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Research Article

Sibship size and height before, during, and after the fertility decline: A test of the resource dilution hypothesis

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Stefan Öberg[1]

Abstract

BACKGROUND
There is still much to learn about the explanation for the often-found negative association between sibship size and different child outcomes. A plausible explanation is resource competition between siblings in larger families, as suggested by the resource dilution hypothesis.

OBJECTIVE
This study contributes to our understanding of these mechanisms by investigating the association between sibship size and height before, during, and after the fertility decline to test predictions based on the resource dilution hypothesis.

METHODS
The investigation is conducted using information from universal conscript inspections linked to a longitudinal demographic database. Regression analyses estimate a model derived from the resource dilution explanation and analyze the association between sibship size and height among men born in 1821–1950 in southern Sweden.

RESULTS
The results show that the association between sibship size and height was negative from the mid-nineteenth century until the mid-twentieth century. There is no association in the early nineteenth century. The strength of the association is gradually weakened over time for men born from the 1840s until the 1940s. It is most consistent among men born from 1881–1921, corresponding closely to the time for the fertility decline in the area. The association is not a result of confounding by observable demographic or socioeconomic differences between families.

CONCLUSIONS
The results are in line with resource dilution being an important explanation for the negative association between sibship size and height. Resource dilution in larger families still seems to be dependent on the societal and historical context.

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1. Introduction

A negative association between the number of children in a family, the sibship size, and the heights of the children has been shown many times for 20th century populations in high-income (Douglas and Simpson 1964; Olivier and Devigne 1983; Mednick et al. 1984; Lawson and Mace 2008; Suliga 2009) and low-income countries (Desai 1995; Jordan et al. 2012; Manley, Fernald, and Gertler 2012), even though no association has been found in some populations (Desai 1995). A negative association between sibship size and the children's outcomes has not only been observed with regard to height, but also, and in an even larger number of studies, with regard to the children's educational outcomes and social mobility (Blake 1981, 1985; Downey 1995, 2001; Sacerdote 2007; see also the review by Steelman et al. 2002).

The association between sibship size and child outcomes is thus firmly established, at least in 20th century high-income populations. Much less is known about the mechanisms that lead to these negative associations. The most-used explanations are resource dilution in larger families and confounding. The mechanisms behind the negative associations have implications for our understanding of family dynamics and behavior, and also for our understanding of the demographic transition (e.g., Becker 1993). The presence of the associations in historical populations also has implications for, for example, unified growth theory (Galor 2012) or the theory of the technophysio evolution (Floud et al. 2011). Both theories assume that resource dilution affects child outcomes and this is the most important (Galor 2012), or one of several (Floud et al. 2011), mechanism(s) generating dynamic effects in the models.

The fertility decline has also been proposed as an explanation for the secular increase in height and improving health of children from the late 19th century onwards (Reves 1985; Weir 1993; Schneider 1996; Hatton and Martin 2010a). Hatton and Martin (2010a), for example, retrospectively extrapolate based on cross-sectional data from 1930s Britain and suggest that about 25% of the increase in height should be attributed to the fertility decline. These suggestions also make it interesting to test how the association between the sibship size and the living conditions of children has developed longitudinally.

This paper contributes to the discussion on the causes behind the negative association between the sibship size and the living conditions of the children by investigating how the association between sibship size and height has changed over time. The study uses individual-level data from the Scanian Economic Demographic Database (SEDD) on the population in a confined geographical area in southern Sweden from 1821 until 1968 (Bengtsson, Dribe, and Svensson 2012). The database contains longitudinal data on demographic events, household structure, occupations, and landholding and has now been linked to heights from universal conscription inspections of men born in 1797–1950 (Öberg 2014a: Paper 5).

The long time period covered by the data used here makes it possible to test for differences in the association before, during, and after the fertility decline. If resource competition within families is an important explanation for the negative association between sibship size and child height, we should expect that the association is influenced by the average level of income. The resource dilution hypothesis therefore leads us to expect that the association between sibship size and child height has become more weakly negative over time. Other developments of the association than becoming more weakly negative over time require other explanations or that the behavior or social conditions of families have changed over time. More frequent or severe exposure to disease of children in larger families is one possible alternative or complementary explanation. While it is not possible to discriminate here between influences on growth and height from nutrition and disease it is not obvious that any negative influence from disease would become weaker over time. To the extent that disease exposure is influenced by housing quality and other preconditions for good hygiene, it is not separate from the resource dilution explanation.

The detailed longitudinal information in the SEDD also makes it possible to investigate the causes further by testing how much of the association can be explained by potential confounders. This provides excellent opportunities to test the resource dilution hypothesis through the following two research questions, addressed in this paper. Firstly, what was the association between sibship size and child height before, during, and after the fertility decline? Secondly, can the association be explained by confounding by observable differences between the families?

2. Previous research

Differences in height between individuals and families are strongly influenced by genetic factors, but systematic differences between other groups are a result of environmental influences (Eveleth and Tanner 1990). The different average heights of children with many or few siblings reflect differences between these groups in their standards of living during growth. Plausible explanations for the negative association between the number of children in the family and their heights include resource competition within families and confounding, i.e., that families with many children are different from families with fewer in some observable or unobservable way. Resource competition implies that the association between the number of siblings and the child height is causal, i.e., that it is the number of children that are causing the worse living conditions in the larger families. This explanation has been termed the resource dilution hypothesis (Blake 1981, 1985; Downey 1995, 2001; see also Steelman et al. 2002).

The dilution of parental resources, and hence competition and resource scarcities in large families, is probably the most-used explanation for the negative association between sibship size and child outcomes, explicitly or implicitly (see e.g., Becker 1993). The resource dilution hypothesis has received a great deal of support in previous research (Downey 1995; Hertwig, Davis, and Sulloway 2002; Jæger 2009; Lawson and Mace 2009; Bras, Kok, and Mandemakers 2010; Lordan and Frijters 2013). If resource competition and scarcities within families, affecting nutrition and/or disease exposure, are important negative influences on heights in large families, we would expect the association to become weaker with rising real incomes (compare also e.g., Becker 1993: Ch. 6 and esp. 271).

Individual heights are largely determined by genetic and other biological factors, but are also, as mentioned, affected by environmental influences during childhood and adolescence. Negative environmental influences, such as suboptimal nutrition or disease, hinder individuals from reaching their genetic and biological height potential. When all the requirements and needs are met, more resources, for example nutritional, will have few positive influences on growth (Steckel 2008). Heights are consequently a better measure of resource deficiencies than of abundance. With rising real incomes we therefore also expect that children with many siblings will obtain enough resources to attain their height potential, even if resources are relatively scarcer in large families than in smaller ones. While desires for different kinds of consumption can change over time and thus change the meaning of limited resources alongside income levels (e.g., Alter 1992), human nutritional needs have not experienced any dramatic changes over the last 200 years. If resource dilution is an important explanation for the negative association between sibship size and child height, we can therefore safely expect rising real incomes to weaken the negative association.

The more or less explicit assumptions in the resource dilution hypothesis (as well as in e.g., Becker 1993) are that the limited and fixed resources provided by the parents are shared among all the children in the family without any economies or diseconomies of scale in the household production (for a discussion on the assumptions, see e.g., Desai 1995; Downey 2001 or Hertwig, Davis, and Sulloway 2002). If there are fundamental differences in the validity of any or several of these assumptions in different periods of time, then the association between family size and child heights could also change over time. Increasing costs of raising children and/or the costs of children falling increasingly on the biological parents could, for example, counteract the effect from a rising average level of income. Changing social patterns in living conditions and fertility behavior would also lead to the confounding of the association changing over time.

The negative association between sibship size and height has been highly persistent over time since the 1930s in both Britain (Rona, Swan, and Altman 1978;

Hatton and Martin 2010a, 2010b; Kuh and Wadsworth 1989; Li, Manor, and Power 2004; Mascie-Taylor and Lasker 2005; Li, Dangour, and Power 2007) and Sweden (Cernerud 1993). There are some possible signs of a weakening of the association over the 20th century in both countries. Cernerud (1993) investigates the association among schoolchildren in Stockholm born in 1933, 1943, 1953, and 1963. He finds that the effect is about 20% weaker for the 1963 cohort than for the 1933 cohort. Li and Power (2004) find a similar decline when comparing the members of the British 1958 birth cohort with their offspring (born 1973–1987). Cernerud (1994) further finds no effect of the number of siblings on height among schoolchildren in Stockholm born in 1981. These results indicate a weakening of the relationship over time in these high-income populations, just as predicted if the association is caused by resource dilution.

Nothing is known about the association between sibship size and child height among those born before c.1930. If resource competition and scarcity are the causes, we would, as discussed, expect the association to be stronger in the 19th and the early 20th century than later. A few studies consider how the association between sibship size and other child outcomes, for example educational and social attainment, has changed over the very long run. Bras, Kok, and Mandemakers (2010) find that the negative effect of sibship size on chances for social status attainment in the Netherlands strengthened from the mid-19th to the early 20th century. Regarding social mobility, Van Bavel (2006) and Van Bavel et al. (2011) find negative effects of having many siblings during the fertility decline around 1900 in Belgium but do not investigate whether the effect changes over time. Studies on late 20th-century Indonesia (Maralani 2008), China (Lu and Treiman 2008), and Brazil (Marteleto and de Souza 2012) show that the relationship between sibship size and educational attainment has changed over time because of societal development and changing policies. The results of these studies are in line with the assumption that societal and economic changes can increase the parental costs of children over time and/or strengthen the confounding of the association.

