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THE DEMOGRAPHY OF AN EARLY MORTALITY TRANSITION: LIFE EXPECTANCY, SURVIVAL AND MORTALITY RATES FOR BRITAIN'S ROYALS, 1500-1799

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Abstract

This paper details the statistical sources, methods and findings that underpin the demographic evidence offered by Johansson (2010) in support of her thesis regarding "Europe's first knowledge-driven mortality transition," namely the pronounced and sustained rise in the expectations of life that took place among the 17th and early 18th century birth cohorts of members of Britain's royal families. The consequent interest in exposing the existence of systematic demographic effects of changes in the medical treatments and healthcare regimens received by this elite makes it germane to establish the statistical significance of a particular pattern of inter-cohort changes in the royals' mortality experience – namely, one whose timing and age- and sex-specificity make it plausibly attributable to the historical improvements in the medical knowledge and practice of their doctors, as has been documented by Johansson (1999, 2010). Complete genealogical data for the members of Britain's royal families born c. 1500 – c.1800, due to Weir (1996), permits construction of cohort life expectancy at birth and at age 25 for royal males, royal females, as well as for the small number of male monarchs, their female consorts and the queens. Inter-cohort comparisons of life table mortality schedules are obtained by using the 5-year average survival rate distributions for the successive birth cohorts to estimate for each cohort the parameters of Anson's (1991) general model of age-specific mortality hazard rates – the empirical probability of dying within 5 years of age *x*, conditional on having survived to that age. A variety of tests show the gross changes of interest to be statistically significant. The discussion contrasts the mortality transition among the royal families' members with the contemporaneous demographic experience of rural and urban segments of the English population at large.

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1. Introduction

This paper's purpose is to detail the statistical sources, methods and findings that underpin the demographic evidence recently presented by Johansson (2010) in support of her heterodox contention that the pronounced and sustained rise in the expectations of life which took place among the 17th and early 18th century birth cohorts of members of Britain's royal families are be attributed primarily to the contemporaneous improvements in the efficacy of medical care provided by their doctors. Because, as Johansson (1999, 2010) shows, "Europe's first knowledge-driven mortality transition" was effected by a variety of measures most of which were inaccessible and unaffordable to all save the uppermost economic and social stratum of society, the impact of advances in medical knowledge upon the expectation of life in the population at large remained negligible until they began to be re-focused upon the provision of public health measures.

1.1 Background and motivation

Johansson (1999, 2010) documents numerous developments from c. 1500 onwards in various branches of European medical and pharmacological knowledge and practise, which she contend deserve greater emphasis than they currently receive in discussions of the history of health and mortality transitions in the West. Although medical knowledge (defined broadly to include both its private and public forms) is now widely accepted as having been a driving force in the *modern* rise of life expectancies, the efficacy of medical care in reducing mortality rates in "historical," pre-late nineteenth century populations continues to be just as widely doubted. Correspondingly, explanatory accounts of the late eighteenth and early nineteenth century mortality transition in the West marginalize the role of medical scientists and practitioners in favour of placing almost exclusive emphasis upon economic developments that brought about improvements in nutritional status -- notably the escape from caloric insufficiency. Johansson (1999), however, called attention to an empirical problem with the view that economic development alone was sufficient to drive the transition to high life expectancy. She pointed to the statistics for Europe's elites assembled by Peller (1965), and the estimates yielded by her re-analysis of Hollingworth's data on the demography of the British Peerage, both of which show that the very first social groups to undergo anything recognizable as a secular rise in longevity were the already established wealthy and well fed elites, rather than the poor and chronically malnourished masses.[1]

Indeed, at the beginning of the 16th century Europe's ruling elites lacked virtually any reliable information about how best to use their ample material resources to

[1] Johansson (1999) points especially to the demographic findings of Peller (1965), and Hollingsworth (1965), as well as her re-analysis of Hollingsworth's data on the mortality of the British ducal families. The incomplete recording of the deaths of children under age 10 in Hollingsworth's data for the ducal families, and *a fortiori* for the lower ranks of the Peerage, prompted Johansson's (2010) further research on the consistency between the complete genealogical records available for members of the Britain's royal families and her findings regarding the changes taking place in the medical care received by the upper echelon of the British aristocracy.

prevent, manage and cure the ill-health that caused so many premature deaths among them. Yet, as Johansson (2010) shows, after c. 1500 medical knowledge and practice was advancing at quickening pace in Western Europe and successive discoveries and inventions were proving to be quite useful – even as judged by modern standards -- in preventing disease, reducing “life-style” risks, managing illness and providing cures for some of the debilitating and deadly diseases that beset members of the royal courts. Access to medical expertise was limited, and highly priced; moreover, many of measures and regimens that the leading doctors could prescribe were so costly to implement as to be essentially beyond the means of even very prosperous town-dwelling families. Thus the few effective forms of innovative medical care remained available only within a very restricted elite stratum of British society throughout the era stretching from the sixteenth through the eighteenth centuries.

By contrast, Britain’s ruling families in this epoch were in a position to benefit to an exceptional degree among the European elites from the contemporary progress of English medical practice. Being London-based, their surroundings continued to leave them exposed – as were the urban poor -- to life-shortening endemic and epidemic disease. Nevertheless, it is found that the royals’ expectation of life at birth (for males and females together) rose from the average level of 25.3 years in the birth cohort of c.1500-c.1599 to 32.4 years in the cohort born during 1650-1749. More remarkably, this gain of 7 years in longevity was driven by the improvements taking place in the expected survival rates of royal families’ *adult* members: their expectation of life at age 25 (e_{25}, for men and women together) had increased by fully 9 years between those two cohorts.

This paper is devoted to presenting the details of the statistical analysis that underlies the demographic side of the evidence presented by Johansson (2010). Given that purpose and the consequent interest in the existence of systematic changes in the mean survival rates among Britain’s royals, it is germane for the argument to establish the statistical significance of a particular pattern of inter-cohort changes in the royals’ mortality experience – namely, one whose timing and age-and sex-specificity make it plausibly attributable to the historical course of improvements that Johansson (1999, 2010) has shown were taking place in the medical care administered to this elite population.

While the available genealogical data for Britain’s royal families are complete, due to the work of Weir (1996), the number of observations is small and distributed across three centuries. Nevertheless, it has been possible to construct – for each of five overlapping extended birth cohorts – the cohort life expectancies at birth, and at age 25 for royal males, royal females, as well for the still small numbers of male monarchs, their female consorts and the queens. Further, inter-cohort comparisons of life table mortality schedules have been obtained by using the 5-year average survival rates distributions for successive birth cohorts to estimate, for each cohort, the parameters of Anson’s (1991) general model of age-specific mortality. A variety of tests based upon these measures show that despite the restricted dimensions of the database, the gross inter-cohort variations that are of special historical interest --in view of the nature and timing of the medical advances documented by Johansson

(2010) – were indeed sufficiently pronounced to be accepted as statistically significant.

The mortality transition observable among royal adults had become visible as early as the middle of the seventeenth century among the men, whose e_{25} increased from a mean of 27.8 years in the 1500-1599 birth cohort to 32.6 years in the cohort born during 1550-1649. But there were no parallel early gains in longevity among the royal women, and marked declines in royal infant and child mortality did not emerge until the first half of the 18th century. These findings are of notable importance for the support they lend to the argument advanced by Johansson (1999, 2010), because medical care of male adults formed the main preoccupation of the doctors attending the royal families during that era. Furthermore, it was only in the second quarter of the 18th century that regular small-pox inoculation of the royal children virtually eliminated what had previously been major cause of infant and child mortality, so that the greater part of this first mortality transition involved the marked increase in longevity among the adults – in stark contrast to the subsequent transitions in western European populations.

1.2 Methods and organization of the paper

It should be re-emphasized that the main purposes here are descriptive, in two senses. First, the goal in sections 2 and 3 is to detail the demographic sources, methods and findings. While it should be understood that because the motivation for the statistical analysis presented here stems from the interest in the systematic effects of improved medical treatment on the mean survival rates among the royal families, is simply to establish the statistical significance of the sequence of inter-cohort variations in the royals' mortality experience; our objective is not to test hypotheses about explanatory factors affecting the structure age-specific mortality rates, trends in the expectation of life among elite populations, or, still more specifically, the causes of the altered mortality patterns among Britain's royalty born in the epoch between the 15th and the 19th centuries.

Rather, these pages display the quantitative evidence about those changes that are discussed and interpreted with reference to explanatory factors by Johansson (2010). The central statistical challenge was the extraction from Alison Weir's (1996) marvelously complete, but nonetheless quite sparse dataset, two types of robust descriptive quantitative statements contrasting the mortality experiences of populations that lived in different historical epochs. Statements of the first kind concern the existence and magnitudes of trends in longevity, whereas statements of the second kind describe alternations in the structure of average age-specific rates of mortality among Britain's royal families.[2]

[2] As is noted in Johansson (2010), the dataset based upon Weir (1996) relates to members of England's royal families which, during the year prior to the union of England and Scotland (1603), would exclude Scotland's royals during the 1500s. But, as James VI of Scotland (born 1566) later became James I of England, he is included among the nominal 'kings'.

Questions always can be raised about the validity of demographic generalizations based on population sampling. Yet, the royal families' genealogy in question is not a sample, but a complete account the universe of ages at death experienced by the specific historical population under examination. Thus, one may say that averages calculated from this data represent the particular historical universe. Unfortunately, completeness in this case is the other side of the coin of small numbers of observations: only 49 males, and 52 females, *in toto,* were born in the British royal line between 1485 and 1799, the span of the dataset on which the analysis of this paper has focused. This means that individual-to-individual variations in susceptibility to disease, and heterogeneity in the frailty of the population's ability to combat infections, as well as the vagaries of their exposure to pathogens and other insults, could give rise to essentially random variations in the morality experience of small groups within this universe. Furthermore, this population lived under different conditions in distinct eras within that long span of time, and their mortality experience varied not only between birth cohorts widely separated in time, but among sub-groups of contemporaries.

Consequently, it remains very pertinent to ask whether or not observed differences among the distributions of ages at death for successive birth cohorts within this three-century-long epoch can be deemed to be statistically "significant."[3] "Significance" used in this sense is a purely statistical matter, concerned with whether or not observed variations are sufficiently pronounced as to make it unlikely that they were the products of the purely random variations in ages at death that would be typical within any "samples" of such small sizes, even though they had been drawn from a populations characterized by essentially the same systematic mortality conditions.

The main task of Section 2 is to answer questions of that kind, which are in a sense posed by the time-series movements of the mean ages of death – such as those that appear in Figures 1(a) and (b), and 2(a) and (b).[4] Thus, in addition to discussing the tables of the cohort means, their standard errors and the average death dates of the respective cohorts (used in constructing the graphs in Figures 1 and 2), Section 2 also discusses the results of statistical tests of inter-cohort differences in the mean ages at death and the distributions of age-specific survival rates for each of the several sub-populations that have been defined within the complete royal genealogy. The statistics referred to in this section are present in Tables A1.1 through A1.4 of Appendix 1. Appendix 2 documents the estimates of the expectation of life at birth, and at age 25, for royal males and females, on the basis of which the experience of the successive royal birth cohorts can be compared with the average life expectancies among other, much larger portions of England's population (see the discussion of Table 2 in Johansson (2010).

Section 3 deals with a different descriptive challenge, the response to which appears in the mortality rates graphed in Figures 3(a) and (b). There we explain the

[3] Were the motivation purely genealogical there would be no point to such analysis, inasmuch as the available genealogy is complete (and in this instance highly exact), so that the record of the durations of the lives of all the members in this small universe is what it is.

[4] These correspond to Figures 2(a) and (b), and 3(a) and (b) of Johansson (2010).

statistical procedure that has permitted the extraction age- and sex-specific mortality rate schedules (of the sort one would find in empirical life-tables constructed for 5-year age groups) from the sparse genealogical data-based average age-specific survival rates for overlapping historical cohorts. The methodology involves fitting Anson's (1991) parametric mortality model to the available cohort-specific distributions of survivorship, and retrieving the cohort-specific age-specific mortality hazard rates from the respective estimated parameters. Section 3 concludes by presenting statistical tests of inter-cohort differences among the empirical survivor distributions, supporting the discussion of the temporal shifts observed in the estimated age-specific mortality rate schedules.

Section 4 describes the demographic course of Britain's first mortality transition, as it appears from the foregoing quantitative exercises. Rather than proceeding to narrate the changing mortality conditions among the several distinct groups within the royal families of each birth cohort in turn, the discussion is organized by stratifying the several sub-populations, and following the cohort-to-cohort experiences of each. Where possible, comparisons are made with other, much larger segments of the national population. Thus, the mortality transition among the royal adults is followed in section 4.1, and that of adult males and females, separately, in section 4.2; the kings and queens appear in section 4.3, and the royal infants and children in section 4.4. A summing up of the demographic evidence relating to the transition concludes the paper in Section 5.

2. Mean ages of death statistics and significance tests for inter-cohort differences

Life expectancy data for the ruling family of England/Britain can be extracted from the exceptionally detailed royal genealogy compiled by Alison Weir.[5] In England, with a few exceptions, age at birth/death data for kings and princes was complete and, in most cases accurate to the day by c. 1550, with few exceptions. The data for queens and princesses was almost as exact, but among the women who married into Britain's royal families,[6] and who were not royal by birth there were some whose exact date of birth remained obscure even in the post-1550 cohorts. Remarkably, it appears from the genealogical data that all royal infants' birth/deaths in England's ruling families were recorded (most to the exact day) from the 1500s onwards – not omitting those that were stillborn.[7]

When the definition of "royal families" is restricted to include only kings, queens and the legitimate births to formal marriages, the resulting population is quite small. Table A.1.1 of the Statistical Appendix shows the counts of all the royal males, and the females separately, when the genealogical entries are grouped form overlapping century-long birth cohorts.[8] In all, the dataset provides observations on the age at death for only 49 males and 52 females born between the end of the 15th and the 18th

[5] Over several decades Weir (1996, rev.ed.) has periodically revised and expanded her genealogical data base, so that it now includes what is known about royal mistresses and their illegitimate children. In England the birth and death dates of royal males were known with a high degree of exactness from the late middle ages, while birth or death dates for some royal females remained uncertain. But after 1500 those females born to England's royal family also had exact birth/death/marriage dates, although not all women marrying into the royal family did. Royal infant deaths must have been fully recorded after 1500 as well, if only because there were so many of them! Moreover, after 1500 royal live births were being carefully distinguished from royal stillbirths. Weir was even able to include some data on royal miscarriages, which, presumably (see Hatcher, 1986), were observed by contemporaries after the first trimester.

[6] Although the following text refers to "Britain's" royals, this label applies strictly only for the period following the Act of Union (1603) with Scotland. For the sake of greater temporal comparability, the data studied here pertain to England's royal families during the long sixteenth century (1 January 1485 to 31 December 1606, thereby including all the children born to Henry VIII). Omitting the Scottish royal families in the 1500s has the desirable effect of maintaining greater consistency in the geographical setting of the royal households to which the time series examined here pertain.

[7] Peter Razzell (1999) also used Weir's (1996) genealogical data to calculate royal life expectancy, but he combined data for the English and Scottish royal families. In the 1500s, the Scottish royal family had much higher infant and adult mortality than their English counterparts, with the result that Razzell (1999: p. 7) gives the combined English/Scottish royal family a life expectancy at birth of 15.2 years for the 1500s and 1600s. That compares with the average of 24.8 for England's royal males and females combined (as seen from Appendix Tables A1.2b, and 2d, Cohort 0).

[8] The century-long duration of these cohorts therefore facilitates comparisons with the cohort expectation of life statistics presented in Table 1, based on Peller's data, and affords sufficiently large sample densities to keep the variances of ages at death reasonably small in relation to the respective cohort means. See the Notes to Table A.1.1 and the accompanying text in the Statistical Appendix for the rationale of the two deviations from exact 100 year spans in the delimitation of these birth cohorts. In the case of Cohort 0 the actual span is 1485-1606, rather than 1500-1599; correspondingly, in Cohort III the span is 16o6-1699 and not 1600-1699. These departures from the nominal designation of the birth cohorts "1500-1599", and 1600-1699" are taken into account in calculating the mean death dates reported for these cohorts in Tables A1.2 (a, b, c, d), and used to plot values of the cohorts' mean ages at death in Figures 2 (a, b, c, d).

centuries. The eighteen males and twenty-five females that had been born into, or married into Britain's ruling family during the 17th century had average life expectancies at birth of 29.9 and 23.0 years, respectively. This was already a slightly higher mean age at death than Peller (1965: Table 10, p. 98) found for the men of Europe's (mostly continental) ruling families; but the mean age of death among the female royals in Britain was already 11 years below that of the corresponding Europe-wide figure.

To arrive at generalizations about temporal changes in the mortality experience of Britain's royals, the rather sparse age-at-death data for royal family members have been grouped into 5 over-lapping, century-long birth cohorts, starting with that labeled *1500-1599,*[9] and proceeding thereafter by half- century overlaps: 1550-1549, 1600-1699, 1650-1749, and 1700-1799. For each of these cohorts it is possible to distinguish 6 population sub-groups: (i) the entire birth cohorts of male royals, and female royals, (ii) all the royal males whose cause of death was not violence, and among the females all those who escaped maternal (childbirth) mortality; (iii) and those within the sub-populations defined by (ii) who survived beyond age 25. The average ages at death of the sub-populations defined in (i), and (ii) yield measures of male expectation of life at birth inclusive ($\boldsymbol{e_0}$) and exclusive ($\boldsymbol{e_0'}$) of deaths by violence, respectively, and corresponding measures of female , inclusive and exclusive of material mortality. Average ages at death computed for the population groups defined by (iii) provide corresponding measures of male and female "adult" life expectancies ($\boldsymbol{e_{25}'}$) excluding violent and maternal mortality, respectively.

This scheme gives rise to 15 distinct historical populations of British royal males, and another 15 relating to the females. A corresponding set of 30 measures has been obtained by confining attention to the much smaller sub-populations within the collection of Britain's royal families -- consisting of the 26 "kings" and 27 "queens." For this purpose "kings" have been defined comprehensively to include male adult heirs apparent, and the spouses of female monarchs, whether or not they had attained the formal title[10]; "queens" here are defined, symmetrically, to include the wives of

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[9] Unlike the subsequent hundred-year long birth cohorts, Cohort 0 covers the "long sixteenth century" -- beginning on 1st January 1485and extending through 31st December 1606, thereby including in all of the offspring born to Henry VII (at the end of the 15th century, Henry VIII among them) and all of the children of James I (in the first decade of the 17th century). The rationale for this rests on the possible importance of shared family-of-origin effects upon individuals' survival probabilities. Conveniently, the offspring sets of later monarchs are left intact by the imposition of cohort demarcations at the ends of the 17th and 18th centuries.

[10] While the main principle in adopting conventions for these classifications is apply them consistently, one must acknowledge that there is an unavoidable degree of arbitrariness about them. Edward, the fourth son born to Henry VIII in 1537 was given the title "King Edward VI", but died in 1553 well before reaching the age of majority and is not included in with the kings in Cohort (0). the first son of James I – who is included in the "long sixteenth century" Cohort (0) along with all his siblings, for the reasons noted above --- is counted as an heir apparent although strictly he was not heir to the English throne. In any case, he died following an accident in which he fell from a boat into the Thames, and so is the sole member of that cohort of whose death is treated as "violent." Among the husbands of female monarchs, Phillip II of Spain (born 1527) has been counted as a 'king' in Cohort (0), being the husband of Queen Mary I, although he spent no time in England to speak of. Queen Anne's husband (Phillip of Denmark, born 1653) is included in Cohorts (I and II). The husband to Mary II, William III, was King of England in his own right.

