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Is Menopause Optimal?

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Abstract

Various theories have been put forward to explain the fact that humans experience menopause while virtually no animals do. This paper aims to investigate one such theory: children provide a savings technology into old age, but as human babies are usually large and have long gestation periods, a substantial risk of death exists for the mother as she bears children. It seems therefore appropriate to impose a stopping rule for fertility. Given an objective (support for old age) and demographics (mortality of mother and children), an optimal age for menopause can be calculated. Using demographic data from populations that have seen little influence from modern medicine, this optimal age is compared to empirical evidence.

Journal of Economic Literature Classification: J13; D13; D91

Keywords: menopause; demography; fertility; stopping rule; recursive problems.

Is Menopause Optimal?

Honor thy father and thy mother that thy days may be long upon the land.
Exodus 20:12

1 Introduction

Researchers in natural sciences are still puzzled by the fact that women have to go through menopause, that is, why nature imposed on human females infertility over an extended period in which they are not affected by senility. It is quite common in the animal kingdom to find extended waiting periods for sexual maturity for both sexes, but there are very, very few examples of menopause: the short-finned pilot whale (*Globicephalia macrorhynchus*) in its natural habitat, rhesus monkey (*Macaca mulatta*) and some species of mice in controlled environments. Why would evolution (an invisible hand...) do this to humans? Why waste opportunities to multiply? Why only humans?[1]

Several theories try to explain why female humans suffer from infertility after a certain age. The first states that this is simply an artifact of humans, benefitting from progress in medicine, living longer than what nature intended them to live. Empirical observations, however, hardly corroborate this theory. While animals that live much longer in controlled environments like zoos sometimes are infertile at old age, such infertility appears systematically only for rhesus monkeys and some mice species. The other cases appears to be related to senility. This theory also fails to explain why only female fertility is affected for humans, but not male fertility.

A popular theory is the so called *grandmother hypothesis*. Observing how much food members of various tribes are able to gather, some have observed that the most efficient gatherers are grandmothers, that is women past menopause but still healthy as to contribute to the community. They are efficient because of their superior skills, their experience and because they are less burdened by child bearing duties (Hawkes et al. 1989, 1997). One can, however, suspect that such an hypothesis is only valid for communities where the livelihood does not depend on heavy work, for example farming. Also, the impact of this help from grandmothers seems to be too small to give menopause a selective advantage (Hill and Hurtado 1991, 1996, Rogers 1993).

Menopause could also be justified from a different perspective, namely that having children increases the number of people carrying one's genes, and that at a certain age the marginal rate of return of an additional child is lower that the marginal return of taking better care of the existing children (and grandchildren). Indeed, it is documented that mainly older women are food gatherers in traditional societies. Additionally, human children need a disproportionally long time to become self-sufficient compared to other animals. Such fertility stopping rules could be observed in some demographic surveys of traditional societies, where some women choose to become abstinent once they had reached a certain number of living children (Sembajwe 1981).[2]

[1] As Diamond (1996) puts it: "Along with the big brains and upright posture that every text of human evolution emphasizes, I consider menopause to be among the biological traits essential for making us distinctively human — something qualitatively different from, and more than, an ape".

[2] Menopause is different from such abstinence: it establishes a particular age as the end of fertility, regardless of the number of births or living children.

Another related theory finds its premises in the fact the child bearing and childbirth is much riskier for humans than for other animals. Indeed, the upright position as well as the larger than usual brain (and head) and the prolonged gestation period all lead to significant higher rates of death at childbirth for humans compared to, say, primates.[3] Furthermore, these rates increase strongly with age, while the quality of the children declines, at least as documented for modern societies. Given that the objective of a woman would be (selfishly) to have the support of as many children as possible as long as possible during old age, it could make sense to impose a stopping rule on fertility in order to guarantee that the fruits of many years of child bearing are not annihilated by one more, unlucky pregnancy. Of course, this requires that children are indeed able to contribute to old-age security, in other words that having children brings a return and not a burden. Evidence from agricultural societies shows that children are a good investment. In his survey, Cain (1982) shows that the net cumulative calorie production of children becomes positive somewhere between 15 and 28 years of age.[4] Caldwell (1978), Lucas and Stark (1985), Bergstrom and Stark (1993), and Cox and Stark (1994) point out how important transfers from young adults to their elder parents are and how the youngs expect a similar behavior from their children, as the introductory quote hints to.[5]

