Adverse Selection in Public Finance: Life-contingent Contracts in Early Modern Europe

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Abstract

This paper reviews the history of the life-contingent borrowing schemes that were popular among governments in early modern Europe. It summarizes previous work on selection effects in the nomination of private-sector lives for this debt and briefly discusses allegations of self-selection and aggressive speculation in the markets for these debt issues. It then explores new sources of primary data on two particular life-contingent debt issues and presents convincing numerical evidence that adverse selection was not merely occurring, but was being consciously exploited by savvy investors. Calculations show that conscious selection of lives by Genevan bankers was able to improve the survival probability of nominees by as much as 50% over a 55 year period.

1 Introduction

Selection – particularly adverse selection – is a well known and often studied subject in the field of economics. Many empirical applications of the contemporary understanding of selection are, by nature modern. In part, this reflects the dearth of data that could be used for early empirical investigations. A modern life-insurance industry – a natural place for an empirical study of selection effects – did not substantially arise until the nineteenth century, and, as such, commensurately little data exists to study it in this context.

In this paper, I look for evidence of selection in a heretofore under-studied sector: the market for life-contingent public-sector debt. Largely because of anti-usury laws, many local and central governments in early modern Europe made use of the sale of life-annuities and other life-contingent debt to finance deficit spending. Such contracts required the maintenance of records of purchase, nomination (of the contingent life), and death. What remains of the records of these contracts thus provides fertile ground for a study of the interplay between public sector and private sector understandings of basic selection.

An understanding of the proper pricing of life-annuities as an asset developed substantially over the course of their use as a financial instrument. Such developments led to discrete changes in government policy – for example the adoption of age and gender-based pricing schemes to supplant flat-rate pricing. Hence, history has presented us with a number of "natural experiments" with which to further study the degree to which selection played a role by purchasers of those annuities.

I begin in Section 2 by providing an historical overview of the use of life-contingent contracts in early modern Europe. In Section 3, I provide a brief survey of previous literature that has touched upon the role of selection in this context – particularly in France and the Netherlands – and I discuss and elaborate on these results. Section 4 provides a detailed history of Great Britain's use of life-annuities and other life-contingent debt schemes from the late 17th century to the early 19th century. This provides a background for the empirical investigation of two primary data sources of two particular schemes which I undertake in Section 5. In Section 5, I present two major results: new quantitative evidence on the de-

gree to which a broad "investment-class" was able to observe and act upon self-selection opportunities in the early 1800s and on the degree to which an analytically savvy group of "elite" investors was able to exploit the arbitrage opportunities inherent in the pricing of life-contingencies. Section 6 offers some conclusions and suggestions for further research.

2 Historical Overview

The history of life contingent contracts is a rich one. In it, we can observe early examples of developments in mathematics, economics and demography playing an explicit role in the determination of government policy.

There is recorded use of life-annuities by municipal governments as early as 1260 [32, p. 13], and recorded use by the church as early as the 14th century [10, page 2][1]. In the 16th century, Venice and Amsterdam were among the cities to make extensive use of the sale of life annuities to raise funds [32] [30]. Though Holland continued to raise funds via life-annuities after the establishment of the Republic of Holland in 1572, the debt continued to be explicitly issued by the individual cities within Holland and not by the central government itself[2]. As such, the first use life-contingent financial instruments by a central government[3] appears to have been by France in 1689 [19, page 120], when they issued the first recorded "tontine." Named after their inventor, Lorenzo Tonti, tontines are also known as "life-annuities with benefit of survivorship." In its simplest form, a tontine consists of a group of individuals who have each paid a lump sum up front. In exchange the group receives a fixed payment each year, which is divided evenly among the surviving members of the group. Upon the death of the last member, the payments cease.

Three years after the first French tontine, the English also attempted to raise money by a tontine issue. Because it was under-subscribed, they instead issued standard life-annuities in the following year [33][4]. Notable about these life-annuities was that they were issued at the flat price of 14% for all ages and genders–this in spite of the clear difference in the present value of a life-annuity on a young life versus an old life. Most municipally issued annuities up to that point had also been priced at a flat rate, generally quoted in terms of "years purchase," i.e. the ratio of the principal to the monthly payment [19, page 118-119]. The exception to this rule was Amsterdam, which had begun to make its life-annuity prices age-dependent in 1672 at the urging of the grand pensionary of Holland, Jan de Witt [19, page 131].

It is of some surprise that life-annuities were sold for so long without regard to age, since the valuation of simple life-contingent contracts as a function of age had been done as early as the third century for the purposes of valuing estates [30, page 187]. Nevertheless, no serious attempts to determine the expected value of a simple life-annuity were undertaken until de Witt's *Valuation of Life Contingent Annuities in Comparison to Redeemable Annuities*, published in 1671 [12], wherein de Witt developed a theoretical model of death rates, which he substantiated with data analyzed by himself and Jan Hudde on the mortality experiences of earlier life-annuitants in Amsterdam. This work was made possible only by the development, some twenty years earlier, of the concept of an expectation value (by Huygens[5].)

The age-dependent pricing begun in Amsterdam in 1672 speaks to the ability of governments to move in the direction of more accurate pricing of annuity sales, but two major developments still had to occur to make this pricing practical and efficient. Once the theoretical hurdle of applying the newly emergent probability theory to the valuation of life-contingencies was crossed, the primary obstacle to performing such valuations was constructing an ac-

[1] And the church seems to have made use of life annuities as early as the 8th century [27, page 2].

[2] See, for example, [32], chapter VI.

[3] With the possible exception of Spain under Charles V. See [32], pages 22–24.

