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A new estimate of permanent sterility by age: Sterility defined as the inability to conceive

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Introduction

The proportions of couples already and definitely sterile by woman's age have been estimated by various authors. Vincent (1950) gave estimates based on the proportions of newly married couples which remained childless, by age at marriage. Henry (1961) did the same on other samples and derived new estimates based on the comparison of the fertility rate for later fertile couples and the overall fertility rate at a given age. Other authors applied the same methodologies to other populations. These estimates are all based on two main approaches: the first one counts as sterile any couple remaining childless from the time of marriage to the end of the reproductive period; the other one derives the sterility rates from the distribution of age at last live birth. In both cases the data must come from populations where birth control is supposed to be absent or inefficiently used.

We must also be aware of the fact that the two approaches do not measure the same thing. The estimates based on childless marriages refer to *primary sterility*: they can reveal a *pure age effect*, if the newly married women at age x are supposed to have not been exposed to any reproductive event before age x. This is not the case with the other approach: the sterility rate estimated at age x results from the age effect *plus* the possible consequences of previous pregnancies. It is, e.g., likely that a risk of becoming sterile is associated with the delivery, at least in populations with poor medical assistance at birth, which was the case for historical populations. But since not all women have previously had a child, it is *a mixture of primary and secondary sterility.*

In both cases, the level of sterility which is measured is the probability of being unable to have *a live birth*, not of being unable to conceive: if a woman has failed to deliver a child after some age x, this may be because she was unable to conceive or because the pregnancies have ended in spontaneous abortions. For some applications it is unfortunate to mix up these two dimensions, the decrease of fecundability and the increase of foetal wastage when the woman (and possibly the man) gets older. Clinicians for instance, especially those working on assisted reproduction technologies (ART), are usually interested in *conceptions*: what happens later to the pregnancy is a separate story, involving different risk factors.

From a very practical point of view, it might be interesting to estimate:
- the probability, for a woman of a given age X, to conceive during a month of exposure (or during a specific duration),
- the risk of miscarriage for a pregnancy started at age X or soon after,
- the risk, for the woman or the couple, of being permanently sterile from age X on.

Based on these estimates, one may calculate the probability for a woman of age X to have a live birth within some delay (an year e.g.) (see Leridon, 2004). This requires deriving *new rates of sterility by age, reflecting the sole effect of aging on the probability of conceiving, and that may be later combined with the risks of spontaneous abortion.*

In this paper, we will first review the previous estimates of sterility, then present the methodology used for our estimation, and finally compare the results with those from previous works.

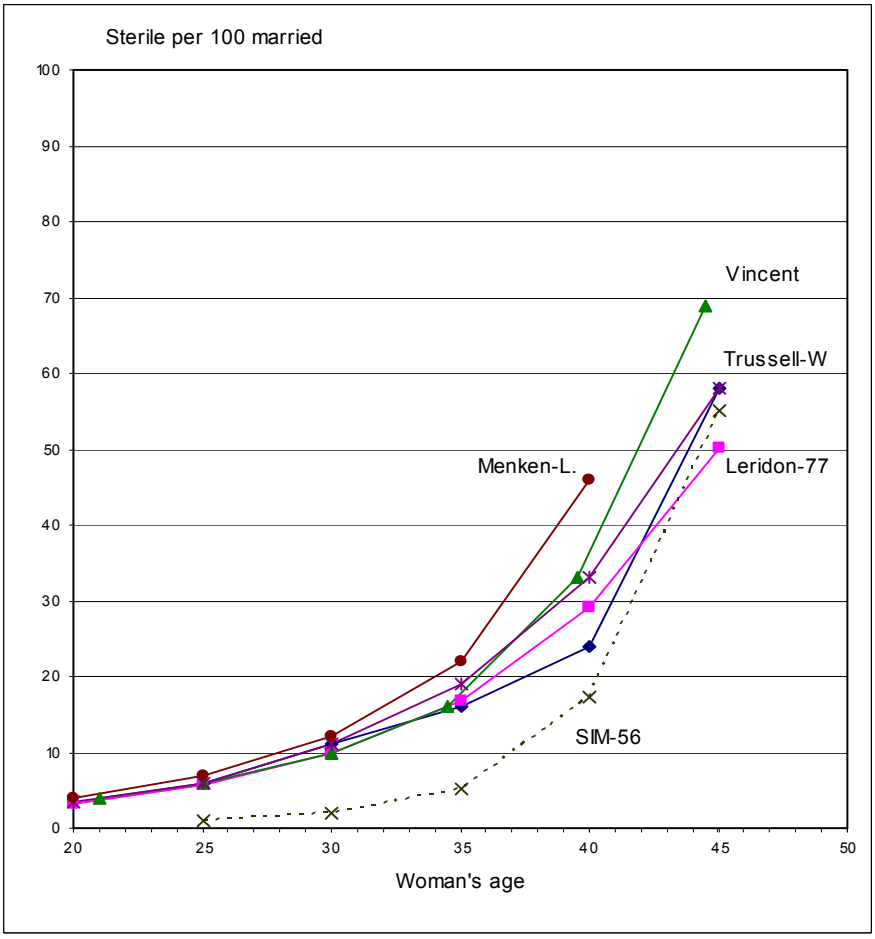
The currently available estimates of primary sterility