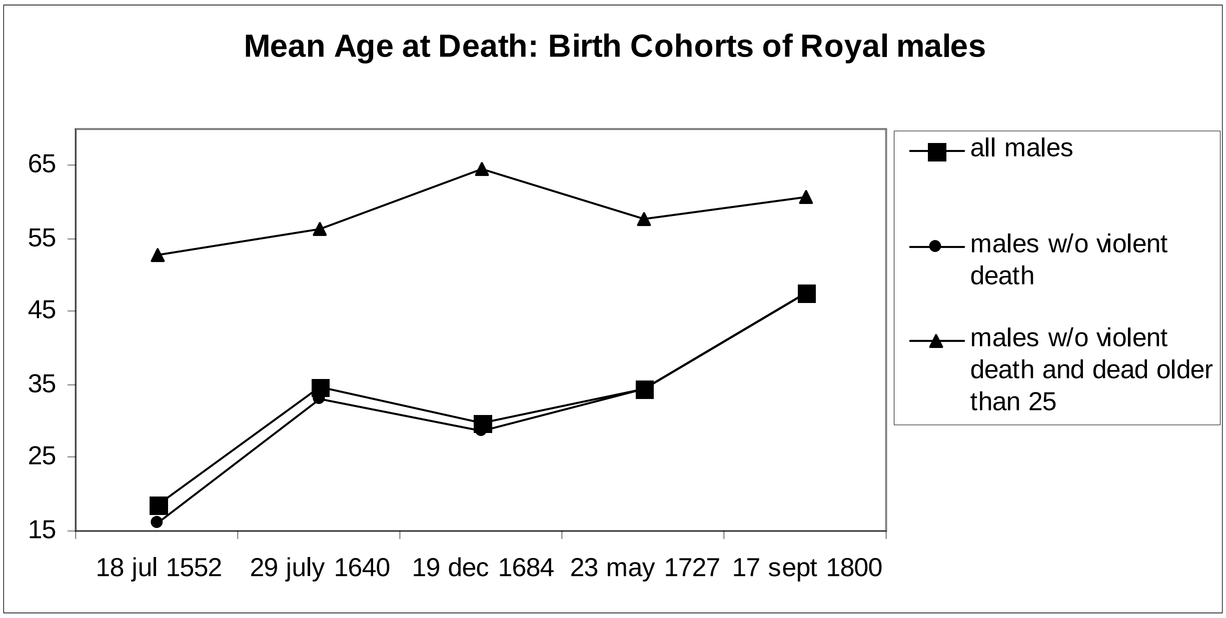
male monarchs. The distribution of the 177 members of the royal families among the 60 "populations" thus defined is shown in Table A1.1. From there is will be seen that the sizes of the resulting birth cohorts for even the biggest of the sub-groups remain diminutive as demographic samples go – not exceeding 19 observations in the case of "All" males, and 25 observations in the case of "All" females; the corresponding cohort sizes for the "kings" and "queens" are miniscule, in the ranges 4-6, and 4-8, respectively.

That being the case, it is particularly important to keep in mind the variances around the means of ages of death that are reported for these cohorts, inasmuch as misleading impressions of inter-cohort changes in the gender-specific life expectancies may readily be created by the presence of a very few individual cases of unusually early or long-postponed death. Furthermore, the durations of these cohorts are sufficiently protracted that altered conditions affecting mortality rates could contribute substantially to within-cohort variability in the distributions of ages at death. Although the intention in forming overlapping birth cohorts is to mitigate the possible effects of a few cases falling on one or the other side of a cohort boundary, and thereby creating spurious impressions of the longer-term secular trends, this device is no substitute for consulting the standard deviations that are associated with the mean ages at death presented in text Figures 1(a and b) and 2(a and b).

Tables A1.2 in Appendix 1 present those cohort means and standard deviations, for the kings, the royal males, and queens, and the royal females – in panels a, b, c and d, respectively. From the entries pertaining to all the royals it is seen that before the 18th century birth cohort (IV) the estimated standard deviation was approximately equal to the mean life expectancy at birth, but then decreased to 0.60 of the mean in the case of the males, and to 0.28 of the mean for the females. The latter relative change (which the contrast between Cohorts III and IV indicates was a development of the second half of the 18th century) is somewhat less pronounced in the inter-cohort comparison for royal women excluding cases of maternal mortality. As one might expect, the relative variations in age at death among the "adult" sub-populations are considerably smaller, reflecting the removal of the variability due to infant and child mortality. Furthermore, the ratio of the standard deviations to the means show a striking rise starting among the post-1650 birth cohorts: it rises from its former range of 0.14 to 0.17 to 0.27-0.29, a contrast with the pre-1650 birth cohorts that was not accompanied by an increase rather than a reduction in the mean age at death.

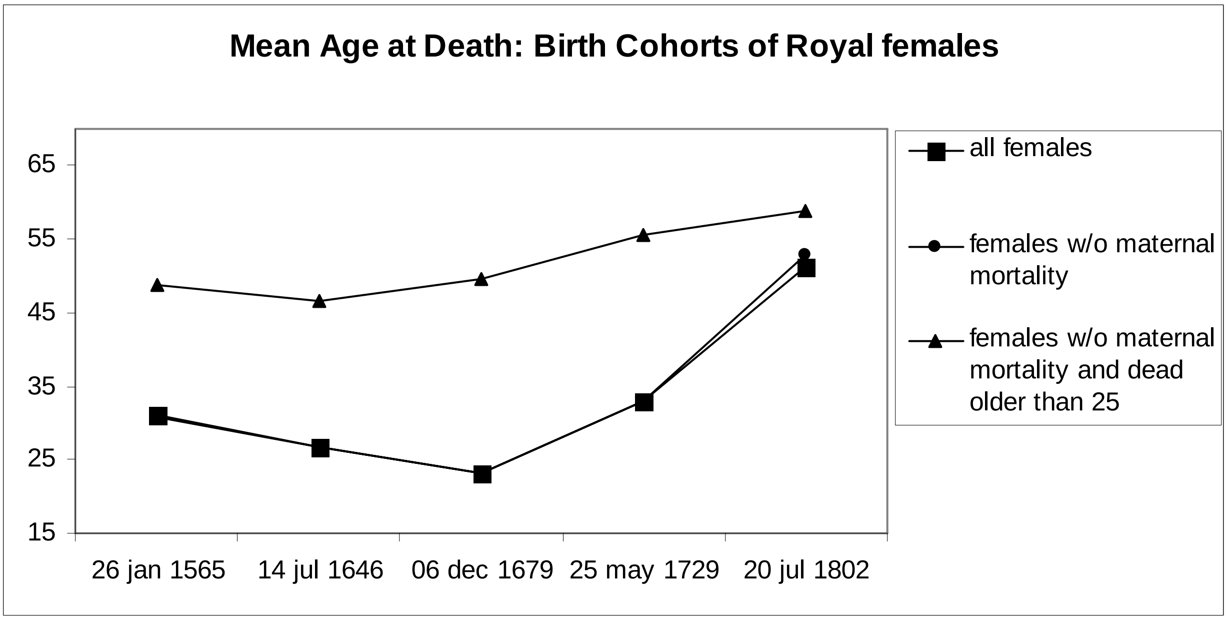
This shift points to *gains in the longevity of adult male royal cohorts born after the midpoint of the 17th century*, a change that – as one might expect --is evident also among the kings, for whom the relative standard deviation rises from the 0.14-0.18 range to c. 0.24 in the post-1650 birth cohorts. By contrast, the distribution of ages of adult death among the queens, and also among the royal females as a whole, give no indications of a parallel shift toward greater adult longevity. Although the royal females as a whole exhibit the same late-18th century compression in the absolute and relative variance of ages at death that is seen among the royal males –which appears associated with a decline in royal infant mortality rates, the movements of the ratios

Figure 1(a)



Note: Means of age at death for each cohort are plotted at the cohort's mean death date.
Source: See Appendix Table A1.2b.

Figure 1(b)



Note: Means of age at death for each cohort are plotted at the cohort's mean death date.
Source: See Appendix Table A1.2d

of the standard deviation to the means among the royal women are lower for the two cohorts born after 1650 than they were for the three earlier cohorts.

While the foregoing movements in relationship between the first and second moments of the distributions of ages at death fill out the picture of the temporal trends in royal mortality that are shown graphically by Figures 1a and 1b (for the royal males and females, respectively), they do not indicate whether the apparent inter-cohort differences in life expectancy are sufficiency marked to be regarded as statistically significant. That is to say, one wants to know whether they reflected some systematic alteration in mortality experience, rather than the variability of small samples drawn from an essentially unchanged demographic universe. The results obtained from the statistical tests necessary to permit statements of the former kind are presented in Appendix Table A1.3a for comparisons between the 16th century birth cohort (Cohort 0) and subsequent cohorts of male and female royals. The corresponding inter-cohort tests of significance among the four subsequent cohorts (Cohorts I – IV) are reported in Appendix Table A1.4a. Tables A1.3b and A1.4b repeat these tests for the kings, and the queens, respectively.

Two kinds of test results are indicated in these tables. In the left-most stub of each, next to the designation of the pair of cohorts involved, a "dagger-marks" appears where a non-parametric (Kolmogorov-Smirnov) test finds the statistically significant inter-cohort differences between the distributions of the survival rates constructed for five-year age group.[11] Significance at the 95 percent confidence (.05 percent error) level is marked by H, with double-daggers (HH) and triple-daggers (HHH) for the 97.5 and 99 percent confidence levels, respectively. *These results establish that the differences between the mortality experience of the 16th and the 18th century birth cohorts was weakly significant in the case of the male royals (but not the kings), and strongly significant in the case of the female royals and the queens.* Further, as may be seen from Table A1.4a, the differences between the age at death distributions for royal males belonging to the birth cohorts of the 1600's and 1650-1749, on the one hand, and the birth cohort of the 1700's also are large enough to be significant at the 97.5 percent level of confidence or higher. The same holds, a fortiori, for comparisons between the distribution of the 1700-99 female birth cohort's ages at death, and that for all four of the preceding birth cohorts.

The second type of statistical test reported by these tables are the (single-tailed) "t"-tests for the inter-cohort differences in the estimates of $\boldsymbol{e_0}$, $\boldsymbol{e_0'}$ and $\boldsymbol{e_{25}'}$. The 95, 97.5 and 99 percent confidence levels are indicated by single-, double- and triple-asterisk next to the estimated difference between the pair of cohorts' mean ages at death. They correspond to the Type I error of concluding that the cohort life expectancies are different when they are simply random variations in samples drawn from a population that has same mean expectation of life.[12] Looking first at the

[11] Note that the Kolmogorov-Smirnov tests reported here pertain to the full population-samples of royal males and females, and, correspondingly, to all the kings, and all the queens in the indicated birth-cohorts. Calculation of survivorship proportions *l(x)* for five-year age groups are widely used as a device for obtaining more precise estimates of life table rates. Section A2 for further discussion.

[12] The "t-statistics" for each test are calculated by dividing the difference between the cohort means by the pooled standard deviation that appears in the adjoining column of the table. The latter are computed from the corresponding (Table A1.2) standard deviations (s1 and s2) for the pair of age of death

differences between the birth cohort of the 1500's and the 1700's, one find that the increase in the life expectancy at birth for the royal males is strongly significant (i.e., at the 99 percent confidence level, and actually slightly above that when violent deaths are excluded).

That statement holds also for the case of the kings, although the apparent increase in adult life expectancy by 8 years for those who escaped violent deaths, and by 10 years in the case of the kings, are not statistically significant. While it was found that the shift in the age at death distribution of female royals (and the queens, specifically) was strongly significant, the increase in e_0 was only half as large as the 28 years gained by the male royals and is significant at a considerably lower confidence level; a parallel difference appears also from the comparisons of the differences in the e_0' estimates for the male and the female royals. On the basis of these results it is justifiable to place considerable confidence about the upward slope of the time trend between the earliest and the latest of the points plotted for the royal males and royal females in Figure 1(a); and similarly, in regard to the comparison between the experiences of the 16th and 18th century kings, and that for the queens (albeit with slightly greater reservations) which appears in Figure 4 (b). The historical context of these trends receives further discussion in section 4, below, where here we are concerned with questions of statistical significance.

Turning to Table A1.4a, it is seen that the 18-year gain in e_0 between the 17th and 18th century's birth cohorts of royal males is weakly significant, as is the 13-year gain experienced by the kings among them. The rather bigger differences in comparisons of 18th century mean ages at death of kings with their counterparts from the birth cohorts of 1550-1649, and 1600-1699 are no less significant. On the basis of the entries in Table A1.3b and 4b, therefore, one may conclude that following the 1500's there had been a continuous century-to-century upward trend in the longevity of Britain's kings – is as depicted by Figure 4(a) in section 4.3, below. Although the pattern of inter-cohort gains in life expectancy among the kings omitting violent deaths e_0', and those attaining age 25 (e_{25}') resemble those for the birth cohorts including all the kings, in the former sub-groups the changes were in every instance were rather less pronounced; only the differences between the cohort of the 1700's and that for 1550-1649 are found to be statistically significant. Among the royal females the differences between e_0 for the birth cohort of the 1700's and its level in every one of the previous birth cohorts are strongly significant, but until one reaches the abrupt 18-year gain in life expectancy at birth among girls born during 1700-99, compared with those born only a half-century earlier, none of the successive inter-cohort changes are statistically significant.

To summarize: It is found that the mortality transition that took place among Britain's royals over the course of the two centuries preceding c. 1750 had not notably involved sustained reductions in infant and child mortality, and its effects upon adult

distributions, and the number of observations (Table A1.1) in the birth cohorts (n1 and n2). The pooled standard deviation is found from the estimate of the pooled variance:

$(s_p)^2 = \{(n_1 + n_2)[n_1(s_1)^2 + n_2(s_2)^2]\}/\{(n_1 + n_2 - 2)n_1 n_2\}$, with degrees of freedom: $df = (n_1 + n_2 - 2)$.

male mortality -- especially that of the monarchs -- was statistically more pronounced and persistent than the changes experienced by successive birth cohorts of females among the royal families. The demographic evidence therefore accords closely with Johansson's (2006, 2010) account of the evolving course of medical attention received by Britain's royal families during the sixteenth and seventeen centuries, in which the treatment of adult males initially was the primary concern of the doctors attending the court, and it was not until the later part of the seventeen century that changes in cultural norms regarding female modesty began to remove the constraints upon the abilities of physicians to diagnose and treat internal medical conditions afflicting the royal families' adult women.[13]

[13] See Johansson (2010: Part 2) for further discussion of the latter point.

3. Life-table estimates for birth cohorts of Britain's royal families: a "sparse data application" of Anson's parameterized mortality model

The foregoing observations may be seen to be just the pattern of changes implied by the more pronounced downward shift of the mortality rates among male royals in the 5-year age groups above 40-44, which appear directly from the estimated life-table schedules that are plotted in Figures 3(a) and 3(b).[14] It was not until the second half of the 18th century that one sees a marked reduction in the infant and child mortality rates. The latter is reflected in the contrast between the mortality curves for the 1650-1749 and 1700-1799 birth cohorts, which is not matched by comparably large inter-cohort changes elsewhere in the age distribution.[15]

Obviously, it is illuminating to be able to thus characterize *the distributions* of mortality experience among historical populations in a summary form that manifests their meaning in terms of the life course of a representative individuals – which is to say, in age-specific life table measures of the probabilities of dying (or surviving) – that are drawn from different epochs. Figures 3(a) and (b) serve that purpose in the present context. But, the sparseness of the available data on the life-spans of individual members of the royal families poses a considerable obstacle to straightforward reliance upon familiar empirical methods of obtaining even 5-year average mortality rates.

For the birth cohorts formed from different portions of the extended time-span that is of present interest, direct computations from what are in some instances very small numbers of age-specific observations, and in others no observations at all, are not a practical route to arriving at reasonably stable gender- and age-specific mortality rates – even those rates pertaining to 5-year age groups. Another technique to which historical demographers have been able to have recourse in studying populations at large, however, would permits the use of fragmentary data from particular samples. It does so by statistically identifying corresponding members of a family of model life tables based upon much more extensive population data. But application of that approach, using the well known regional model life tables would be of dubious validity, because the temporal and social circumstances of the elite population with which we are concerned are so removed from those of the large historical and contemporary populations upon whose demographic experience those model life tables are based.[16]

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[14] These figures correspond to Figures 5(a) and 5(b) in Johansson (2010).

[15] The inter-cohort difference for the latter pair of age-specific survivorship distributions is found to be statistically significant by the Kolmogorov-Smirnov tests reported below in Table A2.3.

[16] In addition, the assumptions of stability or quasi-stability that underlie the model life table approach are problematic in the context of the long intervals defined for our cohort-specific distributions. See Coale and Demeny (1966), and the United Nations revisions of these regional life tables, specifically Annex III: *Regional Model Life Tables for Developing Countries,* which are available at http://www.un.org/esa/population/publications/Model_Life_Tables/Model_Life_Tables.htm,. While the foregoing double-entry systems are based on empirical life table data from twentieth century populations, a more flexible model life table system that integrates life tables for some nineteenth century western European populations (France, Bavaria, Sweden, and Norway) is provided by S. Ledermann, *Nouvelles Table-Types de Mortalité*, INED Travaux et Documents, Cahier No. 53. Paris:

The approach that has been devised to meet this challenge is simple enough in concept, but the details of its application in obtaining the actual estimates – which, to the best of our knowledge, are the first set of complete mortality schedules pertaining to Britain's royal families in the era before the nineteenth century -- are intricate enough to warrant description in some detail. Therefore, rather than working within a system describing the mortality patterns of a stable or quasi-stable population, we utilize the available cohort observations on ages at death to estimate the parameters of the general descriptive model of age-specific mortality developed by Jon Anson (1991). The first step entails forming survival rates for 5-year age groups for members of those birth cohorts that are numerous enough to provide enough distinct survivorship averages to permit statistical fitting of a general model survivorship function. The second step involves use of regression analysis to estimate the particular survivorship functions for each of the selected birth cohorts. As the functional specification for this purpose describes the negative of the logarithm of the age-specific survival rate as a fifth-order polynomial of the age-group, we are restricted to fitting the model to those birth-cohorts that provide – at very least – seven observations of the mean survivorship rate over 5-year intervals. This would allow at least one degree of freedom after fitting the five coefficients of the polynomial equation and its constant term, from which the implied schedule of mortality rates can be recovered. The later operation is the final step of the procedure.

3.1 Anson's parametric mortality model

The particular logic of this approach will be more readily grasped if one begins with the specific of the general parametric model of age-specific hazard rates, y, the empirical probability of dying at age x, conditional having survived to that age. Anson (1991) postulates a universal age axis X on which the typical U-shaped mortality curve has a centre ($X = 0$), at empirical age ξ. The universal axis is there for defined by the empirical axis,

$$X = \sigma(x - \xi), \qquad (1)$$

where its mortality scale is given by σ. The position of the mortality curve with respect to the empirical mortality axis, y in this system will vary with the level of mortality, and the parameter λ fixes the level of mortality at the curve's central point ξ. The population-specific mortality curve can then be described by the general quartic equation:

Presses Universitaires de France, 1969. Ledermann comments on some limitations of the widely used Coale-Demeny system. W. Brass (*Methods for Estimating Fertility and Mortality from Limited and Defective Data*, Chapel Hill, N.C.: Laboratories for Population Statistics, 1975), does not present compilations of numerous model tables, but uses a logit system to transform a standard table based on two parameters – an approach resembling that introduced by Ledermann.

$$y = [\sigma(x-\xi)]^4 - \phi[\sigma(x-\xi)]^2 + \tau(x-\xi) + \lambda. \tag{2}$$

Anson (1991: p.141) notes that the values given by eq. (2) are not affected by the units in which age x is measured, and that this scale invariance can be preserved in the corresponding survivorship function (l_x) by integrating (2) with respect to ***X***, to obtain,

$$-\ln(l_x) = \tfrac{1}{5}[\sigma(x-\xi)]^5 - \tfrac{1}{3}\phi[\sigma(x-\xi)]^3 + \tfrac{1}{2}\tau[\sigma(x-\xi)]^2 + \lambda\sigma(x-\xi) + \delta. \tag{3}$$

The constant of integration which appears in eq. (3) as δ is interpreted as a displacement parameter, allowing adjustment for the high level of peri-natal mortality and its subsequent rapid decline. By the first birthday, i.e., the first value of l_x after the radix (=1) of the survival schedule this peri-natal force is exhausted and so serves only to fix the level of the survivorship function at that point on the age-axis.