[4] In fact, the legislation for raising funds by the 1692 tontine had a clause stating explicitly that if the tontine were under-subscribed, the subscribers would be allowed to purchase life-annuities at very favorable rates instead [23].

[5] And while it may not seem so to those of us with some familiarity with statistics, the leap to regarding a randomly selected human life as analogous to the roll of a die is not a trivial one!

curate life table. Hudde had constructed an empirical one, and de Witt had developed a theoretical piecewise-constant model of mortality. But Hudde's data were not made public until 1897 [7, page 5], and de Witt's method was extremely cumbersome to implement – as well as of questionable accuracy[6]. Some semblance of a life table based on empirical evidence was ingeniously compiled by John Graunt in 1662. This table was compiled from a register of deaths in London. This register contained a description of the cause of death; Gruant (loosely) inferred age at death from the cause of death [16]. A more accurate and complete life table was first constructed by Halley in 1693 [20]. It was based on a birth and death register that had fortuitously been kept at Breslau, in Silesia. Using this table, Halley was able to convincingly compute the value of a life-annuity for the first time.

A secondary development was also needed for and implementable scheme for valuing life-annuities, for Halley's method needed to be streamlined and made more computationally efficient. This development was afforded by de Moivre. De Moivre assumed that nobody lived past 86 years of age, and further assumed that an individual alive who was at age A would be equally likely to die in any of the years between A and 86[7]. He noted that this assumption fit Halley's data quite well; the key feature of this assumption, however, was not its exact fit to the data but rather that, under this assumption, the calculation of the value of a life annuity was reduced to a simple, manageable formula – for *any* rate of interest. So, after 1724, when de Moivre published his work *Annuities on Lives* [11], valuation of annuities was a task that anybody well trained in mathematics could undertake.

The central governments of Britain and France could therefore have undertaken such calculations in pricing the life-annuities they continued to sell throughout the eighteenth century. They did not always do so: France was still issuing flat-rate life-annuities through the 1780s, and Britain's did not make pricing age-dependent until 1808. As such, there was a clear opportunity for the private sector to take advantage of these naive pricing rules.

The century following de Moivre's developments was the "golden age" of life-contingent contracts. Much of France's borrowing in the 18th century was through tontine and life-annuity issues. Indeed, in 1740, approximately 8% of French tax revenue was devoted to payments on life-annuities and tontines. By 1788, this had risen to over 21% [34, table, page 103]. In section 3.2 I look in more detail at this French debt.

Britain focused far less on life-contingent debt in the 18th century, and, as a percentage of total debt, life-contingencies were trivial [25]. Nevertheless, there were no fewer than 7 distinct issues of life-contingent debt in Britain in the 18th century. It was not until 1808, when the government undertook a policy of converting their perpetual and terminable debt into life-annuities, that life-annuities began to play a central role in British finance. Section 4 will survey and summarize the British life-contingent debt issues, and Sections 5.1 and 5.2 will undertake an empirical examination of two of these issues.

3 Survey of Extant Literature and Data Sources

One would expect selection to be present in the purchase of any non-trivial life-contingent contract: annuitants will tend to live longer than the average population, while purchasers of life-insurance will have shorter life expectancies. While this was recognized by de Witt and others[7, page 11], it was first empirically established for annuitants in 1746, by Déparcieux [30, page 207][8].

Beyond these basic selection effect, the discussion in the preceding section reveals another source of se-

[6] It is interesting that de Witt's original *calculations* agreed quite well with Hudde's empirical data – but only due to a calculational error: he stated that the probability of death would be greater at higher ages, but used just the opposite when he actually performed his calculations. On this see, for example, [30, page 209].

[7] Hence, he assumed that the mortality rate followed a (scaled) harmonic progression from 86 down to the earliest of ages considered by de Moivre.

[8] It is worth noting, however, that higher life expectancies of annuitants could, instead, be due to a version of "moral hazard" if it is the income generated by the annuities that helps to extend life.

lection effects in the sale of early government life-annuities: early life-annuities were priced without consideration for age or gender[9]. Since the value of a life-annuity is clearly related to the age of a purchaser (though not monotonically, given high mortality in early youth) one would *a priori* also expect to see life-annuitant nominees selected on the basis of age and gender. This *a priori* conclusion is tempered somewhat by the observations by Halley, de Witt, and others that life-annuities were priced so as to offer a higher rate of return than the going interest rates, and, as such, one might instead expect most classes of individuals to wish to invest in life-annuities[10], partially offsetting this selection effect[11]. It is crucial to note, however, that, for life-annuities issued in early modern Europe, *the life on which the annuity was contingent* (the nominee) *did not have to coincide with the life of the purchaser of that annuity.*

If life-annuities were purchased solely for risk-neutral investment purposes then, we would expect to see severe selection effects in this market: we would expect all nominees to be drawn from the healthiest classes of the population – the worst ones from the point of view of the government (generally 5-7 year old girls who had already lived through smallpox.) Of course, life-annuities insurance characteristics as well, so in practice we would not expect the selected distribution of nominees to be so narrow.