This paper is an exploration of this last stopping rule theory. I define the objective of the woman in a way that reflects her desire for support at old age. I then describe the demographics of fertility and mortality during her life span. Given those constraints, I solve for the optimal stopping age, that is menopause. Of course, such an exercise is meaningful only if one obtains quantitative results, as is it seems quite obvious that some age for menopause will emerge as an optimum. The interesting result is the answer to whether the obtained decision rule is in line with empirical observations of the age of menopause.

It is quite clear that no woman can decide when she enters menopause, and increasingly many venture into medical procedures to get by that date or to reverse it. I assume that in some way evolution found the optimal age for menopause, and I want to check whether this age is the one a woman would have picked if she could, given that contraceptive measures or abstinence were not available to her. In other words: what age for menopause would she have picked at a young age, without knowing what the number of her living children would be, and would this age correspond to the one determined by nature? Of course, no woman nowadays has the objectives I described as the ways of modern life have brought us more pleasures than the simple preservation of a gene pool. Also, the modern economy and the government now give us more ways to guarantee a decent old age that do not rely directly on our own children.

The data for this exercise should therefore not be modern data, but rather data from populations that have not been influenced by modern medicine and the modern way of life. Such demographic

[3] One can argue that during the rapid evolution of humans, the age of menopause was a softer and easier to "configure" component of evolution relative to brain size, for example. The fact that expected lifetime differs so much across mammals may corroborate this.

[4] Note that in this theory it is not necessary that the cumulative return of children be positive, all that is needed is a positive return when the parent needs it, in old age. This holds especially if there are no other ways to substitute intertemporally.

[5] A variation of this theory is discussed in Packer (1998). The risk can also be viewed from the perspective of the surviving children who lose the support of the mother when she dies at childbirth. This is interesting as it can be justified from an evolutionary standpoint. I look, however, at the optimality of the age of menopause from the perspective of the mother, without any altruistic aspects.

data exists from research in two fields. One is historic demography, which is the study of the demographic structures of ancient populations using various indices (bones, tomb inscriptions, historical records). The other is anthropodemography, which studies traditional societies. I use here examples from both.

The paper is structured as follows. Section 2 deals with the economics, that is describing the investment model of the women. This model is solved using dynamic programming techniques. Section 3 details data issues and finds ways to parametrize the demographic parameters of the model. It also reviews empirical evidence in the literature regarding the objective function of the woman. Section 4 then provides results along with sensitivity analysis for the crucial parameters in this model. Finally, concluding remarks close the paper.

2 Modeling Menopause

Let us describe the demographic events during the life of a woman as follows. At each age i, there is a probability of dying $pdeath_i$. Once she attains sexual maturity, the woman gives birth with probability $pnewborn_i$. During this period of fertility, the survival probability is lower due to risks during child birth, labeled $pbirth_i$: $(1 - pdeath_i) \cdot (1 - pbirth_i)$. Once the woman enters menopause, she reverts to a situation without pregnancies and their associated risks. Finally, she needs the support of her children during her last years, the period during which she earns the return from the successful pregnancies. The stock of children is accumulated during her fertile years: there is at most one new child every year, each with probability $pnewborn_i$. But children also die, with probability $pchild_i$, a probability that varies with the age of the mother, as computed by mortality tables.

Let us now describe the state space of a woman during her life. She is characterized by her age, i ($0 < i < I$), her ability to bear children, b_i ($b_i = 0, 1$), and by the number of children alive, n_i. A woman becomes fertile at age F and enter menopause at age M. At age S, she starts needing the supports of her children.