A regression model is obtained on the basis of equation (3) by adding a stochastic disturbance to

$$-\ln(\mathrm{l}_x) = b_0 + b_1 x + \tfrac{1}{2}b_2 x^2 + \tfrac{1}{3}b_3 x^3 + \tfrac{1}{4}b_4 x^4 + \tfrac{1}{5}b_5 x^5 \tag{4}$$

Anson shows that from the estimated coefficients ($\mathbf{b_0}$, $\mathbf{b_1}$... $\mathbf{b_5}$) it is possible to recover estimates of the six parameters ($\sigma, \xi, \phi, \tau, \lambda, \delta$) of the function describing the underlying population-specific mortality schedule *:(x)*, namely by sequentially solving the following set of equations:

$$\begin{aligned}
\sigma &= {}^5\sqrt{b_5},\\
\xi &= -b_4/4\sigma^5,\\
\phi &= -b_3/\sigma^3 + 6\sigma^2\xi^2,\\
\tau &= b_2/\sigma^2 + 4\sigma^3\xi^3 - 2\phi\sigma\xi,\\
\lambda &= b_1/\sigma - \sigma^4\xi^4 + \phi\sigma^2\xi^2 + \tau\sigma\xi,\\
\delta &= b_0 + \tfrac{1}{5}\sigma^5\xi^5 - \tfrac{1}{3}\phi\sigma^3\xi^3 - \tfrac{1}{2}\tau\sigma^2\xi^2 + \lambda\sigma\zeta.
\end{aligned}$$

3.2 Estimating Anson's model from the survivorship data for cohorts of royals males and females

By fitting the fifth-order polynomial function in age --derived from Anson's (1991) general parametric mortality model, as eq. (4), above -- to logarithmic transforms of the available empirical age-specific rates of survivorship, one may produce continuous and complete survival rate schedules for the particular populations of royal males, and royal females who were members of selected historical birth cohorts. This approach is somewhat analogous to the practice (by now quite familiar among historical demographers) of using incomplete and imperfect information from population samples to select a "suitable" stationary or quasi-stable model life-table, e.g., by using an estimate of average ages at death observed in a disease region of the world, or a society that has attained a stage of economic development. But, in the present context its application has the considerable advantage of particularizing a flexible general model that does not impose one or another structure of life-table relationships, none of which may be appropriate to the historical circumstances and conditions to which the empirical data relate.

The selection of historical cohorts in the present application of this approach has been (inevitably) constrained by the sparseness of the available observations on the distribution of ages at death. Although no deaths of royals at all are recorded in some 5-year intervals, it remains possible to interpolate estimates of survival rates in the (0, 1) interval from the fitted model, which is, of course, one of the objectives of the procedure. Nevertheless, there are limits to the tolerable degree of sparseness in the data. One must have observations on at least seven different 5-year age intervals for any given birth cohort, in order estimate the coefficients of the polynomial survivorship function with one remaining degree of freedom, and, of course, more degrees of freedom are desirable if the precision of the estimates is a matter of any concern.

In fitting the fifth-order polynomial specification (with the constant term) derived from the Anson mortality model by ordinary least-squares (OLS) regression,[17] we have chosen to work with data organized into the same century-long birth cohorts that are examined in Section A1. The main reason for rejecting the device of assuring adequate distributional coverage by pooling observations from adjacent birth cohorts is simply that to do so would yield life table estimates that could obscure shifts of mortality conditions that had taken place within the resulting greatly extended historical time-spans.[18] Consequently, it proved feasible to obtain population-specific estimates of the Anson model for only 4 of the century-long birth-cohorts of royal

[17] Anson (1991:p.142) calls attention to a potential problem in using OLS to estimate this survivorship model from samples of life-table values for l_x. Because the latter are a series of cumulated products, the rates forming the life table are autocorrelated, as well as heteroskedastic. In such circumstances OLS regression can yield biased estimators of the coefficients, and Anson proposes to allow for that by estimating the model using weighted least-squares regression. But those concerns are not apposite in the present context, as we do not regard the parametric model and its corresponding polynomial survivorship function as "the true data-generating process" that produced the distributions of ages at death that are found in the genealogical record. Although age is a plausible casual factor, were our purpose to model the process generating deaths among the royals, considering only powers of the individuals' ages would surely yield an econometric specification that was plagued with "omitted variable" biases. What we are doing in this section, however, is not econometrics. Rather, is the *calibration* of a descriptive function whose parameters control certain features and relationships exhibited by the life tables of human populations. The goal is to obtain coefficients that fit the pattern (however fragmentary) that appears in the empirical observations of each population cohort -- which is to say, the coefficients that best "predict" those data. In other words, our aim in fitting the Anson model plainly resembles the use of fragmentary and imprecise data to identify an appropriate model mortality table, or to transform a standard life-table --as in Brass's (1975) approach -- so that it reflects some population-specific particularities. OLS regression provides best linear predictors of the age-specific survivorship rate, given that we know the individuals' age interval, regardless of whether the distribution of survivorship rates is affected by auto-correlation, heteroskedasticity, endogeneity -- or any of the other maladies that may beset the econometrician seeking to estimate the causal process underlying her data.

[18] Consecutive, and not the overlapping cohorts, of course, would be "pooled", as to pool the latter would double-count observations that fell in intersecting half-century.

males (1550-1649, 1600-1699, 1650-1749 and 1700-49), and in for the royal females only the latter 3 birth cohorts. Estimates for the 1500-1599 cohort in the case of males, and for the 1500-1599 and 1550-1649 cohorts of females could not be computed, because in every one of those cases the deaths were recorded in fewer than seven different 5-year age-intervals.

Appendix Figure A2.1 displays the empirical ("actual") survivorship rates and the corresponding "fitted" survivorship function obtained by this procedure – the first part (a) for the selected cohorts of males, and the second (b) for the selected cohorts of females. The statistical fit to each series of empirical survivorship rates (reported for each of the graphs plots in the Figure) is in general very close, as one well might expect when using a higher-order polynomial to describe the data. Indeed, the fit of the regression curve to the observed survival rates was in some respects even closer than the graphs' details suggest. This is due to a technical problem encountered with this estimation method: the predicted probability of survival is not constrained by the specification of equation (4) to be a monotonically decreasing, and there were some (few) instances in which the "predicted values" increased with age; these movements of the survivorship curve were very small, but large enough to yield negative values for the implied hazards of mortality. There is nothing really pathological about this, as it is simply an artefact of the small number of observations used in fitting the model, which results in discontinuities and flat portions of the empirical survival rates -- which the estimated polynomial function seeks to fit by moving upwards over some short age range. But because such movements have no meaningful interpretation, we have dealt with the anomalies by a general procedure of calculating the fitted" survivorship rates that appear in the graphs of Figure A2.1 from values predicted by the estimated regression equation under a restriction requiring monotonicity – the values are thus allowed to change only by decreasing.

3.3 Population-specific parameter values for the Anson mortality model

The mortality hazards shown below in Figures 2(a) and 2(b) are obtained from these "restricted" fitted survivorship rates, for, they correspond to the population-specific versions of the general Anson model in equation (2), whose respective parameters are presented in Table A2.1, along with the regression coefficients from which they have been derived. From there it will be seen that while the polynomial regression predictions closely track the empirical observations, the precision of the regression coefficients is almost uniformly low – those for the female birth cohort of 1700-1799 being a notable exception. Bearing in mind the small number of observations, and the still fewer degrees of freedom, this is only to be expected. Inasmuch as the purpose here is not hypothesis testing, but parameter estimation, what matters is that however imprecise they may be, these coefficients provide unbiased maximum likelihood estimators of the Anson mortality model's population-specific parameter-sets.

Figure 2(a)

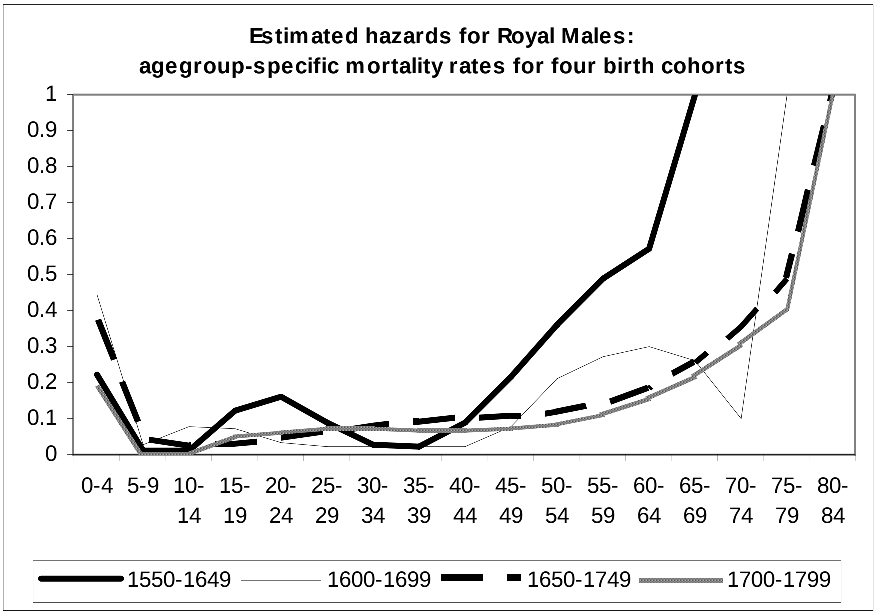
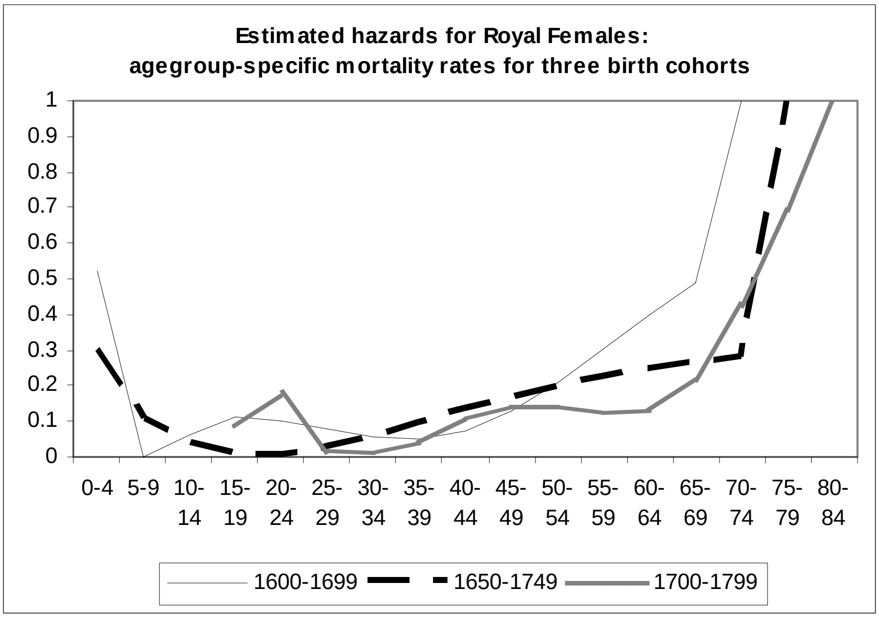


Figure 2(b)



Sources: See Statistical Appendix, Sect. A.2, for statistical parametrization of Anson's (1991) mortality model using royals' 'birth cohort-specific 5-year age group survival rates.

Notes: The right tail of age-specific mortality hazard rates plotted in Figures 5(a) and (b) is truncated in cases were there are no empirical observations of survivorship beyond the indicated age ranges. For males: the estimates stop with at 70-74 age-interval in the 1550-1649 cohort, at the 75-79 age interval in the birth cohort of 1600-1699, and also in the 1650-1749 cohort. For females: no estimated age-specific mortality hazards are shown in the plotted hazard rates in age groups 0-4, 5-9, and 10-14 of the 1700-1799 cohort, due to the absence in the underlying genealogical data of any recorded deaths at those ages.

Some explanatory remarks are now in order concerning details of the picture presented by the cohort mortality rate schedules for the successive birth cohorts graphed in Figures 2(a) and 2(b). A first point to be noted is that the right tail of age-specific mortality curve is truncated where there are no observations of survival beyond the highest age-range. Thus, for males (see Figure 2(a)) the estimates stop before the 70-74 age-interval in the case of the 1550-1649 cohort, before the 80-84 age-interval in 1600-1699 cohort, and before ages 85-90 in the 1650-1749 cohort. *This rightward secular shift of the mortality curves' upper truncation points bears striking testimony to the longevity gains experienced by successive cohorts of adult royal males, and particularly to the striking improvements that had occurred in the course of the 17th century.*

A second point to be notices is the absence in Figure 2(b) of estimated values of age-specific mortality hazards appear in the three youngest age groups (0-4, 5-9, 10-14) --pertaining to royal females belonging to the 1700-1799 birth cohort. The explanation for this is simply that, rather remarkably, the underlying genealogical records no infant and child deaths among the 20 females born into the royal families during the 18th century.[19] Infant and early childhood mortality rates for royal girls evidently had fallen very substantially between the birth cohorts of the 1600's and 1700's, but in graphing the mortality hazards it was thought inappropriate to suggest that by the 18th century the likelihood of surviving to age 14 had approached certainty for females in Britain's royal families. Twenty cases is, after all not a very big number: it is true that if the probability of a girl child surviving to age 10-14 had remained around the 0.6 that had characterized the experience of the 1650-1749 birth cohort, the survival of 20 independent individuals was a quite rare contingency (4 in 1000); but had the likelihood of survived to ages 10-14 had improved by half-again, so that it was 0.9 among females born in the 1700's, then there would be a chance of 12 in 100 of finding 20 independent survivors. Such considerations have led to the suppression of the predicted mortality rates of zero in displaying the mortality rate profile of the 1700-1799 cohort, although in the case of the 1600-1699 the plotted mortality curve is allowed shown to touch the age-axis in the 5-9 age-interval.

3.4 A counterfactual experiment with the Anson model's parameters

We conclude this section by reporting briefly on an investigation whose results underscore the contention that the mortality transition that had been experienced among the members of Britain's royal families was involved a complex set of changes that were at each stage differentiated in their effects upon the survival chances of males and females, and selective in their incidence among individuals at different stages of the life-cycle.

The parameters σ and ξ are those having the most straightforward effects upon the Anson model mortality schedules: they jointly define the "universal X-axis," as

[19] Consequently, although the corresponding actual survivorship rates to which the Anson model was fitted remain at the radix level (=1) in the first three age-groups, the (unconstrained) probability predicted from the fitted regression equation rises slightly above 1 in the 0-4 age-interval.

described by equation (1), and σ controls the normalization of the "force of mortality" (μ/σ). Thus, the larger is the proportional scaling of the force of mortality, $\mu(x)$ that is acting to depress the level of empirical age-specific survivorship, the bigger will be the estimated value of σ that is recovered from the fitted coefficients of the polynomial equation for (- ln $l(x)$), as shown in Table A2.1. Similarly, the parameter ξ fixes the location of the centre-point of the characteristic U-shaped, "bath-tub" profile traced by age-specific mortality schedules--defined with reference to the universal (X,Y)-plane of the Anson model. The larger is its value, the higher is the empirical age after which mortality rates cease declining and commence their accelerating rise.

Within the framework of Anson's parametric system, one may explore the question of whether the historical transformations that are found to have taken place in the shape of the mortality schedule can be viewed simply as one affecting the overall intensity and timing of mortality. In the case at hand, the question of prime interest translates as whether it is adequate to view the 17th and 18th century mortality transition experienced by the male royals of Britain as a transformation that displaced the centre of the "bath-tub" profile of mortality rates towards the upper end of the age-range while uniformly weakening the force of mortality, and hence lowering the whole hazard schedule.

We have undertake to assess the validity of this simplifying conceptualization by carrying out the following counterfactual quantitative exercise, using the parameter set obtained by fitting the Anson model to the data for four birth cohorts of the royal males. First, we re-estimated the coefficients of the polynomial regression model by fitting it to the empirical survivorship rates for 5-year age-intervals computed from the pooled age at death data of those born between "1500" (1485) and 1649, which we treat for this purpose as the "pre-transition" bench-mark pattern of mortality. Values of σ and ξ derived from the estimated regression coefficients for the two following birth-cohorts, 1650-1749 and 1700-1799, i.e., those appearing in the left-hand panel of Table A2.1, were then imposed upon the system relating the parameters and coefficients obtained from the benchmark birth cohort. This serves to fix "counterfactual" values of regression model coefficients b_4 and b_5, and using the values of the four other parameters obtained from the estimation of the (pooled pre-transition) benchmark model, it is possible to use the rest of the relationships from equation set (5) to recover consistent values for the counterfactual coefficients b_0, b_1, b_2 and b_3. From the resulting set of six coefficients one can then generate a *counterfactual* age-specific survivorship rates for each of the "transition-era" birth cohorts, thereby showing the differential effect of the change from the pre-transition benchmark values of the parameter-pair (σ, ξ) to their subsequent 1650-1749 and 1700-1799.

To the extent that the shape and positions of those counterfactual life table schedules could have accounted for the main inter-cohort movements of the empirical survivorship and mortality rates – or those of the corresponding predicted rates obtained by fitting the unconstrained regression model to the empirical observations for those birth cohorts, it could be said that the quantitative essence of the historical the mortality transformation was "captured" by the alteration of just the key parameter-pair. Putting it another way, a close correspondence between the counter-factual "fitted" survival schedules and the empirically "fitted" schedules would establish the sufficiency of this reductive description of the altered pattern of cohort mortality.

But that is not what one finds: there are large and systematic differences between the counterfactual and the actual fitted age-specific survival schedules for the male birth cohorts of 1650-1749 and 1700-99 compared, both in absolute terms and compared with the differences between the actual and fitted schedules for the (1550-1649) benchmark cohort. The resulting gaps between our counterfactual constructs and the empirical realities bear concrete quantitative testimony that the observed inter-cohort difference in mortality are not amenable to anything approaching a substantially faithful description in such reduced parametric terms.[20]

The upshot of this experiment, therefore, is that the historical reality of demographic change in this instance (at least) proves too complex, involving too many dimensions of alternations in the incidence of mortality over the course of the representative royal life-span for the male members of Britain's royal families, including the extension of the life-span itself. If there is a lesson to be read in this statistical "failure," it is that a far richer, detailed account of the intricate and mutable interplay of intellectual, social, economic, environmental and biological factors that re-shaped the pattern of mortality in this privileged European population is not an indulgent embellishment. Rather, an account of that kind is a necessity if one hopes to arrive at a proper understanding this historical experience and its larger significance.

[20] The statistical results from these "failed" experiments are not displayed here, but can be made available on inquiry of the authors.

