Economics and Human Biology 37 (2020) 100833

Contents lists available at ScienceDirect

Economics and Human Biology

journal homepage: www.elsevier.com/locate/ehb

Male fertility between biology and the socioeconomic context news from the past (Alghero, 1866–1935)

M. Breschi[a], A. Fornasin[b], G. Gonano[a], S. Mazzoni[c], M. Manfredini[d,*]

[a] University of Sassari, Italy
[b] University of Udine, Italy
[c] Institute of Economics, Geography and Demography (IEGD-CCHS-CSIC), Spanish National Research Council, Madrid, Spain
[d] University of Parma, Italy

ARTICLE INFO

Article history:
Received 26 June 2019
Received in revised form 17 October 2019
Accepted 3 December 2019
Available online 12 December 2019

Keywords:
Male fertility
Socioeconomic status
Health
Hazard models
Italy

ABSTRACT

In the process of fertility decline, the role and participation of men have hardly been considered in the demographic literature. It has grown only as fertility was dropping dramatically in most Western countries, but very little has been done to analyze such an issue in historical populations. Based on individual-level data, the present paper aims at investigating, by means of hazard models, the role of males in the reproductive pattern of the pre-transitional population of Alghero, Sardinia (1866–1935). The results show a slower decrease of male fertility (-23% at 40–49 years; around -50% at 50+) compared to female fertility (about -40% already at 35–49 years), with significant differentials by socioeconomic status (SES). Wealthier men present, in fact, lower fertility than poorest ones, with a gap that, however, reduces with age and even reverses at 50+ years. The reason for such a change is likely to be partly associated with the better health conditions of the wealthy group, developed especially in adulthood, given the absence of a significant relationship between height and fertility SES differentials.

1. Introduction

The twentieth century saw deep demographic changes affecting primarily the two classic natural components of population growth: birth and death. The great transformations in fertility and mortality have been measured, described and analysed as never before thanks to modern data collection, innovative and powerful data processing and a general improvement in statistical techniques. However, there remains a strong asymmetry in the methods of measurement and in approaches to studying reproductive behaviours (Poston and Chang, 2005). In the process of fertility decline and subsequent social evolution, the changing role of men has hardly been considered in the demographic literature. Fertility theories that are used for explaining changes in human fertility have rarely included men and empirical demographic analyses of fertility tend to concentrate on women. This occurred mainly in relation to the uniqueness of menopause, which makes also more certain and precise the measure of fertility when calculated on females.

Only in recent years a new way of thinking about the role of men has arisen in the demographic field (Bledsoe et al., 2000), stimulated by the numerous studies that have proved the decline of male fertility with age (Nordfalk et al., 2015; Dinkel and Milenovic, 1993; Schoumaker, 2017; Christiansen, 2002; Bribiescas, 2006; Bribiescas and Burke, 2017; Ge Rondi and Tanturri, 2008). Although there is general consensus among researchers about the obvious and intrinsic differences between menopause and male reproductive senescence (andropause) and about the fact that reproductive decline is a key feature also of male reproductive life-histories, especially after the age of 40, some disagreement still exists about the causes and reasons for such a decline. In fact, biomedical studies on the effects of male age on semen quality and motility as well as on general reproductive functions have produced results that are sometimes conflicting and only occasionally conclusive on the effectiveness of such changes to produce significant reductions in fertility (Kidd et al., 2001; Auger and Jouannet, 2005; de La Rochebrochard et al., 2003; De La Rochebrochard et al., 2006; Bribiescas, 2006; Zitzmann, 2013; Sharma et al., 2015). Other scholars have shown how biological changes related to old age affects reproductive outcomes, increasing the chances of preterm births, fetal deaths and congenital birth anomalies (Lian et al., 1986; Alio et al., 2012; García-Ferreyra et al., 2018; Brandt et al., 2019).

* Corresponding author at: Dept. of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Parco Area delle Scienze 11/A, 43124 Parma, Italy.
E-mail address: matteo.manfredini@unipr.it (M. Manfredini).

http://dx.doi.org/10.1016/j.ehb.2019.100833
1570-677X/

Thus, while there is no doubt that the decline in male fertility occurs as men get older, it is not clear yet whether such a decline is attributable to just biological and/or to socioeconomic factors. Some recent studies, in fact, would not seem to exclude a possible role of social and/or behavioural factors (Matorras et al., 2011). Some anthropologists have introduced the concept of "social andropause" just to identify the "inability or unwillingness of older men to procure access to fecund females" (Bribiescas, 2006, 137), and the lower reproductive value of men after the age of 40. In this view, the decline in male fertility with age would be the result of their lower fitness, associated with physical degradation and somatic changes that may cause unattractiveness and limited access to younger and more fertile women. Besides, somatic degradation, which was quite early in the Sardinia of that time, may well also mitigate sexual desirability and sexual desire, thereby reducing the frequency of sexual intercourses and, consequently, overall fertility. It is likely, then, that this behaviour could be more relevant among poor people than among wealthy ones, thus contributing to create socioeconomic differentials in fertility. The consequence of the above assumptions is that male fertility in old age cannot be studied independently from woman's age, which implies that the younger the woman, the larger the expected offspring size for males of whatever age.

It is evident, then, that all the elements above mentioned are strictly connected with health status and lifestyle factors. The association between health status and male sub-fertility or infertility is well-known, and it has been assessed for many pathologies, such as cancers, diabetes, high blood pressure or metabolic syndromes (Glenn, McClure and Lewis, 2003; Ventimiglia et al., 2015; Michalakis et al., 2013; Cazzaniga et al., 2018; Salonia et al., 2009). Similarly, there is a growing literature on the negative impact of some lifestyle elements on male fertility, such as stress (Li et al., 2011; Ilacqua et al., 2018). They can all affect male reproduction through alteration of the spermatogenesis as well as through a further reduction of the fitness. In this view, bad health status and/or the existence of chronic health conditions in old age should be good predictors of reduced fertility.

Unfortunately, interest in male fertility and its decline with age has grown as fertility has fallen in most western countries, casting some doubts that the reduced reproductive outcome of older males might be the consequence of industrialization and birth control rather than real reduction of the male fertility potential. In order to overcome, at least in part, these difficulties, the age effect on male fertility can best be studied for pre-transitional populations when no deliberate attempt was made to limit family size (Henry, 1961). The few studies investigating male fertility in (pre-)transitional populations, however, are all basically based on aggregate-level data (Karmel, 1947, 1948a, 1948b; Brouard, 1977; Kuczynski, 1932; Tietze, 1938; Anderson, 1975; Payeur, 2008; Payeur and Desjardins, 2009; Ge Rondi and Tanturri, 2008).