The objective of the woman is to have as many living children as possible during her old age that starts at age S. Specifically, I assume a yearly return function

$$u(n_i, i) = \begin{cases} 0 & \text{if } i < S \\ n_i^\alpha & \text{if } i \geq S. \end{cases}$$

There are no fertility decisions as the woman's probability of giving birth is exogenous. However, nature (for example evolution), decides on an optimal age for menopause M while maximizing lifetime discounted utility. Note that I do not endogenize the age of fertility F.[6]

Specifically, the Bellman equations $V(b, i, n)$ for each fertility period are:

before fertility, $1 \leq i < F - 1$:
$V(0, i, 0) = \beta(1 - pdeath_i)V(0, i + 1, 0),$

[6]There is, however, a good argument for endogenizing F: many societies use various schemes to delay the first child birth to prevent overpopulation, including the institution of marriage. But then, if there is overpopulation, this society has evolved faster than nature intended and should be considered modern.

at onset of fertility, $i = F - 1:$
$V(0, F-1, 0) = \beta(1 - pdeath_{F-1})V(1, F, 0),$

during fertility, $F \leq i < M - 1:$
$$V(1, i, n) = \beta(1 - pdeath_i)(1 - pbirth_i)\Big[$$
$$pnewborn_i\Big((1 - pchild_i)V(1, i+1, n+1) + pchild_i V(1, i+1, n)\Big) +$$
$$(1 - pnewborn_i)\Big((1 - pchild_i)V(1, i+1, n) + pchild_i V(1, i+1, n-1)\Big)\Big],$$

at onset of menopause, $i = M - 1:$
$$V(1, M-1, n) = \beta(1 - pdeath_{M-1})(1 - pbirth_{M-1})\Big[$$
$$pnewborn_{M-1}\Big((1 - pchild_{M-1})V(1, M, n+1) + pchild_{M-1} V(1, M, n)\Big) +$$
$$(1 - pnewborn_{M-1})\Big((1 - pchild_{M-1})V(1, M, n) + pchild_{M-1} V(1, M, n-1)\Big)\Big],$$

after menopause, $M \leq i \leq S - 1:$
$$V(0, i, n) = \beta(1 - pdeath_1)\Big($$
$$(1 - pchild_i)V(1, i+1, n) + pchild_i V(1, i+1, n-1)\Big),$$

when in need of support, $S \leq i \leq I:$
$$V(0, i, n) = n^\alpha + \beta\Big((1 - pchild_i)V(1, i+1, n) + pchild_i V(1, i+1, n-1)\Big),$$

This problem can be solved backwards numerically, provided the various parameters can be measured. This is the goal of the next section.

3 Measuring Demographic Parameters and the Objective Function

A major task in this problem is to determine the relevant parameterization of the demographic processes. As argued in the introduction, I need data from very particular populations, those that were not influenced by recent human progress, especially medicine, and are therefore close to a state that evolution (only) brought them to. Such populations can have disappeared, in which case demographic data has to be reconstructed from remains or, rarely, from ancient documents. Alternatively, the few remaining traditional societies can be studied. But it is very difficult to find a complete description of the data as I need here. Mortality data is available for various samples, but fertility data is especially difficult to come by, in particular by age. Historic demographers are usually confined to measuring or deducing gross replacement rates of populations.

I also need to characterize the possible objective function of the woman. For this I review in the second part of this section the scant empirical evidence, which evolves essentially around the

marginal returns of children in traditional societies.

I have calibrated the demographics using a study of families of Geneva (Switzerland) around 1600. This is based on a study by Henry (1956), who used a wealth of genealogies to draw fertility and mortality tables. Henry used data from families whose (male) head of household was born between 1550-1899. I restrict myself to 1550-1650 as mortality figures are markedly higher than for later generations, a sign that medicine did not yet have a significant impact. This data covers about 1500 people, with life expectancy at birth of about 30 years, at 20 years of age of about 40 years. I find that fertility F starts at age 15.