Vincent (1950) has published the first estimates based on the proportion of newly married couples remaining childless. The data came from marriage cohorts in England and Quebec. Henry (1953) used first the same sources and slightly revised Vincent's estimates, and then turned to the estimation of sterility among already married couples. These first results have been extensively discussed in the papers by Leridon (1977a) and by Trussell and Wilson (1985), and these authors provided revised estimates still applying to historical populations (France or England). In their paper Trussell and Wilson computed rates by current age *and* age at marriage; the first point of each curve gives an estimate for "duration of marriage zero", which is thus comparable to Vincent's approach. Menken and Larsen (1986) also provided a set of similar estimates for populations of the XXth century; the average value of their seven populations will be given here, after interpolation to get estimates at exact ages. Larsen and Menken (1989) later proposed a method to estimate sterility from incomplete birth histories, and applied it to contemporary populations of Africa, which raises other issues.

This set of estimates derived from historical populations is shown on Figure 1. The curve in dashed line will be discussed later.

The curves are almost confounded up to age 35 years, excepted for the Menken-Larsen estimate. The agreement is not as good beyond that age: at age 40 years the proportions range between 24 and 37 % (and even 46 % for Menken-Larsen), and at age 45 years between 50 and 75 %. We will not discuss here the reasons for these discrepancies since we want to set out another estimate: let us just suggest that the assumptions to be made in the estimation process are probably more fragile beyond age 35.

Figure 1. Proportion (%) of couples definitely unable to have a live birth, by age of woman (estimates based on newly married)