In this paper, we will investigate the pattern of male fertility in an Italian population not yet deliberately controlling fertility. The use of a life-history approach will allow us to not only to study in depth the age-related reduction in males but also to examine some characteristics of such a pattern, in particular whether it may change with socioeconomic status. In historical communities, where the access to resources could vary a great deal by social group, males and couples with better social status may have suffered less from hard work, physical hardship, deprivation and stress in their life, thereby showing a less precipitous process of reproductive aging with respect to individuals from poorer social strata. The starting point is the population of Alghero, one of the most important cities in Sardinia, located in the north-western coast of the island and characterized by a diversified socioeconomic structure. The analysis covers the period from 1866 to 1935.

The work is divided into six sections including this one. In the next, we describe the social and economic characteristics of Alghero. The third section is dedicated to a description of the dataset characteristics and to illustrate the statistical methods used. Section four provides a descriptive analysis of the male fertility pattern in Alghero in the relevant period. We then proceed, in the fifth section, to investigate male fertility at the micro-level. In particular, we applied extended Cox regression models in order to analyse the influence of the husband's age on fertility, after controlling for some possible confounding factors. The results are finally discussed in the last section.

2. A slowly-changing community: Alghero, 1866-1935

The analysis concerns couples that had children between 1866 and 1935. During this period Alghero gradually changed, but the effects of these changes only became clear in the decades following the Second World War. According to the data collected in the first census after the unification of Italy (1861), Alghero was, in population terms, the third largest centre in Sardinia, behind Cagliari and Sassari. The population of Alghero increased gradually between 1861 and 1936, rising from 8831 to 15,998 inhabitants. However, the socioeconomic characteristics of Alghero remained stationary in this period of growth: the primary sector (agriculture, zootechny, forestry, hunting, and fishing) employed, in fact, more than 70 percent of the active population of the town. Numerous were also the activities in the handcraft and in the trade and services sector (about 25%). Only a small number of persons – about 6% of the population – enjoyed much better living conditions than the rest. This small group was made up of skilled middle-class professionals – as defined by the HISCLASS code (Van Leeuwen and Maas, 2011). The typical inhabitant of Alghero lived, instead, in humble conditions and often suffered from illnesses like trachoma, tuberculosis, and malaria (Cau et al., 2007; Melis and Pozzi, 2010) whose effects were amplified by poor domestic hygiene and by poor nutrition: the diet, in fact, was essentially based on vegetables, often consumed in a single meal per day and largely insufficient to cover the caloric requirements (Niceforo and Galeotti, 1934). Conversely, the upper class could expect better health, tended to be 10 cm taller and, more generally, had lower mortality both in their early years and in childhood (Breschi et al., 2011; Cau et al., 2007; Mazzoni et al., 2017).

The population of Alghero, like that of the entire island, did not typically use birth control. Moreover, Sardinia was, before the most recent falling off in fertility, the Italian region with the highest levels of legitimate fertility (Livi Bacci, 1977). To sum up, in the period under study here, the very largest part of the population of Alghero did not control fertility and tried to maximize the reproductive capability to the limit of the biological threshold. In the next sections, we will, therefore, provide a descriptive analysis of the fertility pattern, focusing on specific features of male fertility and in particular on socioeconomic differentials.

3. Materials and method

To reconstruct the demographic history of Alghero, we used the official documentation in the Historical Archive of the Municipality. The individual records on births, deaths, and marriages have been integrated and controlled for coherence with data from other different kinds of civil sources (parts of the population register; family sheets taken from the 1921 population census; parish registers; military recruitment lists, etc.). Lastly, the demographic information derived from the civil status registers was combined with data in the parish registers of baptisms, burials, and marriages. The linkage procedure across sources have involved a deterministic approach, which compares an identifier or a group of identifiers (i.e. name, surname, birthdate, etc.) across the different databases and creates a link when they all agree. The final result has been then verified through a direct check on the sources, which also allowed us to refine the results obtained through the record linkage procedure. Eventually, we have reconstructed a unique historical dataset at individual and family level. Based on this documentation, it was possible to analyse the reproductive history of couples who lived and had children in Alghero between 1866 and 1935. The complete dataset has about 18,000 births which mean approximately 65,000 couple-years, and a total of 5325 Alghero couples. For the Italian context, it is the largest individual-level dataset before the onset of fertility control. Moreover, it deals with an urban population, which presents, unlike rural communities, a large population size, a diversified socioeconomic structure and, most of all, a group of rich and wealthy families belonging to the upper class.

The use of married couples as a unit of analysis implies that the study will be limited to marital fertility. This restriction prevents us from investigating some of the socio-anthropological mechanisms, noted above, associated with "social andropause". Moreover, we decided to analyse only couples observed for at least 4 years of marriage as a way to limit the analysis to unions minimally stable and not touched by a premature dissolution. The dataset is therefore of longitudinal nature and Cox regression models were estimated to investigate the effect of the father's age, once the mother's age has been controlled for, on the risk of having an additional child. The models are based on episode-structured data in order to estimate event-history models. The time is measured as time (years) from the previous event (birth) and where the "clock" is reset to zero after each event interval. The resulting model is therefore

$$h(t,\ X) = h_0(t)\exp(\beta_i X_i)$$

where h is the hazard at time t and X_i the vector of explanatory variables. Actually, we have estimated extended Cox regression models, which represent one of the possible choices when the assumption of hazards proportionality is not respected, as occurred in our models for some of the covariates. This technique, which has been already used in fertility studies (Rahman and Hoque, 2015), extends the basic form of Cox regression to a model that includes time-varying variables and their products with a function of time (Zhang et al., 2018). The resulting equation is

$$h(t,\ X) = h_0(t)\exp(\beta_i X_i + \sigma_i X_i g(t))$$

where g(t) is a function of time, expressed in years since childbirth in our models. In other words, the coefficients are formed by a fixed part at time t = 0 - namely, childbirth - and a time-varying part which indicates the variation of the coefficient for each time unit since t = 0. For obvious reasons associated with the biology of reproduction, the comments will concern only hazards for $t \geq 1$, that is starting from one year after the previous birth.[1]

The population at risk is formed by all the fertile couples who had children in Alghero between 1866 and 1935, that is only those couples who have already had at least one child. Firstborns are excluded from the analysis, which decreases to 4544 the number of couples analysed. The advantage of this choice, as noted by Goldman and Montgomery (1989), is in comparing the same kind of intervals, that is to say, intervals always preceded by a post-partum period.

To evaluate the improvements in model fit between models without interaction and models with interaction terms the Likelihood-Ratio test (LR) was used. This test checks whether the difference in log-likelihood between two nested models is significantly different from zero.

Table 1
Mean age at first marriage by Socioeconomic status (SES). Alghero.1866–1935.