I also conduct computations for alternative specifications of the demographic parameters. Pison (1982) has computed mortality tables for the Peul Bandé, a tribe from Western Senegal, over the years 1975 to 1980. This data is quite similar to those obtained for other African populations in the sixties, and it is often argued that they do not differ from those valid early in the century. This data set is particularly interesting because it also includes fertility data by age. Another set of mortality data deals with Egypt at Roman times and is based on tomb inscriptions. This data, collected by Hombert and Préaux (1945) and cited by Russell (1958) covers 813 people, in majority males and most probably from wealthier classes. It is also expected from such data that mortality rates at very young ages are understated. However, it appears that reported ages are rounded below, and that therefore ages at death are understated, which may compensate for the wealth bias. But this is, of course, only conjecture. Fertility data is not available for this period, so I use the Geneva data for this experiment.[7] Next, demographic data from Sweden is used, fertility and mortality for women in 1751–1760, as well as data from Quebec, mortality for the cohort born in 1801 in conjunction with fertility data from 1891. Survival rates are higher in these two samples, which may indicate that they have already experienced some level of effective medical innovations.

These demographic statistics are based on a population that experiences menopause (on average at age 40), but for the experiments I need to imagine what fertility rates would be with other ages for menopause. Also, I need to fill some blanks and extend the surviving rates of the children. I therefore assume the modified parameter values of fertility in Table 1.

One potentially important dimension of demographics that this data is lacking is information about the quality of new-born children as the mother grows older. Indeed, if mortality rates of children born to older mothers is higher, as suggested by modern data, this would give additional incentives have menopause earlier. Henry (1956) reports survival rates of children by age of mother. This is not a perfect measure, but it would not be reliable to tabulate mortality rates by own age and age of mother with the limited sample size. This data is presented in Table 3, along with the assumptions I made to fill the blanks.

In addition, I need to determine the risk of dying while giving birth. The World Health Organization estimated that the countries with the highest incidence of maternal mortality are Sierra Leone and Afghanistan, with respectively 1800 and 1700 deaths per 100'000 deliveries. I assume a mortality rate of 2%, arguing that even in these two worst case scenarios a fraction of the population has access to some decent health care.[8] The last demographic parameter that needs to be determined is the age at which mothers need to rely on the children (age of senescence, S). Lacking good evidence, I experiment across reasonable values.

[7] Another interesting data set is that of the !Kung reported by Howell (1979). Unfortunately, these Kalahari hunters and gatherers have atypically low fertility.

[8] Packer (1998) reports even a rate of 3%, which would hasten menopause and make the results even stronger.

Table 1: Demographic parameters, part I.

	Geneva 1550-1650			Peul Band´e			Roman Egypt
Age	fertility rates	modif. fert. rates	survival rates	fertility rates	modif. fert. rates	survival rates	survival rates
0		.000	.767		.000	.813	.850
1		.000	.894		.000	.929	.981
2-4		.000	.969		.000	.929	.981
5-9		.000	.971		.000	.980	.986
10-14		.000	.986	.024	.024	.993	.983
15-19	.344	.344	.992	.270	.270	.991	.977
20-24	.461	.461	.988	.298	.298	.989	.960
25-29	.426	.426	.990	.250	.250	.988	.960
30-34	.380	.380	.977	.220	.220	.987	.972
35-39	.281	.281	.981	.163	.163	.986	.962
40-44	.132	.220	.980	.086	.163	.986	.962
45-49	.017	.220	.980	.022	.163	.986	.956
50-54		.220	.980	.012	.163	.982	.951
55-59		.220	.975		.163	.976	.946
60-64		.220	.959		.163	.964	.941
65-69		.220	.952		.163	.946	.940
70-74		.220	.861		.163	.916	.933
75-79		.220	.850		.163	.878	.939
80-84		.220	.803		.163	.826	.913
85-89		.220	.870		.163		.879

Table 2: Demographic parameters, part II.

	Sweden 1751–1760			Quebec 19^{th} century		
Age	fertility rates	modif. fert. rates	survival rates	fertility rates	modif. fert. rates	survival rates
0		.000	.950		.000	.829
1		.000	.950		.000	.850
2-4		.000	.974		.000	.986
5-9		.000	.988		.000	.994
10-14		.000	.994		.000	.992
15-19	.023	.023	.994	.029	.029	.990
20-24	.135	.135	.993	.194	.194	.989
25-29	.232	.232	.991	.302	.302	.989
30-34	.249	.249	.988	.283	.283	.989
35-39	.190	.190	.989	.196	.196	.989
40-44	.102	.150	.985	.102	.170	.987
45-49	.024	.150	.985	.012	.170	.984
50-54		.150	.981		.170	.979
55-59		.150	.975		.170	.969
60-64		.150	.964		.170	.954
65-69		.150	.952		.170	.930
70-74		.150	.919		.170	.893
75-79		.150	.882		.170	.840
80-84		.150	.795		.170	.767
85-89		.150	.795		.170	.683

Table 3: Alternative specifications for survival rates of children according to the mother's age, Geneva 1550-1650.

