

# Post-reproductive longevity in a natural fertility population

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## **ABSTRACT**

*Fertility patterns may be useful markers for rates of biological aging. Based on evolutionary and socio-demographic approaches to historical data from the population of Québec (taken in the Registre de population du Québec ancien at the University of Montreal), we examine the effects of reproduction on longevity. Using Cox hazard models on about 2,000 couples married in the colony before 1740, we show that women bearing their last child late in life had longer post-reproductive lives, suggesting that late menopause is associated with an overall slower rate of aging. Increased parity had an opposite, detrimental effect on women's post-reproductive survival. On the other hand, husband's longevity was less sensitive to parity and reproductive history. For husbands increased effective family size (EFS; the number of children who survived up to age 18) in a "compressed" reproductive time-span meant higher chances for survival past age 60. Children may serve as strong economical assets on farmstead during colonization, which would mostly benefit fathers. In a collaborative effort to unveil post-reproductive aging patterns in historical populations, the results are compared to previous analyses conducted on the Utah population database and evolutionary and socio-demographic theories are addressed in light of the results.*

## INTRODUCTION

It is well established that childbirth has significant health effects on mothers during childbearing years. Far less is known about the influences of fertility patterns on longevity of both men and women. Following Smith and colleagues (Smith et al., 2002), we address this question from biological and social perspectives. We briefly review the theories on both subjects and, using historical data from Québec, attempt a replication the original study based on the Utah population, and compare the results obtained from the two populations.

Demography has traditionally addressed the interplay between aging and fertility in terms of population dynamics and structure. Lower infant mortality mechanically increases life-expectancy, and reduced fertility leads to an increased proportion of the population at older ages. Based on the theory of natural selection, bio-demographers posit additional theoretical connections between the two phenomena. Natural selection has no interest in longevity *per se* but indirectly moulds it through reproductive success (Charlesworth, 1994; Hamilton, 1966), which depends on parents' survival (Kirkwood, 1997; Smith et al., 2002; Vaupel et al., 1998; Wachter et al., 1997; Westendorp and Kirkwood, 1998). There are three evolutionary mechanisms through which fertility may interact with longevity. First, as selective pressure becomes low past reproductive years, (genes are already passed on to the next generation), deleterious mutations become free to accumulate at older ages. This hypothesis, referred to as the "mutation accumulation" hypothesis, is believed to have originated in a discussion between Medawar and Haldane about Huntington's disease in the 1940s.

The second, related hypothesis confers a more active role to natural selection. Instead of supposing passive accumulation of detrimental mutations after reproductive age, it posits the antagonistic action of so called “pleiotropic genes” that would favour reproduction at younger ages but would reduce vitality at older ages. Favouring reproduction at the expense of longevity, such genes would be actively preserved by natural selection. Put forward by Williams (1957), the theory predicts that early and higher levels of fertility should correlate with reduced life-span (Le Bourg et al., 1988; Le Bourg et al., 1993)

A third mechanism, proposed by Kirkwood (1977), could also lead to an association between early age at first birth and reduced prospects for old age survival. Each organism makes trade-offs between investing resources into somatic growth and maintenance or into reproduction (Kirkwood, 1977; Kirkwood and Holliday, 1979; Lycett et al., 2000). It would be selectively advantageous for higher organisms to adopt an energy saving strategy of reduced accuracy in somatic cells to accelerate development and reproduction, leading to faster post-reproductive deterioration and death. According to the “disposable soma” theory, young ages at first birth and high parities would entail high somatic costs, with the consequence of a shorter post-reproductive life span.

The three theories posit different evolutionary mechanisms but each of them lead to the prediction that the action of forces postponing the period during which female reproduction occurs will postpone aging and increase female longevity. Empirically, provided that polymorphism in populations is maintained through sufficiently high mutation rates, later ages at last birth among females (a proxy for late menopause) should be associated with greater post-reproductive female longevity. In addition, Kirkwood’s

disposable theory would lead to the prediction of a shorter life for women with high parities and early ages at first birth.

The above evolutionary arguments do not seem to apply to males with the same relevance as they do for females. From an evolutionary standpoint, men's reproductive success does not critically depend on their longevity because they invest much less on their progeny, at least traditionally, than their female counterparts. Consequently, very few human biologists have theorized on the effect of reproduction patterns on men's longevity. Sociologists and demographers, on the other hand, may offer some clues. They also furnish ways to reinterpret women's reproductive life history traits.