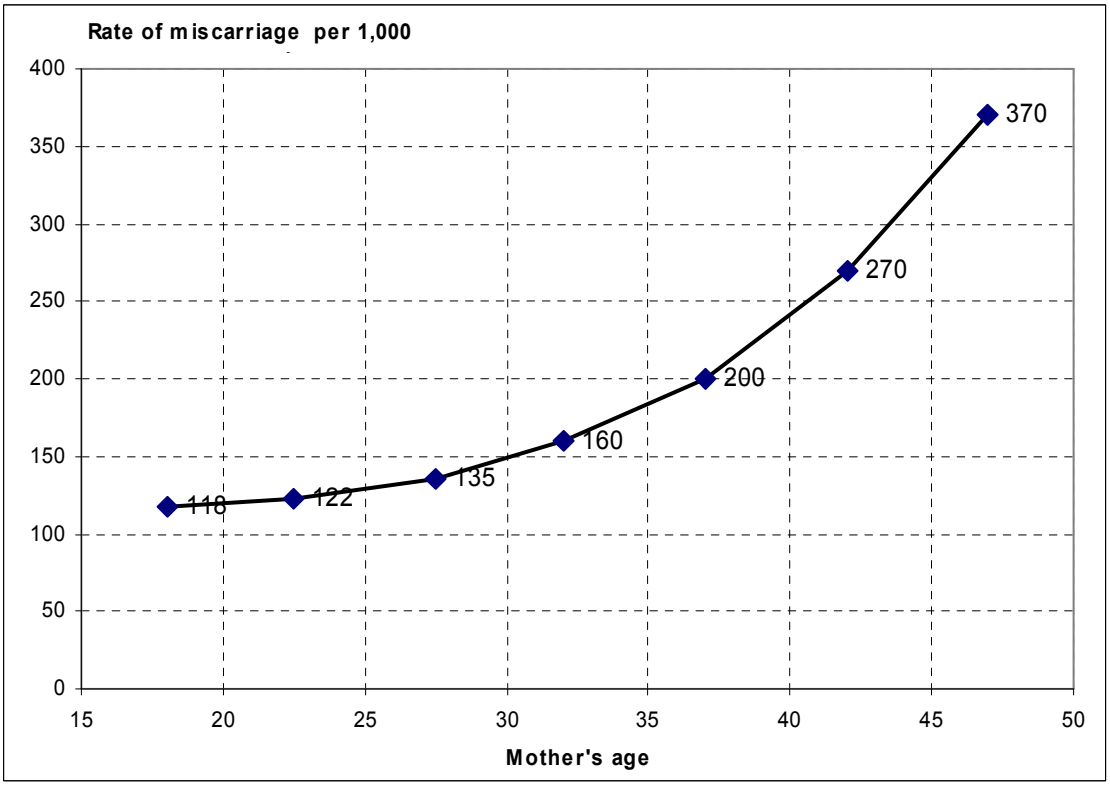
The calibration of the model

We have used a Monte Carlo simulation model to assess the impact of modern assisted reproduction technology on fertility (Leridon, 2004). The inputs of the model, for natural conceptions, are the following: the monthly risk of conception (fecundability); the probability of having a miscarriage in the case of conception; the duration of the non-susceptible period (pregnancy plus post-partum sterility) for a live birth and for a spontaneous abortion; the age at which permanent sterility occurs. Fecundability is supposed to vary between couples and with woman's age. Foetal wastage is a function of age. The non susceptible period varies from one pregnancy to another, whether the next pregnancy occurs to the same woman or not. The model has been calibrated by comparing some demographic estimates of the model (number of births per woman, age at last birth, interval from marriage to first birth…) with data issued from the large and representative sample of historical data on France gathered by Louis Henry (Séguy, 2001).

Data on foetal wastage have been taken from contemporary populations. Mean rates usually range between 12 and 15 per 100 pregnancies (Leridon 1976, 1977b; Wood, 1994). Figure 2 summarizes a set of 12 data (Leridon, 1977b): the rate reaches 20% at age 37, 30% at age 44 and 40% at age 48 years. These high probabilities, based on

solid data, will explain much of the difference between our old and new estimates of sterility.

Figure 2. Mean proportion of pregnancies ending in a miscarriage (per 1000 pregnancies), by age of woman at conception



For estimating fecundability and the age at onset of permanent sterility, and to control the aggregate results of the model, Louis Henry'data were used.

Henry has published a series of studies to analyse the demographic behaviour of pre-transition populations. It can be assumed that fertility control did not exist in these populations, or that if it existed it was fairly ineffective (except in a small proportion of the population, such as prostitutes or highly educated women). This situation was called 'natural fertility'. Henry carried out a representative survey of the French population between 1670 and 1830 based on parish registers before the Revolution and on civil registrations after the Revolution. All vital events had been counted in a sample of 378 parishes, and all families were fully reconstituted in a sub-sample of 40 parishes. This sub-sample was limited to rural France (86% of the total population was rural in 1750). A computerised file became available recently (Seguy, 2001). This file includes more than 106,000 children born between 1670 and 1819, and more than 34,800 marriages during the same period. We use the data for first marriages occurring before 1790, with completed fertility, i.e. where the husband and wife were still living together at age 50, and where all ages (births and deaths of both spouses and all children) were known. This left 3,508 families, which is much more than in any previously published article, and is a representative sample of completed families in the whole rural French population of the time.

The reason for restricting the sample to completed families is that we need unbiased data on age at last birth under natural fertility conditions. This only makes sense if

the woman was actually at risk of conceiving until age 50 at least. More generally, this makes it possible to analyse uncensored data from the last years of the reproductive period and estimates fertility over the whole reproductive period.

Women who married at age 20-24 between 1670 and 1789 had 7.0 children on average and 3.7 % remained childless. Women who married at age 25-29 had a mean of 5.7 children and 5.0 % remained childless. Women who married at 30-34, had a mean of 4.0 children and 8.2 % remained childless. We also looked at the interval between marriage and first birth. If we define the month of marriage as month zero and make a life-table analysis, the birth rate was maximum in month 10, which corresponds to conceptions in month 1. One in ten births (9.8 %) occurred between months 1 and 8, as a result of premarital conception. This means that the women giving birth during month 10 (and thereafter) were already slightly selected, as some of the most fecund women had conceived beforehand. The conception rate was highest for women who married at age 25-29: 17.5 % during month 10, 17.2 % for month 11. These rates only take into account live births, as no data on other pregnancies were available. Henry estimated that about 2 % of children who died within one or two days of birth were not registered and that about 5 % of birth registrations have been lost (probably less when the first birth occurred quickly after the marriage). We will consider that about 5 % of first births were omitted and have corrected the rate of conception accordingly: 18.4 %. This estimate of what is called *effective fecundability* by demographers can be transformed into an estimate of *apparent fecundability*, including foetal deaths (see below). Finally, assuming that the premarital conceptions slightly selected the population, we will use an average value of 23 % for age 20 to 30 years.