Age of mother	published surviving rate of children	modified surviving rate of children
15-19	.947	.947
20-24	.962	.962
25-29	.967	.967
30-34	.955	.955
35-39	.985	.985
40-44	.928	.928
45-49	.943	.943
50-54	.941	.941
55-59	.990	.990
60-64		.947
65-69		.944
70-74		.940
75-79		.936
80-84		.932
85-89		.927

I still need to establish the returns of scale of the children, that is the parameters of the utility function of the mothers. From Antebellum United States, there is evidence that parents at a certain age have let their children farm the domain in return of a share of the crop (Sundstrom & David 1988). Therefore there is a return. There is also anecdotal evidence that the more children there are, the lower the share that is required from them. This is a way of saying that the returns to scale of children are decreasing. I could, however, not pinpoint by how much and therefore have to experiment across various values for $\alpha < 1$. Finally, I set $\beta = 1$. Discounting does not appear to change my results.

4 Optimal Solutions

The results of the experiments are summarized in Table 4, giving the optimal age of menopause for each value of the age of senescence and for various returns of scale of children.

From these results, it appears that it is very important to have a good estimate of the returns to scale of children α, and I currently do not have such an estimate. With high α, it becomes more interesting to have more children, and one is more willing to accept a higher age for menopause. In fact, in many cases the optimal age is at a corner solution and menopause occurs just before senescence. For lower values of α, however, the age of senescence does not have an important impact on the optimal age for menopause, which occurs then around the observed age.

With the alternative specification of demographics in Geneva that takes into account the fact

Table 4: Optimal age for menopause.

Geneva 1550–1650

$S \downarrow$ $\alpha \rightarrow$	0.20	0.40	0.60	0.80
40 (0.455)	39	39	39	39
45 (0.412)	40	44	44	44
50 (0.373)	40	49	49	49
55 (0.336)	40	53	54	54
60 (0.297)	41	55	59	59
65 (0.240)	43	57	64	64
70 (0.188)	46	59	69	69
75 (0.089)	49	62	74	74

Sweden 1751–1760

$S \downarrow$ $\alpha \rightarrow$	0.20	0.40	0.60	0.80
40 (0.649)	38	39	39	39
45 (0.602)	39	41	44	44
50 (0.557)	39	42	49	49
55 (0.504)	40	42	54	54
60 (0.441)	41	43	54	59
65 (0.362)	40	43	54	64
70 (0.273)	40	44	55	69
75 (0.171)	40	45	55	73

Peul Bandé 1977–1980

$S \downarrow$ $\alpha \rightarrow$	0.20	0.40	0.60	0.80
40 (0.484)	39	39	39	39
45 (0.452)	40	44	44	44
50 (0.420)	42	49	49	49
55 (0.384)	44	54	54	54
60 (0.339)	46	56	59	59
65 (0.282)	48	58	64	64
70 (0.214)	50	60	69	69
75 (0.138)	52	61	74	74

Quebec 19^{th} century

$S \downarrow$ $\alpha \rightarrow$	0.20	0.40	0.60	0.80
40 (0.578)	39	39	39	39
45 (0.542)	40	44	44	44
50 (0.501)	40	48	49	49
55 (0.450)	40	49	54	54
60 (0.385)	41	50	59	59
65 (0.304)	42	51	64	64
70 (0.212)	44	52	69	69
75 (0.121)	45	53	70	74

Roman Egypt mortality rates with Geneva fertility rates

$S \downarrow$ $\alpha \rightarrow$	0.20	0.40	0.60	0.80
40 (0.334)	35	39	39	39
45 (0.276)	35	40	44	44
50 (0.220)	35	40	49	49
55 (0.172)	35	40	54	54
60 (0.130)	36	40	59	59
65 (0.096)	38	40	64	64
70 (0.071)	40	42	69	69
75 (0.050)	40	46	74	74