While proposing appealing biological arguments, evolutionists generally fail to account for social factors, subsuming these factors into the "environmental component", a residual or nuisance category that complicates further an already complex model. It is well established that access to social and family support leads to better health and lower levels of mortality (Connidis, 2001; House et al., 1988). After spouse or marriage partner, children are generally regarded as the most important component of an adult's social and family network (Lye, 1996). In agricultural and pre-industrial societies, children may also serve as important assets, particularly during the first phases of the colonization of a new territory. They may add valuable work force in the fields when young, and, as adults, provide health-enhancing social and economic support to their elderly parents. On the "pioneer front", the crude number of family members may determine which kin group will take over the best available resources (best lands, proximity to water, etc.)(Gagnon and Heyer, 2001a; Gagnon and Heyer, 2001b).

However, the upward flow of resources (social support, workforce, income) from children to parents was found to be small in pre-industrial families (Lee, 1997) as well as in contemporary families (Hogan, 1993). Moreover, as pointed out by Smith *et al.* (2002), upward genealogical transfer may be limited by the fact that adult children are themselves rearing offspring of their own. Given that fertility patterns are transmitted across generations (Anderton et al., 1987; Gagnon and Heyer, 2001b), the capacity of children to provide assistance to their parents may be further reduced in high parity lineages. This argument suggests that, in natural fertility populations, parents with many children could be adversely rather than beneficially affected, since their children will devote resources to their own children (Smith et al., 2002).

Concerning the interplay between the timing of fertility and the flow of resources in families, parents bearing their first children at younger ages will be more likely to invest their limited resources to children rather than to their own personal health and development (Hofferth, 1984; Waldron et al., 1998). In historical times, the production of children, if too early in life, may have increased the likelihood of physical exhaustion. It also would have impeached or slowed down the accumulation of critical resources for later days. On the other hand, women bearing children at very old age could have experienced adverse health consequences, because of an extended period of child rearing (Smith et al., 2002) during years in which individuals' frailty increases dramatically.

## *Hypotheses*

The evolutionary theories (ET) and social theories (ST) linking reproduction with longevity lead to the formulation of several hypotheses to explain pre-industrial mortality patterns. Table 1 lists a series of hypotheses taken from Smith et al. (2001).

### TABLE 1 ABOUT HERE

Scenarios with effects pointing toward opposite directions are more amenable to the formulation of tests that could delineate the action of social and biological/evolutionary forces; it is easier to assess the underlying forces that link longevity with either (H2) parity or (H3) late age at last birth than to (H4) age at first birth (for which the relation is positive in both cases).

As high parities do not necessarily lead to high numbers of children who survived (high parity often comes with high infant mortality), Smith *et al.* (2002) introduced the “number of children who died before age 18” as a control in their various models. In the present paper, we also used this control variable. We additionally introduced and tested another, related variable: the “Effective Family Size” or EFS (Gagnon and Heyer, 2001b), defined for a family as the number of children who reach adulthood. Parity alone would capture physiological processes affecting women’s reproductive health and (perhaps) longevity, while the EFS would more appropriately capture the socio-economic benefits or costs of having many or few children, for both women and men. Exceptionally high parity may lead to physical exhaustion that cumulates over the years and results in lower female post-reproductive chances for survival. Large EFS, on the other hand, may lead to a strong advantage in family workforce for taking over freely available resources

in a colonization context. We suppose that females' longevity will be more influenced by figures pertaining to total parity than to EFS, while the converse would be true for males.

## **DATA AND METHODS**

### *Data and selection of cases*

The data used here originated from the *Registre de population du Québec ancien*, compiled by the *Programme de recherche en démographie historique* (PRDH) at the University of Montreal (Desjardins, 1998; Légaré, 1988). The database contains, for individuals that lived in the Saint-Lawrence Valley in the 17<sup>th</sup> and 18<sup>th</sup> centuries, the date and place of birth, death and marriage(s), names of parents and spouse(s) and secondary information on occupation (if available) and places of residence and of origin. The population remained quasi-closed until the 19<sup>th</sup> century, because of particular historical and geographical circumstances, so the usual problem of missing observations because of migration was greatly reduced. The database covered information on the entire period of French rule. Births were matched with individuals up to the year 1770, and deaths up to around 1830 (relating to people born before 1730). All the ancestors of every individual who married before 1800 were traced back to the founders of the population. Previous studies have shown that the population of that period lived under 'natural fertility' conditions, as defined by Henry (1972) as it was free of deliberate fertility control (Charbonneau, 1993; Desjardins et al., 1994; Desjardins et al., 1991).