SES	$TMFR_{20\text{-}49}$	m	Age at first marriage		
			M	F	Diff.
High profession	5.3	0.105	30.5	24.5	6.0
Other SES groups	7.3	0.060	26.8	21.9	4.9
Total	7.4	0.057	27.2	22.2	5.0

4. The reproductive pattern in Alghero: males vs females

Legitimate fertility in Alghero did not decline much in the seventy years between 1866 and 1935, with a $TMFR_{20\text{-}49}$ which fluctuated around 7.4 children per married woman and a correspondent figure of 9.4 children per married man. These values indicate a population not practicing any form of birth control, as confirmed by the little value (0.057) of the Coale-Trussell's m index (Table 1).[2] The pattern is similar across SES groups, although the levels of marital fertility are definitely different. The group of high professions (see section 5 for a more detailed description of this SES category) shows, in fact, definitely lower fertility levels compared to the other socioeconomic categories (5.3 and 7.3 children per married woman, respectively), which could be attributed to lower infant mortality rates, with associated limited replacement levels, and to the late access to marriage, 30.5 years on average for males, 24.5 for females, about three years later than the rest of the population.

The differences in marital fertility by socioeconomic status emerge much more clearly looking at the age-specific marital fertility rates (Fig. 1, left). The gap is maximum at the age of 20–24 and then decreases to be almost null at the age of 45–49 years. Men displays the same pattern, apart the shift in the age group showing the highest SES differential, which is here the 25–29 group. Thus, the fertility rates of wealthy and not wealthy individuals appear converging in the course of the reproductive life. Ultimately, the population controlled marriage behaviour (late marriages and high levels of celibacy among both men and women) to limit the total number of births and adapt family and population size to available resources (Corridore, 1902; Breschi et al., 2014). The typical family formation system, characterized by "simple neolocal households and late marriage for both sexes" (Viazzo, 2003), in which spouses were expected "to arrive at the wedding with the means necessary for creating a self-sufficient household" (Oppo, 1990b, 1990a: 486), provides further explanation of the reasons why in Sardinia (and in Alghero) total fertility was much lower with respect to the Italian average while, on the other hand, married couples had higher marital fertility and started to reduce family size later than in other areas of Italy (Livi Bacci, 1977).

The age pattern of legitimate fertility of the population of Alghero, separately for females and males, is shown in the right graph of Fig. 1. It depicts the classic pattern of legitimate fertility typical of pre-transitional populations that did not attempt to reduce fertility. As expected, legitimate fertility decreases more slowly for males than for females. For the latter group, fertility peaks at 20–24 years, to start a rapid decline from the age 25–29 onwards. Female fertility appears then to stop at the age of 45–49 when menopause sets in. For males, the peak occurs earlier (15–19 years) and the drop is slower, with a clear decrease only starting at

[1] Children born less than one year after the birth of the previous sibling amount to just 1.6% of total births.

[2] Usually, the first signs of fertility control are reported for m>0.2.

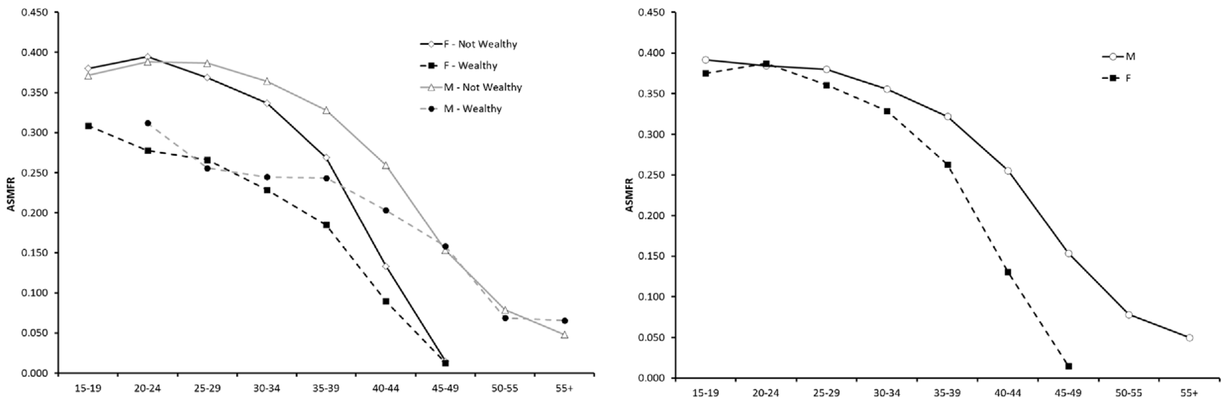

Fig. 1. Marital age-specific fertility rates by socioeconomic status (left) and gender (right). Alghero, 1866-1935.

Table 2
Age-specific marital fertility rates (ASMFR) according to age combination of spouses.Alghero.1866–1935.

Wife age	Husband age								Total
	<25	25–29	30–34	35–39	40–44	45–49	50–54	55+	
15–19	364	380	380	423	*367*	–	–	–	375
20–24	404	396	373	356	394	320	*476*	–	387
25–29	378	370	367	355	310	359	203	*199*	361
30–34	355	331	341	338	311	299	290	214	329
35–39	*228*	265	289	286	270	240	211	184	263
40–44	–	*134*	171	184	175	123	98	75	131
45–49	–	–	–	*56*	39	19	13	*4*	15
Total	384	380	356	322	256	154	79	50	

Notes: – removed because of few cases; *italics* rates with fewer than fifteen births. Six males were excluded due to age misreporting.

about 40 years of age. Such a decline appears to slow down from the age of 50, when we count 79 children per 1000 married men in the age group 50–54 and 50 children per 1000 married men in the group 55 +. Thus, the gap between male and female fertility appears to widen with age, being narrow until 30–34 years (+7.6%), and then more and more ample: At 45–49 years of age, in fact, male fertility is 90% higher than female fertility.

Table 2 displays marital fertility rates according to the age combination of the two spouses. For each female age group, legitimate fertility does not appear to decline substantially as the husband's age increases, at least up to 50 years of age. Conversely, the drop in marital fertility within male age groups is more remarkable as wife's age increases, owing to the obvious fact that biological constraints are stronger among females. This proves once again that in populations not experiencing any form of birth control fertility is largely controlled and regulated by woman's age.

