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Alain Gagnon

University of Western Ontario, agagnon4@uwo.ca

Ryan Mazan

University of Western Ontario

Bertrand Desjardins

Université de Montréal

Ken R. Smith

University of Utah

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by

Alain Gagnon¹, Ryan Mazan¹,
Bertrand Desjardins², and Ken R. Smith³

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- 1 – Population Studies Centre, Department of Sociology, University of Western Ontario;
2 – *Programme de recherches en démographie historique*, Département de démographie
University de Montréal;
3 – Huntsman Cancer Institute, University of Utah, Salt Lake City, USA.

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**Population Studies Centre
University of Western Ontario
London CANADA N6A 5C2**

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Alain Gagnon¹, Ryan Mazan¹, Bertrand Desjardins², and Ken R. Smith³

1 – Population Studies Centre, Department of Sociology, University of Western Ontario;

2 – *Programme de recherches en démographie historique*, Département de démographie
University de Montréal;

3 – Huntsman Cancer Institute, University of Utah, Salt Lake City, USA.

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Address for correspondence: Alain Gagnon. Population Studies Centre, University of Western Ontario, Room 5326, Social Sciences Centre, London, (Ontario, Canada). N6A 5C2. Tel. (519) 661-2111 ext. 82850. Fax: (519) 661-3200. e-mail : agagnon4@uwo.ca.

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 from 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 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 evolutionary 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 by Smith *et al.*, 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 deeper theoretical connections between the two phenomena. Natural selection has no interest in longevity *per se* but indirectly moulds it through action on reproductive success (Charlesworth, 1994; Hamilton, 1966), which depends on survival of the parents (Kirkwood, 1997; Smith et al., 2002; Vaupel et al., 1998; Wachter et al., 1997; Westendorp and Kirkwood, 1998). There are three evolutionary-induced mechanics through which fertility may interact with longevity. First, as individuals exceed reproductive ages, there are fewer and fewer evolutionary incentives to preserve them alive. Since genes are already passed on to the next generation, the selective pressure on genes for continued survival become very low, and deleterious mutations become free to accumulate at older ages (they are no longer filtered out by natural selection). 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 favor reproduction at younger ages but would reduce vitality at older ages. By favoring reproduction at the expense of longevity, such genes would be actively preserved through the action of natural selection. In other words, senescence would have evolved by selection for genes with different effects on fitness at different ages. 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)

An association between early age at first birth and reduced prospects for old ages survival could also arise by a third evolutionary mechanism. Evolutionary theorists argue that each organism makes trade-offs between investing resources into somatic or physical growth or into reproduction (Kirkwood, 1977; Lycett et al., 2000). Given a set of mortality constraints that may act early or late in life (predation, pathogens, etc.), each individual would try to maximize its reproductive success. According to this “disposable soma” theory, young age at first birth and high parity would entail high physical (somatic) costs, with the consequence of a shorter post-reproductive life span. This third mechanism, proposed by Kirkwood, appears to be more concerned with the “proximal” determinants of mortality, rather than with its “ultimate” evolutionary causes. Simply, those individuals who spend a lot of energy in rearing children at early ages would have

fewer resources available at older ages and would thus be expected to suffer higher mortality at those ages. However, the mechanics of investments, expenditures, and costs involved in the disposable soma theory have deep evolutionary consequences. Over the long run, species that have “decided” (or were forced) to invest their limited resources in early reproduction will keep in their gene pool those variants that help them to do so, and genes useful for soma maintenance will concomitantly decline in frequency. Consequently, members of such species will age faster than those who “chose” (or had the opportunity) to delay reproduction.

The three theories are based on different mechanisms but each of them lead to the prediction that the action of forces prolonging the period during which female reproduction occurs will postpone aging and increase female longevity. Empirically, provided that polymorphism 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. There is some evidence that late menopause itself would be related to increased survival (Cooper and Sandler, 1998; Snowdon et al., 1989). Other intervening mechanisms such as parental investment – or even “grand parental investment” (c.f. the grand mother hypothesis (Beise and Volland, 2002)) – offer additional rationales for a strong link between fertility and longevity. A woman must survive long enough to provide her offspring with sufficient resources, and pass along that “survival ability” to the next generations.