The empirical results regarding the strengthening of the negative association between sibship size and child outcomes are strongly linked to education and other investments in human capital. Resource dilution might be less influential on children's heights than on, for example, their schooling. Parents are more likely to make sure they have enough resources to feed all their children than enough to educate them all, in line with Maslow's hierarchy of needs (compare also Downey 2001). If resource dilution, affecting nutrition and/or disease exposure, is an important explanation for the negative association between sibship size and child height, our first guess would therefore still be that the association has become weaker over time with rising real incomes. Because we would expect all parents to try to do their best to feed and care for their children, any negative association between sibship size and height would provide support for resource scarcities in large families.

An alternative explanation is, as mentioned, that families with many children are different from families with fewer in some observable or unobservable way that also affects the living conditions of the children. It could be, for example, that families with lower socioeconomic positions on average have more children than families with higher socioeconomic positions. The association between the number of children in the family and their living conditions is then confounded by the families' socioeconomic position and the number of children cannot be considered the (only) cause behind the association.

Previous studies have shown that confounding by observable or unobservable characteristics can be part of the explanation for the negative association between sibship size and child outcomes. Millimet and Wang (2011) find a negative effect on height from having more than one sibling in late 20th-century Indonesia, also when controlling for the possible endogeneity of the fertility choice. However, the effect is fully explained by differences between families in place of residence and parents' ages and level of education. The negative effect of family size on height in the 1958 British national birth cohort is also weakened a lot (the coefficients are weakened by more than 50%) when adjusting for parental heights and other controls (Li, Manor, and Power 2004; Li, Dangour, and Power 2007; see also the similar results in Lawson and Mace 2008 and Lordan and Frijters 2013). The relationship between the number of siblings and height in the 20th century thus seems to be interrelated with other family characteristics that more consistently influence height.

That part of the association is explained by socioeconomic control variables should make us aware that even larger parts could be explained if we had better control variables. There could also be other differences between the families that affect the association that are even harder to observe and control for, such as differences in parental behaviors, preferences, or abilities. Some results from late 20th-century populations suggest that mothers who have unintended or unplanned pregnancies are also more likely than others to be associated with circumstances and/or behaviors that can affect fetuses and children negatively (Gipson, Koenig, and Hindin 2008). Zaba and David (1996) show convincingly that the risk of infant and child mortality is unevenly distributed between women but that the risk is most often uncorrelated with the number of children the women have. They do find a small (<5%) group of women with increased risk of child mortality who also had an unusually large number of children with short birth intervals. Kippen and Walters (2012) find similar results when studying a population in 19th-century Belgium. If the characteristics of the parents who chose to have few or many children changed over time, this could also have changed the association through strengthening or changing confounding. We investigate this here by considering how much the association changes in the different sub-periods when we adjust for confounding while allowing the effect from the confounding variables to vary over time.

3. Description of the data

The data used come from the Scanian Economic Demographic Database (SEDD), which covers the population in five closely situated rural parishes in southern Sweden: Kävlinge, Hög, Kågeröd, Sireköpinge, and Halmstad (M) (Bengtsson, Dribe, and Svensson 2012). The database is a collaborative project between the Regional Archives in Lund and the Centre for Economic Demography at Lund University and has been underway since 1983 (Reuterswärd and Olsson 1993). All individuals born in or migrating into the included parishes are followed from birth or entry until death or out-migration. The database has been constructed from catechetical examination registers (*husförhörslängder*) and has been linked to tax registers (*mantalslängder* and *inkomstlängder*) and checked against church books on births, marriages, migrations, and deaths (Dribe 2000). The data include all demographic events as well as information on occupations and landholding. Moves into and out of households are known from the catechetical examination registers. People moving into and marrying in the parishes before 1896 have been traced to their parish of origin to collect information on the socioeconomic status of the family at their birth.

Men born between 1797 and 1950, with a known family background and whereabouts around the time of conscription, have been traced in lists from universal conscript inspections (Öberg 2014a). About 80% of the men searched for in the lists were successfully linked. The populations in Kävlinge, Hög, and Kågeröd were included for the full time period. The creation of the longitudinal demographic database is highly labor intensive and time consuming. The data covering the populations in Sireköpinge or Halmstad (M) after 1895 were not yet completed when collecting the conscript data.

The conscript inspections were organized in a similar way throughout the studied period (Öberg 2014a: Paper 5). They always included a physical inspection and a height measurement. The men were then either accepted for conscript training or freed from duty if they were deemed unfit to benefit from the training. Up until 1860 there was a formal minimum height requirement to be accepted and an effective requirement was in practice in place until 1886. The age of conscription was 21 years from 1818 until 1914 (birth cohort 1893). It was lowered in 1914 (birth cohort 1894) to 20 years, in 1949 (birth cohort 1930) to 19 years, and in 1954 (birth cohort 1936) to 18 years. Some men appeared for inspection before or after the age of conscription but more than 90% were of the age for compulsory inspection or one year older.

In this study we use a sub-sample of the conscripted men. The measure of sibship size used here is a time-weighted average of the number of children present in the family during the first ten years of the man's life. The men included in the sample therefore have to have lived for at least some part of their life from birth until the age of ten years in the database parishes. All the men included in the sample were born between 1821 and 1950 and were aged between 17 and 25 years at inspection. We only include men with mothers aged 17–50 years at their birth, to reduce the risk of errors in the data. The socioeconomic status of the head of household, usually the father, at the birth of the child is used for the socioeconomic variables. This reduces the difference in the information available for migrant and non-migrant families. Only men with information on the occupation and/or landholding of their family at their birth are included in the sample. Two men with heights below 140 centimeters have been excluded as potentially influential outliers. The final sample consists of 3,651 men from 2,322 families. The truncated regressions are in practice estimated using only the 3,320 observations (from 2,176 families) with information on height and for whom the height is above the minimum height requirement.

4. Method

As described above, there was a minimum height requirement in place during most of the 19th century. The height of men freed from conscription duty was not recorded in the lists until the latter part of the 19th century. For most of the 19th century, and especially among men born during the first half, there are therefore quite a few men with no information on their height in the inspection lists (Table 2). This led to a shortfall of heights at the lower end of the distribution (Öberg 2014b). Truncated regressions estimated using maximum likelihood were therefore used to account for this problem (Komlos 2004).[2] Many of the men lacking information on their height were shorter than the minimum height requirement. The implicit assumption of the truncated regressions used is that all were shorter than the minimum height requirement. This is most likely not true but was deemed sufficiently accurate for using the truncated regressions.

The data hold different numbers of observations for different families. Large families and/or families with many sons can add more observations to the analyses. This is compensated for here by weighting the observations by the multiplicative inverse of the square root of the number of inspected sons in the family. For example, in

[2] The truncation points used are 160.5 cm for men born 1813–1842, 160 cm for men born 1843–1865, and 156.9 cm for men born 1887–1950. See Öberg (2014a), Paper 5, or Öberg (2014b) for further discussion on the shortfall and truncation points.

the cases in which there are four men from the same family in the sample, each of the four brothers is down-weighted to add the equivalent of a one-half observation to the estimated regressions ($1/\sqrt{4} = 0.5$). We chose this, admittedly somewhat arbitrary, weighting as a compromise between not giving too much weight to families with many sons while still allowing for the fact that we do have more information on height for these families. All the standard errors are clustered at the family level to adjust for the expected correlations between brothers.

No attempts are made to adjust for the possible simultaneity or endogeneity bias caused by the parents' dynamic decisions on how many children to have and how much to invest in each. The point of the results is to determine whether there was an association and whether this varied over time, so it is not essential to have true estimates of causal relationships. The results should still be interpreted with the necessary caution.

4.1 Theoretical model

The resource dilution hypothesis leads to a non-linear functional form of the relationship between sibship size and child outcomes (Downey 1995, 2001). The amount of resources spent on each child, y_{ij}, is the family's total resources, Y_j, divided between the number of children, n_j; $y_{ij} = Y_j/n_j$. The negative effect of having many siblings should therefore be stronger for the first siblings added than for higher parities.[3]

The estimation of the relationship between the number of siblings and their heights here starts from the functional form expected from the resource dilution hypothesis. It then rests on the assumption that the relationship between the resources invested in the child, y_{ij}, and the child's height, h_{ij}, is log-linear. Diminishing returns in height to increases in family incomes or resources are in line with Becker's (1993) models, the theoretical expectations about environmental influences on growth (Steckel 2008), aggregate relationships between average height and level of income across countries (Baten and Blum 2012), and within most countries historically (Öberg 2014a: 24–26). Assuming a log-linear association between resources and height also has the crucial advantage of making it possible to estimate the model using linear regression, since it then turns out to be (see the Appendix for further discussion of the model):

$$h_{ij} = \beta_Y ln\, Y_j - \beta_n\, ln\, n_j + X_j\beta_j + X_{ij}\beta_{ij} + \varepsilon_j + \varepsilon_{ij}$$

The natural logarithm of the family income, $\ln Y_j$, is approximated here with dummy variables indicating occupational status and landholding. From the derivation of

[3] Downey (1995) and Fernihough (2011) find support for a $1/n$ shape of the association.

the model we should expect a negative value of the coefficient, β_n, on the natural log of the number of children in the family, $\ln n_j$. A negative coefficient requires that differences in family income are adequately captured by the included variables and that the underlying assumptions of the resource dilution hypothesis are valid, e.g., that there are no strong economies of scale. $X_j\beta_j$ and $X_{ij}\beta_{ij}$ represent the family- and child-level control variables included in the estimations and ε_j and ε_{ij} the family- and child-level residuals, respectively.