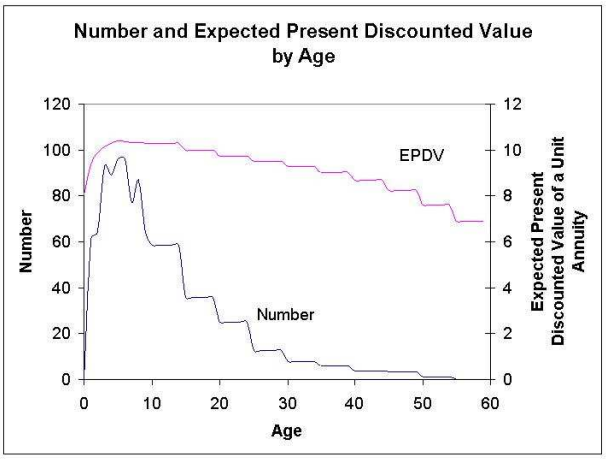

Figure 1: Source: [7, page 29]

3.1 Selection in Holland

Alter and Riley [7] and Alter [6] offer some discussion of selection, particularly with regards to Amsterdam life-annuities and the French tontine of 1696. They examine the life-table construction studies of Hudde and Struyck (published in French) and tabulate the age breakdown of purchases for the 1586-1590 Amsterdam life-annuities (used by Hudde) and the age-gender breakdown of the 1672-1674 Amsterdam life-annuities (used by Struyck)[12]. Furthermore, they use (modern) parametric life tables to estimate the expected present discounted value (EPDV) of each of these annuities by age and gender[13].

Figure 1 plots the number of life-annuities purchased on nominees of each age and the estimated EPDV of those life-annuities[14] as calculated by Alter and Riley. There is a clear tendency for "bunching" at the best-value life-annuities. Especially considering that few 5-7 year-olds are likely to purchase their

[9]The gender differences in mortality were first established by Struyck in 1740 [30, page 207].

[10]Halley and de Witt calculated the value of a life-annuity under the assumption of risk neutrality. Depending on the reasons for purchase, risk-aversion could raise or lower the private value. Someone who purchased an annuity on her own life to insure against outliving her assets would value them more highly, while a risk-averse entity with a long time frame purchasing the life-annuity on someone else's life purely for investment purposes would value them less.

[11]A competitive resale market for life-annuities would bring back these selection effects, but given the informational asymmetries in such a resale market, it would not be perfectly competitive.

[12]See the tables on pages 29 and 30 of [7].

[13]They use the going interest rate on perpetuities of 8.33% to compute the EPDV of the earlier annuities, and a 5% interest rate to compute the EPDV of the later issue. They do not make it clear why they choose the 5% factor. Given that de Witt's contemporary calculations had assumed a 4% interest rate [30, pages 55 and 209], which appears to have been the interest rate on perpetuities between 1655 and 1672 [32, page 211]. The French invasion in 1672 may have driven up interest rates, however.

[14]That is to say: for a unit stream of income from those annuities.

own life-annuities, this is strongly suggestive evidence of selection[15].

As mentioned in the preceding section, the Amsterdam life annuities sold from 1672 to 1674 *were* price dependent. Prices are given in the following table:

Age	Price	Age	Price
0-19	10.00	50-54	7.50
20-29	9.50	55-59	6.75
30-39	9.00	60-64	6.00
40-44	8.50	65-69	5.00
45-49	8.00	70-74	4.00

Table 1: Pricing of life-annuities in Amsterdam from 1672 through 1674

An examination of figure 2, which plots the fraction of nominees by age for the 1586 and 1672-74 Amsterdam life-annuity issues suggests that purchasing patterns were indeed affected by this new pricing rule[16]. What is less clear is whether these patterns were due to selection effects.

Figures 3 and 4 are similar to plot 1; they plot the male and female nominees of the 1672–1674 Amsterdam life-annuities separately. The evidence of selection is still present, but is far less dramatic than in figure 1. This may be due, in part, to the fact that the data is pooled into five-year age bins, making the pattern less discernable. Furthermore, as mentioned above, the EPDV calculations of Alter and Riley may not be as well determined (because of their unjustified choice of a 5% interest rate.) Nevertheless, annuity purchases are still concentrated at the peak of the EPDV curve. The up-ticks that do occur in the right tails of the distribution of nominees – at age 40 for males and at ages 30 and 50 for females – do

[15]It is not by any means a "smoking gun," however. Were nominees randomly drawn from a population with a population bulge between 5 and 7, we would see similar results, for example. More plausibly, life-annuities may have been purchased on 5-7 year old girls to provide a dowry upon marriage.

[16]Although with 100 years in between, mortality patterns among other things are likely to have changed significantly. Some of these changes may also be reflected in the buying patterns

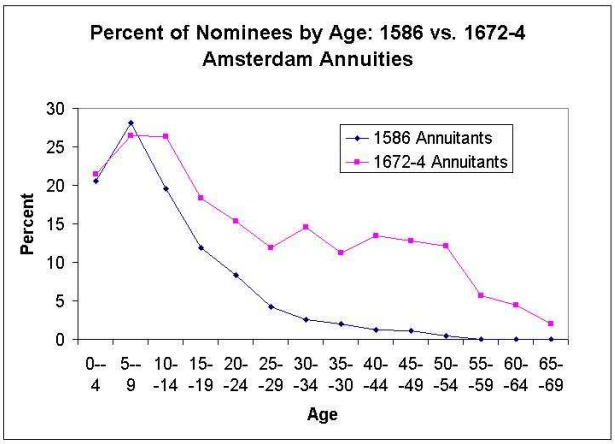

Figure 2: Source: [7, pages 29-30]

coincide with a decrease in the price of the annuities at that age, which could be interpreted as *attempted* selection by annuitants. But if Alter and Riley's assumptions about mortality and interest rates are accurate, it is clear from the decline in the EPDV curve at those ages that is was an unsuccessful attempt[17]. In point of fact, and in contrast to what we will observe in the following two sections, the 1672 annuity issue was a case in which the government was almost certainly *more* informed and calculating than the private sector purchasers. Indeed, the Grand Pensionary of Holland at the time, de Witt, was among the foremost mathematicians of his time, and he had *just* published his *Value of Life Annuities in Proportion to Redeemable Annuities* – the first major publication on the valuation of life-annuities.