The database contains more than 712,000 vital rate certificates spanning over more than two centuries. However, the highly constraining selection criteria pertaining to

longevity studies, as well as the necessity of a complete knowledge of couples' reproductive histories, resulted in this study in final samples of 1,923 women and 1,926 men. For comparability purposes, we used the exact same criteria as in the Utah study, except that we made two separate samples, one for each sex, in order to preserve a reasonable sample size. For simplicity and homogeneity, only first marriages were considered. Given the current advancement of the record linkages at the PRDH, this criterion led us to retrieve all couples who married before 1740, thus leaving both husbands and wives the opportunity to complete reproductive life within the database limits, and to survive up to age 100. Husbands were no more than ten years younger or fifteen years older than their wives, which reduced large differences in age and cohort experiences. Wives were required to have married no later than their thirty-fifth birthday in order to ensure that they had a clear opportunity to bear children. All these selected women lived to at least age 60 to assure that they would all have completed child bearing. Women whose husbands died before their 60<sup>th</sup> birthday were removed because of the critical lack of resources and social support to their surviving wives. Bias-free analysis also required couples with husbands fathering past age 60 to be removed because they would have, by definition, lived over the "time origin" of our study.

### *Variables*

The main variables of interest of this study were (1) age at first birth, (2) age at last birth, (3) parity and (4) EFS. Each of these variables was first entered as a continuous in various models (Table 3) and then with categorical specifications (Table 4). Although the focus was on reproductive history, we examined the possibilities of coincidental associations by including a set of control variables such as the year of marriage, the

number of children who died before age 18, the residential status (urban or rural), and the geographic location (East or Western part of the colony).

Table 2 A and B present the descriptive statistics concerning our variables of interest and controls, as well as the response variable, i.e., age at death, or, more appropriately, the number of years lived over age 60. Age at death did not differ appreciably between the sexes. It was approximately 74 years, which means that both sexes survived on average 14 years after the cut-off point of age 60. One woman was very close to give the colony its first centenarian. Marguerite St-Julien Daragon was born the 28 of January 1714. She died almost 100 years later, the 28 of August 1813. In her death certificate, the priest declared that she was 106 years old. This demonstrates once again why demographers interested in longevity should be extremely careful with declared ages. The latter were shown to be consistently exaggerated, especially for older people (Desjardins, 1999).

Figures and numbers pertaining to fertility were quite high, although not uncommon for natural fertility population. Families averaged 10.3 children, of whom about 6.3 could survive up to age 18 or marry in the colony. Mean age at first birth was 22.9 years for wives and 27.5 years for husbands. Women gave birth to their last child at a mean age of 41, while men had their last child five years later on average. About 20% of these selected individuals lived in Québec city, Montréal or Trois-Rivières (urban areas).

TABLE 2 A and B ABOUT HERE

## *Survival Methods*

A series of Cox regression models were fitted to the data in order to test whether the predictors had any influence on survival times. The Cox regression model expresses a transformation of the hazard as a linear function of the predictors. A continuous hazard function is a rate with no upper bound and thus, the logarithm of the hazard is treated as the outcome variable (Singer & Willet 2003: 514):

$$\log h(t_i) = \log h_o(t) + [\beta_1 X_1 + \beta_2 X_2 + \dots + \beta_i X_i].$$

The log hazard  $\log h(t_i)$  equals the baseline function  $\log h_o(t)$  plus a weighted linear combination of predictors  $\beta$  that measure the effect of the covariates on  $\log h(t_i)$ . There are two main assumptions involved in the Cox regression model. First, there is a log-linear relationship between the covariates and the underlying hazard function. Second, there must be a multiplicative relationship between the underlying hazard function and the log-linear function of the covariates. This is also known as the proportionality assumption. It is assumed that the hazard function of any two individuals with different values of the covariates have parallel age (time) patterns (Elandt-Johnson and Johnson, 1980). In other words, the hazard ratio should not be time-dependent.