4. The Course of Britain's First Mortality Transition

It is useful to begin by forming an overall comparative view of the British royal families' early mortality transition from Table 1, where the birth cohort averages of mean life expectations are presented for the male and female royals taken together. These appear in the left-most panels, which shows the estimated expectations at birth (e_0), and at age 25 (e_{25}) for each of the five royal birth cohorts, together with the number of observations from which these have been calculated. In the central panel of Table 2 corresponding estimates are given for 26 English parishes studied by Wrigley et al. (1997).[21] Also shown, in the column on the right, are roughly comparable estimates of the expectation of life at birth for males and females in England's national population. [22]

One must bear in mind that there are significant male-female differences in age-specific mortality rates and in resulting expectations of life at birth, as well as at subsequent points in the life cycle. These will be considered subsequently, and the comparisons afforded by combining the sexes for the purposes of Table 1 serve nicely to reveal the broad quantitative outlines of the transformation taking place during the late 17th and 18th centuries in the relationship between the mortality experience of Britain's urban dwelling royal families and the population of the country at large.

4.1 The Mortality Transition among the Adults of the Royal Families

In the birth cohorts of the epoch stretching from the end of the fifteenth century through the end of the seventeenth century the royals' mortality disadvantage *vis-à-vis*

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[21] The underlying decennial averages of e_0 are given for males and females combined (M+F) by Wrigley, Davies, Oppen and Schofield (1997), Table 6.21 (p.290); corresponding estimates of e_{25} are given in Table 6.19, for 1640-49 onwards. The series is extended to earlier dates using the decade average values graphed in Figure 6.15 (*Ibid.*, p. 283) for 1600-09 through 1630-39. Consult the text of Statistical Appendix A3 for the methods used to fix the time intervals over which underlying birth cohort and period estimates of e_0 , and also the decadal e_{25} observations, were averaged to form estimates that were approximately comparable with those presented for the century—long birth cohorts of royal family members (M+F). As is noted in Appendix A3, achieving strict comparability between cohort and period estimates of life expectations poses a considerable technical challenge for demographers.

[22] The notes and sources for Table A3.1 of Statistical Appendix A3 detail the way in which the "national population" entries in Table 2 were obtained – briefly, by forming weighted averages of the quinquennial values of e_0 based on *period* life table estimates obtain from Wrigley et al. (1997: Appendix 9, Table A9.1). The latter were derived (from aggregative birth and death time series for some 400 parishes in England) by application of the method of generalized inverse projection, and represent a revision of the earlier "back projection" estimates presented by Wrigley and Schofield (1981). The problem of translating period measures of life expectation into cohort measures is a technically challenging one for demographers. As Appendix A3 acknowledges, the procedure that has been adopted in constructing Table A3.1 (and hence the national population entries e_0 averages in Table 2 for intervals corresponding to the royal birth cohort averages) is *ad hoc* and inexact. But, inasmuch as the averaging intervals are long and the underlying time series of quinquennial period e_0 series exhibits neither pronounced short-run volatility, nor strong secular movements prior to the 1760s, inaccuracies in the intervals defined for averaging are unlikely to result in serious non-comparabilities that could vitiate their usefulness in the context Table 2's comparisons with e_0 averages based on birth cohort data for the royal families and the reconstituted English parishes.

Table 1. Expectation of Life at Birth and at Age 25 for Royal Cohorts: Males and Females Combined. Compared with Reconstituted English Parishes and England's National Population

Royal Birth Cohorts	Royal Families				26 English Parishes (derived from Wrigley et al. (1997)		National Population of England
	Average Expectation of Life at Birth: M and F		Average Expectation of Life at Age 25: M and F		Expectation of Life at Birth: M and F	Expectation of Life at Age 25: M and F	Expectation of Life at Birth: M and F
	No. Obs.	e_0	No. Obs.	e_{25}	e_0	e_{25}	e_0
1500-1599	**31**	**25.3**	**12**	**24.8**	**n.a**	**n.a.**	**34.6**
1550-1649	**22**	**30.1**	**11**	**25.1**	**38.8**	**22.2**	**36.9**
1600-1699	**43**	**25.9**	**18**	**30.3**	**36.1**	**35.5**	**33.8**
1650-1749	**44**	**32.4**	**14**	**33.8**	**35.8**	**32.6**	**35.9**
1700-1799	**37**	**49.5**	**16**	**34.6**	**40.8**	**35.9**	**37.0**

Source: For Royal Families see Appendix 1, Tables A1.1 and A.1.2; for National Population, Table 2, and Appendix 2, Table A2.

the national population varied between 7 and 9 years difference in the expectation of life at birth.[23] It would appear that during 1550-1649 the gap vis-à-vis rural villagers in England was even wider than that– by at least 2 additional years. This may be seen from the difference between the average levels of e_0 for the royal males and females in the predominantly although not exclusively rural group of English parishes studied by Wrigley et al (1997).[24] The prevailing contrast between the mortality situation of

[23] An earlier set of e_0 estimates was obtained by Wrigley and Schofield (1981) for England's national population by "back projection" – which made use of the structure of mortality indicated by the earliest of the (then) available life tables for England and Wales (1841). This produced estimates of average life expectancy at birth for ordinary English people during latter half of the 1700s that bracket the recent family reconstitution-based estimates (40/41 years, females and males, respectively) for that period: the lower of the pair is 34/36 years, whereas the higher value is given as 45 years (see Wrigley and Schofield (1981), p. 252: Table 7.24.

[24] Of course, this difference mirrors the 2 year gap (roughly, 38 *vs*. 36 years) separating average e_0 in the 26 parish sample from the estimated average for England's national population. As a whole, those families whose demographic event histories could be reconstituted for study by the Cambridge

royalty and that of the mass of the population – characterized by vastly different material income levels but also situated in markedly different environments in terms of their exposure to disease, had thus been substantially worse than the classic notion of "pre-modern parity between princes and paupers."

What then is noteworthy in Table 1 is the improvement in both the absolute and relative survival rates experienced by members of the royal families belonging to the 1650-1749 birth cohorts, resulting in a 5.3 year gain in their average expectation of life at birth above the level of e_0 that had prevailed among those born during 1500-1650. The movement of e_0 from the neighborhood of 25 years to a level somewhat above 30 years brought the mortality experience of royal adults closer to parity with that of the predominantly rural parish population, reducing the average gap between them to only 3.5 years.

This is all the more remarkable in view of the very substantial portion of the year that members of the royal families were residing in or near the disease-ridden environs of London, and hence lived in close quarters with servants who were not isolated from direct contact with tradesmen, footmen, servants of other elite households, not to mention their own families and friends in the metropolis. During the seventeenth century the average expectation of life at birth in a sample of London's parishes is estimated to have been 20 years or less (Landers, 1990).[25] Which would imply that the average e_0 of royal males and females in the birth cohort of 1600-1699 (at 26.4 years) already gave them at least a six year longevity advantage in comparison with London's commoners.

The differentially larger improvements of the elites' expectations of life continued into the next century, so that among those forming the royal birth cohort of 1700-1799, the average age at death (males and females combined) exceeded that of the mostly rural parish-dwelling population by 8.7 years, and surpassed that of the (somewhat more urban) national population by as much 12.5 years. It should be appreciated that these relative gains in the royals' longevity emerged even though the expectation of life at birth in the country at large also increased between comparable periods in the seventeenth and the eighteenth centuries.

Whereas the gains in e_0 for the royals vis-à-vis commoners in the 26 reconstituted parishes are seen to have been remarkably large between the birth cohorts of 1650-1749 and 1700-1799, that was not the case with regard to adult life expectancy (e_{25}). The men and women commoners in those parishes enjoyed slightly bigger absolute gains in longevity than their royal, palace-dwelling counterparts so that when they

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Population Group led by A. E. Wrigley are a selective sample of their respective parish populations, in that they lived all or most of their lives in one parish. See Wrigley et al. (1997), Ch. 3 on "representativeness" of the reconstituted parish population. Their Table 6.27, *(Ibid*. p. 308) presents e_0 for males' and females' separately, each averaged over 25-year intervals starting in 1625, and the notes to Figures 3 (a and b) described how these have been plotted for comparability with the averages based on the means of ages at death for the birth cohorts of royal males and females.

[25] In London recorded infant baptisms/burials translate to an infant mortality rate of about 300/1000. Since there was extensive under registration of illegitimate births and births quickly followed by death, the real infant mortality rate in London must have been substantially higher (Razzell, 1999). In rural areas infant mortality rates were about half the unadjusted London average.

reached age 25 they too could expect to live another 36 years – actually about one and a half years longer. This calls attention to a third aspect of the royals' mortality transition, namely, that only in the last phase, during the eighteenth century did it involve a notable sustained increase in the survival rates among infants and children. Thus, the impressive absolute and relative gains in the expectation of life at birth among the royal families born during the eighteenth century, and particularly during its second half, reflected mainly the increased likelihood of their surviving to age 25, rather than beyond: the increase of 17 years in the average e_0 between the royal birth cohort of 1650-1749 and that of 1700-1799 was accompanied by less than a one-year rise in life expectancy at age 25 (e_{25}).

Comparisons between royal and ordinary adults of both sexes such as those that have just been made are complicated by the fact that populations of the 26 reconstituted parishes -- here representing, for the most part, the ordinary people of England's country villages and small towns -- were not homogeneous economically, geographically, or with respect to their local disease environments. A few of the reconstituted parishes that are described as urban had higher than average death rates.[26] The healthiest (longest-lived) ordinary people seem to have lived in the most remote parishes. In those exceptionally sheltered locations some ordinary families may have continued to live longer on average than the royal family, even in the 1700s. In the higher density parishes however, where rural industry was developing rapidly, ordinary people probably fell more and more behind the ruling family, just as was the case for their London counterparts. To the extent that these environmental inhomogeneities had their primary impact upon the survival of infants and children, the differences observed between the mortality trends among adult royals and commoners are less ambiguous in their import.[27]

4.2 The Mortality Transition among the Royal Males, and then among the Females

Yet, further can be light is thrown on the nature of this early mortality transition by turning now to examine the course of change life expectancy among the males separately, and then among the females of Britain's royal families. From the following discussion, it will be seen that the transition had two quite different aspects, each distinguished from the other by both the temporal separation of the shifts taking place in the longevity of members, and by the portions of the structure of age- and sex-specific mortality rates that were primarily affected during each phases. The transition to lower rates of age-specific mortality among this elite population began with the improvement in the survival rates of the men during the latter half of the seventeenth century – which is to say that it was largely confined to males who

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[26] For further details, drawn from material in Wrigley et al (1997), see the notes to Table 4, below and the accompanying text discussion.

[27] Furthermore, it is possible separately to examine the changing relationship between the mortality of royalty and commoners at the lower end of the age distribution – as is done below, with the aid of Table 4.

reached age 25, and found no parallel in the average experience of the women of the royal families. The second phase of the gain in royal life expectancies was shared more equally among the males and females and was a development of the eighteenth, for it was driven by the pronounced drop in rates of infant and child mortality (for both sexes) that was especially marked among the royal family.

More will be said about that part of the story after considering more closely the magnitudes of the preceding differential evolution of adult survival rates for the men and the women of Britain's ruling families, and those changes impacts upon the increased longevity of males and females in the royal households between the sixteenth and seventeenth centuries. The contrasting experiences of the sexes in this regard appears immediately from a comparison between Figure 3(a) and Figure 3(b).

Firstly, it is seen that among those who had survived to age 25, the mean age of death (i.e., $e_{25} + 25$) among men in the first three of the royal birth cohorts (plotted in at the mean date of death for each cohort) lay in the range from 53 to 64 years, well above the expectation of life ($e_{25} + 25$) for the corresponding sub-group of women. Furthermore, while the average expectation of life at age 25 among the women for these sixteenth and seventeenth century cohorts remained unaltered at the level of 24-25 years, for the men e_{25} had soared from 28 to 39 years.[28] It should not be supposed that the male-female difference in this regard might have reflected a reduction in the frequency of "violent" and accidental death among royal adult males whilst there had been no accompanying reduction of the incidence of maternal mortality among royal adult females. The estimates graphed in Figures 2(a) and 2(b) pertain to males who had died "naturally" (i.e., without violence) at ages above 25; and to females who escaped maternal mortality and survived beyond age 25.

But the remarkably high average rate of survival among these adult males who had been born during 1600-1699 was not sustained in the next century, and the extension of longevity among adult women that became discernable in the birth cohort of 1650-1749 therefore reduced the male-female difference in e_{25} to a mere 2 years. A closer look at the underlying data, however, reveals that the century-long cohort averages, while providing somewhat more precise estimates of the cohorts' mean expectations of life, mask the fact that the mortality transition among the adult females in the royal families lagged that among the males by fully a century. The rise in e_{25} among the women that becomes visible in the average for the cohort born 1650-1749 was notable particularly among those who entered it late in the second quarter of the eighteenth

[28] The resulting difference between male and female adult mortality in the birth cohorts of 1600-1699 was 14.9 years, a staggeringly large difference (considering that it did not reflect the differential exposure of the royal women to maternal mortality, or any reduction in the exposure of the men to violent deaths, as the text below points out. The small sizes of the samples notwithstanding, that difference in the mean ages at death for who survived to age 25 (without a subsequent violent or maternal death) is so large that it is found to be statistically significant at the 95 percent confidence level – on a one-tail *t*-test, using the pooled estimate of the standard errors of the means for the adult males and the females (from Statistical Appendix Tables A.1.2). Although in the 1550-1649 birth cohort there are quite substantial male-female differences in between the corresponding means for adults (9.8 years) and for the average e0 of all the males and females (6.7 years), the standard errors are too large to allow them to rise above conventional levels of confidence levels. See Appendix A1, footnote 7 on the calculation of pooled standard errors and df for such tests.

Figure 3(a) Comparative Levels of Male Cohort Life Expectancy

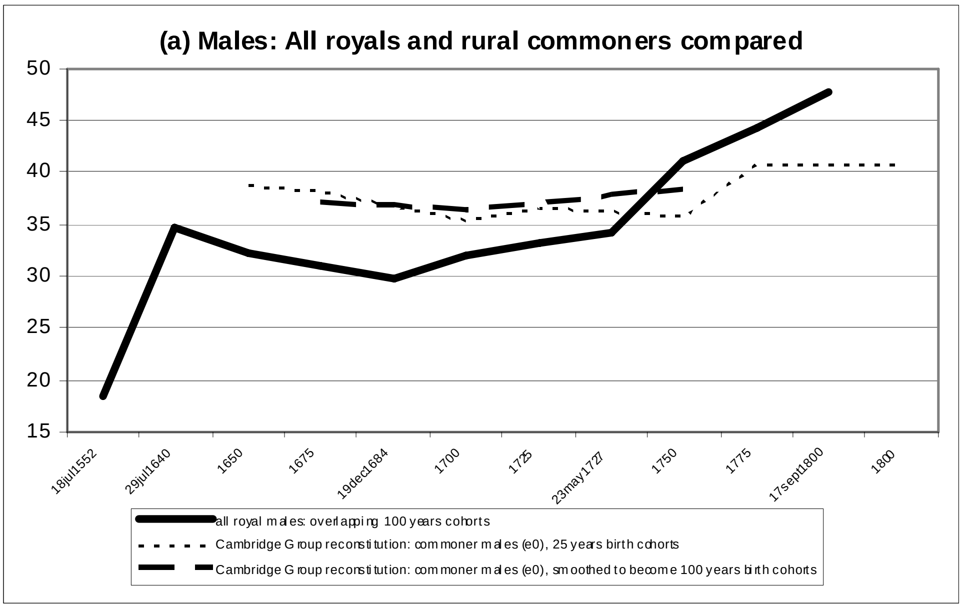
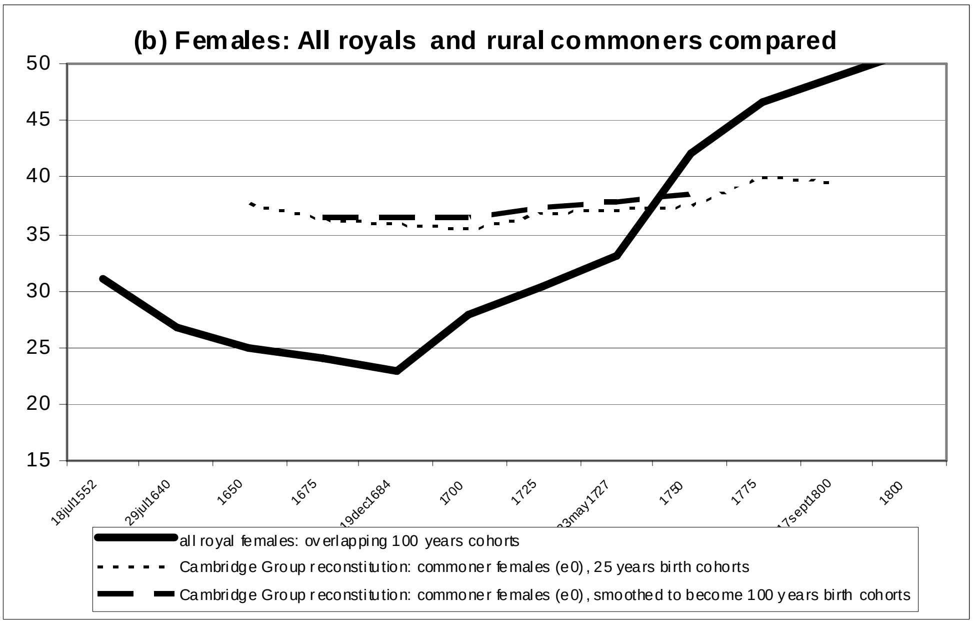


Figure 3(b) Comparative Levels of Female Cohort Life Expectancy



Sources and Notes: Cohort e_0 data for royals from Statistical Appendix Tables A1.2b, A1.2d; 25-year for commoners, from Wrigley, Davis, Oppen and Schofield (1997), Table 6.27.

The following are the cohorts' respective mean dates of death, with the dates of the interpolated values of the series indicated in italics:

For the male royals: Cohort 0 (1550-99): 18 jul 1552; Cohort I (1550-1649): 29 jul 1640; *1675*; Cohort II (1600-99): 19 dec 1684; *1700* ; Cohort III (1650-1749): 23 may 1727; *1750* ; *1775* ; Cohort IV (1700-99): 17 sept 1800.

For the female royals: Cohort 0 (1550-99): 26 jan 1565; Cohort I (1550-1649): 14 jul 1646; *1675* ; Cohort II (1600-99); 6 dec 1679; *1700* ; *1725*; Cohort III (1650-1749): 25 may 1729; *1750* ; 1775 ; 1800; Cohort IV (1700-99): 20 jul 1802.

century, specifically George III's wife, his daughters and daughter-in-law – all of whom were born after 1740.[29]

The effect of the royal mortality transition that began with the adult males is seen in the upward trend of cohort average expectations of life at birth among all royal males in the seventeenth century, and contributed substantially to lifting the average age at death of those in the eighteenth century birth cohort (n = 17) to 47.6 years, a level exceeding by 11.6 years the estimate given by Peller(1965) for all the European ruling families in the 1700s.[30] The lagging rise of the mean age at death among Brtain's royal females that is noticeable after the seventeenth century birth cohort (n=20), bringing the average during 1700-99 slightly above 51 years, which put it fully 13 years higher than the corresponding figure from Peller (1965).