3.2 Selection in France

While there is a substantial amount of data and discussion on French debt in the 18th century – much

[17]It is not necessarily unsuccessful we are observing selection effects combined with an increasing demand for life-annuities with age.

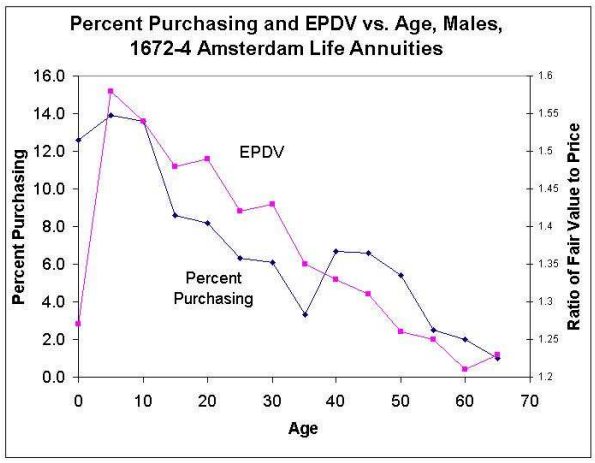

Figure 3: Source: [7, page 30]

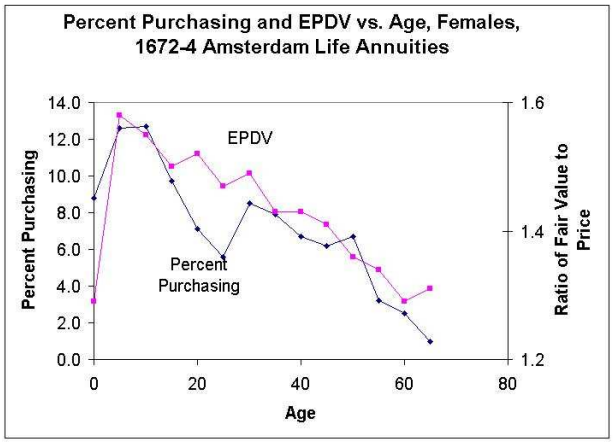

Figure 4: Source: [7, page 30]

of which was in the form of life-annuity and tontine debt – much of the literature and data sources have not been translated into English to date. To the best of this author's knowledge, papers by Weir [34] and Velde and Weir [33] are the only English-language studies in the secondary literature to analytically examine life-continigent French debt.

Weir tabulates French and British tontine issues of the 18th century, and calculates the internal rates of return on a selection of those tontines [34]; we will return to his work below.

Velde and Weir [33] discuss French life-annuities in the context of default risk and the public finance system in France. They argue that, contrary to the claims of others, life-annuities did not have excessive yields. Indeed, they argue that life-annuities were issued at times when the central government found it extremely difficult to raise additional funds by standard borrowing – i.e. precisely when the default risk was perceived by the market to be the highest. As such, while the yields were indeed high as compared with the "official" interest rates, they were not when compared with the "actual" interest rate as derived from an examination of the secondary market for government debt.

Velde and Weir point out that in the first half of the 18th century, the private sector may not have had the know-how to accurately price annuities; this is in accord with the discussion in Section 2 of the present paper. However, especially in light of the publication of Deparcieux's *Essay on the Probabilities of the Duration of Human Life* (1746, in French) by the second half of the century they almost certainly did. As table II below indicates, it was precisely in this second half when life-annuity issues took off.

Years	Millions of *livres tournois*
1730-39	34
1740-49	61
1750-59	197
1760-69	164
1770-79	197
1780-89	643

Table II Life Annuity Borrowing in France, 1730-1789. Source: [33]

Some of these annuity issues were age-graded in terms of pricing, but the majority of them had flat prices. Velde and Weir do not discuss the selection effects of this *per se*, but rather argue that the flat-pricing was not "imbecility" on the part of the government, but rather a conscious decision made in a time when they were desperate to raise funds. Still, Velde and Weir allude to the well-documented increase in investor savvy over this time period, saying:

> Technological changes on the demand side of the market for life annuities made the flat rates increasingly costly over time [33, page 31].

In particular, Velde and Weir allude to a scheme developed in the 1770's in Geneva known as *trente demoiselles de Genève*. In this scheme, banks purchased annuities on the lives of groups of young girls from healthy families in Geneva. Velde and Weir present clear graphical evidence of these investment-by-selection schemes (in the form of a histogram of payment amounts by nominee age of these investment-related purchases [33, figure 6, page 32].)

Though Velde and Weir are forced to acknowledge the large costs to the French government of their 'naive' pricing schemes, they still argue that the government was not making a major mistake; they show that in the few cases when life-annuities did trade on a secondary market, they traded at a premium over other debts, within 5% or so of the original issue price. Hence, they argue, the government did *not*, in general, badly mis-price these assets. Instead, they argue, the premium reflected the greater default risk associated with life-annuities[18] [33, page 35]. One issue that they appear to overlook in their discussion is the adverse selection involved in the secondary market for life-contingent debt. An annuity on a carefully selected life is of much more value to the person who selected that life, and, indeed, the life-annuities most likely to be sold on the secondary market are most likely to be the "lemons" anyway[19]!

[18]This greater default risk presumably comes from the fact that they were largely subscribed by foreigners (Genevan banks in large part) and had high nominal yields.

[19]Their failure to note this is striking, especially in light of Weir's recognition of this in a previous paper [34, page 111]. Indeed, in this previous paper, Weir argues that the French may have used tontines (and life-annuities) precisely because the lack of a resale market would keep the default-risk premium from appearing on secondary markets.