Potential violations of the proportionality assumption were checked with  $\log S(t)$  plots of the categorical variables and with Schoenfeld residual plots of all covariates. For women, the main variables of interest showed no deviation from the time invariance assumption. Additionally, there were no significant correlations between the residuals and the time variable (years lived over age 60) for each of the covariates. Some of the control variables (for instance Urban/rural), however, had a significant interaction with

time. Consequently, we introduced cross product terms with time for any of these variables when necessary. For men, the picture was much less clear and one must exercise caution in interpreting the corresponding coefficients. Since we observed several crossing of the hazard functions for the categorical variable on Age at first birth, we introduced a term for interaction with time for this variable. This interaction term proved to be significant at the .056 level. There was some evidence that this variable interacted with the EFS. The variables Age at last birth, Parity and EFS, however, appeared to meet the proportionality assumption after visual inspection of Schoenfeld residual plots and more formal tests. All Cox models were run in STATA, using robust estimators to account for eventual clustering in risks of death. Shared frailty models and parametric models including unobserved heterogeneity were also briefly tested for women, with no important variations in the parameter estimates and their significance from the results obtained from the Cox models (not shown here).

## **RESULTS**

Table 3 lists results for several Cox proportional hazard models for females (upper panel) and males (lower panel). All variables were measured as continuous variables (except for East and Urban, which are categorical by nature). When each of the reproductive history variables were introduced separately (Models 1-4), only age at last birth was found to affect female post-reproductive survival. However, the simultaneous inclusion of all three fertility measures appeared to remove the “suppressor effect” on parity (it become significant at the 0.1 level). Note also the increase (in absolute terms)

on the parameter estimate for Age at last birth from Model 2 to Model 4 (from  $-.018$  to  $-.024$ ). Women who had few (relatively!) children and who bore their last one at a late age would have had lower risks of mortality past age 60. For example, a delivery of 1 more child would have increased the post-reproductive hazard rate by about 1.9% ( $e^{0.0186} = 1.0188$ ), while a decrease of one year in the Age at last birth would have increased this rate by 2.4% ( $e^{0.0239} = 1.0242$ ). A woman terminating reproduction five years earlier with five more children than the corresponding average figures would have face a hazard about 24% greater than the average ( $e^{5(0.0186 + 0.0239)} = 1.237$ ). Age at first birth and EFS had no significant effects. The best model simultaneously included age at last birth and parity (Model 5). These results largely agree with those reported by Smith *et al* (2002) for the 19-20<sup>th</sup> centuries Utah population. There are only two slight differences. First, in the Utah population, the variable that stood alone with a significant effect was *parity*, not *age at last birth* as in Québec. Second, we found no significant interaction between age at last birth and parity. The effect sizes of most variables, however, were surprisingly close in both populations (between  $.010$  and  $.025$ ), a striking result considering that they refer to different populations at different epoch.

Table 3 also shows that none of the reproductive history variables, when measured as main effect on a continuous scale, significantly affected male survival. When only one of the reproductive history variables was entered, the overall fit was slightly better for men than for women, but this was because of a stronger implication of the (not-listed) control variables in the case of men. For instance, wife's age at death strongly influenced husband's age at death, while the converse was not true. Adding more variables did not seem improve the fit, suggesting that factors pertaining to the

intensity and the timing of reproduction did not have much effect on males' survival. Nevertheless, a significant interaction between age at first birth and EFS was detected (Model 8). As the parameter is negative, increasing both variables multiplicatively increase males' longevity, meaning that, typically, men who started reproducing later, but who still had many children *who survived*, had the best prospects to reach older ages. For example, an individual who would have begun reproduction ten years later than average age and who have still ended up with five more children than average would have faced a hazard that was 84% of the hazard faced by individuals with the average for these two variables ( $e^{-0.0035 \times 10 \times 5} = 0.839$ ,  $p < .05$ ).

#### TABLE 3 ABOUT HERE

In principle, nothing “forces” the relationship between survival and reproductive history to be strictly linear. To explore further the relationship, Cox models were re-estimated with the fertility indicators included as categorical variables (Table 4). Categorized hazard coefficients largely confirmed previous results. Again, when entered alone, the most important variable for women was the age at which they terminated reproduction (Model 2). Having a child late appeared to be a sign of a slower rate of aging, with a reduction of about 10% in the post-reproductive hazard ( $e^{-0.1054} = .90$ ,  $p < .05$ ) for women who bore their last child after age 44, relative to modal women who bore their last child between ages 38 and 43. In comparison with women having their last child before age 38, these women could expect to be submitted to hazard rates about 28% lower ( $e^{-0.1054 - 0.2302} = .72$ ,  $p < .001$ ) in the post reproductive period.