It has been seen from Figure 3(a) that the absolute and relative time-series movements in the mean expectation of life at birth remain virtually unaltered when instances of violent death are excluded from the observations for the males. The same can be said of the trends exhibited for the royal females in Figure 3(b), except that in this case all of the gains in life expectancy had come for those born after the mid-1600s, and so are reflected in the rise shown by the graph to have occurred following 1679 (6 December), that being the average date of death of the females belonging to the royal birth cohort of 1600-99. Here again, exclusion of instances of maternal mortality leaves the picture unchanged both in levels and trend. These gains in expectation of life among members of Britain's royal families, particularly those between the levels attained by the birth cohort of the 1700s and the two previous century-long birth cohorts, were so pronounced that (in spite of the small numbers of lives involved in those comparisons) the differences in cohort means can be accepted as statistically significant.[31] Indeed, these findings are confirmed by the results of more stringent statistical tests of the inter-cohort differences in the distributions of the

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[29] It should not be supposed that the male-female difference in this regard might have reflected a reduction in the frequency of "violent" and accidental death among royal adult males whilst there had been no accompanying reduction of the incidence of maternal mortality among royal adult females. The estimates graphed in Figures 3(a) and 3(b) pertain to males who had died "naturally" (i.e., without violence) at ages above 25; and to females who escaped maternal mortality and survived beyond age 25.

[30] Royal male's mean expectation of life at birth in this epoch approximately matched that for the males in ducal families, according to the data compiled by Hollingsworth (1977: p. 32). See also Johansson (1999) for further discussion of the evidence from the ducal genealogical data that is consistent with the thesis advanced here, and Johansson (2010:Table 1) on Peller's (1965) estimates of European elite families' life expectancy at birth.

[31] See Statistical Appendix, Tables A1.3a and A1.4a, for results of one-tail t-tests of inter-cohort differences means (for royal males and royal females, respectively) , between Cohort IV and Cohort 0 (the 1500s), and Cohort II (the 1600s). The gain of 27.8 years for the males in the first comparison is significant at the 1 percent error level, whereas the 17.8 year gain in the second comparison is significant at the 5 percent error level. For the royal females, the gain in life expectancy (14.7 years) between the birth cohort of the 1500s and that of the 1700s was less pronounced than that among the males, and is significant only at the 5 percent level; whereas the differences between the mean age at death of females born in the 1700s and those born in 1549-1650 (24.4 years), and those born in 1600-1699 (28.1 years) , and in 1649-1750 (18.2 years) are in each case significant at the 1 percent error level. See further discussion in the text of Statistical Appendix section A.1.

5-year survival rates, indicating that the significant differences between expected ages at death reflect changes in the whole structure of mean age-specific mortality rates.[32]

Thus, statistical comparisons with earlier birth cohorts and with the experience of ruling families in Western Europe as a whole support the conclusion that the members of Britain's royal families born during the eighteenth century survived much longer on average than their forerunners. It appears that they also were outliving contemporary royalty on the Continent – at least in the era following the shared seventeenth century setback in the average life expectancy at birth among the males and females of ruling families on both sides of the English Channel. While, like most elites, Europe's ruling families enjoyed gains in longevity between the 1600s and 1800, the royals in Britain on average were making greater progress towards extended survival, and making it somewhat sooner.[33]

Among the residents of London, *life expectancy at birth* rose from a low of c. 20 years during the seventeenth century to c. 26 years by 1750-80, which meant that by the latter period ordinary Londoners had attained life expectancy levels enjoyed by Britain's royal families a century earlier. Even among the relatively well educated, prosperous and typically abstemious Quaker families living in London towards the end of the eighteenth century, life expectancy at birth is estimated to have been only 28 years.[34] By that time the royal family had gained a 20 year mortality advantage over Middle class Quakers, and, as has been noted previously, a still larger one vis-a-vis London's poor. Signs of an accelerated middle class catch-up would not become evident until well into the nineteenth century.

When life expectancy at birth for England's (urbanized) royals is compared to those for England's predominantly rural residents, however, the picture that emerges is quite different, which is to be expected inasmuch as the local disease environments of the two populations are not being held constant. In the 1600s the royal family had a

[32] Statistical Appendix Tables A1.3 and A1.4 present the summary results of Kolmogorov-Smirnov tests of the inter-cohort differences in 5-year survival distributions, a test that asks, in effect, whether it is possible to reject the hypothesis that the two sets of mean age-specific survival rates (for the indicated pair of cohorts) are drawn from a common underlying mortality structure. Although, as noted in the text, the e_0's is found to be a sufficient statistic in this context, there are some notable variations in the details of the K-S tests. The 1500-99 and 1700-99 survival distributions for royal males are significantly different at the 2.5% error level, and the differences between the 1700-99 and both the 1600-99 and 1649-1750 cohorts' distributions were more strongly significant. In the case of the royal females, the 1500-99 vs. 1700-99 difference in survival rate distributions is significant at the 5% level, whereas the comparison of the 1700-99 distribution with those for the 1600-99 and 1649-1750 cohorts shows differences that are significant at the 1% error level.

[33] It is not possible to give error bounds for the differences between the British royals' mean life expectancies at birth and those for Europe's ruling families, because no standard deviations for the latter were presented by Peller (1965). But, in view of the much larger sample sizes for the century long birth cohorts of European elites (see the notes to Table 1), there good ground for supposing that the pooled standard deviations employed for the inter-cohort tests reported among the ruling family members in Britain (detailed in the Statistical Appendix) would be far smaller than those calculated from the British data alone.

[34] See Landers 1991:25. Buer's (1926) history still offers the most detailed, disease-specific account of how a series of medical campaigns and public health reforms initiated in the 1700s began to improve access to health care for ordinary people

marked life expectancy at birth *disadvantage* when compared to ordinary county people, who, simply by virtue of being rural, enjoyed a less exposure to epidemic diseases and polluted air and water.

Estimates of the *life expectancy at birth* of males, and of females dwelling (mainly) in rural parishes are available a twenty-five year averages after the first quarter of the seventeenth century, and these have been graphed in Figure 2(a) where they are juxtaposed with the corresponding estimates for the royal males that were just discussed.[35] The comparisons reveals how striking was the transformation in differential mortality that took place between the end of the sixteenth and the end of the eighteen century: during 1600s England's (urbanized) royal males' lives were about 7 years *shorter* than the average 37 year span of male commoners, whereas a century later the royals could expect to enjoy an 8 year advantage in longevity. Royal females born in the 1600s had a life expectancy of birth of only 23 years, while ordinary females from predominantly rural families are estimated to have had a life expectancy at birth that averaged 36.4 years, indicating a royal longevity *disadvantage* of about 13 years – almost twice as great as that which existed among the males! In the latter half of the 1700s, by which time royal life expectancy at birth for royal women had risen to average 51 years (as may be seen from Figure 3(b)), these women had acquired more than a 10 year advantage *vis-a-vis* the females commoners dwelling in the largely rural parishes.

The picture that emerges from comparisons of life expectancy levels for those adults who survived to age 25 suggests that something closer to the classic "princes/peasants" parity in mortality (depicted in Figure 1) had come to exist among mature adults in England early in the seventeenth. That was the case at least for the royal males in the birth cohort of 1550-1649 who survived to age 25, as their mean age at death was 57.4 which put them at approximate parity with their adult counterparts in the predominantly rural parishes. But, a comparison just made, between adult male survival rates and the survival rates for men and women taken together in the population at large implicitly raises the question of whether the rural men were outliving the women in these parishes. This is a matter that unfortunately cannot be definitively resolved, yet surely deserves some consideration.

To the extent that the incidence of maternal mortality differentially abridged the lives of adult women, there are grounds for supposing that parity of survival rates between royal adult males and their counterparts in the country parishes would not have been achieved until the former clearly were outliving the adult men and women of those rural villages.[36] In any case, that was not long in coming, for adult life

[35] In addition to being plotted directly, the 25-year average estimates of e0 drawn directly work of Wrigley, Davies, Oppen and Schofield (1997, see Notes to Figure 3a and 3b) have been averaged to form overlapping century-long averages that are comparable with the birth cohort estimates for the royal males and the royal females.

[36] From Table 2 it is seen that at 57.4 years, these royal adult males' expectation of life (25 + e25) exactly matched the reconstitution parish average for men and women combined. But female mortality rates were systematically well above those for males throughout the age range from 25 to 44, due to the incidence of material mortality. The female mortality rate for ages 25-34 averaged 63 percent above that of the males in the period 1640-1809, according to Wrigley, Davies, Oppen and Schofield.(1997:

expectancy among the urban-dwelling royal males of the 1600-1700 birth cohort rose markedly, pushing their mean age at death above 64, and therefore well above of that typical among country-dwelling commoners.[37] Apparently, being based in London for much of the year no longer imposed a heavy mortality penalty on men in the royal families.

Could this have simply been due to the early winnowing of all but the hardiest from the ranks of the royal males? Because so few of the males in these families survived infancy and childhood (as will be seen from Table 2, only 42 percent of the birth cohort of 1600-1699, and 30 percent of the 1650-1749 cohort lived to celebrate their 25th birthdays), one might suppose that those who did so were exceptionally robust. What makes this suggested explanation for the increase longevity of the adults unpersuasive is that it cannot account for the increase from the level of adult expectation of life that had prevailed among the royal in the sixteenth century, which infant and child survival rates were no better (only 38 percent of the c.1500-1599 birth cohort reached age 25). Moreover, the view of the royal adult survivors of the latter part of the seventeenth century as selected hardy bunch is difficult to square with the fact that England's adult royal males that era have been referred to as "the sickly Stuarts" by a medical doctor-historian, and with good reason.[38] The royal women were, if anything, even less healthy, which may account for their still not achieving parity in survival rates with England's adult (mostly rural) women during the 1700s.

Finally, it should be noted that the apparent stability of royal male life expectancy at age 25 (see Figure 1a) should be interpreted with caution, because the underlying distributions of the ages at death rest on such small samples and therefore are so different in the two successive cohorts after that of 1600-1699: in that birth cohort of the eight males born to royal parents and surviving to age 25, only one lived past 70 years of age, and he was neither raise nor resident in England. By contrast, in the cohort of 1700-1799 there were 13 royal male survivors to adulthood, five of whom lived to be 70 years or older, but this remarkable longevity is masked in the cohort

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Table 6.26, and pp. 302-03), who comment on the temporal stability of these sex-differential. On the other hand, after the end of the span of childbearing years, the female/male mortality ratio in the parish population rapid declines from rough equality at age 45-49 -- putting the men at a 36 mortality disadvantage by the time they reached ages 55-59. Thus, although partial life expectation estimates for those in the 25-65 age range (*Ibid*., Fig. 6.20, p.305) show a slight degree of absolute excess female mortality during the second quarter of the seventeenth century, the situation clearly was reversed throughout the second half of the century and remained that way during 1700s, despite the persistence of excess female mortality in the 25-44 age range. So, it is not implausible to think that adult male's rural parishes may have ceased to enjoy a survival advantage vis-à-vis their town-dwelling royal counterparts as early as latter third of the seventeenth century.

[37] This can be seen by comparing the royal adult ages at death in Appendix Table A.1.1b with the 26 parish estimates in Table 2, and referring to the discussion in the preceding footnote.

[38] See Holmes (2003). As patients, typically they were being treated for more than one serious medical condition. In the 1600s a series of books on life at court written by prominent doctors all agreed that that irrespective of location, royal courts were unhealthy places, and "courtiers" themselves were particularly unhealthy people (see W. Kummel, 1990). This would seem to have been a rather long-standing condition of Europe's princes. For example, Dr. Ann Carmichael (1989: p.34), after examining the extensive descriptive material on the individual health status of the Medici family (rulers of Florence in the 1400s and 1500s), concludes that suffering mediated the lives of the Medici as much as it did the existence of their poorer, and less advantaged contemporaries."

average by the others who died before their fiftieth year. The obvious point of caution to insisted upon here is that as small as the entering sizes of these adult cohorts are, the numbers thin out quite drastically so the experience of a few long-lived individuals may be pulling up the average – or their absence may depress it substantially – hence the large standard errors associated with these means (presented in the Appendix Table A1.1) must be continually kept in mind.

There are, however, some further facets of the quantitative evidence that serve to support and refine the foregoing generalizations, and these are best considered by taking the two aspects in turn, focusing first on the changing mortality of the adult males and females in the royal families. A clearer view of the temporal changes that were taking place in the different portions of the age-specific schedule of mortality among the entire royal male populations is afforded by returning to examine Figure 2(a), which displays estimates of the mortality hazard rates for each of the successive birth cohorts. These are just the sets of age-specific mortality rate schedules of the sort one would find by constructing empirical life-tables for each birth cohort, were there a sufficiently large body of royal genealogical observations to permit such calculations to be made for 5-year age groups, let alone on a single year basis. Lacking that, it will be recalled that the sets of estimates presented graphically in Figure 2 have been obtained by statistically fitting the Anson (1991) parametric mortality model to the available cohort-specific distributions of survivorship, from whose estimated parameter values it is possible to retrieve the implied age-specific mortality hazard rates.[39]

Three features of Figure 2(a) are notable in connection with improvements in adult male mortality. First, the mortality rate schedule for those born in the 1600-1699 cohort drops persistently below that of the preceding (1550-1649) cohort most markedly in the 55-64 age range, and lies below it throughout the age range from 50 to69. This locates the onset of the transition among the mature adult males in the latter half of the 17th century. Second, the movement towards elevated rates of survivorship rates among the male royals continues into the next century, can be seen from the downward displacement of the schedule for the cohort of 1650-1749 which brought its level beneath that of the 1600-1699 cohort in the age range from 50 to 64. Third, the mortality transition among the royal males was essentially completed by that point, as can be seen from the close coincidence between the hazard schedules for the cohorts of 1650-1749 and 1700-1799 throughout the entire age span above 25.[40]

[39] The irregularities in the age-specific mortality schedules reflect those in the underlying cohort observations on ages at death, which are sparse (indeed non-existent) for some of the 5-year age groups. See Table A2.1a of the Statistical Appendix for the estimated coefficients of the 5-order polynomial regression model (Appendix eq. 4) fitted to the empirical age-specific survivor functions for each of the four birth cohort of royal males for which this procedure could be carried out, and Figure A2.1a displays the actual and the fitted survivor functions. Corresponding details for the three cohorts of royal females are given in Appendix Table A2.1b, and Figure A2.1b. The irregularities in the age-specific mortality schedules reflect those in the underlying cohort observations on ages at death, which are sparse (indeed non-existent) for some of the 5-year age groups.

[40] Table A2.2 of the Statistical Appendix presents the results of non-parametric (Kolmogorov-Smirnov) tests for differences between the empirical distributions of survival rates for all the royal males in various pairs of birth cohorts. Only the differences between the1500-1599 and 1700-1799 birth cohorts

4.3 The Mortality Transition among the Kings and Queens

A brief concluding focus on the demographic history of the people occupying the very pinnacle of the ruling elite during these centuries proves to be quite illuminating. It is so because the circumstances and individual details of the lives of the 15 men and the 20 women who here are counted as Britain's 'kings' and the 'queens', respectively, are known far more completely than is the case for most of the others in the royal families, and therefore can provide an interpretive context that gives the demographer's measures a significance beyond that which (in the case of these small and select population samples) statistical analysis alone can impart.[41] Moreover, because the data for these groups relate to the evolution of the expectation of life among men and women who had to be married, and/or to come to the throne – even if not all survived beyond age 25, they serve to filter out the effects of the volatile swings in royal infant and child mortality and contribute a direct view of the impact of the changes in adult mortality rates on the expectation of life at birth.[42]

The upward trend in e_0 among the kings in each of the successive birth cohorts continued after that, as can be seen from Figure 4(a): over the course of the long sixteenth century, between the cohorts of 1550-1649 and 1600-99, and again into the eighteenth century. For the kings who survived beyond age 25 and escaped violent death, the average gain in longevity between the cohorts of 1550-1649 and 1650-1749 therefore amounted to 17.4 years.[43] The contrasting experience of the queens should then be noted (from Fig. 4(b)): here the inter-cohort increases of the average age at

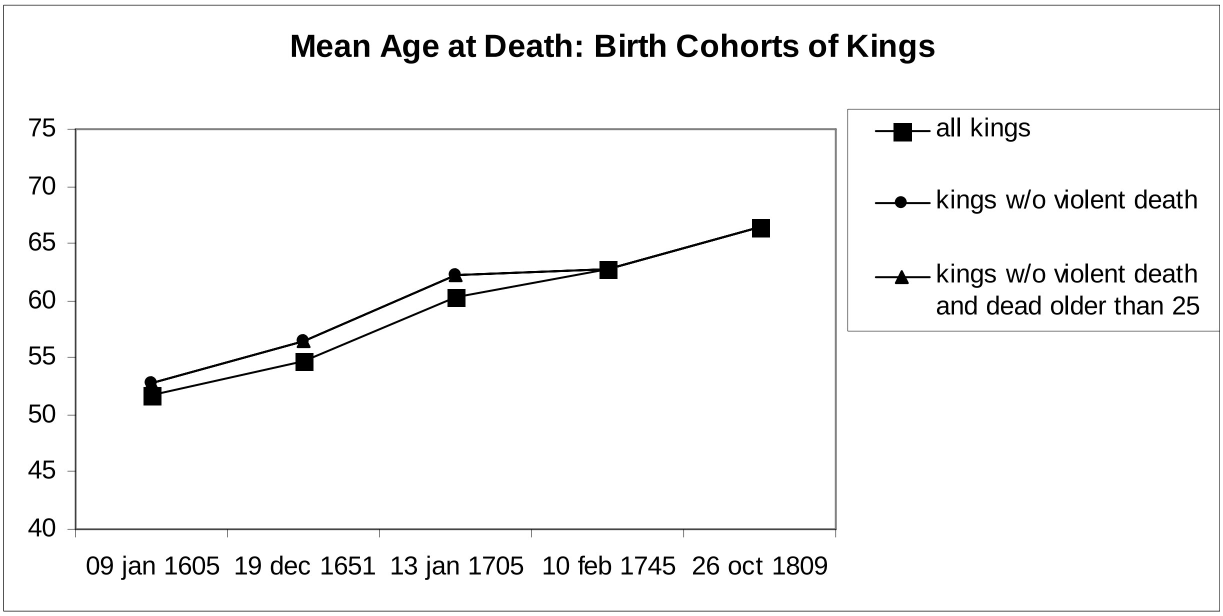
are found to be significantly, at the .05 level of error. Similarly, Table A2.3 reports a slightly stronger result for the difference between the males in the 1700-1799 birth cohort, and in both the cohorts of 1600-1699 and 1650-1749 – both pairs being significantly different at the 0.025 level of error. The results of all the pair-wise K-S test results that were carried out are noted in Tables A1.2a and A1.3a. The absence of notations of significance at the 95% (confidence level or higher) should be read to indicate that the *entire schedule of mortality rates* are not found to be statistically different for the pairs of Cohorts I and II, and II and III that are discussed in the text above, in connection with the reductions that were occurring in the mortality rates of mature males. Only after the fall in royal infant and child mortality had taken place in the latter 1700s, do comparisons between the survival distributions of the 1700-1799 Cohort (IV) and earlier cohorts show differences that are statistically significant. The latter point is emphasized in the text (below), as it is particularly germane to second aspect of the royals' mortality transition.

[41] That is not to say, however, that it is pointless to conduct and report formal tests of the statistical significance of inter-cohort differences in expectations of life for these sub-populations within the royalty. Quite the contrary, as will be noted below in reference to the results in Statistical Appendix A1: Table A.1.4b.

[42] It is perhaps worth emphasizing that the interest here is in the *changes* in these conditional expectations of life, rather than in their levels. The conditions for become a King (i.e., a monarch proper) generally imply that there will be some upward selectivity bias in the resulting average levels of longevity, even among those who attained age 25 (and subsequently escaped a violent end): typically, one must wait for a father or uncle to die.