The analyses above show clearly that age affects negatively also male fertility. At this point, however, it is not possible to say to what extent such a depressive effect should be linked to a reduction in male fertility (reproductive senescence), to a decline in coital frequency, or to an increase in the frequency of conception that does not end with a birth.[3]

[3] Permanent sterility also seems to be an important factor. If we consider, in the analysis, complete couples with women married between the ages of 20-34, the percentage of women who did not have any children is 6.0%. The older the wife's age at marriage, the higher the proportion of couples in this situation: 4.1, 8.0 and 9.8 per cent for, respectively, women married at 20-24, 25-29 and 30-34 years of age. These values have the tendency to increase when the husband is much older (at least ten years older than his wife). Actually, the percentage of sterile couples reaches 9.1% (with an increase of more than three points) and have the tendency to go up from women aged 20-24 (5.4%) to those aged 25-29 (8.3%). They, then, double (17.2%) in the admittedly small group of wives aged 30-34 years married with "much older" husbands, i.e. at least ten years older.

5. Reproduction from a micro-level perspective

As it has been previously pointed out, the "male age effect on (marital) fertility" has a complex framework. Descriptive analyses only take us so far. In this section, we will analyse this effect using risk models, on the copious information from individual and couple life stories in our sample. There is little evidence, based on longitudinal micro-level data, from which marital fertility combined with parent's ages can be followed over time.

The combined effect of the father's age and mother's age is estimated taking a series of possible confounders into consideration. The first covariate included in the model is the marriage order. We will contrast marriages between two never-married individuals against any other type of marriage. This in the hypothesis that unions involving remarried individuals present peculiarities, with respect those involving only never-married persons, that may affect their fertility (Breschi et al., 2009; Manfredini and Breschi 2006). Another categorical variable controls for the effect on fertility of the survival status of the previously born child. Although still subject to scientific debate, this variable is aimed at capturing the replacement effect on fertility, that is an acceleration of reproductive behaviour, and, therefore, a reduction in the intergenesic interval after the death of the previous child. Then, the complex effects of specific historical events on fertility (such as the effects of the First World War or the Spanish Flu of 1918) are controlled for with a time categorical variable in which the entire period is subdivided into four sub-periods, namely <1900, 1900-14, 1915-18, and 1919-35.

The age variables of husband and wife have been categorized according to the fertility curve shown in Fig. 1 (right). The rationale is to highlight possible fertility differentials at old ages with respect to younger ones. Finally, the socioeconomic status. Here, we have used the husband's occupation as a proxy (the wife's

Table 3
Cox regression: Schoenfeld hazard-proportionality test. Males, Alghero.1866–1935.

	Rho	Chi2	p-val
Period (ref. < 1900)			
1900-14	−0.001	0.02	0.878
1915-18	−0.012	2.58	0.108
1919-35	−0.030	16.44	<0.001
Marriage order (ref. first marriage)			
Remarriage	−0.019	6.52	0.011
Unknown	−0.015	4.23	0.040
Previous child status (ref. alive)			
Dead	−0.217	908.26	<0.001
Father's age (ref. < 40)			
40–49 years	0.005	0.44	0.537
50+ years	−0.064	80.05	<0.001
Mother's age (ref. < 35)			
35+ years	0.022	9.26	0.002
Father's SES (ref. Not wealthy)			
High Professional	−0.022	9.12	0.003

occupation is not usually informative), differentiating between high professionals, as defined by the HISCLASS code (Van Leeuwen and Maas, 2011), and the rest of the population. The high professionals' category includes here people who have occupations in the public administration or services and a small number of men employed as doctors, pharmacists, lawyers, as well as the wealthy and landowners. This variable has been introduced because of its close connections with health status, access to resources, education level, and, consequently, with fertility. It is therefore expected that people in the highest social strata may display higher fertility especially at old ages, in which health status and physical conditions are likely to be more effective in conditioning fertility.[4]

As anticipated in the Methods section, application of the Cox regression model violates the assumption of hazards proportionality for some of the above variables, as proved by application of the Schoenfeld test on residuals (Table 3).

Thus, the extended Cox regression was applied (Table 4), which allows to estimate time-varying coefficients for Marriage order, Survival status of the previous birth, Mother's age, Father's age, and Father's SES. As for the effect of age on male fertility, the hazard model confirms substantially what emerged at the descriptive level. There is, in fact, evidence of a fertility decrease with age, but slower than that of females. At 40–49 years, the hazard of having a further child is 23% significantly lower compared to married men younger than 40.

Then, the risk drops significantly and more precipitously for men of 50+ years, being -51% one year since the birth of the previous child and -58% after two years. As a comparison, females 35+ run a 45% lower hazard of having a further child compared to younger ones just one year after childbirth, hazard ratio which then reduces to -43% after two years.[5]

By introducing in the model an interaction term between father's and mothers' age (Table 5 and Fig. 2), it is possible to appreciate to what extent female fecundability conditions couple's fertility. Every man married with a woman of <35 years shows, regardless of his age, a hazard of having another child which is always higher than the hazard of men of whatever age married with women aged 35+, after two years since the birth of the previous child (Fig. 2).[6]

In particular, the combination of old men 50+ with women 35+ shows the lowest hazard of having a further child, -79% compared with the youngest couple formed by a man <40 years and a woman <35 two years since the birth of the previous child (Fig. 2). Old men over 50 years of age present also the largest differential in marital fertility when contrasting marriages with women <35 years and marriages with women 35+ (-69%), against a reduction of 44% among men 40–49 and of 40% among those aged <40.

As for control variables in model 1 (Table 4), we will limit the comments to Father's SES. The coefficients suggest that, one year since the birth of the previous child, both SES groups present similar hazards of having a further child.

However, the sign of the SES differential changes over the birth interval: -7% after two years and -15% after three years from childbirth. These results confirm that the lower fertility of wealthy individuals was also due to their slower pace of reproduction, which was likely not motivated, however, by parity-dependent fertility-control behaviours, but by other mechanisms, such as household economy (Van Bavel, 2004). Differential rates of miscarriage and fetal deaths by SES may be also involved in producing differentials in the length of the birth interval (Palloni

Table 4
Extended Cox regression: hazard ratios of higher-order births. Males, Alghero 1866–1935. Model 1.

	Main (t = 0)		TVC		
	HR	p-val	HR	p-val	Mean
Period (ref. < 1900)	1.000				41.5
1900-14	0.980	0.295			24.2
1915-18	0.749	<0.001			6.6
1919-35	1.038	0.054			27.7
Marriage order (ref. first marriage)	1.000				79.3
Remarriage	1.233	0.002	0.938	0.010	9.3
Unknown order	0.942	0.348	0.992	0.741	11.4
Previous child status (ref. alive)	1.000				80.4
Dead	5.952	<0.001	0.584	<0.001	19.6
Father's age (ref. < 40)	1.000				53.5
40–49 years	0.770	<0.001	0.989	0.527	32.3
50+ years	0.567	<0.001	0.861	<0.001	14.2
Mother's age (ref. < 35)	1.000				54.8
35+ years	0.532	<0.001	1.032	0.086	45.2
Father's SES (ref. Not wealthy)	1.000				94.1
High Professional	1.139	0.095	0.906	<0.001	5.9
N = 4544					
Log likelihood = -167,900.2					
LR chi2(17) = 5115.8; p < 0.001					

Table 5
Hazard ratios of the interaction Mother's age vs Father's age. Model 2.