4.2 Measuring sibship size

The number of children in the family can be measured in a number of different ways; for example as the total number of children ever born in the family, the total number of surviving children (Van Bavel 2006; Van Bavel et al. 2011), or, as here, the time-weighted average of the number of children present in the household during each man's childhood (similar to Dribe 2000; Bengtsson 2009; Kippen and Walters 2012). Different measures do not necessarily produce the same results for the association between sibship size and child outcomes (Kippen and Walters 2012). The measure used here was judged to be best in line with the resource dilution hypothesis. The time-weighted average used here is calculated using the continuous information and is the cumulative sibship size exposure until age ten. We count the number of children present in the household for each time period of observation from a man's birth or first appearance in the database parishes until his tenth birthday. The measure includes the observed man himself, so that a man without siblings has a sibship size of one. A man with one sibling present from his birth until the age of ten, for example, obtains a value of 2 (himself + his sibling). The number of children present is not counted only in full integers, so if another child had been born at the man's exact age of five years, he would have received the value 2.5. Siblings dying are counted while present in the household, but not afterwards.

It is possible that it is the birth order within a sibship that has a negative effect on the living conditions during childhood, rather than having many siblings. There are conflicting results in the literature regarding the influence of birth order on height (compare e.g., the conclusions in the overviews: Mascie-Taylor 1991; Silventoinen 2003). Alter and Oris find a positive relationship between birth order and stature among conscripts in 19^{th}-century Belgium (Alter and Oris 2008: 51). Negative associations between birth order and height have been found for populations in Britain throughout the 20th century (Kuh and Wadsworth 1989; Alberman et al. 1991; Terrell and Mascie-Taylor 1991; Li and Power 2004; Li, Dangour, and Power 2007; Hatton and Martin 2010b). Lundborg, Ralsmark, and Rooth (2013) show that the association between height and birth order was negative among men in Sweden born later during the 20th century (1965–1978).

We include the birth order of the men in the estimated models. The birth order is counted as births to a specific mother and all known, including deceased, siblings are included in the measure of birth order. Children not observed at birth but only, for example, living with a mother when moving into the database parishes are included in the birth order (as well as the sibship size measures). Births occurring outside the covered parishes and for which the child died before the move into the observed population are not included. Births occurring after leaving the parishes are also omitted. There is therefore some miscounting of the total number of births and children present. The birth order should still reflect whether the child is born early or late among the children included in the calculations of the sibship size variable. Summary statistics of the sibship size variable and other measures of family configuration are presented in Table 1.

Table 1: Summary statistics of family configuration

Years of birth		Period 1 1821–1860	Period 2 1861–1890	Period 3 1891–1920	Period 4 1921–1950
Mothers' perspective					
Children ever born	Median	6	6	4	2
	Mean	6.2	5.9	4.7	2.9
	St. dev.	2.5	2.7	2.7	1.9
Experienced an infant or child (below age 5 years) dying	Share (%)	65	50	24	7
Number of mothers[a]		460	387	568	1028
Child perspective					
Sibship size	Median	3.6	3.6	3.8	2
	Mean	3.8	3.8	4.0	2.7
	St. dev.	1.5	1.7	1.9	1.7
LN(sibship size)	Mean	1.24	1.24	1.26	0.84
	St. dev.	0.43	0.47	0.53	0.58
Birth order	Mean	3.6	3.5	3.5	2.4
	St. dev.	2.3	2.3	2.4	1.8
Birth order index	Mean	0.95	0.97	1.04	1.07
	St. dev.	0.48	0.47	0.44	0.38
Dependency ratio	Median	1.06	1.30	1.73	1.00
	Mean	1.23	1.41	1.85	1.34
	St. dev.	0.86	0.95	0.96	0.88
Number of men		708	550	971	1422

[a] The mothers contribute observations to the same periods as their sons, i.e. some mothers contribute to more than one period here.

Birth order is quite naturally highly correlated with the number of children present in the household (r = 0.73). The number of children present will tend to be higher for the men born as middle children. The measure of sibship size used here captures this variation. The additional control for birth order is intended to capture any systematic differences in height between children born early or late in the sibship. Since the birth order and the sibship size are highly correlated, it is not possible to include both measures in the estimated models as they are. We therefore use the birth order index proposed by Booth and Kee (2009).[4] The index is a measure of relative birth order standardized so that the average is equal to 1 in all the families and in the population. The index is still positively correlated with the sibship size (r = 0.30, r = 0.32–0.41 within the sub-periods used in the analyses) but can now be entered into the regression models without causing problems of multicollinearity. A resource dilution framework should lead us to expect a non-linear association between the birth order and the family resources available per child (Hertwig, Davis, and Sulloway 2002). The birth order index is therefore included both as a linear and as a quadratic term.

4.3 Model specifications

The regression models used here to test the influence on height of the number of children in the family are in line with that proposed by Van Bavel (2006). They are what Van Bavel calls "child perspective models", since they also control for child-specific characteristics such as birth order. The models deviate from Van Bavel's in the measure used for sibship size.

Three different models are estimated. The first, Model A, includes the natural logarithm of the number of children present in the household during the first ten years of the men's lives and birth order along with individual-level control variables. The included controls are the decade of birth, age at inspection[5], whether the man volunteered for conscription before the compulsory age or was a hired recruit, and an indicator of whether the man was not living in the database parishes during all the years from birth until the age of ten years.

Model B includes the variables in Model A along with other demographic controls: an indicator of families with only one observed child and an indicator of whether the mother or father in the family died before the age of 50 years. It is possible that the

[4] The birth order index is the sibship-size standardized relative birth order and is calculated using the formula: $Birth\ order\ index = Birth\ order/((Number\ of\ children + 1)/2)$ (Booth and Kee 2009: 378f). The within-family and overall average is 1, with lower values for early born children and high values for later-born children. The range of values in the data analyzed here is 0.133 to 1.857.

[5] Because of the limited variation in age at inspection we include age as the deviation (in years) from the compulsory age. Since the age for inspection changed over time the reference category also changes.

single birth was a result of these families being disadvantaged through, for example, a worse health status of the parents. This group always constitutes a small minority of the families, at least during the 19th and the early 20th century (Table 2), but might influence the estimates of the association between sibship size and child height. Families in which a parent died prematurely can be expected to have fewer children, while the children can also be expected to have had worse living conditions growing up. The included indicator should control for this variation.

Table 2: Summary statistics of the dependent variable and control variables

Years of birth		Period 1 1821–1860	Period 2 1861–1890	Period 3 1891–1920	Period 4 1921–1950
Dependent variable					
Average height (cm)		166.9	170.4	172.5	175.5
Men in sample with height measure (%)		79	91	97	97
Truncated observations (%)		28	10	4	3
Individual-level controls					
Age at inspection (years)		20.8	20.6	19.7	18.9
Young volunteers/hired recruits (%)		6	16	2	2
Man not observed age 0–10 years (%)		18	31	41	60
Demographic controls					
Only child (%)		2	2	4	15
Parent died prematurely (%)		20	12	10	4
Socioeconomic controls					
Occupational status	Lower-skilled manual worker (%)	47	41	43	50
	Skilled manual worker, incl. farmers (%)	41	35	35	28
	Non-manual occupation (%)	6	6	9	14
	Unknown occupation (%)	6	17	13	8
Landholding	Landless (%)	36	51	71	62
	Small-scale (%)	49	32	17	6
	Large-scale (%)	15	17	12	5
	Unknown landholding (%)	0	0	0	27

Model C includes the variables in Model B plus controls for socioeconomic status. Socioeconomic status is measured here as the occupational status and landholding of the father at the birth of the man. If there is no information from birth, the first available information from before the man's fifth birthday is used. The occupational status is based on the historical occupational class scheme HISCLASS (van Leeuwen and Maas 2011). Only three groups are separated: lower-skilled manual workers (HISCLASS 9–12), skilled manual workers (including farmers, HISCLASS 6–8), and non-manual workers (HISCLASS 1–5). Landholding is also separated into three categories: landless (including unknown) and small- and large-scale landholding. Missing information on occupation or landholding is included as separate categories. For further discussions on the socioeconomic indicators, see Öberg (2014a: Introduction, 2014b).

When estimating associations over long periods of time it is important to allow the effect of control variables to change over time. All the controls here were allowed to have different effects in the different time periods. This is achieved by interacting all included variables with indicators for three periods, excluding the fourth, latest period as the reference category. All effect estimates presented for periods other than the reference period, Period 4, are combined coefficients found by adding coefficients.

Only model C estimates the association as set out in the formal model specification, since this requires controls for the family's available resources. Only the coefficients for the sibship size variable are presented in Table 4. The controls are not presented in the paper since they are only included to estimate the formal model and to investigate the amount of confounding (the full results are available in the Appendix). Table 2 presents summary statistics for the control variables, except the variables describing the family configurations, which are shown in Table 1. Table 3 shows how the distribution of sibship size developed over time.