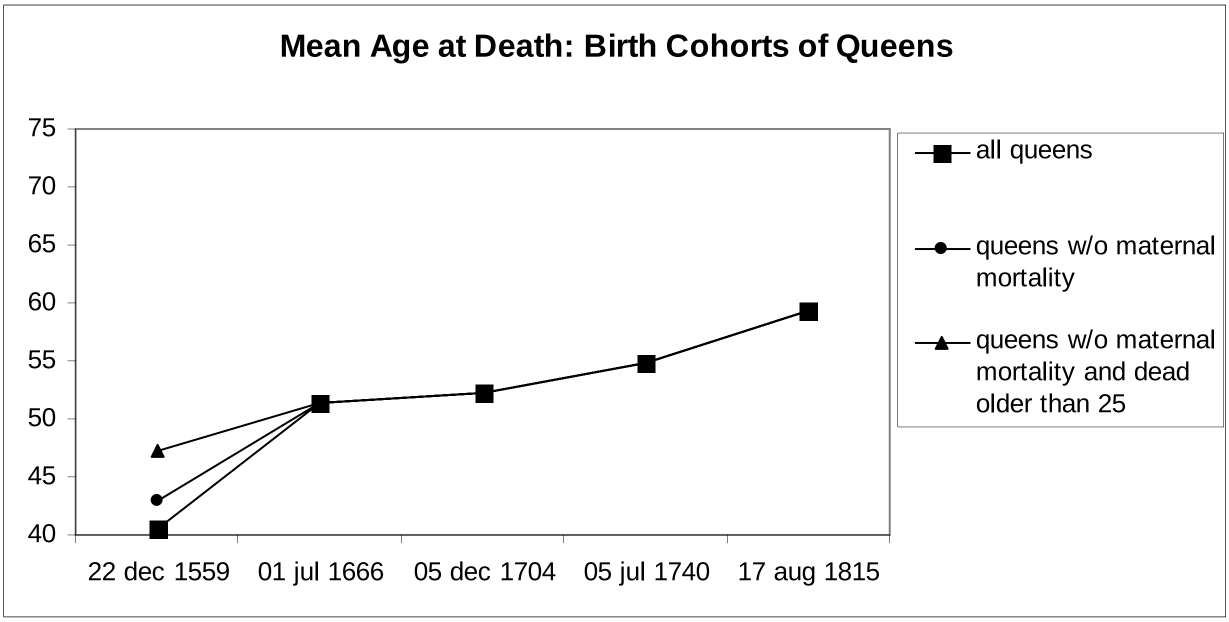
[43] Note (from Statistical Appendix Table A1.4b) that the increase between Cohorts (I) and (III) is sufficiently large to be statistically significant at the 0.025 error level. This is found also to be the case for the slightly larger inter-cohort gain (19 years) averaged by all the kings, not just those surviving beyond age 25. Measured from the level of the 1500-99 birth cohort, the gains in average longevity from birth are still larger, and they are statistically significant for the kings as a whole, for those who escaped violent death and, starting with the 1650-1749 birth cohort, also for those who survived to ages above 25 – as may be seen in Appendix Table A1.4a.

Figure 4(a)



Note: Means of age at death for each cohort are plotted at the cohort's mean death date.
Source: See Addendum Table A1.2a

Figure 4(b)



Note: Means of age at death for each cohort are plotted at the cohort's mean death date.
Source: See Addendum Table A1.2c

death are much more modest throughout the entire two-century-long period, and that was the case *a fortiori* for the sub-population that survived beyond age 25. [44]

Thus, for the kings, survival into old age became the norm in the 1700s. From the birth of Henry III in 1207 to the birth of George I in 1660 *none* of England's *titular* male sovereigns (a category excluding heirs apparent and royal spouses) lived long enough to reach 70 years of age. In contrast, of those British sovereigns who *reigned* in the 1700s and early 1800s, three out of four survived to reach 70 or more years. But, comparing kings and queens it appears that reaching 70 years of age became normal for kings about a century before it that was the case queens. For people living in England, dying in old age did not become demographically normal until the mid-twentieth century. Among the 'queens' -- a category, which it will be recalled, here includes all royal spouses, whether or not they formally held the title Queen -- of those born after 1200 and before 1700, none lived to be 70 years of age or longer, although Elizabeth I came close, having survived age 69. The wife of George III, Queen Charlotte (born in 1744), was therefore the first British queen who lived 70 years or longer.

The ages at death of England's kings during the centuries with which the preceding discussion have been preoccupied may be viewed in a broader and longer perspective.[45] Doing so underscores the central observation that the mortality transition that was underway among the adult male members of the county's ruling elite during the 1600s really did represent a demographic discontinuity, a break from past experience. These century-long averages show no sign of a sustained rise in life expectancy (e_0) among the English kings born between 1200 and 1599. In contrast, among the titular Kings of France the cohort averages of age at death by century of birth had been drifting upwards steadily until the 1500s. This trend raised the possibility in one historical demographer's mind of an early medieval royal health transition that had been interrupted in the sixteenth century (Houdaille, 1972: 1132). Evidently, if there is any substance to that suggestion, it cannot comprehend the quite different prior experience of England's monarchs – who in that period were related by intermarriage to the Kings of France.

Turning now to consider the lot of Britain's queens, and to the phenomenon of excess female mortality in adulthood that has been noted previously in discussing the experience of both the royal families and population of the country at large, it should be noted (from the comparison of Figures 4b with 4a) that for married queens of England, which is to say all the female adults, save Elizabeth I) it was "normal" to die before their husband. If one excludes those marriages in which the king had taken a second or a higher-order wife --and therefore might be expected, on average, to have

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[44]. Unlike the experience of the kings (see fn. 25), only the approximate longevity gain of 21years that had accumulated between the cohort the 1500s and that of the 1700s in the case of the queens considered *in toto* is statistically significant; for those in the sub-group that survived age 25 and escaped maternal mortality, the average cumulative gain of 14 years is not significant at the 95% confidence level (as the one-tail t-test statistic, is 1.71, falling clearly short of the critical value of 1.83 (for df=9). See the tests of differences between Cohort 0 and subsequent cohorts in Table A1.3b.

[45] Johansson's (2009: esp. Table 3) discusses this longer view is discussed more fully, with the aid of comparative data.

out-lived at least one of them -- the male-female differences in mean ages at death remain arrestingly large. Among the ten such married pairs, beginning with Henry VII (b. 1457) and ending with William IV (b. 1765), only two royal wives outlived their husbands, and in one of the two marriages the King (Charles I) met a pre-mature death on the Executioner's block. These male-female mortality differences averaged 11 years in the cohort of the 1500s, widened to 17 years in the cohort of 1650-1749 and then settled back at 13 years the cohort of 1700-1799. Large enough, surely, to call for some explanatory comment rather than a dismissal on the grounds that the numbers are too few for these to be of significance in the statistical sense, especially as that actually is not correct in the case of the kings and queens of the 1650-1749 birth cohort.[46]

To explain this phenomenon on the grounds that their biological difference left married women exposed differentially greater risks of pre-mature death, however, is not so straightforward a matter. Although maternal mortality does appear to have been a major cause of premature death among these privileged women as late as the 1500s,[47] from the 1600s through the 1700s no queen of England died in childbirth despite the continuation of very high fertility rates.[48] Thus, among the cohorts born between 1600 and 1749, when maternal mortality had ceased to be a cause of death among the married queens, they nonetheless were dying long before their husbands -- at an average age of 52 years.[49]

There is reason to suspect that frequent pregnancy rather than maternal mortality *per se* was the culprit – or at least a major causal factor -- in the persistent excess adult mortality observed among England's queens. Extended pregnancies themselves can take a toll even when live births do not ensue. In the past no less than in the present, the state of pregnancy temporarily suppresses a woman's immune system, and compromises her body's natural capacity to fight disease. Moreover, delivery of a still-born infant, like that of a live baby, might leave in its wake serious cervical, uterine and bladder damage that could compromise her health.

To consider the risks of pregnancy it is necessary to know more of the queens' histories than the chronology of their live births, from which it appear that royal fertility rates on average were quite moderate during the 1600s, averaging 4.6 live

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[46] These difference are found by comparing the e_0 entries (average ages at death) in Statistical Appendix Tables A.1.2 for all the "kings", with those for all the "queens."

[47] In the latter part of the fifteenth century, of the seven royal women who were married to Tudor monarchs three died giving birth, including the wife of Henry VII and two wives of Henry VIII. Among Henry VIII's six wives, his third died giving birth, as did the last in wife in the sequence -- who had remarried after being widowed by Henry's death.

[48] There is one close case. The first wife of James II died in 1671, while her husband was still heir apparent. She died 42 days after giving birth, but contemporaries blamed her death on an advanced case of cancer, not childbirth.

[49] In the l700s no queens or queens apparent died in childbirth, or even up to a year after giving birth. For another royal maternal death historians must look to the daughter of George IV, Princess Charlotte Augusta, who died giving birth in 1817. By that time maternal mortality among queens/princesses was considered so medically avoidable, that the presiding physician (one of three attending) was criticized for incompetence and killed himself.

births per queen. The dispersion around that mean was so large, however, that the average for this small sample is particularly deceptive: only one queen among the four came even close to realizing that average. Indeed, more typically, royal wives in this epoch either had borne more than six live infants (closely spaced) or none at all. Moreover, in the chronicles of the lives of those nulliparous royals' wives one finds records of multiple stillbirths and miscarriages.[50] The genealogy of the royal family reports Queen Anne as having been delivered of five live infants, but she also had endured 13 other pregnancies that ended in stillbirths, as well as one observed miscarriage. Frequent pregnancies, and especially those terminating in stillbirths -- of which there were in all 26 to England's "queens" in the 1600s, half of them being those to Queen Anne -- could well have lastingly compromised the health of these economically and socially privileged women and contributed to shortening their lives.

Being able to consider these women's histories of pregnancy, rather than simply focusing upon measures of live births and the hazards of childbed mortality, permits the emergence of a clue to the differences in male-female longevity, beside those seen between the kings and queens. This explanatory hint may be no less germane to understanding the source of the statistically significant 14.9 year gap that has been observed between the average ages at which adult males and females from the entire royal birth cohort of 1600-1699 were dying – even when the men escaped violent deaths and the women did not die in childbirth.

The long-standing pattern of excess female (adult) mortality among England's queens continued among eighteenth century royal birth-cohort – albeit in a somewhat attenuated form – before ending abruptly with the reign of Queen Victoria. She survived to age 82. Her nine pregnancies notwithstanding, and the wives of Edward VII and George V (also born in the 1800s) similarly survived into a ninth decade, dying at ages 81 and 86 respectively. So, in the nineteenth century, long after the 1700-1799 birth cohort of Britain's kings was able to expect to survive into their seventies, living to an advanced old age also became the norm for an entire birth cohort of Britain's queens.

4.4 The Mortality Transition among Royal Infants and Children

Looking back at the graphs of the mortality rate schedule for successive royal birth cohorts in Figures 2(a) and 2(b), one should now take note of a fourth feature, additional to the three upon which the preceding discussion commented explicitly. This is the downward shift of age-specific hazard of mortality that appears at the lowest end of the age range; and which was mainly responsible for the statistically significant difference between the schedule of age-specific survival rates experienced

[50] As there are no signs of deliberate fertility control (in any sense of that term) among the royals families before the twentieth century, declining pregnancy rates cannot be though to have contributed to the slightly longer lives led by royal women in the 1600s or 1700s. In Peller's data (1943: 436) there was very little difference between the death rates of women who were childless or fertile. But those eventually married royal women who remained single into their 20s and 30s had lower death age-specific death rates than their already married royal counterparts.

by the birth cohort of the 1700s and that had been experienced by the preceding cohort overlapping with theirs (i.e., those born during 1650-1749). A fuller and more detailed view of the timing and extent of these changes in royal infant and child mortality and of their relationship to contemporaneous developments in the English population at large will be gained by looking at the entries in Table 2.

From these estimates it is evident that English royal expectations of life at birth for males and females were so very low during the sixteenth and seventeenth centuries primarily because their infant mortality and child mortality rates were so extraordinarily high. Taking males and females together the average combined mortality before age 5 was 639 per 1000 for the cohort born during the 1500s, and was not much lower (581 per thousand) in the birth cohort of the 1600s.[51] Deaths in infancy which had occurred at rates in the range from 444 to 419 per 1000, accounted for most of these losses, as may be seen directly from the entries in the left-hand panel of the table. The contrast with the situation reflected in the English parish registers of the latter part of the sixteenth century and the seventeen centuries is striking indeed: for the commoners in the mostly rural parishes studied by Wrigley et al. (1997), the right-most pair of columns in Table 4 indicate that mortality rates for male and female infants combined (${}_0q_{1,\ M+F}$) averaged in the range from 169 to 179 per 1000 over those two centuries.[52] The corresponding average child mortality rates (${}_1q_{4,\ M+F}$) lay in the range from 87 to 109 per 1000.

The magnitude of these differences is startling, and much exceed what might be supposed to be the result of contrasting the common lot of English babies born in rural settings with their town-born counterparts. An attempt to gauge the effect of that differential is offered in the columns of Table 2 headed "Urban Parishes". The measured differences (during the period 1675-1750) between 5 urban parishes within the group of 26 reconstituted English parishes, were drawn from the work of Wrigley et al. (1997) as the notes to the table explain, and those proportional urban differential have been applied to provide corresponding "urban-adjusted" averages rate of infant and child mortality for all of the 50- and 100-year time period from the mid sixteenth century to the end of the eighteenth century. The result is that when the infant mortality rates in the royal family are compared with the corresponding "urban-adjusted" rates in the 50-year intervals between 1550 and 1650-99, the latter are found to be about 47 percent higher. Performing the same calculation based on the two series of child mortality rates reveals that the gap between the royal child mortality rate and the "urban-adjusted level" in the country parishes was 94 percent, almost twice that for infant mortality. Therefore if differences in disease environment really

[51] Were James II's many offspring to have been excluded in calculating from the royal birth cohort of 1650-1699, the average royal mortality rates for the rest of that cohort (i.e., Queen Anne's children) would be ${}_0q_1$= 428 (7 obs.) and ${}_1q_4$ = 500 (2 obs.) – not lower over all than the infant and child mortality rate implied by the rates given in Table 2. Queen Anne's pregnancy history was (painfully) unique in other respects, as the discussion of excess adult female mortality in the preceding sub-section has noted: she had 13 still-births (a still-born conception rate of 0.75!), whereas the corresponding rate for James II's two wives was 0.25.

[52] The underlying English parish register data implies that) infant mortality rates averaged over a range of 148- 195 per 1000 for males, and 132-163 per 1000 for females, depending on the parish.

Table 2. Infant and Child Mortality per 1000: Royals and Commoners, c.1500 – 1799

	Royals: (M + F) [a]				Commoners: (M + F)			
	Infant mortality per 1000		Child mortality per 1000		Infant & Child mortality per 1000: Urban parishes [b]		Infant & Child mortality per 1000: All 26 parishes [c]	
	$_0q_1$	*no. obs.*	$_1q_4$	*no. obs.*	$_0q_1$	$_1q_4$	$_0q_1$	$_1q_4$
1500 - 1599†	444	*36*	200	*16*	n.a.	n.a.	n.a.	n.a.
1500-1549	467	*30*	125	*16*	n.a.	n.a.	n.a.	n.a.
1550-1549	333	*6*	500	*4*	236	115	169*	87*
1600 - 1699	419	*31*	278	*18*	239	133	172	100
1600-1649	222	*9*	143	*7*	229	121	164	91
1650-1699	500	*22*	364	*11*	250	145	179	109
1675 - 1749	242	*33*	80	*25*	270	149	193	112
1700 - 1799	29	*35*	59	*34*	244	146	175	110
1700-1749	58	*17*	0	*16*	266	152	191	115
1750-1799	0	*18*	111	*18*	223	140	160	106

Sources: **(Cols. a)** Average infant mortality and average child mortality for male and females together are computed for each of the indicated birth cohorts from data underlying Statistical Appendix Tables A1.1b, and A1.c. The larger number of observations for births permits working with 50-year cohorts within each century and dispensing with the overlapping century-long cohorts employed for the analysis of adult mortality.

(Cols. b) These estimates are derived for all cohorts *save for that of 1675-1749* by adjustment of the $_0q_1$ and $_1q_4$ rates, respectively, for the 26 reconstituted parishes (in Cols. c), using the adjustment multipliers 1.396 (for $_0q_1$) and 1.328 (for $_1q_4$). The multipliers were computed as the ratios between the respective entries for infant mortality, and for child mortality, in the "urban parishes' (Cols. (b)) and those for "all 26 parishes" Col. (c). For the source of the col. (b) entries in 1675-1749, see the source notes for Col. (c).

(Cols. c) Wrigley, Davies, Oppen and Scofield (1997), Table 6.1 (p.215) give decennial averages for $_0q_1$ and $_1q_4$ from 1580-89 through 1790-99, which were arithmetically average to obtain the rates corresponding the intervals defined in this table for the royal birth cohorts. From Table 6.16 (*Ibid*., p.270) it is possible to obtain the all parish infant and child mortality rates for the period 1675-1749, and also to calculate the corresponding averages rates for 5 "urban" parishes that appear in Cols. c. This was done by first averaging the respective rates for the 4 urban places that were not low-lying (and hence less affected by malaria): Alcester (Warwicks.), Banbury (Oxon.), Gainsborough (Lincs.) and Lowestoft (Suffolk). Their average rates for $_0q_1$ and $_1q_4$, respectively, were given a weight of 2/3 and combined with the mortality rates for March (Cambs.) the single low-lying urban parish in the sample of 26, and the one having the highest rates of infant and child mortality.

Notes: (*) Averages of decadal rates for 1580-89, 1590-99, 1600-09.

(†) Cohort dates run from 1485 through 1606, as explained in Appendix section A.1.

mattered, these differentials offer an implicit measure of the extra-lethality for the youngest among the royal families of their London environs -- compared with the conditions of town-life elsewhere in the realm.

Against this background, it can be seen that the dramatic gains in average life expectancy at birth enjoyed by the London-based royal families in the eighteenth century's birth cohort are attributable largely to the spectacular decline that occurred after 1699 in the average rates of mortality among their infants and children. The detailed timing of the precipitate falls in both the infant and child mortality rates among the royal families, starting with the birth cohort of 1700-1749, stands out starkly in Table 2. Remarkably, there were no instances of child mortality among the 1700-49 birth cohort, and only 2 child deaths among the 18 children of the 1750-1799 birth cohort. More striking still is the virtual cessation of infant mortality, with only a single case among the 17 babies born to royal families during the first half of the eighteenth century, and none at all among the 18 born during the rest of the century. The contrast with royal infant mortality rates that were above 400 per thousand in the seventeenth century is dramatic indeed, as is the comparison with the stability of seventeenth and eighteenth century infant and child mortality rates among the commoners, whether in the urban parishes or all 26 of the parishes reconstituted by Wrigley et al (1997).

This transformation cannot be attributed to royal households in eighteenth century England having begun regularly to flee the city for refuge in more salubrious rural surroundings. That had been a practice of much longer standing for the royalty, and in the by the eighteenth century most urban-dwelling gentry customarily retreated from the city to the country during the summer months. But, when royals took up residence in country palaces, they brought with them significant elements of the Metropolis' high-exposure disease environment. Europe's royal courts by the sixteenth century, and the English court with them, were major institutions employing hundreds, and sometimes thousands of people. Foreigners, soldiers, trades-people, servants, craftsmen and laborers came and went. When they arrived, the pathogens of diseases prevalent in the metropolis where they normally lived and worked, or from the towns and ports through which they had passed, arrived with them.[53] It is not surprising, then, that Razzell (1999) has found that during the 1600s the chances of a royal infant born in England surviving its first year of was much the same for those in urban and in suburban palaces.