In summary, Velde and Weir convincingly establish the presence of selection by age in the flat-rate pricing at the end of the 18th century in France. Genevan bankers were the first to recognize and exploit this selection scheme beginning in the 1770s. This fact will play an important role in section 5, where I present evidence on the Swiss nominees in a British tontine issue in the 1770s.

In contrast to the life-annuity selection in favor of the young, David Weir shows that the prices of French tontine issues in the 18th century were calibrated to be much better deal for the old [34]. Table III below transcribes a portion of a Weir's table; it contains the EPDV of a unit tontine by age of nominee for sever French tontine issues[20]:

Age	**1696**	**1733**	**1745**	**1759**
2	7.13	7.13	6.65	6.99
7	7.13	7.13	6.98	6.98
12	7.12	7.12	7.31	7.48
17	7.11	7.11	7.64	7.48
22	7.10	8.31	7.97	7.97
27	7.08	8.30	8.30	7.96
32	7.05	8.28	8.96	8.96
37	7.01	8.26	9.62	8.94
42	8.22	9.94	9.94	9.94
47	8.15	9.90	10.25	9.90
52	9.84	9.84	10.54	10.36
57	9.73	9.73	11.15	10.27
62	12.26	12.26	11.72	10.65
67	12.04	12.04	11.86	10.37
72	13.62	11.60	12.18	11.03

Table III Calculated EPDVs of a selection of French tontine issues. Source: [34]

As discussed with regards to the apparently ignorant pricing schemes for French annuities, Weir argues that this old-age tilted tontine pricing scheme was, in fact, intentional on the part of the French

[20]Note that these calculations are non-trivial; the value of the tontine depends on the distribution of ages in the tontine class.

government. He argues that this was a means of subsidizing retirement in order to solidify the political support of older middle-class Frenchmen. Unfortunately, he provides no direct evidence of the ages which preferentially chose to purchase tontines. If his thesis is correct, one would expect to see the highest purchasing rates in the upper tail of the age distribution. But even if data were presented to show this, it would not be particularly strong evidence of selection effects at work: if tontines *were* used for retirement – to insure against living a longer than expected and running out of resources – then one would expect bunching at the upper tail of the distribution *anyway.* When we turn to an examination of the Irish Tontine of 1775 in section 5, it will be the *lower* tail of the age distribution where we will be most interested looking.

4 A Detailed History of Life-Contingent State Finance in Great Britain

4.1 From 1688 to 1808

The British relied primarily on funded perpetuities for state finance after the glorious revolution in 1688. That is, the bulk of their borrowing needs were met by issuing perpetual annuities, whose income stream was "backed" by a particular source of tax revenue[21]. From the glorious revolution to 1808, however, there were no fewer than 7 life-contingent debt series issued, though most of them were insignificant from a governmental finance point of view. They are described in some detail below. For additional details, good sources are Grellier [17] and Leeson [23]. It should be noted that in all cases, the contingent lives could be freely selected; they did not have to coincide with the purchaser or the claimant of the income stream.

1. **The Tontine of 1693:** The British attempted to raise £1 million by this tontine, but the tontine was under-subscribed and was cancelled. However, the tontine was paired with an alternative: the right to purchase a 14% life-annuity should the tontine be under-subscribed. Grellier [17, page 26] and Weir [34, page 114] show that the life-annuity was a far better bargain than the tontine at the posted rates. As such, it should not be surprising that the latter was not chosen by investors.

2. **Life-Annuities of 1703 and 1704:** These annuities were not mentioned in Leeson's otherwise thorough catalog. But Marshall [25, page 21] lists an item in 1704 as "lives" in his list of government debt issues in 1704. This is corroborated by Grellier [17, page 60-61]. The funds raised by the issue were less than $\frac{1}{3}$ of the total funds raised by borrowing in those years, which were not, in turn, years of notably large borrowing.

3. **The Life-Annuities of 1745, 1746, and 1757:** These life-annuities and the life-annuities issued in 1746 and 1757 were issued as "bonuses" to those who subscribed a minimum amount in a state lottery for raising funds. As such, the total life-annuity issue was small. Some records of the purchasers of these annuities survive, including a register from the 1745 issue of all of the purchasers and nominees and their dates of death [24]. Lacking the birth dates of the nominees, this data is not terribly useful for the purposes of this paper, however.

   In his report to parliament in 1829, John Finlaison notes, in regards to these life-annuity issues:

   > "In the second set, viz. those of 1746, a very large proportion of the capital was supplied by Dutchmen, who almost universally nominated children, and in a decided majority, girls. Whereas the English contributors named people of every sex and age indifferently, up to fifty or sixty. It would appear that the Dutch were at this time better informed on those matters than others" [14].

[21] See [26]. Weir [34] argues that it was this mechanism for raising funds that made Britain less likely to default and therefore avoid a French-style revolution in the late 1700s.

There is some hard evidence of Finlaison's claim: Leeson has compiled and published a list of the residences of the nominees of these annuities [23, page 7]. A condensed version of this table appears below:

Residence	**1745**	**1746**	**1757**
Britain	650	1121	1769
Netherlands	98	661	64
Others/Unstated	236	76	100
Total	984	1858	1933
Status	**1745**	**1746**	**1757**
Male "Professions"	287	456	369
Widows	24	63	31
Spinsters	117	217	149
Others	2	5	6
Unstated	554	1117	1378
Totals	984	1858	1933

Table IV: Numbers of nominee by residence and status in the life-annuities of 1745-7. Source: [23]

Table IV shows the upsurge both in Dutch participation in 1746 and the upsurge in women subscribed[22]. On the other hand, there is no direct evidence in these tables that it was the Dutch who nominated the women as Finlaison claimed. It would therefore be nice to track down the original data on which Finlaison's remarks were based so as to conduct a more thorough investigation of this phenomenon.

