. This result shows evidence of the negative scarring effect. If a grandmother from a high social class gave birth during a year of economic hardship, and her daughter could survive beyond reproductive age, then the adverse effect of economic hardship might be expected to be passed on to the grandchild. We can argue here that this negative scarring effect is in line with the fetal origin hypothesis (Almond et al., 2018; Bruckner and Catalano, 2018) regarding a stress mechanism during pregnancy. Here, the transgenerational transmission of health is consistent with Classen and Thompson (2016) and Coneus & Spiess (2012). Additionally, in Serpeloni et al. (2017), they underline the biological mechanism that has a mediating role in the transmission of stress to subsequent generations. Here, epigenetic inheritance can be described as the development of germ cells (future grandchild) in the fetus (mother), which develop in the body of the grandmother.

On the other hand, because our mediation models were unlikely to account for all potential confounders, we provide evidence of

associations rather than causal relationships. Although the literature claims that mediation analysis is based on the assumption that no confounders influence both the mediator and the outcome (Coffman, 2011), mediation analysis has the same assumptions as standard regression (Thompson et al., 2019). As Thompson et al., (2019, p. 113) said, "while a more nuanced, less certain interpretation is warranted, it does not mean that mediation analyses are ipso facto not worth undertaking". Even if we do not have the results to present causal chains based on the mediation analysis in this study's findings, the associations we found will support future research on transgenerational studies.

Furthermore, broader and more current data covering multiple generations may help to establish a higher degree of accuracy and provide new evidence on the effects of earlier generations' environmental exposure on their descendants.

7. Conclusion

Our study investigated whether *in utero* exposure to economic hardship during a grandmother's pregnancy has a transgenerational effect on her grandchildren's health condition. We used rich historical individual data collected for the Rendalen municipality in Norway in the 18th and 19th centuries. One of the most important findings to emerge from our study is that among grandchildren born to a family from the lower social class, there was a positive and significant relationship between economic hardship during the grandmother's pregnancy and the grandchild's life span. This discovery is significant evidence of a positive culling effect in the context of transgenerational transmission. Additionally, the findings show that economic hardship had an impact not only on the lower social class but also had a negative scarring effect on subsequent generations of the higher social class. These findings provide important insights into the three-generation pathway that was studied to show how *in utero* economic hardship influenced consecutive generations' health conditions. Future research can also provide new evidence regarding the impact of previous generations' environmental exposure on their descendants by using broader and more recent data covering several generations.

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CRediT authorship contribution statement

Emre Sari: Conceptualization, Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization, Project administration. **Mikko Moilanen:** Conceptualization, Supervision, Resources, Writing - Review & Editing. **Hilde Leikny Sommerseth:** Resources, Data Curation, Writing - Review & Editing.

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Declarations of interest

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ehb.2021.101060.

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