Table 3: The distribution of different sibship sizes among the men

		Period 1	Period 2	Period 3	Period 4
Years of birth		**1821–1860**	**1861–1890**	**1891–1920**	**1921–1950**
			Shares of the men (%)		
Sibship size	1 (only child)	2	3	5	17
	1.01–1.99	7	8	6	17
	2.00–2.99	24	21	22	29
	3.00–3.99	28	25	21	16
	4.00–5.99	18	18	16	9
	5.00+	21	25	30	12
	Total	100	100	100	100

The men are divided into four groups, to investigate how the association between sibship size and height changed over time. The periodization is based on previous knowledge of the fertility transition in the studied area. The fertility transition started around 1890 in Scania, at approximately the same time as in the rest of Sweden (Bengtsson and Dribe 2014). There were some differences in behavior between older and younger mothers, but overall there was a strong period effect in the fertility decline in Sweden (Stanfors 2003; Dribe 2009; Bengtsson and Dribe 2014). The men in the studied sample are therefore divided into groups based on their years of birth: Period 1: 1821–1860; Period 2: 1861–1890; Period 3: 1891–1920; and Period 4: 1921–1950. The first and second periods correspond to the pre-transition era. The third period covers the early and the fourth the late/post-transition period. The fourth time period is used as the reference since it provides sizeable numbers of observations for all the categories.

To further investigate the change of the association over time we also estimate a ‘rolling regression’. In this case this is 111 regressions, each estimated to include men born within a moving 20-year period. In this way we can see how the coefficient on sibship size changes over time in more detail than in the coarser periodization. The results are presented graphically in Figure 3. The estimated model is the same as Model C, except that the control for decade of birth is specified as an indicator for the later 10 years of birth included in each sample.

5. Context

The average height of conscripts increased almost linearly over time among men in the SEDD starting with cohorts born after the 1820s (Öberg 2014b: Figure 1). The secular trend in heights in the SEDD data is similar to the trend in Sweden in general. Both the secular trend in height and the long-term trend in real wages (Lundh 2008) show improving conditions in southern Sweden at least from the mid-19th century. Before the fertility decline the average mother had about 6 children and the average child about 2.5 siblings present in the household during childhood (Table 1). The average number of children ever born to a mother declined clearly in the third and fourth periods to about 2 children in the last period. This illustrates well the fertility decline in the SEDD population previously described by Bengtsson and Dribe (2014). Despite this the average number of children present in the household is stable from the early 19th to the early 20th century. This is probably, at least partly, a result of the falling infant and child mortality that can be followed in the drastically declining share of the families experiencing any deaths (Table 1). Most families (65%) experienced an infant or child dying in the early 19th century but the share fell for each time period, reaching a low 7% in the mid-20th century.[6] Another possible explanation for the rising number of children present is that the children remained for longer in their parents’ household over

[6] Adult mortality also declined, as seen by the also-falling share of parents who died before the age of 50 (Table 2).

time. The number of children present in the household changed only in the fourth period, among men born from 1920 onwards (Tables 1 and 3). In the fourth, late/post-transitional period, the distribution is clearly different from that in the preceding periods.

6. Results

The regression results show that sibship size is negatively associated with height in all the time periods and all the specifications (Table 4). In Model A, with only individual-level controls, the coefficient varies in strength over time and is most strongly negative and statistically significant in the third period. Adding the controls for single child families and parents dying prematurely brings out a stronger negative association in all time periods (Model B).

Table 4: Change in the association between sibship size and early adult height over time

Dependent variable: height	Year of birth	Period 1 1821–1860	Period 2 1861–1890	Period 3 1891–1920	Period4 1921–1950
Model A. Individual level variables					
LN(sibship size)	Coeff.	–0.7	–0.6	–0.8*	–0.5
	(s.e.)	(0.97)	(0.80)	(0.49)	(0.39)
Model B. Model A + other demographic controls					
LN(sibship size)	Coeff.	–0.8	–1.1	–1.2**	–0.8*
	(s.e.)	(1.06)	(0.85)	(0.55)	(0.47)
Model C. Model B + controls of socioeconomic status (theoretical resource dilution model)					
LN(sibship size)	Coeff.	–1.3	–1.2	–1.3**	–0.7
	(s.e.)	(1.03)	(0.87)	(0.54)	(0.47)

Note: Single (Period 4) and combined coefficients (Periods 1–3) from truncated regressions estimating the association between the natural logarithm of the time-weighted average number of children present in the household and the early adult height. Standard errors clustered at the family level are shown within parentheses below the coefficients of interest. The complete regression results are available in the Appendix. Statistical significance of the single or combined coefficients are indicated as: * p<0.10, ** p<0.05, *** p<0.01.

Men who were the only children in the family were considerably shorter than others in all periods. The coefficient (or combined coefficients) is large (between –1.4 and –2.6 cm) in the first three periods but not statistically significant (results in the Appendix). Also, men with a parent dying before the age of 50 years were shorter than others. The coefficients are again sizeable (between –0.4 and –1.6 cm) but only statistically significant in the third period (results in the Appendix). The negative effect of a parental death increases in strength over the 19th century and is strongest in the third period (men born 1891–1920).

Model C is the first to estimate the theoretical model set out in Section 4.1, since this includes controls for the resources available to the family. The negative coefficients for the first three time periods are very similar across periods and vary between –1.2 and –1.3. The corresponding height penalty between men growing up with different numbers of siblings present in the household during childhood increases with the number of siblings but with diminishing strength ($\beta_n = -1.3$; 1 sibling: –0.9 cm, 2 siblings: –1.4 cm, 3 siblings: –1.8 cm, 4 siblings: –2.1 cm, 5 siblings: –2.3 cm).

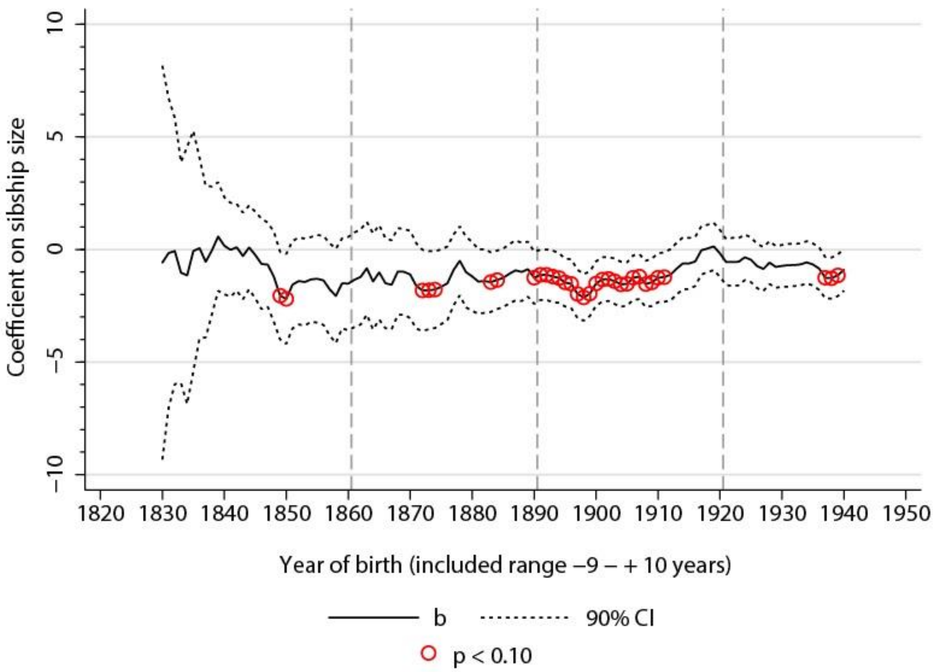
Model C includes a control variable for single children. Even if the coefficient never reaches statistical significance it should be remembered that the association between sibship size and height is both non-linear and includes a negative shift for single children. Single children were on average of about the same height as children with two or more siblings. The height differences were therefore in practice small. The purpose of the present study is not to explain the within-population variation in height but to investigate if resource dilution within larger families resulted in shorter stature of the children. That early adult height indeed was negatively associated with sibship size is, as discussed above, a strong indication of resource dilution in larger families.

The estimated coefficient on sibship size from Model C is almost constant across the first three periods until the last late/post-transition period. This is not what we would expect if resource dilution were an important explanation of the association. The periodization used for these regressions is coarse and could conceal considerable variation. We therefore investigated the change of the association over time using rolling regressions (Figure 1).

The results from the rolling regression do indeed qualify the results. The graph shows that the periodization used for the results above conceal how the association changed over time. There are three dominating patterns: firstly, the lack of a negative association in the early 19th century; secondly, the long-term decline of the strength of the negative association from the mid-19th century until the mid-20th century; and thirdly, that the association is statistically significant primarily between the late 1880s and early 1910s.

There was no association between sibship size and height of the sons among men born between 1821 and c.1840. The confidence interval is very large, especially for the first decade, but the estimated coefficient varies close to zero. There are several possible reasons why there was no association in the early 19th century, which are discussed further below.

Figure 1: Results of a rolling regression of the association between sibship size and early adult child height (log-linear specification), men in Southern Sweden born 1821–1950



Note: The vertical dashed lines indicate the limits for the periodization used in the paper. The regressions underlying this figure each included men born during a 20 years period. In the figure the results are shown for the year in the middle of the range. The variables included are the same as for Model C. The only difference was that decade of birth was controlled for by an indicator variable unique for each sample for the men born during the ten later included years.