The distribution of age at onset of sterility will be estimated from the distribution of age at last birth (next section). Let us first compare the results of the model with data computed on Henry's sub-sample, as defined above. Two indicators have been listed in Table 1: the mean final number of children (completed family size at age 50 years) and the proportion of married women remaining childless. The agreement is very good for ages at marriage 30, 35 and 40 years. It is a bit less satisfactory for women marrying at ages 25 and 45 but the discrepancies are not large enough to invalidate the model.

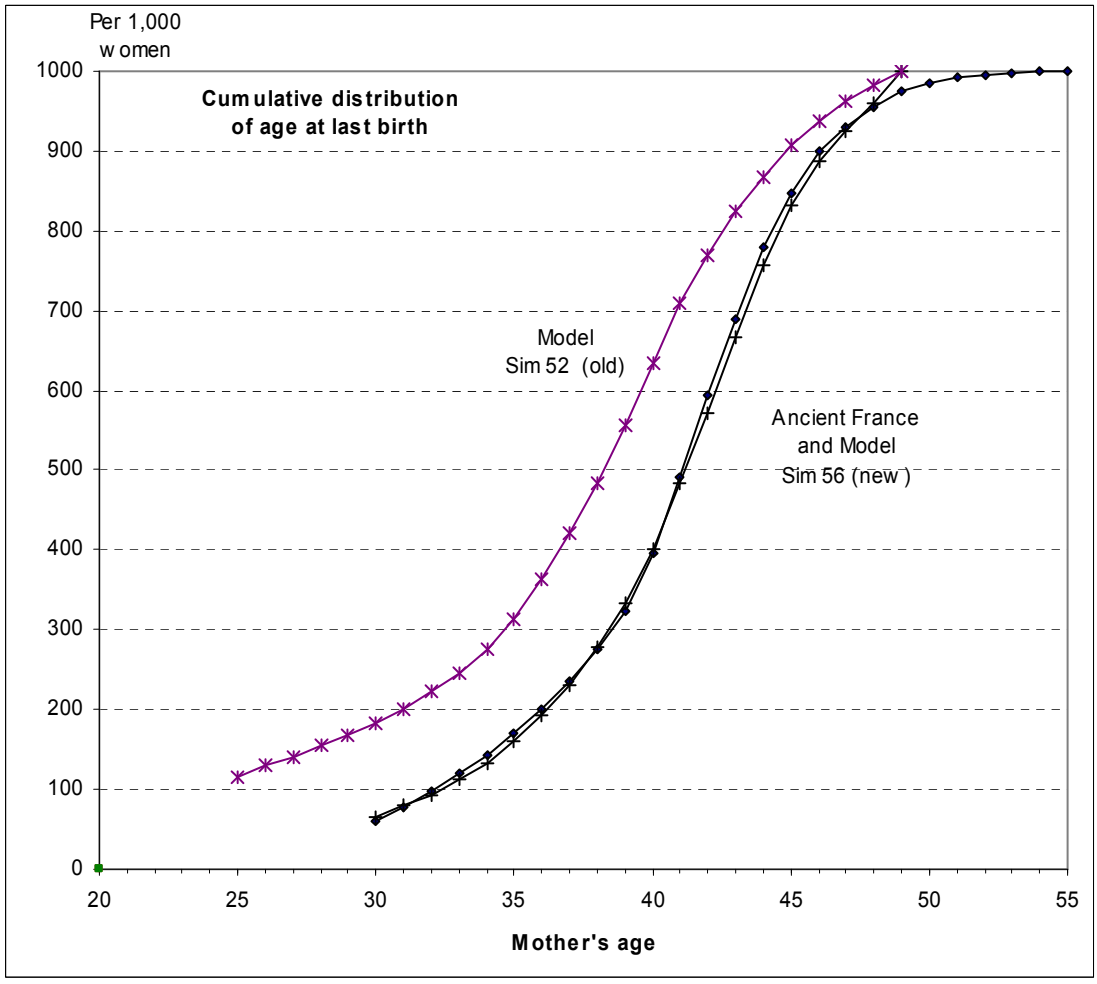
Table 1 – Estimates from the model compared to Henry's data on France