Weir also mentions a tontine issue in 1757, but this tontine was cancelled for a lack of subscriptions – again because of overpricing relative to alternative investments [34, page 116]. Weir mentions that the few subscribers were given the option of purchasing life-annuities instead. Leeson makes no mention of these, but Grellier [17] corroborates their existence.

4. **The Second English Tontine of 1766:** This tontine was a clear failure, as it was under-subscribed by a factor of more than 6, and cancelled.

[22]Though, as to the later, the presence of the large number of unstated professions may be confounding.

5. **The Life-Annuities of 1778 and 1779:** These life-annuity were issued as minor complements to purchases of term- or perpetual annuities. The total amount issued was insignificant [17, pages 304-306].

6. **The Irish Tontines of 1773, 1775, and 1777:** These tontines, known as "Irish" because they were issued by act of the parliament of Ireland, are of some interest. Firstly, records of the lives originally nominated in 1775 are extant [1] and records of the survivors as of 1830 for all three classes also exist [5]. Second, these tontines were issued shortly after the Genevan banks had developed their "thirty demoiselles" scheme for investing in French debt. Third, and relatedly, there was heavy Swiss investment in these tontines. As Leeson writes:

   > There were a number of foreigners nominated in both of these [the 1773 and 1775 issues], and in the 1777 Tontine, which was largely promoted by the great Swiss banker, Thellusson, no fewer than 432 aliens, mostly his fellow countrymen, appear [23, page 13].

   While the original data from the 1777 issue has been elusive, I show in section 5 that there is substantial evidence of the Swiss banking presence in the 1775 issue.

7. **The "Great" English Tontine of 1789:** This tontine was unusual: it too was under-subscribed (by a factor of two). Instead of cancelling the tontine, however, the government chose to nominate a number of other lives as "dummies" to fill out the full subscription. The government was careful in selecting these fake nominees, requiring that they be peers or descendants, justices of the peace or from a number of specific and highly public professions (e.g. fellows of colleges) or "persons duly registered in the Amicable Society for Insurance" [23, page 11]. There are a number of possible explanations for why the government was so cautious in its selection.

Simple record keeping was an obvious consideration. It would be interesting to examine the degree to which the government was selecting lives that were likely to live longest and the degree to which it was selecting lives to match the observable characteristics of the "real" subscribers[23].

The pricing of this tontine issue was carefully calibrated to provide a fair return for all classes of nominees [34, page 117]. This, together with the careful selection process of the 'dummy' nominees shows how dramatically the level of sophistication of the British government had improved over the course of the preceding century.

4.2 The 1808 Act and its Consequences

The next use of life-contingencies in British governmental finance was begun in 1808; this issue was designed for the reduction of the national debt – a continuation of the "sinking fund" operation begun in 1786. In this section, I offer a brief summary of the history of this issue; I further elaborate on it in section 5.2.

Up to 1808, the British sinking fund had operated by the direct re-purchase of the perpetual annuities (consols) which constituted the vast majority of the public debt; these re-purchases drove down interest rates and drove up consol prices, making further reduction of the debt more expensive. 1808 marked a switch from purchasing consols directly to exchanging them for life-annuities – with the ostensible goal of keeping interest rates low (and future borrowing cheap) *without* increasing the costs of debt reduction [27, particularly pages 5-6][24].

The government attempted to price these life-annuities in accord with sound actuarial principles. To this end, they made use of the mortality table developed by Richard Price – arguably the foremost actuary of the 18th century. Price had developed these tables for the purpose of pricing life insurance at The Equitable, which, by 1808, had established itself as *extremely* sound, from an actuarial point of view [28, pages 108-111]. These tables, however, were representative of the mortality of a sample from a general population (from the town of Northampton) – and not from a group of self-selected annuitants[25]; furthermore, these tables did not distinguish between the mortality of males and females. The life-annuities were therefore underpriced in 1808, particularly for females. This was pointed out as early as 1823, but the underpricing continued until 1828, when John Finlaison was able to convince the government of this problem [4]. This led to a change in the pricing structure to account for self-selection and differences in mortality by gender in 1829. The new mortality table developed by Finlaison for the purpose of this new pricing was based on data on the mortality of all previous subscribers to the 17th and 18th century life-contingency issues. As we shall see below, this led to a new opportunity for selection at the older ages.

The historical structure of these debt issues – particularly the discrete change in 1829 – provides ideal for an examination of selection effects. This is undertaken in section 5.2 below.Two other features in the history of these life-annuities are of use in that section: in 1817, life-annuities became available for direct cash purchase (as opposed to via consol redemption), and, in the same year, the age of the youngest permitted nominee was extended from 35 to 21.

5 New Numerical Evidence on Selection in Great Britain

It is clear from the preceding discussion that 17th-19th century British finance provides fertile ground for an exploration of early selection effects in a di-

[23] I have been able to track down a register of the government nominees [2], but I have thus far left it un-analyzed until such a time as I can track down the complementary register of private subscribers.

[24] A noble goal, though perhaps one that could not possibly be expected to succeed. As Murphy puts it "they wanted to have their cake, and eat it too" [27, page 6].

[25] Whether this population was representative of the population of England as a whole is an open question. But Price analyzed the data and compared it with the early mortality experiences at The Equitable and determined that the table was suitably safe for use in life-insurance pricing – and hence, of course, unsafe for use in life-annuity pricing.

verse range of life-contingent debt issues. In this section I perform novel empirical analysis of data from two of these issues: the Irish tontines of the 1770s – particularly the 1775 series – and the "sinking fund" life-annuities of 1808ff.