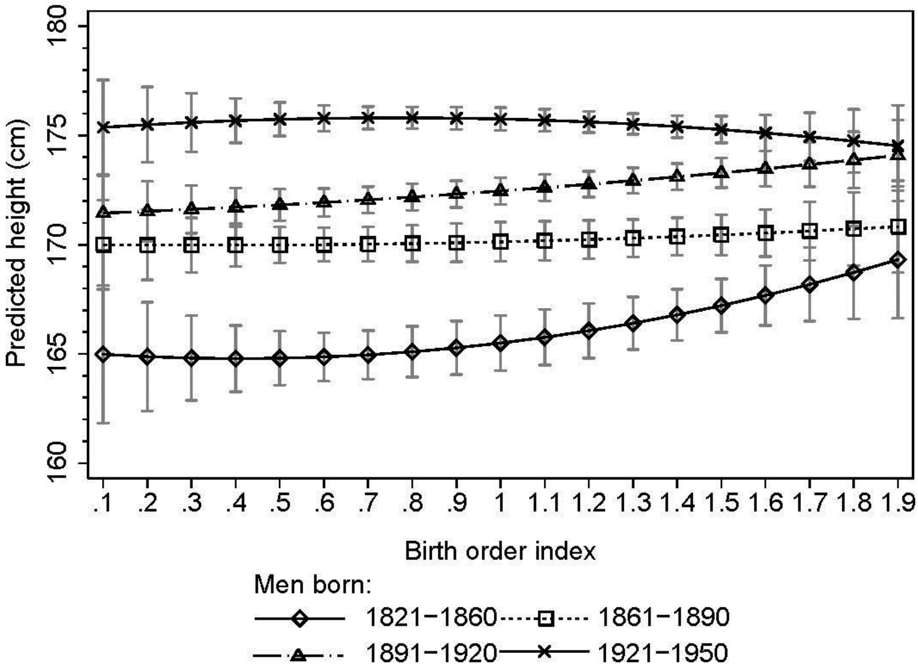
From the late-1840s onwards there is a persistently negative association. The strength varies over time but the association is (weakly) positive only among men born between 1909 and 1929 (coefficients reported for 1918 and 1919). The coefficient becomes more strongly negative for men born from the late 1830s onwards and then stabilizes at about –2. The strength of the association is then gradually weakened over time ending up at about –1 in the mid-20th century. The weakening over time of the coefficients reported from 1845 until 1940 is statistically significant (results not shown).

The association is only steadily statistically significant among men born between 1881 and 1921 (coefficients reported for 1890–1911). The association is statistically significant also in other years but only for three years in a row at most. The coefficients are only statistically significant at a 10% level, so we should be open to the possibility that one out of ten estimates is statistically significant by chance alone. The period when the association is statistically significant corresponds approximately to period three when we found the statistically significant results also in Model C in Table 4. Each period covered by the rolling regression is shorter than the static periods. The sample size in each of the samples analyzed for the rolling regression is therefore smaller than the ones used for the regressions reported in Table 4. This can contribute to the lack of statistical significance in some cases, especially in the early and mid-19th century, but the association does seem to have been most consistent among men born between 1881 and 1921.

Controlling for birth order does not much change the estimated association between sibship size and height. This is in line with previous studies that likewise find that the negative association between sibship size and height remains after controlling for birth order (Belmont, Stein, and Susser 1975; Olivier and Devigne 1983; Li and Power 2004). The association between birth order and height is never statistically significant. It is weakly positive in the first and third periods, so that later-born sons are somewhat taller than earlier-born sons (Figure 2).

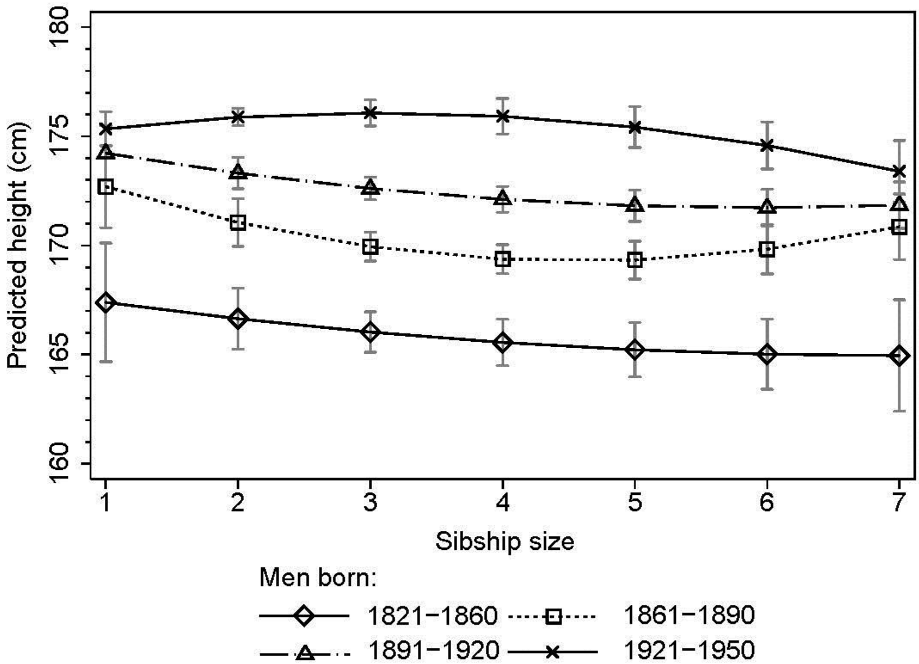
We also carried out a robustness check by estimating the association including the number of siblings linearly and squared (results in the Appendix). This provides a more flexible functional form of the association and can therefore be used to evaluate the theoretical log-linear association. The results show that the log-linear specification indeed seems to be an appropriate approximation, at least in the second and third periods (Figure 3). Figure 3 also provides an additional insight into how the association weakened in the early and mid-20th century, the last period here. The associations in the fourth period change in shape from convex to concave, pointing to a shorter stature especially of the men with the largest number of siblings. The pattern is not strong and the safe conclusion is that there is no strong association between sibship size and height for men born from the 1920s. The association between sibship size and height is most strongly negative in the second and third period also in the quadratic specification.

Figure 2: The association between birth order (index) and early adult child height (log-linear specification), men in Southern Sweden born 1821–1950



Note: The figure was produced using the margins and marginsplot commands in Stata 13.1.

Figure 3: The association between sibship size and early adult child height (quadratic specification), men in Southern Sweden born 1821–1950



Note: The figure was produced using the margins and marginsplot commands in Stata 13.1.

We also checked if the miscounting of sibship size influences the results by repeating the analyses while including only the men that are fully observed for all the first ten years after birth. The results are again very similar but with stronger negative coefficients in the first three periods but a weakly positive coefficient in the last (results in the Appendix). The miscounting for men that are not fully observed therefore seems to reduce the strength of the association just as we would expect from measurement error. The true coefficient is likely to be more strongly negative than the ones reported in Table 4 and Figures 1 and 3.

We also tried including an indicator for any child in the family dying before age five years (results in the Appendix). This is intended as an attempt to control for increased exposure to disease through crowding and secondary exposure from sick siblings. During the early and mid-19th century a majority of families experienced a child death but not all families, even among those with many children (Table 1). The coefficient on this variable is weakly positive (between +0.4 and +0.7) in the first three periods and weakly negative (–0.2) in the last, but is never statistically significant. Including this variable also does not change the estimated association between sibship size and height (results in the Appendix). We cannot exclude that exposure to disease was part of the underlying causes of the negative association based on this. Repeated, non-lethal disease, especially gastrointestinal disease, can reduce growth and might have been part of the explanation (Stephensen 1999; Hatton and Martin 2010a).

7. Discussion

Estimating the theoretical resource dilution model while also controlling for possible confounders (Model C) results in a sizeable negative association between sibship size and early adult height during the 19th and the early 20th century. The presence and the negative sign of the coefficient are in line with a resource dilution explanation of the association.

The estimated associations are overall strongly influenced by observable differences between the families. The importance of confounding does not contradict the resource dilution hypothesis, since for the first three periods the negative associations between sibship size and height are rather concealed than generated by confounding by the demographic and socioeconomic differences between the families.[7] By contrast, the association seems to be somewhat strengthened by confounding in the last period. The confounding of the association hence changed over time.

The change in the confounding from socioeconomic status comes about because there were socioeconomic differences in height (Öberg 2014b), family size (Table 5), and also in the timing of the fertility decline (Bengtsson and Dribe 2014). All other socioeconomic groups had on average more children present in the household than fathers with lower-skilled manual occupations in the first period (Table 5). In the second period it is only fathers with skilled manual or non-manual occupations that have more children present than others. But the elite, and also to some degree middle class, families limited their fertility before the lower-status groups. By contrast, landholding families remained larger than others throughout the studied time period. Sons from better-positioned families, especially with regard to the father's occupation, also remained taller also in the latter time periods but now lived on average in smaller

[7] Preliminary analyses showed that it was very important to allow the effect of the confounders to vary over time. The effects from, for example, birth order and socioeconomic status changed over time. Constricting these influences to be the same in all the time periods distorted the results, leading to an increasingly negative association instead of the results presented here (further results not shown).

families. Controlling for socioeconomic status therefore slightly weakens the negative association between sibship size and height in the late/post-fertility transition period.