Geneva 1550–1650 with alternative child survival rates

$S \downarrow$ $\alpha \rightarrow$	0.20	0.40	0.60	0.80
40 (0.455)	28	35	39	39
45 (0.412)	29	35	40	42
50 (0.373)	29	35	40	43
55 (0.336)	29	35	40	43
60 (0.297)	29	35	40	43
65 (0.240)	29	35	40	43
70 (0.188)	30	35	40	43
75 (0.089)	30	35	40	43

S is the age of senescence, α measures the returns to scale of children. The numbers in parentheses represent the proportion of women still alive at the corresponding age.

that children from older women tend to have higher mortality rates, the results are quite different. Table 4 shows that whatever α and whenever old-age starts, the optimal age for menopause is around the observed value or significantly below. Again, with higher returns, it becomes more interesting to have more children, but the effect eventually wanes out as one needs fewer years of fertility to attain a sufficient number of children for old-age security, especially as the additional children have a higher mortality rates than the earlier ones.

I tend to privilege this last set of results for two reasons. First, it takes into account the critical feature that child quality decreases with the mother's age. Even nowadays, this is taken into consideration for fertility decisions. The other parameterizations are neutral in this respect. Second, the results are more clear cut and depend much less on the two unobservables, α and S. Remember that for Geneva families around 1600, the observed average age at which the women had their last child was 39, which means menopause was at age 40. The last set of results indicates that either:

1. The optimal age for menopause tends to be earlier that what evolution has chosen. All the results are either close to 40 or markedly below. The inclusion of the grandmother hypothesis or altruism in the analysis would put the optimal age for menopause even lower by giving additional incentives to be infertile at a younger age;

2. Returns to scale of children are quite high, as returns to scale of 0.6 or 0.8 appear to be compatible with menopause at age 40. So far, I have no other evidence to back this claim, all I can hypothesize is that this number lies between 0 and 1.

Is this population representative of a traditional society? Has it already outpaced natural evolution when it was measured? If progress in medicine or living conditions has been faster than the evolution of the bodies through the generations, lower mortality would imply higher benefits of having children for support during old-age, and therefore later menopause. Given that I find optimal menopause rather earlier than later than the observed age, it can be concluded that for population that would not yet have outpaced evolution, the discrepancy would be even larger.

5 Summing Up

Human are unique in the animal kingdom: they have large brains, walk upright and experience menopause. The two first characteristics may be linked to the fact that humans suffer from especially high mortality of mothers at childbirth. This may precisely be a reason why menopause appeared among humans. In this paper, I investigated whether menopause can be seen as an optimal response of a woman facing the high risks of having children while needing them for support during old age.

Using data from population that have been little influence from modern medicine, a dynamic model is simulated to find the optimal age of menopause from the perspective of a woman. The results are at first inconclusive, as this age appears to be below the one observed for low returns to scale of children and no menopause appears for high values of these returns. Unfortunately, it was not possible to calibrate these return to a satisfying degree. However, one data set allows to take into account the fact that the quality of children and their survival probabilities decline with the age of the mother. This data yields results that are clear cut: the optimal age of menopause is always below or close to the one observed.

Of course, this exercise has looked at menopause as an optimal strategy for the woman. Evolution follows different incentives, and there is no sense in which the private strategy of the woman would win against others in an evolutive sense: the benefits to the woman appear only once she does not procreate anymore. Still, it is striking that different objectives, private and social, both result in solutions that involve the same unique outcome in the animal kingdom, human menopause. To some degree this is comparable to the welfare theorems of economics: private and social equilibria coincide.

The simple model presented here could be augmented to include other features. For example, the mother could care about the quality of her children or grandchildren by raising them while not being burdened by pregnancies or by helping her daughters. This could for her own good, her children would provide better support during old age, or for the common good, the clan would have better chances of survival, thereby introducing some form of altruism. This would lead to even earlier menopause. So, the real question is: why is menopause so late?

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