5.1 The Irish Tontines of 1773, 1775, and 1777

The Irish tontine issues of 1773, 75, and 77 were each divided into three classes: above 39 (class I), between 20 and 39 (class II), and under 20 (class III). The price of a share in the tontine was independent of age and gender within each class. Selection would therefore favor the younger ages in classes I and II, while favoring nominees from class III around the ages of 5-7 – after high mortality rates in early youth had already passed. A hypothesis of selection at work would also predict a preponderance of females over males.

A. G. Finlaison tabulates the ages and genders of nominees of the three tontine issues [13, pages 79-82]. Figure 5 shows the distribution of nomination ages for males in the first class in each of the three years; they have the expected downward slope. Similar patters appear in analogous plots for class III females and class II males and females. Figure 6 shows the distribution of nomination ages for females in the third class. The region of rising nomination numbers at very low ages is evident in all three years, and the maximum occurs at approximately the predicted ages.

Table V shows the total number of males and females nominated in each of the three years. The predominance of female nominees is clear.

Year	1773	1775	1777
Males	408	372	634
Females	609	539	819

Table V: Numbers of Nominees in the Irish Tontines. Source: [13]

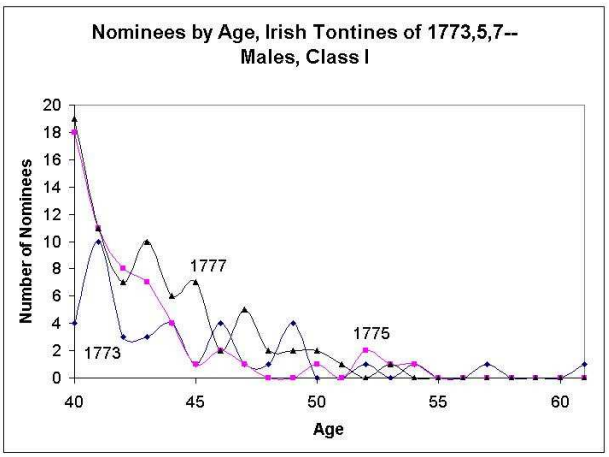

Figure 5: Source: [13]

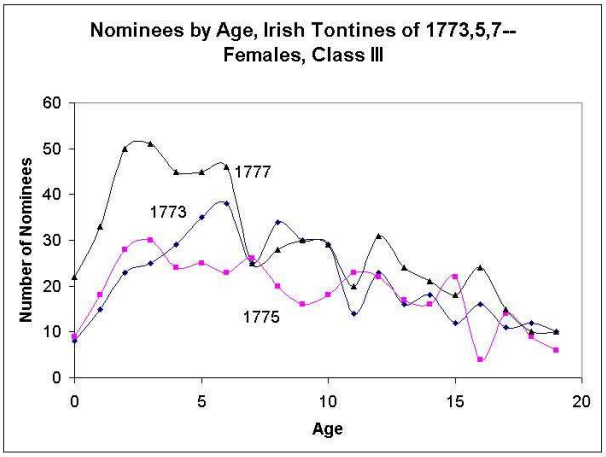

Figure 6: Source: [13]

Finlaison's data is partially instructive; indeed, the data indicate some degree of selection. But given the discussion in section 4.1 above about a Swiss banking presence, we would like to go more deeply into our search for hard evidence of more active and directed selection. To this end, I have located a register of all nominees from the 1775 issue; each entry contains a name, a description (and, implicitly, gender), the place of residence, the subscription amount, and the age of the nominee [1]. To complement this, I have found an analogous register from 1830, containing only the surviving members at that time [5]. By cross-referencing these, I was able to compile a database of 982 nominees, with each entry containing the gender, age, amount, country of residence[26], and a dummy variable for whether the nominee was still alive in 1830.

As described in section 4.1, the timing of this tontine was roughly coincident with the rise of Genevan banks as the primary investors in French state debt. As per the discussion above, it is well known that the Swiss were also heavily invested in the 1777 tontine. Table VI below shows that the Swiss played a minor role in the 1775 tontine as well.

Females	Class		
	1	2	3
Swiss	0	3	27
Others	52	119	374
Males	Class		
	1	2	3
Swiss	29	9	10
Others	34	72	253

Table VI: Swiss Participation in the Irish Tontine of 1775. Source: [1]

It is interesting to note in table VI that the female Swiss participation was almost exclusively at the young age-class – consistent with this being a Swiss investment along the lines of the "thirty demoiselle" scheme[27]. It is also interesting to note the substantial number of male Swiss annuitants – who are predominantly in the oldest age-class. Given the circumstances and the non-trivial participation of the Swiss (virtually all of whom were from Geneva) it is worth looking for hard evidence of selection among the Swiss sub-sample.

A plot of the Swiss and non-Swiss age distributions reveals a clear tendency for the female Swiss nominees of class III to show the distributional features we expected to be indicative of selection more strongly than the rest of the population (see figure 7.) The Swiss males of class I show the expected 'selection-like' features *less* strongly than the non-Swiss population (see figure 8.)

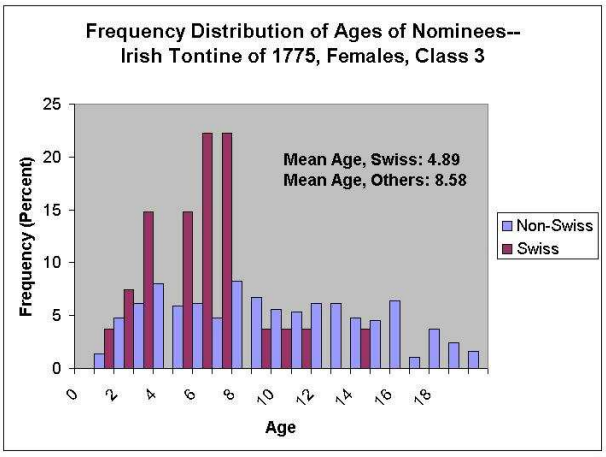

Figure 7: Source: See text

Figure 7 provides evidence of the greater importance of selection by age amongst Swiss female nominees. But there were other methods of selection available, methods that the Swiss were thought to employ, namely the selection of girls who had already survived smallpox, and the selection of girls from households

[26] To save myself time – particularly the time of trying to decipher which counties are in England, which in Scotland, and which in Ireland, I kerned this variable to a dummy for Swiss residence, for reasons alluded to above and described more thoroughly below.