Most ordinary English babies had the advantage of being both rural born and breastfed by their own mothers. Royal babies also were breastfed, but throughout most of this period this was done by wet nurses hired for each child and not by their mothers. How much of a mortality disadvantage this practice imposed is not known, if indeed it imposed any disadvantage at all. Although royal wet nursing continued into the eighteenth century, the exceedingly high infant and child mortality rate of the preceding centuries nevertheless gave way to an average level of ${}_0q_1$ that was astonishingly low: only one among the 35 babies born to royal marriages during the

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[53] See, e.g., Hecht (1956), on the role of domestic servants in the transmission of disease from urban to the country residences of the London-dwelling gentry and aristocracy during the 18th century.

1700s failed to survive its first year, a rate of 28 deaths per 1000. Further, the entries in Table 2 imply a combined infant and child mortality rate that averaged only 86 per thousand for royal births during that century.[54]

Peller (1965:Table 10) put the child mortality rate at 172 per 1000 for the European ruling families during the 1700s, which is almost three time higher than the average rate (60 per 1000) experience among Britain's royal families during the eighteenth century. Thus, in this distinct phase of their mortality transition as in the preceding declines in adult mortality, the elites in Britain were notably ahead of their continental counterparts.

[54] Of 34 live births to five royal marriages during the 1700s, only 1 baby died in infancy, and there were two other child deaths. Including the birth of a child to a royal princess who was married to the adult heir apparent adds nothing to the totals of infant and child deaths. The latter are reflected in the rates in Table 4. Note that Hollingsworth's aristocrats did not do quite as well as the royal family in this respect until the first quarter of the 19th century.

5. A Summing Up – The Morphology of the Elites' Mortality Transition

The life expectancy history of the continental European royalty resembles that of Britain's royal families in general outline. But this particular, insular branch of the European elites had undergone a faster transition to higher levels of life expectancy at birth from the 1600s through the 1700s. In part, as has been seen the difference resulted from the comparatively faster decline of royal infant and child mortality rates that took place in eighteenth Britain, vis-à-vis the continent, due to the earlier introduction of small-pox inoculation. Yet, England's royal adults also did better in terms of survival than most of their continental royal counterparts, although the French were not far behind.

That a sustained royal transition to higher life expectancy levels did not begin before the 1600s, either in England or on the Continent, was not for want of trying. Long before the 1600s, Europe's ruling families did what they could to preserve their health and postpone death. In the early middle ages both popes and monarchs supported the study of medicine at the university level (Siraisi, 1992). Subsequently they hired and handsomely rewarded those physicians and surgeons who were perceived (legitimately or not) as being the most efficacious in their profession. Perceived medical efficacy became very profitable long before we have any evidence that it reduced royal death rates (see Digby and Johansson, 2003).

Although royals themselves were not generally educated at universities, by 1500, if not earlier they all were able to read and write. In contemporary social science research, literacy if found not only to increase access to knowledge, but receptivity to it as well, along with greater willingness to follow medically legitimized advice (Zimmer and House, 2003). Nevertheless, despite the plethora of long standing economic and social advantages that already were in place by the 1500s, royal life expectancy had remained low and unchanging. Thereafter, however, a trend toward greater longevity emerged particularly saliently among Britain's elite families. This movement gathered momentum during the following two centuries.

By the late 1600s, after a surprising amount of new and useful, health-related knowledge had begun to accumulate , increases in the life expectancy of adult members of Britain's royal families became visible -- their more and more urbanized life style notwithstanding. Royal males were the first to undergo this transition, which was subsequently extended to encompass the women when their treatment by male physicians became less circumscribed by cultural norms of female modesty. Subsequently, in the early 1700s, after innovative physicians had begun to publish the findings of their research on the diseases of infants and children, death rates for young royals began to fall precipitously, largely due to small-pox inoculation.

Giving historical significance to the demographic developments that have been described in the preceding pages requires finding a plausible explanation for them. In the case at hand, as Johansson (2010) has shown, there is ample empirical evidence that the surprisingly early rise of life expectancy among the elites in explicable in terms of their differential access to a growing body of useful "medical" knowledge relating to the prevention, management or cure of various diseases that were perceived as prevalent and deadly in early modern Europe. In part these advances in knowledge were stimulated, among the cadre of leading physicians that sought to serve these wealthy and willing patients.

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Appendix 1: Tables and Figures

Table A1.1. Observations in Birth Cohorts of Britain's Royals
Number of Observations Grouped by Gender, Mode of Death and Survival to Age 25

MALES		'Kings'	Royals	FEMALES		'Queens'	Royals
Cohort 0 1500-1599	**All**	4	14	**Cohort 0 1500- 1599**	**All**	8	17
	Non- violent death	3	13		**Non-maternal death**	7	15
	Non violent death and age>=25	3	3		**Non-mat. mort & d. age>=25**	6	9
Cohort I 1550-1649	**All**	5	9	**Cohort I 1550-1649**	**All**	4	13
	Non- violent death	4	8		**Non-maternal death**	4	13
	Non violent death and age>=25	4	4		**Non-mat. mort & d. age>=25**	4	7
Cohort II 1600-1699	**All**	7	18	**Cohort II 1600-1699**	**All**	6	25
	Non- violent death	6	17		**Non-maternal death**	8	25
	Non violent death and age>=25	6	7		**Non-mat. mort & d. age>=25**	8	25
Cohort III 1650-1749	**All**	6	19	**Cohort III 1650-1749**	**All**	7	25
	Non- violent death	6	19		**Non-maternal death**	7	25
	Non violent death and age>=25	6	11		**Non-mat. mort & d. age>=25**	7	14
Cohort IV 1700-1799	**All**	4	17	**Cohort IV 1700-1799**	**All**	4	20
	Non- violent death	4	17		**Non-maternal death**	4	19
	Non violent death and age>=25	4	13		**Non-mat. mort & d. age>=25**	4	16

Notes: "Kings" include both monarchs and husbands of (female) monarchs; "Queens" include both female monarchs and wives of (male) monarchs. See text for discussion of this convention. Cohorts are defined as birth cohorts; *1500-1599* signifies the "long 16th century" cohort, including royals born between 1 January 1485 and 31 December 1606.

Source: Underlying genealogical data from Weir (2001).

Table A1.2a. Representative Dates of Death: Birth Cohorts of Britain`s Kings										
		Cohort`s representative Death date			Cohort Averages: Age of death (in Years)					
					All		Non-violent, death>=25		Non-violent death	
		Mean	Std.err (days)	Median	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
COHORT 0	1500-1599	09 jan 1605	15987	20 dec 1611	51.67	6.70	52.83	7.70	52.83	7.70
COHORT 1	1550-1649	19 dec 1651	15423	30 jan 1649	54.74	9.28	56.37	9.85	56.37	9.85
COHORT 2	1600-1699	13 jan 1705	12630	08 apr 1702	60.23	10.49	62.24	9.91	62.24	9.91
COHORT 3	1650-1749	10 feb 1745	15810	06 may1739	62.78	14.86	62.78	14.86	62.78	14.86
COHORT 4	1700-1799	26 oct 1809	14499	13 apr 1825	66.38	15.90	66.38	15.90	66.38	15.90

Table A1.2b. Representative Dates of Death: Birth Cohorts of Britain`s Royal Males										
		Cohort`s representative Death date			Cohort Averages: Age of death (in Years)					
					All		Non-violent, death>=25		Non-violent death	
		Mean	Std.err (days)	Median	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
COHORT 0	1500-1599	18 jul 1552	19709	16 dec 1530	18.47	23.00	52.83	7.70	16.19	22.22
COHORT 1	1550-1649	29 july 1640	13257	13 may 1629	34.77	25.50	56.37	9.85	33.10	26.72
COHORT 2	1600-1699	19 dec 1684	15051	11 jul 1681	29.86	31.22	64.43	10.75	28.78	31.83
COHORT 3	1650-1749	23 may 1727	18361	06 feb 1718	34.31	30.88	57.62	16.92	34.31	30.89
COHORT 4	1700-1799	17 sept 1800	14185	25 aug 1805	47.64	28.15	60.61	16.45	47.64	28.15

Table A1.2c. Representative Dates of Death: Birth Cohorts of Britain`s Queens										
		Cohort`s representative Death date			Cohort Averages: Age of death (in Years)					
					All		Non-maternal mortality, death>=25		Non-maternal mortality	
		Mean	Std.err (days)	Median	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
COHORT 0	1500-1599	22 dec 1559	11142	07 sept 1548	40.59	14.60	47.32	11.83	42.91	15.90
COHORT 1	1550-1649	01 jul 1666	13043	16 jun 1670	51.30	14.88	51.30	14.88	51.30	14.88
COHORT 2	1600-1699	05 dec 1704	9070	17 mar 1710	52.23	12.72	52.23	12.72	52.23	12.72
COHORT 3	1650-1749	05 jul 1740	15332	14 nov 1726	54.82	12.76	54.82	12.76	54.82	12.76
COHORT 4	1700-1799	17 aug 1815	11772	28 mar 1820	59.30	10.37	59.30	10.37	59.30	10.37

Table A1.2d. Representative Dates of Death: Birth Cohorts of Britain`s Royal Females										
		Cohort`s representative Death date			Cohort Averages: Age of death (in Years)					
					All		Non-violent, death>=25		Non-violent death	
		Mean	Std.err (days)	Median	Mean	Std. Err	Mean	Std. Err	Mean	Std. Err
COHORT 0	1500-1599	26 jan 1565	15901	07 sep 1548	31.05	23.18	48.84	11.79	30.87	24.75
COHORT 1	1550-1649	14 jul 1646	11454	08 sept 1650	26.76	25.71	46.54	17.50	26.75	25.71
COHORT 2	1600-1699	06 dec 1679	13090	03 jun 1678	23.04	26.36	49.56	16.35	23.04	26.36
COHORT 3	1650-1749	25 may 1729	16824	14 nov 1726	32.98	28.64	55.47	15.38	32.98	28.65
COHORT 4	1700-1799	20 jul 1802	13047	12 jan 1812	51.19	21.56	58.77	16.77	52.73	20.98

Table A1.3a Tests of Statistical Significance of Inter-Cohort Differences ROYAL MALES: Birth Cohort *1500-1599* vs. Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	**All**		**Non violent, death>25**		**Non violent**	
	Mean	**Std.err**	**Mean**	**Std.err**	**Mean**	**Std.err**
0 vs I	-14.88	10.49	-3.54	6.91	-15.56	11.10
0 vs II	-9.97	10.27	-11.25	10.73	-11.60	6.95
0 vs III	-14.42	10.11	4.79	10.26	16.77	10.34
0 vs IV †	-27.75***	9.65	-7.78	9.93	-30.12***	9.82

ROYAL FEMALES: Birth Cohort *1500-1599* vs Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	**All**		**Non maternal, death>25**		**Non maternal**	
	Mean	**Std.err**	**Mean**	**Std.err**	**Mean**	**Std.err**
0 vs I	-3.07	5.55	-3.54	6.91	-3.54	6.91
0 vs II	-8.56	5.89	-9.41	6.60	-9.41	6.60
0 vs III	11.10	8.03	9.95	9.35	9.95	9.35
0 vs IV†††	-14.70*	8.63	-13.55	10.12	-13.57	10.12

Notes: Single-tail *t*-test of difference in means is significant: * at .05 error level; ** at .025 error level; *** at .01error level. *Kolmogorov-Smirnov* test of differences in survival distributions for All and N.V. death males, and All females is significant: † at .05 error level; †† at .025 error level; ††† at .01 error level.

Sources: See Statistical Appendix for calculation of test statistics.

Table A1.3b Tests of Statistical Significance of Inter-Cohort Differences BRITAIN'S KINGS: Birth Cohort *1500-1599* vs Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	**All**		**Non violent deaths>25**		**Non- violent deaths**	
	Mean	**Std.err**	**Mean**	**Std.err**	**Mean**	**Std.err**
0 vs I	-23.68	12.85	-7.53	9.70	-25.50	16.14
0 vs II	-29.96**	13.25	-14.75	8.72	-32.71**	13.30
0 vs III	-38.20**	12.95	-20.41*	10.30	-38.38**	14.38
0 vs IV	-42.73**	13.99	-24.94**	8.51	-42.91**	14.86

BRITAIN'S QUEENS: Birth Cohort *1500-1599* vs Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	**All**		**Non maternal, deaths>25**		**Non- maternal mortality**	
	Mean	**Std.err**	**Mean**	**Std.err**	**Mean**	**Std.err**
0 vs I	-16.46	9.16	-9.73	8.46	-14.43	10.02
0 vs II	-11.60	7.88	-4.87	7.99	-9.57	7.13
0 vs III	-11.57	9.96	-4.84	10.54	-9.54	10.78
0 vs IV †††	-21.08**	9.11	-14.35	8.38	-19.05*	9.97

Notes: Single-tail *t*-test of difference in means is significant: * at .05 error level; ** at .025 error level; *** at .01error level. *Kolmogorov-Smirnov* test of differences in survival distributions for All and N.V. death males, and All females is significant: † at .05 error level; †† at .025 error level; ††† at .01 error level.

Sources: See Statistical Appendix for calculation of test statistics.

Table A1.4a Tests of Statistical Significance of Inter-Cohort Differences ROYAL MALES: Birth Cohorts I & II vs Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	All		Non violent, death>25		Non violent	
	Mean	Std.err	Mean	Std.err	Mean	Std.err
I vs II	4.91	11.24	-8.05	6.38	4.32	12.20
I vs III	0.46	11.06	-1.2	7.09	-1.21	11.81
I vs IV	-12.86	10.90	-4.23	6.71	-14.54	11.66
II vs III	-4.45	10.21	6.80	6.52	-5.53	10.48
II vs IV ††	-17.78*	10.04	3.82	6.11	-18.86*	10.31
III vs IV ††	-13.33	9.84	-2.98	6.84	-13.33	9.84
ROYAL FEMALES: Birth Cohorts I & II vs Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	All		Non maternal, death>25		Non maternal	
	Mean	Std.err	Mean	Std.err	Mean	Std.err
I vs II	3.71	8.87	-3.02	8.25	3.71	8.87
I vs III	-6.23	9.15	-8.92	7.79	-6.23	9.15
I vs IV †††	-24.43***	8.61	-12.22	7.83	-25.98***	8.60
II vs III	-9.94	7.78	-5.91	9.56	-9.94	6.60
II vs IV †††	-28.14***	7.14	-9.21	6.47	-29.69***	7.14
III vs IV †††	-18.20***	7.49	-3.30	5.87	-19.75***	7.48

Single-tail *t*-test of difference is significant at error levels: *.05; ** .025; *** .01. *Kolmogorov-Smirnov* tests of differences in survival distributions for all royals (males or females) are significant at error levels: †† .025 for All, and N.V.deaths; ††† .01 for All, and N.V.deaths. See Statistical Appendix Table A2.3.

Table A1.4b Tests of Statistical Significance of Inter-Cohort Differences BRITAIN'S KINGS: Birth Cohorts I & II vs Later Cohorts						
Mean differences of cohort ages at death						
Cohorts Compared	All		Non violent deaths>25		Non- violent deaths	
	Mean	Std.err	Mean	Std.err	Mean	Std.err
I vs II	-6.28	6.19	-7.22	6.79	-7.22	6.79
I vs III	-14.51*	7.87	-12.88	8.31	-12.88	8.31
I vs IV	-19.04**	5.83	-17.41**	6.40	-17.41**	6.40
II vs III	-8.23	8.12	-5.66	8.16	-5.66	8.16
II vs IV	-12.76*	6.16	-10.19	6.21	-10.19	6.21
III vs IV	-4.54	7.85	-4.53	7.84	-4.53	7.84
BRITAIN'S QUEENS: Birth Cohorts I & II vs Later Cohorts						
	Mean differences of cohort ages at death					
Cohorts Compared	All		Non maternal, deaths>25		Non- maternal mortality	
	Mean	Std.err	Mean	Std.err	Mean	Std.err
I vs II	4.87	10.01	4.87	10.01	4.87	10.01
I vs III	4.90	13.88	4.90	13.88	4.90	13.88
I vs IV	-4.62	9.33	-4.62	9.33	-4.62	9.33
II vs III	0.03	14.29	0.03	14.29	0.03	14.29
II vs IV	-9.48	7.71	-9.48	7.71	-9.48	7.71
III vs IV	-18.21	12.59	-3.30	12.59	-9.52	12.59

Single-tail *t*-test of difference is significant at error level: *.05; **.025; ***.01. See Appendix Table A2.3.

Table A2.1. Anson Mortality Model-- Fitted Coefficients and Parameters

Royal Males				Royal Females			
Estimated Coefficient		Model Parameter Value		Estimated Coefficient		Model Parameter Value	
Cohort I : 1550-1649				**Cohort I: not available**			
cons	1.093024	sigma	-0.243060				
age	-1.321210	csi	7.978516				
age2	1.133934	fi	2.878705				
age3	-0.282660	tau	1.187807				
age4	0.027073	lambda	-0.184390				
age5	-0.000850	delta	0.729939				
Cohort II : 1600-1700				**Cohort II : 1600-1700**			
cons	0.733224	sigma	-0.20755	cons	0.972353	sigma	-0.183930
age	-0.28545	csi	7.240976	age	-0.388980	csi	9.093587
age2	0.341085	fi	2.096833	age2	0.361863	fi	2.963799
age3	-0.102400	tau	0.643976	age3	-0.0860	tau	1.894740
age4	0.011154	lambda	0.042387	age4	0.007657	lambda	-0.589070
age5	-0.000390	delta	0.781488	age5	-0.000210	delta	1.311998
Cohort III : 1650-1749				**Cohort III : 1650-1749**			
cons *	0.350818	sigma	0.165483	cons	0.125191	sigma	0.142081
age *	0.161298	csi	7.013497	age	0.319131	csi	10.639030
age2 *	-0.120220	fi	0.578442	age2	-0.19056	fi	0.893096
age3 *	0.034005	tau	0.520689	age3	0.03676	tau	1.676144
age4 *	-0.003480	lambda	0.543713	age4	-0.00246	lambda	1.599489
age5 *	0.000124	delta	0.750912	age5	5.79E-05	delta	1.178213
Cohort IV : 1700-1799				**Cohort IV : 1700-1799**			
cons	0.272341	sigma	0.117293	cons ****	-10.15420	sigma	0.256292
age	-0.108780	csi	-0.32207	age ****	6.58551	csi	9.323273
age2	0.071226	fi	4.819554	age2****	-3.19633	fi	1.163504
age3	-0.007760	tau	5.541139	age3****	0.55713	tau	0.350756
age4	2.86E-05	lambda	-1.12986	age4****	-0.04124	lambda	0.576833
age5	2.22E-05	delta	0.311156	age5****	0.00111	delta	0.510874
significance level: * = .10; ** =.05; *** =.025; **** =.01				significance level: * = .10; ** =.05; *** =.025; **** =.01			

Source: See Appendix section A2 for procedure.