These strong evolutionary inducements for a close link between reproductive life and survival to older ages do not seem to apply to men with the same intensity as with women. 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 interesting and convincing evolutionary 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.* (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 mechanisms theories (SMT) linking reproductive life history traits 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 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.* (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” (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 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 each individual that lived in the Saint-Lawrence Valley in the 17th and 18th centuries, if available, the date and place of birth, death and marriage(s), names of parents and spouse(s) and secondary information on occupation and places of residence and of origin. The population remained quasi-closed until the 19th 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 (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 a final sample of 1,950 couples. For comparability purposes, we used the exact same criteria as in the Utah study (Smith et al., 2002). 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, 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 to ensure that they had a clear opportunity to bear children. These selected women all lived to at least age 60 to assure that they would all have completed child bearing. Couples including husbands who died before their wife's 60th 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 presents 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 10.5 children, of whom about 6.3 could survive up to age 18 or marry in the colony. Mean age at first birth was 22.8 years for wives and 26.9 years for husbands. Wives gave birth to their last child at a mean age of 40, while husbands had 5 their last child 5 years later on average. About 20% of these selected individuals lived in Québec city, Montréal or Trois-Rivières (urban areas).

TABLE 2 ABOUT HERE

Survival Methods

A series of Cox regression models were fitted to the data in order to assess 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 β 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 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 were 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. 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 agreed with those reported by Smith *et al* (Smith et al., 2002) for the 19-20th centuries Utah population. There were 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. Second, we found no significant interaction between age at last birth and parity. The size-effects 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, starting reproduction 10 years after the average age and having 5 more children than average would represent a 19% reduction in the risks of death throughout the post

reproductive period ($1 - \exp(.0035*10*5) = .19$, $p < .05$).

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 regression 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 11% in the post-reproductive hazard ratio ($1 - \exp(.1054) = .11$, $p < .05$) 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 40% lower ($1 - \exp(.1054 + .2302) = .4$, $p < .001$) 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 ($1 - \exp(.1464) = .16$, $p < .01$). 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 “medium” 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 cutoff 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 threshold after which adding more children would result in decreased longevity. Under this threshold (of about 12 births), however, old age survival of French Canadians women was relatively unaffected. Note that this conclusion applied 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 1,950), 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 ($= \exp(-.1475)$, $p < .05$). 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 in light of what it would have meant for their wives (a highly productive 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 ($-.0860$ versus $-.1475$) that was no more significant ($p = .162$). Increasing the cut-off point

from 10 to 11 surviving children resulted in a larger, and more significant parameter estimate ($-.247$, $p=.008$ in comparison with $-.1475$, $p=.035$). 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. In both cases, also, these associations are consistent with predictions based on evolutionary

principles (hypotheses H2 and H3).

However, 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. We also note that figures pertaining to husbands' longevity do not fully agree in the two populations. In Utah, compared to their wives, husbands experienced weaker longevity benefits associated with low parity and late fertility. But the direction of the effects was consistent among the two sexes

In contrast, we observed conflicting influences of the timing of reproduction, as well as a reversal of the effect of the number of children in the Québec population. Although the evidence for men, is for the moment, inconclusive, parameter estimates leads us to believe that an earlier age at last birth was beneficial, while it was the contrary for women. Moreover, reproductive success, as measured by the number of children who survived up to age 18, clearly advantaged men. The fact that parity alone did not make any difference clearly opposes male and female reproductive strategies in this early colonialist population. The men could be viewed as using women's reproductive capacity to enhance their takeover of largely free lands. The extra children would have translated into enhanced survival prospects at older ages through social support. In contrast with 19th and 20th centuries Utah, the economic benefits of large families, and perhaps the associated stronger access to social support through adult children, translated into

longevity gains for post-reproductive males, in agreement with social support theories.