#### TABLE 4 ABOUT HERE

This time, when parity was entered alone, it proved to be significant, at least at the extreme of the distribution. After age 60, women who previously gave birth to 14 children or more had hazard rates that were about 16% higher than those of women who had less children ( $e^{0.1464} = 1.16$ ,  $p < .01$ ). Introducing the two other reproductive history variables, the parameter estimate for this group of women increased from .1464 ( $p = .015$ ) to .1982 ( $p = .002$ ), which demonstrated how a “suppressor” effect can be removed with the adjunction of proper controls. Here, we categorized the variable in order to have approximately 15% of the women at each extreme of the distribution, with the remaining 70% in the modal size family groups. When we categorized the variable as a binary variable, with families comprising more than 13 children in the “large” parity category, the parameter estimate slightly decreased to .183 ( $p = .002$ ). Using family sizes of 12 and then 11 as cut-off points for “large families” resulted in important decreases of the parameter estimates and in a loss of significance; for example, with 11 or more births as the demarcation point, the parameter fell to .052 ( $p = .302$ ). Hence, there could be a threshold after which adding more children would result in decreased longevity. Under this threshold (of about 12-13 births), however, old age survival of French Canadian women was relatively unaffected. Note that this conclusion applies to fertility alone, and not to effective family size (EFS). Comparing Model 6 to Model 5 (highlighted here because it provided the strongest measure of goodness of fit), we observed that the influence of net EFS was, as predicted, less strong, if not negligible, than that of crude parity among women.

The effect of age at first birth was more mitigated and difficult to interpret than that of age at last birth and parity. It appeared to be U-shaped function as both *younger*

and *older* primiparous women enjoyed higher chances for survival than most women, although the significance was not strong for younger primiparous mothers. These results were exclusively based on the complete reproductive history of the selected families. All dates of birth and death for husbands, wives, and first born and last born children were precisely known because they were directly taken from the parish registers. With the technique of family reconstitution, researchers at the PRDH were able to link many children for whom the birth certificate was not found in the registers, but for whom we have a “declared” age. When these “incomplete history” families having some declared ages (admittedly far less precise than confirmed dates, as mentioned above) were added in the sample, the apparent beneficial effect of early age at first birth completely disappeared (not shown here). In this new sample comprising 2,280 families (instead of 1,923), all other measures remained consistent, including those pertaining to parity and to age at last birth.

The picture appeared diametrically inverted among men, for whom Model 6 (and not Model 5) offered the best fit. As predicted, EFS was positively related to males’ reproductive survival, while parity in itself had no clear effect: the hazard ratio of men who had 10 or more *surviving children* to those with 9 or less was .86 ( $= e^{-0.1475}$ ,  $p < .05$ ). As hypothesized by Smith et al. (Smith et al., 2002), early age at first child can be detrimental to men, although the effect was less significant ( $p < .1$ ) in the Québec data. We were surprised to find a strong, positive influence of early age at last child for men. In light of previous results, the best scenario for men was to have a maximum of surviving children in the smallest amount of years! This result is truly intriguing considering what it meant for their wives (a highly intensive and compressed reproductive lifespan).

Although all parameters remained relatively stable in the enlarged sample (N=2,280) for men (while the one pertaining to age at first birth lost significance in the case of women), caution and deeper analyses are warranted.

Would there be also an “EFS threshold” for men (just like there was a parity threshold for women)? Using a cut-off limit of 9 surviving children as for the demarcation for large EFS (instead of 10), we obtained a smaller parameter estimate (-0.0860 versus -0.1475) that was no more significant ( $p=0.162$ ). Increasing the cut-off point from 10 to 11 surviving children resulted in a larger, and more significant parameter estimate (-0.247,  $p=0.008$  in comparison with -0.1475,  $p=0.035$ ). The existence of a threshold, however, does not make much sociological sense. The disappearance of significance with the lowering off of the demarcation point should be interpreted instead as a consequence of sample size. This would also apply to women with regards to parity, albeit the biological constraints and costs involved in reproduction (energy expenditure involved in pregnancy, risks associated to birth delivery, maternal depletion with short birth intervals, etc.) certainly induce a steeper decrease of survival chances with increasing number of pregnancies.