	Main (t = 0)		TVC	
	HR	p-val	HR	p-val
Father's age (ref. < 40)	1.000		1.000	
40–49 years	0.665	<0.001	1.069	0.006
50+ years	0.762	0.232	0.951	0.557
Mother's age (ref. < 35)	1.000		1.000	
35+ years	0.497	<0.001	1.100	<0.001
Father's age 40–49 x Mother's age 35+	1.213	0.043	0.876	<0.001
Father's age 50+ x Mother's age 35+	0.651	0.087	0.886	0.184

Note: For the sake of space, the table shows only the coefficients of the interaction. TVC = Time-varying coefficients.

[4] The category of "High Professionals" presents indicators of socioeconomic wellbeing and health that are significantly different from the rest of the population. There is evidence of their highest stature, lower risk of death, and better economic conditions (Breschi et al., 2011; Mazzoni et al., 2017). This is the reason why we have decided to contrast this sole group with the rest of the population, which, vice versa, was definitely more homogeneous with respect to living standards and health conditions.

[5] The hazards reported are calculated as products of the main coefficient and the TVC coefficient. For example, the hazard of having a further child for men 50+ one year since the birth of the previous child is given by $1-(0.567 \cdot 0.861) = 0.488$.

[6] The coefficients plotted in the interaction figure are reparametrization of the coefficients reported in the table after change of the baseline, which is the couple formed by fathers <40 and mothers <35.

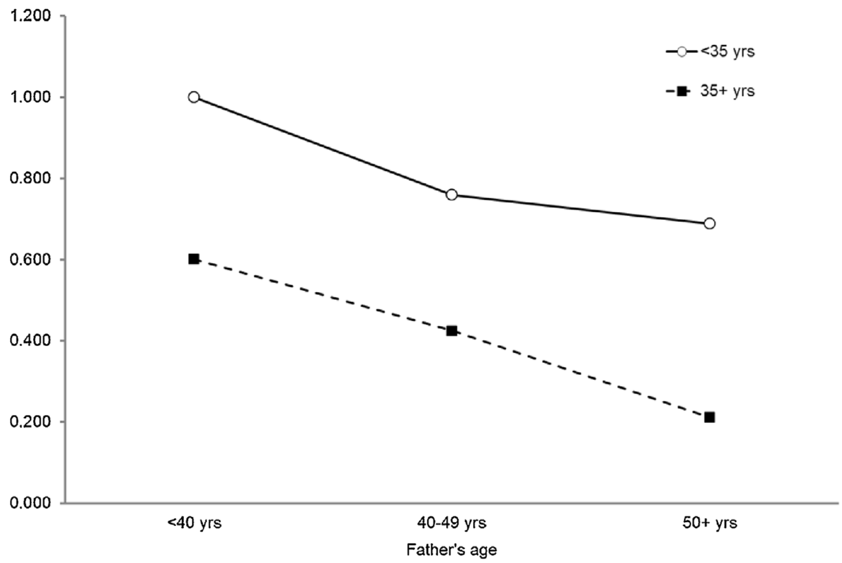

Fig. 2. Hazard ratios of interaction (Model 2). Two years since the birth of the previous child.

and Rafalimanana, 1999), along with the higher rates of infant and child mortality among the poorest. In this latter case, the couple may put in place replacement behaviours which did not depend solely on the death of the last child (which is controlled for in the model), but also by the deaths of other young children in a context where quantity-quality trade-off issues were not present yet in this SES group.

However, being part of the well-to-do social group could have brought, thanks to the better general levels of health and the higher living standard of this class, a reproductive advantage especially in that phase of life where the male is apparently notably less fertile, after 50 years. Pathologies that characterize the lower strata of the local population have, we might suspect, less incidence among these professionals and some factors detrimental to male fertility may be reduced. Malaria, for example, induced conditions favourable to a reduction in sperm quality (Singer et al., 1987); tuberculosis, another typical disease, could generate an infection of the gonads and, thus, reduce fertility (Lenk and Schroeder, 2001; Paick et al., 2000; Tzvetkov and Tzvetkova, 2006). In short, better health conditions can conserve male reproductive capacity, while precarious health, can dampen or damage male fertility (Delamater, 2012; Karraker et al., 2011).

Obviously, such considerations may well concern wives, too. The lower fertility of poorer males beyond fifty years of age could be also a consequence of the poorer health status of their wives, due in part to the greater burden of the higher number of previous deliveries. Essentially, the socioeconomic context may obviously condition the health status of both the members of the couple. Therefore, it was decided to test the hypothesis that men belonging to the better-off part of the population, despite having reduced fertility, could still enjoy a reproductive edge at the most advanced ages. An interaction between the variables related to the age of the man and the professional category was then added to the model.[7] The results are shown in Table 6 and Figure 3, which show the hazard ratios of the sole interaction. The time-varying coefficients resulted almost all statistically significant. This leads to a situation in which, after either two or three years since childbirth, the hazard of having a further child for the poorest SES decreases with age at a faster pace compared with high professionals. However, whilst the poor category presents a higher hazard up to 49 years, the situation changes at 50 + . At that age, the high professionals show a 9% and 14% higher hazard with respect to the poorer group, respectively after two and three years since the birth of the previous child.

Table 6
Hazard ratios of the interaction Father's age vs Father's SES. Model 3.

	Main (t = 0)		TVC	
	HR	p-val	HR	p-val
Father's age (ref. < 40)	1.000		1.000	
40–49 years	0.790	<0.001	0.975	0.165
50+ years	0.584	<0.001	0.843	<0.001
Father's SES (ref. Not wealthy)	1.000		1.000	
High Professional	1.551	<0.001	0.774	<0.001
Father's age 40–49 x High professionals	0.662	0.013	1.244	<0.001
Father's age 50+ x High professionals	0.655	0.149	1.341	<0.001

Note: For the sake of space, the table shows only the coefficients of the interaction. TVC = Time-varying coefficients.

The higher fertility that characterizes wealthy men over 50 years of age can be driven, as above anticipated, by two reinforcing effects. On the one hand, the higher wellbeing and health of the wealthiest socioeconomic group, which could affect positively sexual activity as well as decrease the chances of fetal deaths and miscarriages at older reproductive ages. On the other hand, the worse health conditions of the poorest men (and women) could negatively affect the chances of possible replacement behaviours, which was one of the causes of the faster pace of fertility of this SES group.