	Mean final number of children		Proportion of childless women (%)	
Age at marriage	Henry's	Model's estimate (Sim56)	Henry's data	Model's estimate (Sim56)
25 years	6,2	7,0	5,0	2,3
30 years	4,6	4,9	6,4	6,0
35 years	2,9	3,0	16,0	14,0
40 years	1,5	1,4	36,0	34,8
45 years	0,4	0,3	70,0	78,9

The new estimate of permanent sterility by age

For the onset of permanent sterility, we first used our 1977 distribution. We ran the model with this distribution and compared the distribution of ages at last birth resulting from the model (SIM 52 on Figure 3) to the historical French data. This comparison revealed a clear discrepancy at all ages up to 45 years (Figure 3): the median age at last birth was at 38.2 years for the first data set compared to 40.2 for the second. The reason is that the sterility rates entered in the model included already the effect of foetal wastage, which is however another explicit ingredient of the model.

Figure 3 – Cumulative proportions of last births by woman's age: as observed in Henry's data, old and new estimates of the model



As the distribution of age at onset of permanent sterility is always estimated indirectly, we decided to tackle the problem from another angle and *derive empirically the sterility distribution that fits best with the observed distribution of age at last birth*. The result is also shown in Figure 3. The curves for age at last birth with the model (new estimate: Sim 56) and with Henry's data are almost perfectly superposed. This adjustment is very sensitive to the choice of the distribution of age at sterility, which gives some confidence for the estimation of this distribution. The median age at onset of sterility is now 44.7 years, compared to 50.5 for menopause and 41.2 for last birth.

The new estimate compared to previous ones

Table 2 gives the cumulative proportions of women already sterile by age, year by year, as they are now estimated. They also appear as the dashed line on Figure 1.

Table 2. Proportions (%) of couples permanently sterile; i.e. unable to conceive anymore, by woman's age

Cumulated distribution of permanently sterile couples (unable to conceive) by age of woman, per 1000 married women					
Age		Age		Age	
25	**10**	35	**51**	45	**550**
26	**11**	36	**63**	46	**690**
27	**12**	37	**82**	47	**790**
28	**14**	38	**108**	48	**860**
29	**17**	39	**138**	49	**900**
30	**20**	40	**172**	50	**920**
31	**24**	41	**209**	51	**935**
32	**29**	42	**253**	52	**945**
33	**35**	43	**310**	53	**952**
34	**42**	44	**405**	54	**957**
				55	**960**

Table 3 compares this new series to the previous ones, showing a clear discrepancy: if we count all conceptions, not only those resulting in live births, the proportion of 'sterile' couples are much lower at each age. This shows that there are much more women still able to conceive between 30 and 45 years than we previously thought, but that many of them will not be able to have a live birth.

Table 3 – Proportion (%) of couples definitively sterile by woman's age: previous and new estimate

Age	No more live birth						**No more conception**
	Vincent (1950)	Henry (1953) Angleterre	Henry (1953) Norvège	Leridon (1977)	Trussell-Wilson (1985)	Menken-Larsen (1986)	**Leridon (Sim56)**
20	4	3,5	3,5	3		4	
25	6	6	5	6	6	7	**1**
30	10	11	8	10	11	12	**2**
35	17	19	13	17	16	22	**5**
40	37	33	24	29	24	46	**17**
45	75	58	50	50	58		**55**

In his chapter on sterility, Wood (1994) discussed the fact that the onset of permanent sterility might play a major role in determining the age pattern of natural marital fertility, as suggested e.g. by Wilson et al. (1988). He concludes the chapter by saying that "*when we recall from Chapter 9 that the average age at menopause is*

several years earlier in the developing world than in industrialized countries, 40 is perhaps what we should expect as an average age at last birth in traditional societies even if women do not become absolutely sterile until they reach menopause". In a way, he might be more satisfied by the new estimates, which are – up to age 45 – much lower than previous ones. But this is only due to the fact that we include all conceptions, not only live birth. I am not sure that we can trust all estimates of menopause coming from developing countries, and in any case we know nothing of the situation in historical populations.

From a more practical angle, our result might be useful when advising couples, especially subfecund couples, on their reproductive behaviour. This is also important for assisted reproduction: success rates expressed in conception rates might be misleading at higher ages.

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