## **DISCUSSION**

Replication is not a road often taken by social scientists. It is largely believed that human behaviors are too complex and particular to be repeated and tracked more than once. As shown here, the field of biodemography may offer opportunity to prove the contrary. In both historical Utah and Québec populations, bearing and rearing children

affected the mortality risks of post-reproductive mothers and fathers. Isolating the hypothesized association between longevity and late fertility in a natural fertility population is complicated by the fact that women bearing children at later ages usually have higher parity. Nevertheless, lower parity and late age at last birth were associated with greater post-reproductive longevity among women of both populations. As noted above, the parameter estimates were even surprisingly close in the two populations.

Under a given set of biological or evolutionary constraints, one might expect an upper limit to the number of child deliveries, a threshold over which adding more births would become detrimental, not only for the immediate survival of the mother, but also for her post-reproductive longevity. Women having a smaller number of children spent a lesser amount of energy in child bearing and rearing in their early years, thus preserving their reserve for a longer and healthier life. This association between high parity and higher hazard rates at older ages is consistent with predictions based on the disposable soma theory (H2, Table 1). One must be cautious, however, before discarding a more “proximal” explanation. In principle, frailty may be simply acquired during life-time through physical exhaustion past the “fertility threshold”. It is not necessary to call upon innate heritable variants that would simultaneously affect women’s fertility and longevity.

On the other hand, late age at last birth, which correlates with greater survival prospects, can be taken as a sign for a slower rate of aging, and as a stronger support for an underlying evolutionary mechanism on innate genetic variation (i.e., H3; Table 1). Other psycho-social explanations could also be offered. We could imagine, for instance, that women who had their last child at an “early” age of 35 were less “happy” and less

enthusiastic in their marital relationship about the future and about life in general than other women. Being less enthusiastic, they would also have been less prone to engage in sexual intercourses with their husband, which would have also correlated with lower prospects for old ages survival. Although we cannot fully discard this hypothesis, we believe that in a natural fertility population with no evidence for fertility control (even at advanced reproductive years) the assumption of a close connection in time between menopause and age at last child will generally hold. One could also argue for a selective bias in our samples in that highly fertile women who bore a child at very old ages may have died in the process, and thus escaped the net of our sample selection procedure. This issue certainly deserve further exploration. One must not forget, however, precisely how strong the odds were against these women who bore children in later reproductive life. Maternal mortality is higher at those ages precisely because the cost of child bearing increases with age. In this respect, we should expect, instead, better survival prospects for women who have their last child at a more “reasonable”, early age (thus avoiding physical exhaustion and “extra costs” at “risky” ages, precisely when frailty sharply increases). The fact that the data tell the contrary strongly favours the hypothesis of a slower rate of aging in late parous women, consistent with hypothesis H3.

In contrast with what was found in the Utah population, there is some evidence that late age at first birth enhanced female longevity in old Québec (providing support for both hypotheses H1 and H4), albeit one should not take this evidence for granted because very early age at first child was apparently also beneficial. As said above, this contradictory finding disappears when we used an enlarged sample, but further analyses are warranted before concluding on this aspect. Westendorp et al. (1998) also reported a

longer life for British aristocratic women who started reproduction later, and directly interpreted this evidence as a strong support for the disposable soma theory. We would argue that this conclusion was probably premature because in historical times, age at first childbearing strongly depended on age at marriage, which was determined by a number of factors (kinship systems, inheritance rules, demographic pressure on land, etc.) that have nothing to do with fertility.

In a similar way, using French Canadian data (the same as those used in this article, but at an earlier stage of completion of the database), Le Bourg et al. (1993) failed to find support for Williams' hypothesis of a trade-off between early "fecundity" and later survival. The measure they used in their test as a proxy for early fecundity, i.e., "age at first birth", was probably ill-chosen for the reason given above: the age at marriage is most likely not be affected by the presence or the absence pleiotropic genes, to which Williams' hypothesis refers. The best measure would be the *first birth interval* as a proxy for "fecundability" (i.e., physiological capacity to reproduce). After conducting several such tests on our data, we found no evidence for this association. Quite the contrary, very short intervals seemed to be associated with longer life-spans, although the association was not significant. If such pleiotropic genes exist, they are probably too rare to be detected, at least in historical data. Strong selective pressures would most likely oppose such rare variants (e.g. the critical advantage of prolonged parental investment in women).