Table 5: Socioeconomic differences in the number of children present during the men's childhoods

Socioeconomic background	Year of birth	Period 1 1821–1860		Period 2 1861–1890		Period 3 1891–1920		Period 4 1921–1950	
Number of children present									
Landless, lower-skilled manual workers (ref.)		3.2		3.5		3.9		2.9	
Skilled manual workers		+0.4	***	+0.6	***	–0.1		–0.3	**
Non-manual occupations		+1.2	***	+1.0	*	–0.5		–0.5	***
Unknown occupation		+0.8	**	+0.2		–0.4	**	+0.3	*
Small-scale landholding		+0.4	***	+0.1		+0.4	*	+0.7	**
Large-scale landholding		+0.5	*	+0.1		+1.2	***	+0.7	***
Unknown landholding		—		—		—		–0.3	**
R^2					0.144				
Number of observations		708		550		971		1422	

Note: Table 5 shows the results from an ordinary least squares regression estimating the differences in the time-weighted average number of children present in the household during each man's childhood (0–10 years) related to the socioeconomic status of the father. Statistical significance of the single or combined coefficients are indicated as: * p<0.10, ** p<0.05, *** p<0.01.

The results from the rolling regression show a clear, gradual, and statistically significant weakening of the association among men born from the 1840s onwards. The secular trend in height started in the studied area among men born in the 1830s (Öberg 2014b); real wages started to increase from the mid-19th century (Lundh 2008). This change of the association over time is therefore almost exactly what we would expect if resource dilution were an important factor causing the association. The weak negative association between sibship size and height in the mid-20th century is also in line with a recent study investigating this issue among Swedish conscripted men born in 1965–1978 (Lundborg, Ralsmark, and Rooth 2013).

The negative association between sibship size and child height is most consistent around the time of the fertility decline. This could indicate that having many children placed a strong burden on the parents during this period. Several socioeconomic theories on the fertility decline in Europe and North America discuss how the perceived or real rising costs of children could have contributed to the fertility decline (Leibenstein 1957: chap. 10, 1975; Caldwell 1976, 2005; Ariès 1980; Becker 1993). It is also during this time period that the sibship sizes are largest and the dependency ratios highest (Table 1). That the association between sibship size and height was most consistent during this time is therefore another indication that resources were scarce in large families. The combination of rising expectations of what should be provided for the children (e.g., Alter 1992) in combination with rising sibship sizes could have worsened this resource scarcity around the time of the fertility decline. Another possible explanation of the pattern is that families that were better endowed in some unobserved way both created a more favorable environment for their children and limited their fertility earlier. Both explanations of the pattern are interesting for our understanding of the fertility decline, but unfortunately we are not able to examine them explicitly here.

The persistently negative association between sibship size and height also makes it possible that resource competition within families contributed somewhat to the shorter stature during the 19th and early 20th century. The reduced resource dilution after the fertility decline could therefore have contributed to the increasing heights in the present population. The change of the average sibship size (natural logarithm of sibship size from 1.26 to 0.84) from the third to the fourth period could have contributed to a c.0.5cm change (–1.3×[1.26–0.84]), out of the c.3cm change in average height over the same period. The possible contribution is therefore less than 20% but the magnitude of the effect is similar, if somewhat smaller, to the one reported in Hatton and Martin (2010a).

The estimated coefficient for the earliest years covered is, unexpectedly, weakly negative (Figure 1). There are several possible explanations for this. The weak association could be a result of the fact that, even if resource dilution in larger families is an important part of the explanation of the negative association between sibship size and height, changes in the societal context also influenced the association. Social and societal conditions in the early 19th century might have been less in line with the assumptions underlying the resource dilution hypothesis. The three assumptions are, as discussed above, that: i) all the income or resources come from the parents; ii) the parents do not adjust their income or own consumption when they have more children; and iii) there are no economies or diseconomies of scale in the household production.

There were on average fewer children present in the early 19th century households, so the dependency ratio was lower (Table 1). In the early 19th century it was also more common to have servants living in the household, which helped to stabilize the dependency ratio. It might also be that the association is underestimated for the early 19th century. The measure of sibship size used here risks underestimating the effect of resource competition in the early 19th century, since children were more likely to move out of resource-scarce households early (Dribe 2000: e.g., 183). The measure also risks underestimating the effect of resource competition in the cases in which siblings died as infants or children. Siblings are only included in the measure when they are alive and present in the household. The siblings who died as infants or children most likely used proportionately more of their parents' resources up until they died, and their deaths can also be seen as a stress on the parents' capacity to care for their other children. The share of men missing information on height in the inspection lists and the large share of observations below the truncation points also lead to the coefficient being estimated with less precision. The weaker coefficient in the early and mid-19th century does not necessarily contradict the resource dilution explanation, but indicates that the social context might have been important for the association.

While the negative association points to resource scarcity in large families we cannot conclude much from the results with regard to the underlying proximate causes. Previous research shows that most likely there are also several different proximate causes behind the association between sibship size and child height within a resource dilution framework. Whitley and coauthors (2008) also find a negative association between sibship size and child height in 1930s' Britain also when controlling for household energy consumption and diet. Cernerud (1993) finds that the negative association remains among mid-20th-century schoolchildren in Stockholm, Sweden, after controlling for crowding in the home. The results of Hatton and Martin (2010a), analyzing the same data set as Whitley et al. (2008), support the supposition that familial resources were important for the negative association between sibship size and child health and height. They conclude that both nutrition, from family resources spent on food, and disease, working through housing quality and hygiene, contributed to generating the negative associations. Another possible contributing factor is child and adolescent work. In Brazil in the early 1990s an increasing number of children in the family decreased school attendance and increased the labor force participation of boys and girls and the share of girls having household chores as their main activity (Ponczek and de Souza 2012).

In Sweden in the early 20th century there were differences in diet between large and small families that could have contributed to differences in height. The Swedish Ministry of Health and Social Affairs carried out an official investigation into the living conditions and food consumption of families in the early 1940s (Socialdepartementet 1946: 117–139). They found that the absolute amount of money and the share of income spent on food quite naturally increased with the number of children in the family. However, families with many children spent less per consuming unit[8] on food (see also Logan 2011). Large families still kept their energy consumption on a level similar to that of other families, but their diet was of a lower quality, more monotonous, and focused on cheaper foodstuffs. They consumed more milk, margarine, potatoes, and flour but less butter, meat, eggs, fish, and vegetables. The cheaper, less varied, diets were still very similar across family sizes with regard to macronutrients (compare also Lundh 2013). However, since children require relatively more protein for growing than adults, it is still possible that the diets in the larger families were inadequate. The on average adequate, with regards to macronutrients and energy consumption, diet also

[8] The family members were converted to consuming units, corresponding to an adult male, by weighting them according to their approximate caloric needs.

concealed variation, with some families consuming inadequate diets. The diets of large families also often meant insufficient intakes of, for example, iron and vitamins A and B. If the dietary differences revealed by the Social Board in the early 1940s were also valid previously, these differences could be part of the explanation for the differences in height.

The association between birth order and height changes over time, but is never strong or statistically significant. The strongest pattern found is the positive association in the first, early and mid-19th century period (compare Alter and Oris 2008). This could be the result of resource accumulation in the families making a relatively larger positive contribution to the living conditions of the children in the generally poorer families during the nineteenth century than later.

8. Conclusions

We find a negative association between sibship size and height, thus indicating resource scarcity in large families. The results are in line with the assertion that resource dilution is an important explanation of the negative association between sibship size and child height. This association gradually weakened from the 1840s until the 1940s. The association was most consistent and therefore statistically significant during the fertility decline. The development of the association over time is generally as predicted by a resource dilution explanation. The association is, surprisingly, weakly negative in the early 19th century, but there are several potential explanations for this; for example, the household strategies used to balance the dependency ratio and the socioeconomic differences in fertility during this period. Confounding influences the estimated association, but in the present population mostly works to mask the negative association between sibship size and height during the 19th and the early 20th centuries.