In order to deepen our understanding of the relationship between SES, health and male fertility, a further model including the stature of men at 20 years of age was included. Height was measured for all young men during the medical examination for military service. Stature has been largely used in demographic historical studies as a proxy of health and physical status, especially with regard to early life conditions. Thus, the introduction of height in our models will precisely allow to disentangle the effects more specifically associated with health and socioeconomic conditions in early life from those more specific of adult life, such as working conditions, diet, lifestyle, and so on. Unfortunately, this piece of information is available only for a fraction of the total sample here analysed, and precisely 979 husbands, 18.4% of total couples.

[7] Even in this case, the improvement in model fit of the interaction model was statistically significant with respect to the model without interaction (LR chi2(4) =28.0, p-value=<0.001).

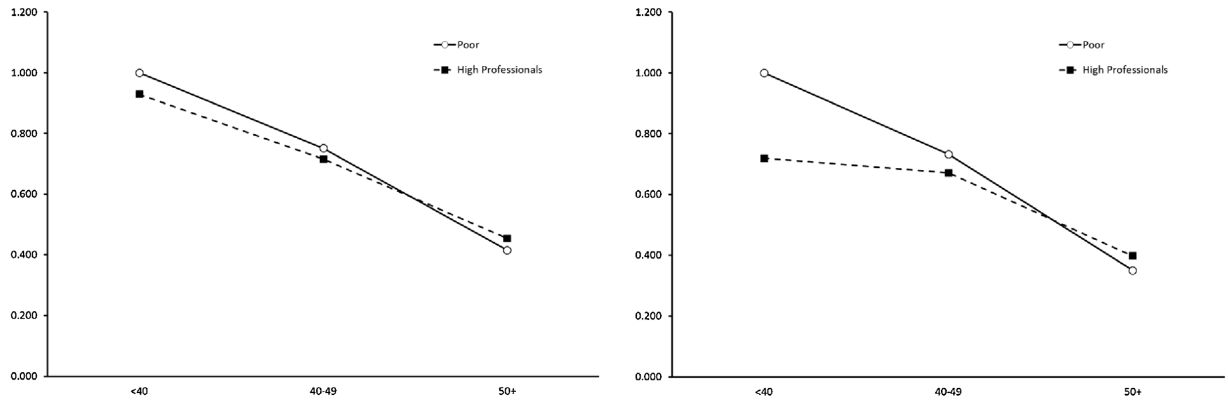

Fig. 3. Hazard ratios of interaction (Model 3).Two years (left) and three years (right) since the birth of the previous child.

Table 7
Extended Cox regression: hazard ratios of higher-order births for the interaction SES vs Height. Alghero 1866–1935. Model 4.

	No interaction		With interaction	
	HR	p-val	HR	p-val
Father's SES (ref. Not wealthy)	1.000		1.000	
High Professional	0.840	0.016	1.662	0.313
Height (ref. Shortest)	1.000		1.000	
Average	0.947	0.120	0.948	0.130
Tallest	0.955	0.244	0.959	0.287
High professionals / Average			0.511	0.194
High professionals / Tallest			0.493	0.168
N	979			
Log-likelihood	−39,945.9		−39,945.1	
LR test	1.6 (2)		0.449	

The Sardinians of this sample were 157.9 cm tall on average, but the variable has been categorized for linearity reasons, thereby differentiating between short, average (medium), and tall individuals. The height intervals were based on quartiles: the shortest 25% (<154 cm), the medium 50% (154–161 cm), and the tallest 25% (162+ cm). The results are shown in Table 7, which refer to models with and without interaction between SES and height. For the sake of space, only the coefficients of these two variables and its interaction are displayed, but the models still control for the same variables shown in Table 4. [8] The model without interaction shows that high professionals have a significant 16% lower hazard of having a further child compared with the poorer SES group (Table 7). On the other hand, the effects of stature are limited in size and not statistically significant. The pattern does not change if we look at the model with the interaction between socioeconomic status and height. In that case, in fact, the introduction of the interaction does not even improve significantly the model fit (Likelihood ratio test = 1.6, p-value = 0.449), making useless any comment about the single coefficients of height. Thus, there is no evidence of the role of early life conditions on male fertility, either in absolute terms nor by socioeconomic status.

6. Conclusions

In the dynamics of the natural decline of human fertility, man's age is certainly less determinant than woman's age, but it is, nonetheless, still important. Only in recent years has scholars from many disciplines paid some attention to male fertility. However, this interest has mainly concerned the medical and clinical contexts of male infertility problems, due not least to the ever higher age at which men have their first child. As regards the study of past populations male fertility has been much more neglected there and the effects due to man's age have often been considered as marginal or negligible. And this is quite surprising as the relationship between age and male fertility can be best approached just in those contexts where fertility control does not bias and/or confound our interpretation of the male pattern.

In the present work, we have studied legitimate male fertility in an Italian population with very low birth control using the most complete and extended dataset at the individual level for pretransitional and early transitional Italian populations. In this context, we found evidence that male fertility does decline significantly with age once controlled for women's age and other confounding factors. This male pattern was probably associated with biological factors, such as aging, physical stress and worsening health status as well as with increased chances of miscarriage. It is also possible, though, that a reduction in sexual activity could play a role here, a factor potentially hindering shared family planning (Das et al., 2011). Nevertheless, such a decline is definitely much slower than that of females, with a gap that increases with age and the absence of any biological age-related limit such as menopause.

The effects of health status on the decline of male fertility with age can be best highlighted just in poor societies where health status worsened quite quickly for the very large part of the population, and only a small part of it could count on sufficient resources. In such cases, in fact, a better state of health, as well as the lower impact of diseases and, more generally, a higher quality of life, might guarantee better use of the couple's and husband's biological capabilities. In the case-study here analysed, the results appear to go exactly in that direction. In fact, despite persistent lower fertility among the wealthiest (and healthiest) men, they show a slower reduction of fertility over the life course with respect to the poorest strata of the population. And more than that, we found evidence of a reversal of the male fertility SES pattern at 50+ years, when the wealthiest males show higher fertility than their poorest peers, other factors being equal. Obviously, part of these effects could be due also to healthier wives. Nevertheless, the substantial equivalence of age-specific marital fertility rates at 45+ years makes this hypothesis less tenable.

Moreover, contrary to findings from other studies (Hayward et al. 2013), we found evidence of the ineffective role of early life conditions, here proxied by height. Although some selection effects due to a lower access to marriage for unhealthy and shorter men could partially influence the outcome (Manfredini et al., 2013), our data lead to suppose that male fertility was rather influenced by

[8] The table does not report TVC coefficients for Father's SES, Height, and their interaction because such variables did not result statistically significant according to the Schoenfeld test for hazards proportionality in this model.

health conditions developed in adulthood and likely caused by different lifestyles, different working conditions, different diet, and so on. This seems in line with what has emerged from some previous studies on contemporary populations (Trost et al., 2014), which found evidence that male fertility was mostly and negatively affected among the less wealthy categories, which had often a poorer health status, frequently associated with a poor and often insufficient diet as well as with unhealthy living conditions.