Table A2.2. Kolmogorov-Smirnov Tests
For Inter-Cohort Differences in Survivorship Distributions: ***1500-99*** **vs.** ***1700-99***

Kolmogorov-Smirnov Tests of Differences: Birth Cohorts *0* vs. *IV*

Royal males:

ALL: ***Difference significant at 5.0%***				NON-VIOLENT DEATH : *significant at 2.0%*			
Smaller group	*D*	P-value	Corrected	Smaller group	*D*	P-value	Corrected
0:00	0.4751	0.036		0:00	0.5392	0.017	
1:00	0	1		1:00	0	1	
Combined K-S:	0.4751	0.072	0.04	Combined K-S:	0.5392	0.033	0.017

Royal females:

ALL : ***Difference significant at 2.0%***				NON-MATERNAL DEATH: *significant at 2.0%*			
Smaller group	*D*	P-value	Corrected	Smaller group	*D*	P-value	Corrected
0:00	0.4778	0.013		0:00	0.4868	0.016	
1:00	0	1		1:00	0	1	
Combined K-S:	0.4778	0.026	0.013	Combined K-S:	0.4868	0.033	0.017

Kings:

ALL				NON-VIOLENT DEATH			
Smaller group	*D*	P-value	Corrected	Smaller group	*D*	P-value	Corrected
0:00	0.75	0.105		0:00	0.75	0.145	
1:00	0	1		1:00	0	1	
Combined K-S:	0.75	0.211	0.164	Combined K-S:	0.75	0.29	0.237

Queens:

ALL : ***Difference significant at 1.0%***				NON-MATERNAL DEATH: *significant at 2.5%*			
Smaller group	*D*	P-value	Corrected	Smaller group	*D*	P-value	Corrected
0:00	0.8889	0.013		0:00	0.8571	0.024	
1:00	0	1		1:00	0	1	
Combined K-S:	0.8889	0.025	0.011	Combined K-S:	0.8571	0.047	0.025

Notes and Sources: The panels of this table report the K-S tests performed using the empirical survivorship distributions obtained from the age at death observations for the respect members of pairs of birth cohorts that underlie Statistical Appendix Tables A1.2a-d. The actual tests were run on the indicated pairs of cumulative death distributions: 1-*S*(a).

Results are reported below *all* the tests comparing Cohorts 0 and IV (1500-1599 vs 1700-1799), i.e., for four populations of males: All Royals, and Kings, and Royals and Kings excluding those with violent deaths; and for the corresponding female populations: All Royals, and Queens, and Royals and Queens excluding those suffering material mortality.

Table A2.3. Kolmogorov-Smirnov Tests of Inter-Cohort Differences in Survivorship Distributions: *Cohorts II vs. IV* and *Cohorts III vs. IV*

Kolmogorov-Smirnov Tests of Differences: Birth Cohorts *1600-1699* vs. *1700-1799*

Royal males:

ALL: ***Difference is significant at 2.5 %***

Smaller group	*D*	P-value	Corrected
3:00	0.0000	1.000	
5:00	- 0.4706	0.023	
Combined K-S:	0.4706	0.046	0.025

Royal females:

ALL : *Difference is significant at 0.2 %*

Smaller group	*D*	P-value	Corrected
3:00	0.0000	1.000	
5:00	- 0.5882	0.003	
Combined K-S:	0.5882	0.006	0.002

Royal males and females combined:

ALL : ***Difference significant at 0.2 %***

Smaller group	*D*	P-value	Corrected
3:00	0.0000	1.000	
5:00	- 0.5882	0.003	
Combined K-S:	0.5882	0.006	0.002

Kolmogorov-Smirnov Tests of Differences: Birth Cohorts *1650-1749* vs. *1700-1799*

Royal males:

ALL: *Difference is significant at 2.5 %*

Smaller group	*D*	P-value	Corrected
4:00	0.0000	1.000	
5:00	- 0.4706	0.023	
Combined K-S:	0.4706	0.046	0.025

Royal females:

ALL: *Difference is significant at 1.0 %*

Smaller group	*D*	P-value	Corrected
4:00	0.0000	1.000	
5:00	- 0.5294	0.009	
Combined K-S:	0.5294	0.017	0.008

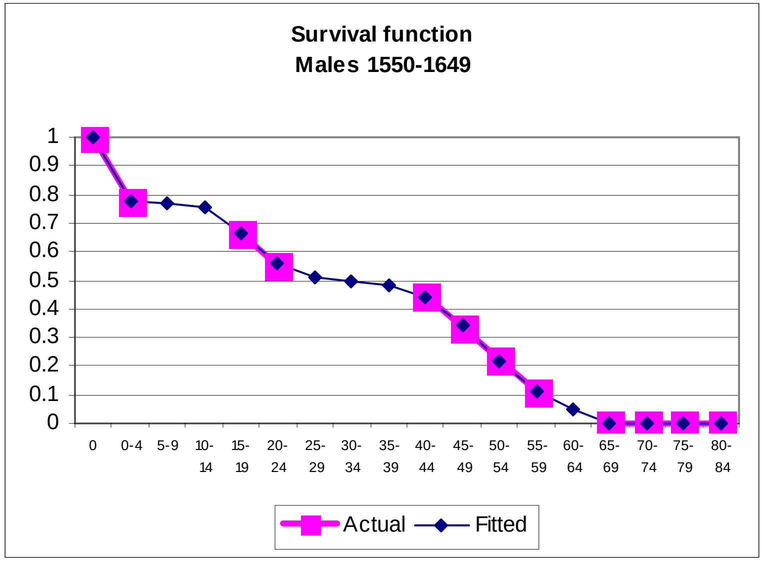
Royal males and females combined:

ALL : ***Difference significant at 1.0%***

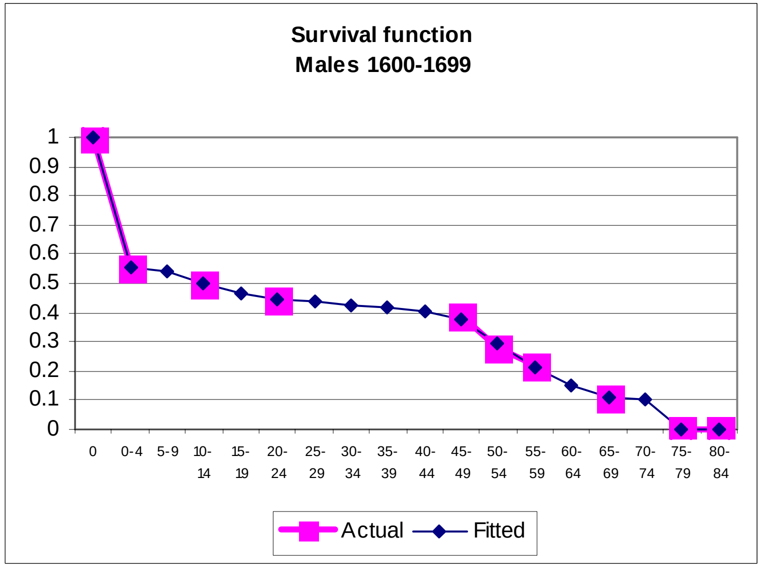
Smaller group	*D*	P-value	Corrected
4:00	0.0000	1.00	
5:00	- 0.4706	0.023	
Combined K-S:	0.4706	0.046	0.025

Notes and Sources: The panels of this table report the K-S tests performed using the empirical survivorship distributions obtained from the age at death observations for the respect members of pairs of birth cohorts that underlie Statistical Appendix Tables A1.2a-d. The actual tests were run on the indicated pairs of cumulative death distributions: 1-*S*(a).

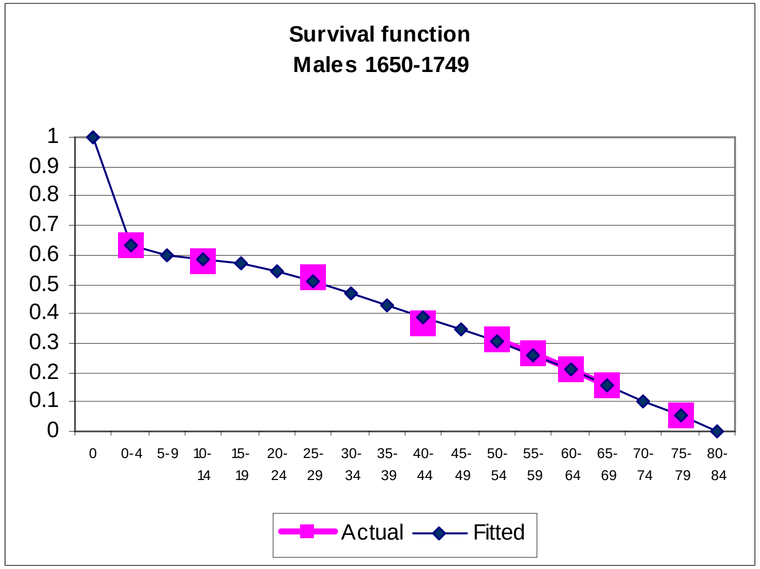
Figure A2.1(a). Empirical and Statistically "Fitted" Survivorship Functions based on Anson's Model for Royal Males



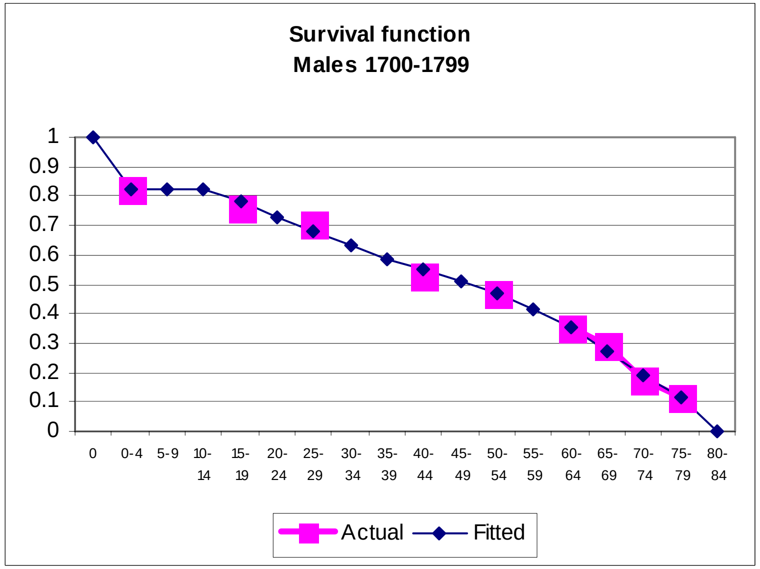
Goodness of fit from Anson regression: F(5,1)= 418.35
Adjusted R^2= .9971



Goodness of fit from Anson regression: F(5,1)= 58.43
Adjusted R^2= .9795

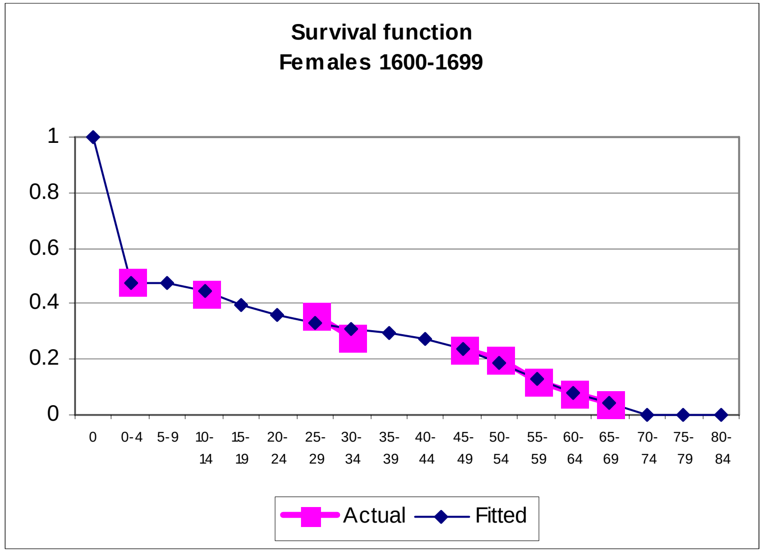


Goodness of fit from Anson regression: F(5,3)= 606.94
Adjusted R^2= .9974

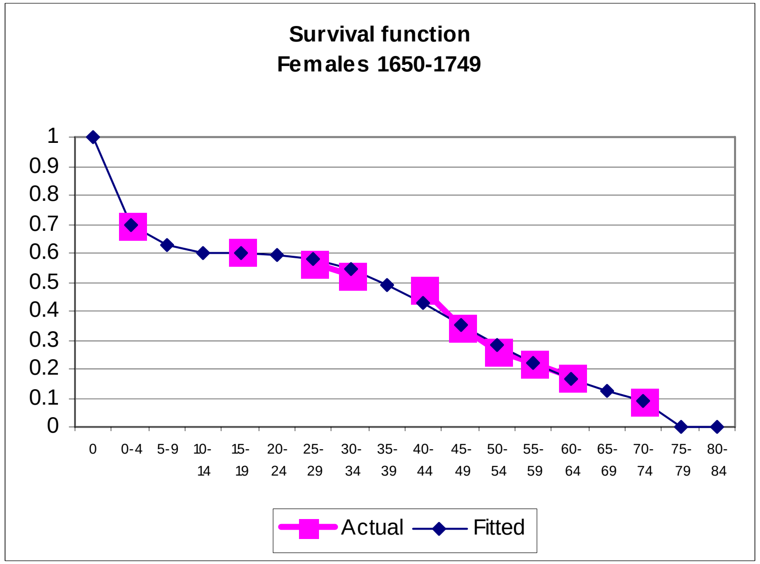


Goodness of fit from Anson regression: F(5,1)= 141.25
Adjusted R^2= .9887

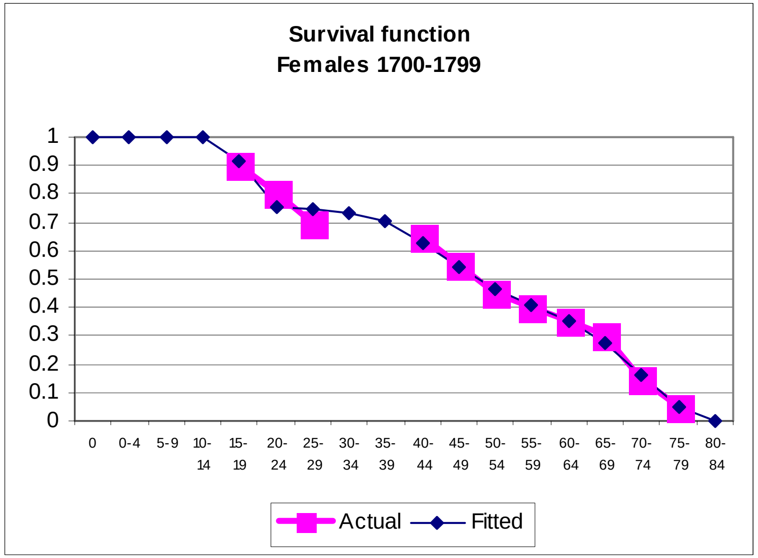
Figure A2.1(b). Empirical and Statistically "Fitted" Survivorship Functions based on Anson's Model for Royal Females



Goodness of fit from Anson regression: $F(5,3) = 107.05$
Adjusted $R^2 = .9851$



Goodness of fit from Anson regression: $F(5,4) = 123.21$
Adjusted $R^2 = .9855$



Goodness of fit from Anson regression: $F(5,5) = 343.31$
Adjusted $R^2 = .9942$

Appendix 2
Comparisons of Cohort Measures of e_0 for Royal Males and Females with Averaged Period Measures of e_0 Estimates for the National Population of England

This short appendix provides the sources and notes explaining the calculations underlying Table 2 of the text, which presents mean expectations of life at birth for each birth cohort of royal males and females combined, compared with corresponding estimates for the national population of England. The construction of the former of these two series is detailed in Table A3.1 and its accompanying sources and notes.

Comparing Expectations of Life at Birth: Notes and Sources for Table A3.1

Sources: Royal males' and females' expectations of life at birth are the means for the birth cohorts of "All Royals," from Statistical Appendix Tables A1.2b and A1.2d.

Numbers of observations for males and females in each birth cohort: see Appendix Table A1.1, for "All Royals".

Underlying estimates of life expectancies at births, for quinquennial intervals from beginning in 1541 and ending in 1836 (i.e., running through 1841) are from Wrigley, Davies, Oppen and Schofield (1997), Appendix 9, Table 9.1.

Notes: The series in Wrigley et al (1997) Table 9.1 are period life table e_0's, not cohort means life expectancies, obtained by generalized inverse projection methods from the aggregative time series of estimated birth and deaths constructed on the basis of a national sample of English parishes. Exact translation of such estimates in to cohort mean expectations of life at birth is not feasible with the available data, and is in any case an arduous technical process. See, e.g., Wrigley et al. (1997), Appendix 6 for discussion of the relationship between reconstitution and inverse projection measures of the adult expectation of life.

The attempt here to achieve comparability of the royal birth cohort e_0's's of males and females combined with those for the national population, necessarily yield only a crude approximation, at best. Its rationale is to identify the time intervals during which most of each birth cohort of royal males, and similarly for royal females, were exposed to mortality, i.e., the intervals within which most the cohorts' deaths would have occurred; and to calculate the average of period e_0 estimates for each of such periods.

These intervals are termed the 'central exposure periods' for the respective birth cohorts, and their the ranges of dates have been fixed in the following way: the median date of death for the males and females belonging to each cohort are given separately in Statistical Appendix Tables A12b and A1.2d, as are the mean durations of life for each of those sub-populations. The mean length of life of the cohort's males was subtracted from the median date of death to fix the lower (earlier) limit of the central exposure period, and half of the average duration of life was added to the median death date to set the higher (later) limit. The dates shown in Table 2 are rounded to the nearest calendar year.

Obviously the comparisons are inexact; because the period expectation of life should in principle reflect the mortality of people born considerably before the initial date of the exposure period, and may in that respect antedate the mortality experience of the royal cohort with which it is being matched. This problem's severity is mitigated when the life expectation of the national population (that for which period measures are averaged) is shorter than that of the population on which the cohort life expectations are based, when the mean age of maternity (on which the period measures are centered) is later than that for the cohort measure population, and when the period expectation of life (in this case that for the national population) is undergoing a strong trend movements or pronounced fluctuations. Broadly speaking, these favorable conditions appear to apply in the historical situation that is of interest.

The forgoing procedure yields two series of average values of the expectation of life at birth for males and females (combined) in the national population, one of which is adjusted to approximate the central exposure periods of the successive cohorts of royal males, the other being adjusted to approximate the central exposure periods of royal females. To achieve comparability with the cohort means of the life expectation of life at birth of royal males and females combined, the adjusted national e_o's are weighted by the respective shares of males and females in each of the royal cohorts.

Table A3.1. Birth Cohort-Specific Expectation of Life at Birth: Males and Females of Britain's Royal Families Compared with National Population Estimates Averaged over Corresponding Periods of Exposure

Royals' Birth Cohorts	All Royals								Comparable National Population				
	Males			Females			Males & Females (weighted)		Males & Females (weighted exposure periods)	Averaged over approximate royal males' exposure dates		Averaged over approximate royal females' exposure dates	
	Central exposure period	No. Obs.	e_0	Central exposure period	No. Obs.	e_0	No. Obs.	e_0	e_0	e_0	Range of years	e_0	Range of years
1500-1599	*1512-1540*	14	18.5	*1518-1564*	17	31.0	31	25.3	34.6	33.9	*1541-1546*	35.3	*1541-1566*
1550-1649	*1594-1643*	9	34.8	*1624-1664*	13	26.8	22	30.1	36.9	37.6	*1596-1666*	36.4	*1626-1661*
1600-1699	*1652-1712*	18	29.9	*1655-1690*	25	23.0	43	25.9	33.8	34.5	*1651-1701*	33.3	*1656-1696*
1650-1749	*1684-1752*	19	34.3	*1694-1744*	25	31.0	44	32.4	35.9	36.5	*1686-1741*	35.5	*1696-1751*
1500-1599	*1758-1830*	17	47.6	*1761-1838*	20	51.2	37	49.5	37.0	34.6	*1756-1836*	39.1	*1761-1841*

Source: See Appendix 2 for notes and sources.

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