Concerning men's fertility and longevity patterns, we note that the figures do not fully agree for Utah and Québec. In Utah, compared to their wives, husbands experienced weaker longevity benefits of low parity and late fertility. But the direction of

the effects was consistent for the two sexes (Smith et al., 2002). As seen in table 3 and 4, in Québec, an earlier age at last birth was detrimental for men, while the contrary was true for women. Reproductive success, as measured by the number of children who survived up to age 18 (i.e., EFS), clearly advantaged men, but not women (it meant a higher parity for them). The most striking result was a positive influence on longevity of an early cessation of reproduction for men, again contrary to what is observed for women. Pending on further model testing (see Data and Methods) the relationships between fertility and survival among men in historical Québec appear to match all the predictions originating from the above social theories (H4, H5A, and H6). Since men's reproductive prospects appear to critically depend on social factors, it is expected that these patterns will vary from one population to another, as seen for Québec and Utah. Since women's reproductive life rests on a set of stronger biological constraints, their reproductive (and, presumably, longevity) outcomes will vary less, and in a more predictable way. Note however that in the Utah study, full couples constituted the basis of the analysis, while sample size limitations constrained us to construct separate samples for husbands and wives in the case of Québec. This may explain in part why husbands and wives coefficients are consistent and have the same sign in the former, while they tend to diverge in the latter.

Particular incentives associated with the peopling of a new territory might have pushed the reproductive capacity of the female inhabitants of the early French Canadian colony to the limits. Ironically, such strong incentives for reproduction seem to have benefited their husbands, for whom a large effective family was probably a key to old age survival. We could portrait these early Québec settlers as “using” women's reproductive

capacity to their benefit, i.e., to facilitate their takeover of largely free lands by increasing their family size. The economic benefits of large families, and perhaps the associated stronger access to social support provided by adult children, may have translated into longevity gains for post-reproductive males, in agreement with social support theories.

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**TABLE 1. HYPOTHESIZED RELATIONSHIPS BETWEEN LONGEVITY AND AGE AT FIRST BIRTH, PARITY AND AGE AT LAST BIRTH FROM EVOLUTIONARY (ET) AND SOCIAL THEORIES (ST).**

	Age at first birth	Parity	Age at last birth
ET	(H1) <i>Positive</i>	(H2) <i>Negative</i>	(H3) <i>Positive</i>
ST	(H4) <i>Positive</i>	Either (H5A) <i>positive</i> (greater access to social support from children) or (H5B) <i>negative</i> (greater wealth flows from parents to children)	(H6) <i>Negative</i>

(Taken from Smith et al. (Smith et al., 2002))

**TABLE 2. DESCRIPTIVE STATISTICS****A) WOMEN (N=1923)**

<b>VARIABLE</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>Std. Dev.</b>
AGE AT DEATH	60.0	99.6	74.1	7.98
Husband's age at death	48.0	99.8	73.1	8.11
Year of marriage	1632	1739	1716	17.94
Immigrant to New France (=1)			.02	.15
Husband immigrant to New France (=1)			.17	.37
Residence in the Eastern part of the colony (=1)			.43	.50
Lived in an urban area (=1)			.21	.41
Age difference between spouses (husband – wife)	-9.3	15	4.7	4.91
AGE AT FIRST BIRTH	14.6	45.2	22.9	4.19
AGE AT LAST BIRTH	18.1	50	40.9	4.34
Mean age at childbearing	18.1	45.2	31.5	2.98
TOTAL NUMBER OF CHILDREN BORN (PARITY)	1	23	10.3	3.66
Fraction of children who survived to age 18 and/or married			.62	.22
Total number of children who survive to age 18 and/or married ("Effective fertility")	0	17	6.3	2.88

**b) MEN (N=1926)**

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VARIABLE	Min	Max	Mean	Std. Dev.
AGE AT DEATH	60.0	94.7	73.2	7.61
Wife's age at death	42.0	97.5	71.0	10.29
Year of marriage	1639.00	1739	1716	18.73
Immigrant to New France (=1)			.10	.29
Wife is immigrant to New France (=1)			.05	.21
Residence in the Eastern part of the colony (=1)			.47	.50
Lived in an urban area (=1)			.20	.40
Age difference between spouses (husband – wife)	-9.5	15.0	5.1	4.53
AGE AT FIRST BIRTH	18.5	44.4	27.5	4.04
AGE AT LAST BIRTH	20.8	57.9	45.9	5.95
Mean age at childbearing	20.8	48.2	36.2	4.12
TOTAL NUMBER OF CHILDREN BORN (PARITY)	1	23	10.4	3.60
Fraction of children who survived to age 18 and/or married			.62	.22
Total number of children who survive to age 18 and/or married ("Effective fertility")	0	17	6.4	2.86