Declarations of Competing Interest

None

Acknowledgement

This study was undertaken within the SEU-FER project, which has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 799123. This publication reflects only the authors' view and the Research Executive Agency is not responsible for any use that may be made of the information it contains.

References

Alio, A.P., Salihu, H.M., McIntosh, C., August, E.M., Weldeselasse, H., Sanchez, E., Mbah, A.K., 2012. The effect of paternal age on fetal birth outcomes. Am. J. Mens Health 6, 427–435.
Anderson, B.A., 1975. Male age and fertility results from Ireland prior to 1911. Popul. Index 41 (4), 561–567.
Auger, J., Jouannet, P., 2005. Age and male fertility: biological factors. Rev. Epidemiol. Sante Publique 53, 2S25–2S35.
Bledsoe, C., Lerner, S., Guyer, J.I. (Eds.), 2000. Fertility and the Male Life-Cycle in the Era of Fertility Decline. Oxford University Press, Oxford.
Brandt, J.S., Cruz Ithier, M.A., Rosen, T., Ashkinadze, E., 2019. Advanced paternal age, infertility, and reproductive risks: a review of the literature. Prenat. Diagn. 39, 81–87.
Breschi, M., Fornasin, A., Manfredini, M., Mazzoni, S., Pozzi, L., 2011. Socioeconomic conditions, health and mortality from birth to adulthood: Alghero 1866–1925. Explorations in Economic History 48, 366–375.
Breschi, M., Fornasin, A., Manfredini, M., Pozzi, L., Rettaroli, R., Scalone, F., 2014. Social and economic determinants of reproductive behavior before the fertility decline: the case of six Italian communities during the nineteenth century. Eur. J. Popul. 30, 291–315.
Breschi, M., Fornasin, A., Manfredini, M., Zacchigna, M., 2009. Family composition and remarriage in pre-transitional Italy: a comparative study. Eur. J. Popul. 25 (3), 277–297.
Bribiescas, R.G., 2006. On the evolution, life history, and proximate mechanisms of human male reproductive senescence. Evol. Anthropol. 15, 132–141.
Bribiescas, R.G., Burke, E.E., 2017. Health, evolution, and reproductive strategies in men: New hypotheses and directions. In: Jasienska, G., Sherry, D.S., Holmes, D.J. (Eds.), The Arc of Life: Evolution and Health Across the Life Course. Springer Press, New York, pp. 77–97.
Brouard, N., 1977. Evolution de la fécondité masculine depuis le début du siècle. Population 32 (6), 1123–1158.
Cau, P., Merella, C., Pozzi, L., 2007. Lo stato di salute della popolazione di alghero fra ‘800 e ‘900. Uno studio condotto attraverso i registri militari. In: Breschi, M., Pozzi, L. (Eds.), Salute, Malattia E Sopravvivenza in Italia Fra ‘800 E ‘900. Udine: Forum, pp. 135–156.
Cazzaniga, W., Capogrosso, P., Ventimiglia, E., Pederzoli, F., Boeri, L., Frego, N., Abbate, C., Alfano, M., Viganò, P., Montorsi, F., Salonia, A., 2018. High blood pressure is a highly prevalent but unrecognised condition in primary infertile men: results of a cross-sectional study. J. Urol. in press.
Christiansen, K., 2002. Anthropology of human reproduction: the male factor. Evolutionary Anthropology, Suppl. 11, 200–203.
Corridore, F., 1902. Storia documentata della popolazione di sardegna (1479-1901). C. Clausen, Torino (Bologna: Forni Ristampa Anastatica 1990), .
Das, K.C., Gautam, V., Das, K.D., Tripathyp, K.T., 2011. Influence of age gap between couples on contraception and fertility. J. Fam. Welf. 57 (2), 30–38.
De La Rochebrochard, E., McElreavey, K., Thonneau, P., 2003. Paternal age over 40 years: the “amber light” in the reproductive life of men? J. Androl. 24 (4), 459–465.
De La Rochebrochard, E., de Mouzon, J., Thepot, F., Thonneau, P., 2006. Fathers over 40 and increased failure to conceive: the lessons of in vitro fertilization in France. Fertil. Steril. 85 (5), 1420–1424.
Delamater, J., 2012. Sexual expression in later life : a review and synthesis. J. Sex Res. 49 (2–3), 125–141.
Dinkel, R.H., Milenovic, I., 1993. Male and female fertility. A comparison of age-specific and cohort fertility of both sexes in Germany. Genus 49, 147–158.
García-Ferreyra, J., Hilario, R., Dueñas, J., 2018. High percentages of embryos with 21, 18 or 13 trisomy are related to advanced paternal age in donor egg cycles. JBRA Assist. Reprod. 22, 26–34.
Ge Rondi, C., Tanturri, M.L., 2008. Uomini, fecondità e figli in Italia tra ottocento e novecento. In: Ge Rondi, C., Manfredini, M., Rettaroli, R. (Eds.), Transizioni Di Fecondità in Italia Tra Ottocento E Novecento. Udine, Forum, pp. 79–102.
Glenn, D.R., McClure, N., Lewis, S.E., 2003. The hidden impact of diabetes on male sexual dysfunction and fertility. Hum. Fertil. 6, 174–179.
Goldman, N., Montgomery, M., 1989. Fecundability and husband's age. Soc. Biol. 36 (3–4), 146–166.
Henry, L., 1961. Some data on natural fertility. Eugen. Q. 8 (2), 81–91.
Ilacqua, A., Izzo, G., Emerenziani, G.P., Baldari, C., Aversa, A., 2018. Lifestyle and fertility: the influence of stress and quality of life on male fertility. Reprod. Biol. Endocrinol. 16 (115) .
Karmel, P.H., 1947. The relation between male and female reproduction rates. Popul. Stud. 1, 249–273.
Karmel, P.H., 1948a. An analysis of the sources and magnitudes of inconsistencies between male and female net reproduction rates in actual populations. Popul. Stud. 2 (2), 240–273.
Karmel, P.H., 1948b. A rejoinder to mr Hajnal's comments. Popul. Stud. (Camb) 2 (3), 361–372.
Karraker, A., DeLamater, J., Schwartz, C.R., 2011. Sexual frequency decline from midlife to later life. J. Gerontol. B Psychol. Sci. Soc. Sci. 66 (4), 502–512.
Kidd, S.A., Eskenazi, B., Wyrobek, A.J., 2001. Effects of male age on semen quality and fertility: a review of the literature. Fertil. Steril. 75 (2), 237–248.
Kuczynski, R.R., 1932. Fertility and Reproduction: Methods of Measuring the Balance of Births and Deaths. Falcon press., New York.
Lenk, S., Schroeder, J., 2001. Genitourinary tuberculosis. Curr. Opin. Urol. 11 (1), 93–98.
Li, Y., Lin, H., Li, Y., Cao, J., 2011. Association between socio-psycho-behavioral factors and male semen quality: systematic review and meta-analyses. Fertil. Steril. 95, 116–123.
Lian, Z.H., Zack, M.M., Erickson, J.D., 1986. Paternal age and the occurrence of birth defects. Am. J. Hum. Genet. 39, 648–660.
Livi Bacci, M., 1977. A History of Italian Fertility During the Last Two Centuries. Princeton University Press, Princeton.
Manfredini, M., Breschi, M., 2006. The role of remarriage in a micro-evolutionary process: considerations from a 19th-century Italian community. Am. Anthropol. 108 (4), 854–861.
Manfredini, M., Breschi, M., Fornasin, A., 2013. Height, socioeconomic status and marriage in Italy around 1900. Econ. Hum. Biol 11 (4), 465–473.
Matorras, R., Matorras, F., Expósito, A., Martinez, L., Crisol, L., 2011. Decline in human fertility rates with male age: A consequence of a decrease in male fecundity with aging? Gynecol. Obstet. Invest. 71 (4), 229–235.
Mazzoni, S., Breschi, M., Manfredini, M., Pozzi, L., Ruiu, G., 2017. The relationship between family characteristics and height in Sardinia at the turn of the 20th century. Hist. Family 22 (2-3), 291–309.
Melis, P., Pozzi, L., 2010. Trachoma, health conditions and social change in sardinia. In: Andresen, A., Barona, J.L., Cherry, S. (Eds.), Making a New Countryside. Health Policies in European History Ca. 1860-1950. Peter Lang., Frankfurt, pp. 25–48.
Michalakis, K., Mintziori, G., Kaprara, A., Tarlatzis, B.C., Goulis, D.G., 2013. The complex interaction between obesity, metabolic syndrome and reproductive axis: a narrative review. Metabolism 62, 457–478.
Niceforo, A., Galeotti, G., 1934. Primi risultati dell'inchiesta alimentare condotta in varie province d'Italia. Quad. Nutr. 1, 1–48.
Nordfalk, G., Hvidtfeldt, U.A., Keiding, N., 2015. TFR for males in Denmark – calculation and tempo-correction. Demogr. Res. 32, 1421–1434.
Oppo, A., 1990a. La nuclearità della famiglia in sardegna. In: Oppo, A. (Ed.), Famiglia E Matrimonio Nella Società Sarda Tradizionale. Cagliari: La Tarantola Edizioni., pp. 73–119.
Oppo, A., 1990b. Where there's no woman there's no home: profile of the agro-pastoral family in nineteenth-century Sardinia. J. Fam. Hist. 15, 483–502.
Paick, J., Kim, S.H., Kim, S.W., 2000. Ejaculatory duct obstruction in infertile men. BJU Int. 85 (6), 720–724.
Palloni, A., Rafalimanana, H., 1999. The effects of infant mortality on fertility revisited : new evidence from Latin America. Demography 36 (1), 41–58.
Payeur, F., 2008. Age Et Fertilité Masculine: Une Analyse Biodémographique. Mémoire Présenté à La Faculté Des Études Supérieures. Université de Montréal.
Payeur, F., Desjardins, B., 2009. Mesure De La Fertilité Masculine En Function De l'age Dans Une Population à Fécondité Naturelle. Paper presented at IUSSP conference. .
Poston, D.L.Jr., Chang, C.F., 2005. Bringing males in: a critical demographic plea for incorporating males in methodological and theoretical analyses of human fertility. Critical Demography 1 (1), 1–15.
Rahman, A., Hoque, R., 2015. Fitting time to first birth using extended Cox regression model in presence of non-proportional hazard. Dhaka Univ. J. Sci. 63 (1), 25–30.
Salonia, A., Matloob, R., Gallina, A., Abdollah, F., Saccà, A., Briganti, A., Suardi, N., Colombo, R., Rocchini, L., Guazzoni, G., Rigatti, P., Montorsi, F., 2009. Are infertile men less healthy than fertile men? Results of a prospective case-control survey. Eur. Urol. 56, 1025–1031.
Schoumaker, B., 2017. Measuring male fertility rates in developing countries with demographic and health Surveys: an assessment of three methods. Demogr. Res. 36, 28.