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Appendix

The following section explains the estimated model. The estimation of the relationship between the number of siblings and their heights starts from the functional form expected from the resource dilution hypothesis. The amount of resources spent on each child, y_{ij}, is the family's total resources, Y_j, divided by the number of children

$$y_{ij} = Y_j/n_j$$

We can separate the family's total resources and number of children by using the natural logarithm

$$ln\, y_{ij} = ln\, Y_j - ln\, n_j$$

The model then rests on the assumption that the relationship between the resources invested in the child, y_{ij}, and the child's height, h_{ij}, is log-linear.

$$h_{ij} = ln\, y_{ij} + \varepsilon_j + \varepsilon_{ij}$$

Diminishing returns in height to increases in family income or resources are in line with Becker's (1993) models, the theoretical expectations about environmental influences on growth (Steckel 2008), aggregate relationships between average height and level of income across countries (Baten and Blum 2012), and within most countries historically (Öberg 2014, 24–26). Assuming a log-linear association between resources and height also has the crucial advantage of making it possible to estimate the model using linear regression, since it then turns out to be:

$$h_{ij} = ln\, Y_j - ln\, n_j + X_j\beta_j + X_{ij}\beta_{ij} + \varepsilon_j + \varepsilon_{ij}$$

The estimated regression equation is:

$$\begin{aligned} h_{ij} = Period_i \times \big(&Sibship\ size + Birth\ order\ index_i \\ &+ Birth\ order\ index, quadratic\ term_i \\ &+ Volunteer/hired\ military + Age\ at\ inspection_i \\ &+ Not\ fully\ observed_i + Only\ child_i \\ &+ Parent\ died\ prematurely_j + Skilled\ manual\ occupation_i \\ &+ Non - manual\ occupation_i \\ &+ No\ information\ on\ occupation_i + Small\ scale\ landholding_i \\ &+ Large\ scale\ landholding_i\big) \\ &+ No\ information\ on\ landholding_i + Period_i \\ &+ Decade\ of\ birth_i + \varepsilon_j + \varepsilon_{ij} \end{aligned}$$

The regressions are estimated on the complete sample including all available observations, regardless of date of birth. The coefficients estimated for the variables listed within parentheses above are allowed to vary across four time periods by including interactions between each variable and the period indicator variables. The tables below present the estimated coefficients along with their standard errors. The effect from a variable for a specific period can be found by adding the coefficient for the reference period (Period 4) with the coefficient for the period of interest. All coefficient estimates presented in the paper for periods other than Period 4 are combined coefficients found in this way. The standard errors and statistical significance levels for the combined coefficients were estimated using the lincom command in Stata 13.1

The rolling regressions were identical, except that they did not include any interactions or a time varying decade of birth indicator for the ten later included years. The estimates for the coefficient on the sibship size variable and its standard error were extracted and used for Figure 1.

Table A1: Regression results underlying Table 4 and Figure 2

Variables	Model A	Model B	Model C
Sibship size:			
Ln(Sibship size) (Period 4)	–0.5	–0.8*	–0.7
	(0.39)	(0.47)	(0.47)
Interactions:			
Period 1 × ln(Sibship size)	–0.2	0.1	–0.6
	(1.04)	(1.16)	(1.13)
Period 2 × ln(Sibship size)	–0.2	–0.2	–0.5
	(0.89)	(0.98)	(0.99)
Period 3 × ln(Sibship size)	–0.4	–0.4	–0.6
	(0.63)	(0.73)	(0.71)
Periods:			
Period 1: 1821–1860	–7.8***	–7.5***	–7.3***
	(2.56)	(2.59)	(2.52)
Period 2: 1861–1890	–1.4	–1.0	–1.1
	(2.07)	(2.08)	(2.10)
Period 3: 1891–1920	–1.5	–0.7	–1.1
	(1.93)	(1.96)	(1.97)
Period 4: 1921–1950	ref.	ref.	ref.
Decade of birth:			
1821–1830	ref.	ref.	ref.
1831–1840	–4.6***	–4.6***	–4.9***
	(1.22)	(1.21)	(1.20)
1841–1850	–0.1	–0.2	–0.9
	(0.89)	(0.89)	(0.86)
1851–1860	ref.	ref.	ref.
1861–1870	–2.7***	–2.6***	–2.8***
	(0.81)	(0.82)	(0.83)
1871–1880	–2.0***	–2.0***	–2.3***
	(0.71)	(0.71)	(0.72)
1881–1890	ref.	ref.	ref.
1891–1900	–1.6***	–1.6***	–1.4**
	(0.60)	(0.60)	(0.59)
1901–1910	–1.0*	–1.1**	–0.9*
	(0.53)	(0.53)	(0.52)
1911–1920	ref.	ref.	ref.
1921–1930	ref.	ref.	ref.

Table A1: (Continued)

Variables	Model A	Model B	Model C
1931–1940	1.2**	1.1*	1.1**
	(0.55)	(0.55)	(0.53)
1941–1950	2.7***	2.6***	2.6***
	(0.50)	(0.50)	(0.58)
Volunteer/hired military (Period 4)	2.9**	3.0**	2.6**
	(1.28)	(1.27)	(1.27)
Interactions:			
Period 1 × Volunteer/hired military	–4.1**	–4.1**	–3.1
	(1.92)	(1.92)	(1.97)
Period 2 × Volunteer/hired military	–1.4	–1.6	–1.2
	(1.74)	(1.75)	(1.70)
Period 3 × Volunteer/hired military	0.1	0.1	0.1
	(1.98)	(1.95)	(1.89)
Age at inspection (centered) (Period 4)	0.5	0.5	0.6
	(0.42)	(0.42)	(0.41)
Interactions:			
Period 1 × Age at inspection (centered)	0.9	0.9	1.0
	(0.99)	(0.99)	(0.97)
Period 2 × Age at inspection (centered)	0.1	0.1	0.1
	(0.82)	(0.82)	(0.76)
Period 3 × Age at inspection (centered)	0.3	0.4	0.4
	(0.71)	(0.71)	(0.70)
Not fully observed age 0–10 years (Period 4)	–0.4	–0.4	–0.5
	(0.38)	(0.38)	(0.39)
Interactions:			
Period 1 × Not fully observed	2.2**	2.1*	2.2*
	(1.10)	(1.10)	(1.16)
Period 2 × Not fully observed	–1.5*	–1.5**	–1.2
	(0.77)	(0.77)	(0.77)
Period 3 × Not fully observed	0.7	0.6	0.9
	(0.61)	(0.61)	(0.64)
Birth order index (Period 4)	0.3	1.5	1.0
	(2.67)	(2.80)	(2.80)
Interactions:			
Period 1 × Birth order index	–2.2	–3.2	–2.6
	(5.03)	(5.18)	(4.88)
Period 2 × Birth order index	–1.5	–1.8	–0.8
	(3.93)	(4.08)	(4.08)

Table A1: (Continued)

Variables	Model A	Model B	Model C
Period 3 × Birth order index	0.1	–0.8	0.2
	(3.47)	(3.59)	(3.57)
Birth order index, quadratic term (Period 4)	–0.5	–1.0	–0.8
	(1.29)	(1.34)	(1.34)
Interactions:			
Period 1 × Birth order index, quadratic	2.7	3.0	2.8
	(2.40)	(2.44)	(2.32)
Period 2 × Birth order index, quadratic	1.3	1.3	0.9
	(1.92)	(1.97)	(1.97)
Period 3 × Birth order index, quadratic	1.0	1.4	0.9
	(1.68)	(1.72)	(1.72)
Only child (Period 4)		–0.9	–0.7
		(0.66)	(0.65)
Interactions:			
Period 1 × Only child		0.2	–1.2
		(3.04)	(3.15)
Period 2 × Only child		–1.5	–1.9
		(2.72)	(2.64)
Period 3 × Only child		–0.6	–0.7
		(1.53)	(1.53)
Parent died prematurely (Period 4)		–0.8	–0.7
		(0.86)	(0.89)
Interactions:			
Period 1 × Parent died prematurely		0.2	0.2
		(1.30)	(1.30)
Period 2 × Parent died prematurely		–0.1	–0.3
		(1.22)	(1.25)
Period 3 × Parent died prematurely		–0.8	–0.9
		(1.11)	(1.13)
Socioeconomic status:			
Low-skilled manual			ref.
Skilled manual, incl. farmers (Period 4)			0.8*
			(0.44)
Interactions:			
Period 1 × Skilled manual, incl. farmers			–2.0*
			(1.03)
Period 2 × Skilled manual, incl. farmers			–1.2
			(0.87)

Table A1: (Continued)

Variables	Model A	Model B	Model C
Period 3 × Skilled manual, incl. farmers			–0.5
			(0.71)
Non-manual occupations (Period 4)			2.2***
			(0.56)
Interactions:			
Period 1 × Non-manual occupations			2.6
			(1.87)
Period 2 × Non-manual occupations			0.1
			(1.44)
Period 3 × Non-manual occupations			–0.6
			(1.06)
No information on occupation (Period 4)			0.7
			(0.76)
Interactions:			
Period 1 × No information on occupation			–2.4
			(2.17)
Period 2 × No information on occupation			–1.0
			(1.20)
Period 3 × No information on occupation			–1.1
			(1.09)
Landless			ref.
Small-scale landholding (Period 4)			–1.6*
			(0.88)
Interactions:			
Period 1 × Small-scale landholding			3.0**
			(1.32)
Period 2 × Small-scale landholding			3.1***
			(1.16)
Period 3 × Small-scale landholding			1.2
			(1.06)
Large-scale landholding (Period 4)			0.5
			(0.89)
Interactions:			
Period 1 × Large-scale landholding			4.1***
			(1.52)
Period 2 × Large-scale landholding			–0.05
			(1.23)

Table A1: (Continued)

Variables	Model A	Model B	Model C
Period 3 × Large-scale landholding			1.5
			(1.17)
No information on landholding			–0.1
			(0.51)
Constant	174.9***	174.8***	174.4***
	(1.41)	(1.42)	(1.45)
Sigma	6.2***	6.1***	6.1***
	(0.09)	(0.09)	(0.09)
Observations	3,320	3,320	3,320
Truncated observations	331	331	331

Robust standard errors clustered at the family level (2176 clusters) in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table A2: Robustness checks (including the quadratic specification used for Figure 3)