This contrast with the Utah situation does not invalidate the results reported in this study. Since men's reproductive patterns are less influenced by biological imperatives than by social incentives, it is expected that these patterns will vary from one population to another. Since women's reproductive life rests on a set of strong biological constraints, in comparison with men, their reproductive (and, presumably, longevity) outcomes will vary less, and in a more predictable way when the factors that affect them are known.

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. Williams' hypothesis refers to pleiotropic action of genes. The age at marriage, which is the strongest predictor of the age at which a woman will deliver her first child would not be affected by the presence or the absence of such genes. 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 lifespan, although the association was not significant. If pleiotropic genes exist, they are probably too rare translate into a detectable effect, at least in historical data. Strong selective pressures would most likely oppose (e.g. the critical advantage of prolonged parental investment in women).

Do these results support (and agree with) the evolutionary theories presented above? Apparently they do. Late age at last birth, which correlates with greater survival prospects, can be taken as a sign for a slower rate of aging, whatever the underlying mechanism. One could argue for a selective bias in our sample in that highly fertile women who bore a child at very old ages may have died in the process, and thus escaped our net. In fact, in the highly selected families of our sample, we did not decipher any upper limit to the age at which women can deliver their last child, although the sharp increase of maternal mortality with age in a more general sample clearly demonstrates the existence of such limit (not shown here). This issue certainly deserve further exploration. One must not forget, however, precisely how strong the odds were against those 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.

In contrast, the fence for an upper limit for parity was quite visible, in agreement with the disposable soma theory. Under a given set of biological or evolutionary constraints, one might expect an optimal 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.

In the early years of the French Canadian colony, particular incentives associated with the peopling of a new territory might have pushed the reproductive capacity of the female inhabitants to the limits. Ironically, such strong incentives for reproduction seem to have benefited men, for whom a large effective family was probably a key to old age survival.

ACKNOWLEDGEMENTS

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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 SOCIOLOGICAL (ST) POINT OF VIEWS.

	Age at first birth	Parity	Age at last birth
ET	(H1) <i>Positive</i>	(H2) <i>Negative</i>	(H3) <i>Positive</i>
SMT	(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 (N=1950 COUPLES)

VARIABLE	Min	Max	Mean	Std. Dev.
Wife's AGE AT DEATH	60.03	99.56	74.14	8.05
Husband's AGE AT DEATH	60.00	94.72	73.41	7.58
Year of marriage	1639	1739	1717	18.60
Age difference between spouses (husband-wife)	-9.48	14.96	4.55	4.448
Wife is immigrant to New France (=1)			.04	.21
Husband is immigrant to New France (=1)			.08	.27
Residence in the Eastern part of the colony (=1)			.48	.50
Lived in an urban area (=1)			.21	.41
Wife's AGE AT FIRST BIRTH	14.60	45.18	22.83	4.15
Wife's AGE AT LAST KID	18.09	49.96	40.95	4.31
Husband's AGE AT FIRST BIRTH	17.91	34.98	26.91	3.25
Husband's AGE AT LAST BIRTH	20.77	54.98	45.29	5.67
TOTAL NUMBER OF CHILDREN BORN (PARITY)	1	23	10.52	3.58
Fraction of children who survived to age 18 and/or married			.63	.22
Total number of children who survive to age 18 and/or married ("Effective fertility")	.00	16.00	6.62	2.85

TABLE 3. HAZARD RATES MODELS FOR SURVIVAL PAST AGE 60. ENTRIES ARE COX HAZARD REGRESSION COEFFICIENTS MULTIPLIED BY 10³.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
WOMEN								
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 ^{&}			
EFS				-7.4		14.8		
χ^2	45.46	57.03	48.67	48.58	58.93	58.67		
Model df vs Null df	12	12	12	12	14	14		
MEN								
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*
χ^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).

χ^2 : Model -2LL vs Null -2LL, EFS: Effective Family Size

[&]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 103.

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

*p<.10, **p<.05, ***p<.01, ****p<.001. χ^2 : Model -2LL vs Null -2LL