Sharma, R., Agarwal, A., Rohra, V.K., Assidi, M., Abu-Elmagd, M., Turki, R.F., 2015. Effects of increased paternal age on sperm quality, reproductive outcome and associated epigenetic risks to offspring. Reprod. Biol. Endocrinol. 13, 35.
Singer, R., Segenreich, E., Sagiv, M., Shohat, B., Livni, E., Bartoov, B., et al., 1987. Decreased semen quality in a male infected with malaria. Int. J. Androl. 10, 685–689.
Tietze, C., 1938. Measurement of differential reproduction by paternity rate. Eugenic Review 2, 101–107.
Trost, L.W., Gudeloglu, A., Ko, E.Y., 2014. The importance of diet, vitamins, malnutrition, and nutrient deficiencies in male fertility. Male Infertility 61–82.
Tzvetkov, D., Tzvetkova, P., 2006. Tuberculosis of male genital system – myth or reality in 21st century. Arch. Androl. 52 (5), 375–381.
Van Bavel, J., 2004. Deliberate birth spacing before the fertility transition in Europe: evidence from nineteenth-century Belgium. Popul. Stud. (Camb) 58 (1), 95–107.
Van Leeuwen, M.H.D., Maas, I., 2011. HISCLASS. A Historical International Social Class Scheme. Leuven: Leuven University Press.
Ventimiglia, E., Capogrosso, P., Boeri, L., Serino, A., Colicchia, M., Ippolito, S., Scano, R., Papaleo, E., Damiano, R., Montorsi, F., Salonia, A., 2015. Infertility as a proxy of general male health: results of a cross-sectional survey. Fertil. Steril. 104, 48–55.
Viazzo, P.P., 2003. What's so special about the Mediterranean? Thirty years of research on household and family in Italy. Contin. Chang. 18 (1), 111–137.
Zhang, Z., Reinikainen, J., Adeleke, K., Pieterse, M.E., Groothuis-Oudshoorn, C.G.M., 2018. Time varying covariates and coefficients in Cox regression models. Ann. Transl. Med. 6, 121.
Zitzmann, M., 2013. Effects of age on male fertility. Best Practice & Res.: Clinic Endocrinol. Metabol. 27, 617–628.