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**TABLE 3. HAZARD RATES MODELS FOR SURVIVAL PAST AGE 60. ENTRIES ARE COX HAZARD REGRESSION COEFFICIENTS MULTIPLIED BY 10<sup>3</sup>.**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
<b>WOMEN</b>								
Age at first birth	-6.4				1.7	1.4		
Age at last birth		-18.1***			-23.9***	-23.7**		
Parity			-1.1		18.6 <sup>&amp;</sup>			
EFS				-7.4		14.8		
$\chi^2$	45.46	57.03	48.67	48.58	58.93	58.67		
Model df vs Null df	12	12	12	12	14	14		
<b>MEN</b>								
Age at first birth	-4.9				-9.2	-9.7	-13.1	16.2
Age at last birth		-2.0			2.3	2.7	3.2	3.6
Parity			-4		-6.5		-6.7	
EFS				-3.5		-11.0		-15.0
Age at first birth*Parity							-2.2	
Age at first birth*EFS								-3.5*
$\chi^2$	58.62	56.91	56.16	56.52	57.19	58.0	59.69	60.83
Model df vs Null df	9	9	9	9	11	11	12	12

Adjusted for marriage year, immigration status, age difference between the spouses, age at death of spouse, number of children who died before age 18 (or the fraction of these children in the case of parity).

$\chi^2$ : Model -2LL vs Null -2LL, EFS: Effective Family Size

<sup>&</sup>p<.10, \*p<.05, \*\*p<.01, \*\*\*p<.001.

**TABLE 4. HAZARD RATES MODELS FOR SURVIVAL PAST AGE 60 WITH CATEGORICAL SPECIFICATIONS. ENTRIES ARE COX HAZARD REGRESSION COEFFICIENTS MULTIPLIED BY  $10^3$ .**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
<b>WOMEN</b>						
<b>Age at first birth</b>						
< 19	80.3				-120.1 <sup>&amp;</sup>	100.1
19 – 26	Ref.				Ref.	Ref.
27+	-217.6**				-219.5**	-208.3**
<b>Age at last birth</b>						
<38		230.2***			221.8**	241.0**
38 – 43		Ref.			Ref.	Ref.
44+		-105.4*			-123.9*	-112.9*
<b>Parity</b>						
<7			86.8		22.5	
7 – 13			Ref.		Ref.	
14+			146.4**		198.2**	
<b>EFS</b>						
<4				69.3		10.9
4 – 9				Ref.		Ref.
10+				59.4		109.4
$\chi^2$	60.6	63.4	54.6	49.8	83.5	78.8
Model df vs Null df	13	13	13	13	17	17
<b>MEN</b>						
<b>Age at first birth</b>						
< 24	86.0				100.5	122.5 <sup>&amp;</sup>
24 – 30	Ref.				Ref.	Ref.
31+	42.0				51.7	11.6
<b>Age at last birth</b>						
<40		136.6 <sup>&amp;</sup>			-136.1 <sup>&amp;</sup>	-202**
40 – 51		Ref.			Ref.	Ref.
52+		62.2			-66.3	-45.5
<b>Parity</b>						
<7			-113.8 <sup>&amp;</sup>		-55.6	
7 – 13			Ref.		Ref.	
14+			-111.8 <sup>&amp;</sup>		-120.1 <sup>&amp;</sup>	
<b>EFS</b>						
<4				-22		80.1
4 – 9				Ref.		Ref.
10+				-112*		-147.5*
$\chi^2$	58.5	62.6	60.3	62.14	68.4	71.7
Model df vs Null df	10	10	10	11	14	14

Adjusted for marriage year, immigration status, age difference between the spouses, age at death of spouse, number of children who died before age 18 (or the fraction of these children in cases where parity is modeled). Standard errors were estimated using the “robust” command in STATA

<sup>&</sup>p<.10, \*p<.05, \*\*p<.01, \*\*\*p<.001.  $\chi^2$  : Model -2LL vs Null -2LL