Variables	Quadratic specification	Fully observed men	+ any child died
Sibship size:			
ln(Sibship size) (Period 4)		0.2	–0.7
		(0.69)	(0.47)
Interactions:			
Period 1 × ln(Sibship size)		–1.7	–0.6
		(1.42)	(1.13)
Period 2 × ln(Sibship size)		–1.6	–0.5
		(1.32)	(0.99)
Period 3 × ln(Sibship size)		–2.1**	–0.7
		(0.98)	(0.70)
Sibship size (Period 4)	1.1**		
	(0.52)		
Interactions:			
Period 1 × Sibship size	–2.0		
	(1.30)		
Period 2 × Sibship size	–3.5***		
	(0.82)		
Period 3 × Sibship size	–2.3***		
	(0.71)		
Sibship size, quadratic term (Period 4)	–0.2***		
	(0.06)		

Table A2: (Continued)

Variables	Quadratic specification	Fully observed men	+ any child died
Interactions:			
Period 1 × Sibship size, quadratic term	0.2		
	(0.15)		
Period 2 × Sibship size, quadratic term	0.4***		
	(0.09)		
Period 3 × Sibship size, quadratic term	0.3***		
	(0.08)		
Any infant/child died in the family			–0.2
(Period 4)			(0.76)
Interactions:			
Period 1 × Any infant/child died in the			0.7
family			(1.16)
Period 2 × Any infant/child died in the			0.8
family			(0.99)
Period 3 × Any infant/child died in the			0.9
family			(0.95)
Periods:			
Period 1: 1821–1860	–5.2	–10.2***	–7.8***
	(3.23)	(3.18)	(2.63)
Period 2: 1861–1890	3.4	–4.0	–1.6
	(2.42)	(2.91)	(2.18)
Period 3: 1891–1920	1.4	–1.0	–1.5
	(2.24)	(2.80)	(1.99)
Period 4: 1921–1950	ref.	ref.	ref.
Decade of birth:			
1821–1830	ref.	ref.	ref.
1831–1840	–4.8***	–5.7***	–4.9***
	(1.19)	(1.47)	(1.21)
1841–1850	–0.9	–1.0	–1.0
	(0.86)	(0.97)	(0.87)
1851–1860	ref.	ref.	ref.
1861–1870	–2.8***	–2.5**	–2.8***
	(0.83)	(0.99)	(0.83)
1871–1880	–2.3***	–2.2**	–2.3***
	(0.71)	(0.92)	(0.72)

Table A2: (Continued)

Variables	Quadratic specification	Fully observed men	+ any child died
Decade of birth:			
1881–1890	ref.	ref.	ref.
1891–1900	–1.4**	–1.7**	–1.5**
	(0.59)	(0.81)	(0.61)
1901–1910	–0.9*	–1.3*	–0.9*
	(0.52)	(0.66)	(0.52)
1911–1920	ref.	ref.	ref.
1921–1930	ref.	ref.	ref.
1931–1940	1.1**	–0.1	1.1**
	(0.53)	(0.89)	(0.53)
1941–1950	2.6***	0.8	2.6***
	(0.57)	(0.87)	(0.58)
Volunteer/hired military (Period 4)	2.6**	2.6	2.6**
	(1.25)	(1.87)	(1.27)
Interactions:			
Period 1 × Volunteer/hired military	–3.1**	–2.5	–3.1
	(1.95)	(2.46)	(1.97)
Period 2 × Volunteer/hired military	–1.0	–0.4	–1.1
	(1.69)	(2.23)	(1.70)
Period 3 × Volunteer/hired military	–0.03	0.02	0.01
	(1.88)	(2.31)	(1.89)
Age at inspection (centered) (Period 4)	0.6	1.8**	0.6
	(0.41)	(0.70)	(0.41)
Interactions:			
Period 1 × Age at inspection (centered)	1.0	–0.02	1.0
	(0.96)	(1.11)	(0.97)
Period 2 × Age at inspection (centered)	0.2	–1.0	0.2
	(0.76)	(0.97)	(0.76)
Period 3 × Age at inspection (centered)	0.4	–0.2	0.4
	(0.70)	(1.04)	(0.70)
Not fully observed age 0–10 years (Period 4)	–0.4 (0.39)		–0.5 (0.39)

Table A2: (Continued)

Variables	Quadratic specification	Fully observed men	+ any child died
Interactions:			
Period 1 × Not fully observed	2.2*		2.4**
	(1.15)		(1.18)
Period 2 × Not fully observed	–1.3		–1.0
	(0.76)		(0.78)
Period 3 × Not fully observed	0.9		1.1*
	(0.64)		(0.66)
Birth order index (Period 4)	0.03	–2.8	0.9
	(2.74)	(4.26)	(2.80)
Interactions:			
Period 1 × Birth order index	–1.4	5.2	–2.2
	(4.85)	(6.20)	(4.89)
Period 2 × Birth order index	0.9	5.0	–0.4
	(4.02)	(5.76)	(4.07)
Period 3 × Birth order index	1.2	1.6	0.6
	(3.51)	(5.22)	(3.56)
Birth order index, quadratic term	–0.4	1.1	–0.7
(Period 4)	(1.31)	(2.00)	(1.34)
Interactions:			
Period 1 × Birth order index, quadratic	2.3	–1.1	2.6
	(2.30)	(2.89)	(2.32)
Period 2 × Birth order index, quadratic	–0.01	–1.7	0.7
	(1.93)	(2.72)	(1.96)
Period 3 × Birth order index, quadratic	0.5	0.2	0.8
	(1.69)	(2.46)	(1.71)
Only child (Period 4)	0.3	–0.5	–0.7
	(0.65)	(1.04)	(0.66)
Interactions:			
Period 1 × Only child	–2.2	–4.4	–1.0
	(3.18)	(4.13)	(3.19)
Period 2 × Only child	–3.8	0.5	–1.7
	(2.56)	(3.51)	(2.66)
Period 3 × Only child	–1.8	–1.6	–0.7
	(1.52)	(2.40)	(1.53)
Parent died prematurely (Period 4)	–0.6	–0.9	–0.7
	(0.91)	(1.13)	(0.89)

Table A2: (Continued)

Variables	Quadratic specification	Fully observed men	+ any child died
Interactions:			
Period 1 × Parent died prematurely	0.2	0.8	0.3
	(1.31)	(1.52)	(1.30)
Period 2 × Parent died prematurely	–0.4	0.8	–0.3
	(1.26)	(1.51)	(1.26)
Period 3 × Parent died prematurely	–0.9	–0.8	–0.9
	(1.14)	(1.42)	(1.13)
Socioeconomic status:			
Low-skilled manual	ref.	ref.	ref.
Skilled manual, incl. farmers (Period 4)	0.7	0.6	0.8*
	(0.44)	(0.68)	(0.44)
Interactions:			
Period 1 × Skilled manual, incl. farmers	–1.9	–1.9	–2.0*
	(1.02)	(1.21)	(1.03)
Period 2 × Skilled manual, incl. farmers	–1.0	–0.6	–1.2
	(0.85)	(1.13)	(0.86)
Period 3 × Skilled manual, incl. farmers	–0.4	–0.2	–0.5
	(0.71)	(1.02)	(0.71)
Non-manual occupations (Period 4)	2.1	1.5*	2.2***
	(0.56)	(0.85)	(0.56)
Interactions:			
Period 1 × Non-manual occupations	2.8	1.7	2.6
	(1.87)	(2.22)	(1.86)
Period 2 × Non-manual occupations	–0.3	0.9	0.04
	(1.35)	(1.85)	(1.43)
Period 3 × Non-manual occupations	–0.5	0.6	–0.5
	(1.07)	(1.31)	(1.06)
No information on occupation (Period 4)	0.5	–0.3	0.7
	(0.75)	(2.90)	(0.76)
Interactions:			
Period 1 × No information on occupation	–2.2	–3.6	–2.3
	(2.16)	(6.57)	(2.17)
Period 2 × No information on occupation	–0.7	0.4	–0.9
	(1.19)	(3.19)	(1.21)
Period 3 × No information on occupation	–1.0	–1.6	–1.1
	(1.09)	(3.68)	(1.09)
Landless	ref.	ref.	ref.
Small-scale landholding (Period 4)	–1.6*	–0.9	–1.6*
	(0.87)	(1.12)	(0.88)

Table A2: (Continued)

Variables	Quadratic specification	Fully observed men	+ any child died
Interactions:			
Period 1 × Small-scale landholding	3.1**	2.3	3.0**
	(1.31)	(1.56)	(1.32)
Period 2 × Small-scale landholding	3.1***	2.0	3.1***
	(1.14)	(1.43)	(1.16)
Period 3 × Small-scale landholding	1.2	0.8	1.2
	(1.05)	(1.36)	(1.06)
Large-scale landholding (Period 4)	0.4	–0.5	0.5
	(0.89)	(1.24)	(0.89)
Interactions:			
Period 1 × Large-scale landholding	4.2***	5.3***	4.1***
	(1.52)	(1.85)	(1.52)
Period 2 × Large-scale landholding	0.01	0.2	–0.04
	(1.22)	(1.61)	(1.22)
Period 3 × Large-scale landholding	1.5	4.0**	1.6
	(1.16)	(1.64)	(1.18)
No information on landholding	–0.2	0.3	–0.1
	(0.51)	(0.84)	(0.51)
Constant	173.1***	176.3***	174.5***
	(1.61)	(2.18)	(1.44)
Sigma	6.0***	6.1***	6.1***
	(0.09)	(0.12)	(0.09)
Observations	3,320	1,870	3,320
Truncated observations	331	233	331

Robust standard errors clustered at the family level in parentheses
*** p<0.01, ** p<0.05, * p<0.1