[27] Is the fact that there are *exactly* thirty Swiss females a coincidence?

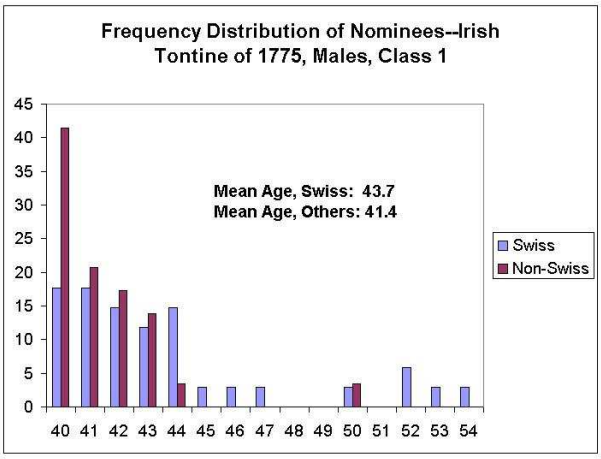

Figure 8: Source: See text

known to be healthy. To search for these other selection methods, we need only ask the question: after accounting for age, gender, and other relevant characteristics, were Swiss nominees more likely to survive to 1830[28]? To answer this question, I ran a probit regression of the following form:

$$A^*_i = \alpha + \beta * GEN_i + \sum_{ages} \gamma_{age} * AGE_{i,age} + \sum_{amts} \delta_{amt} * AMT_{i,amt} + \xi * SWISS_i + \epsilon_i \quad , \tag{1}$$

where GEN is a dummy for male, $AGE_{i,age}$ is a series of dummy variables, one for each age, $AMT_{i,amts}$ is a series of dummy variables, one for each subscription amount[29], and $SWISS_i$ is a dummy for residency in Switzerland. Finally, ϵ_i is a random normal disturbance term, and A^* is an un-observed variable which determines survival until 1830.

The reason for including so many dummy variables rather than an age or amount trend is simply that we have no reason to believe that the survival probability is monotone in either of these variables, and any imposed structural model runs the risk of being *ad hoc*.

I ran a number of different specifications of regression (1). First, I ran the regression separately for class II and for class III. I also ran it for the entire data set[30]. The output from these three regressions appears in the table below in rows (A)-(C), respectively. I also ran the regression separately on the female sub-population for class III; the results from this regression appear in row (D). Row (E) reports the same regression as (B) without the Swiss dummy present, and row (F) reports the same regression as (B) (class III) but with a Gender-Swiss interaction term added. Given the large number of dummy variables used, reporting the δs and γs is impractical. But it is worth reporting that in the regressions (B) and (D) the *only* significant coefficients among these (at the 10 percent level) were the dummies for £600 and £300 (and this later was not *quite* significant in (D): $P = .102$)[31].

	Constant	GEN	SWISS	GEN*SW
(A)	-1.2579	-0.2674	-0.4326	—
	[.5664]**	[.3928]	[.6467]	
(B)	-0.9433	-0.1089	1.3302	—
	[.3405]***	[.1267]	[.5606]***	
(C)	-0.8341	-0.1665	1.0345	—
	[.3328]**	[.1185]	[.2085]***	
(D)	-0.7879	—	1.4589	—
	[.5715]	—	[.2979]***	
(E)	-0.5705	-0.1712	—	—
	[.3186]*	[.1236]		
(F)	-0.9203	-0.0901	1.4196	-0.2929
	[.3416]***	[.1307]	[.2834]***	[.5107]

Table VII: Regression output; see text for description.
Standard errors in brackets. *, **, and *** indicate significance at the 10, 5, and 1 percent levels.

Note that gender is not significant in any of the regressions, even at the 10 percent level. ξ is significant in all regressions except (A) (where it even has

[28]This question is only of relevance to classes 2 and 3, since there were no survivors in the first class.

[29]e.g. £100 – all subscriptions were in integer multiples of £100, and the vast majority of them were exactly £100.

[30]Given that being in class I perfectly predicted non-survival, I could not run a similar regression on class I separately – though it would certainly be interesting to do so.

[31]Given the *apparent* number of ages and amounts, this small a number of significant coefficients would be unlikely indeed (random fluctuations alone would lead to more of them!) But because of small survival rates, many starting ages and amounts had no survivors. Therefore these ages perfectly predicted death prior to 1830, and were dropped from the regression. The actual number of insignificant regressors is therefore much smaller, and the number of significant coefficients is not unreasonable.

the "wrong" sign.)[32] The size of the SWISS coefficient is substantial. Looking at the marginal effect (at the mean value of the other variables[33]), of being Swiss on the likelihood of survival until 1830, we see a huge effect: being Swiss appears to increase the likelihood of survival until 1830 by nearly 50% (46.7% in regression (B)).

From regression (F), we see that there is no evidence of differential Swiss selection by gender. Though we might have expected the Swiss to be better at selecting female lives – given their practice in the French debt-issues – the lack of significance of the interaction term may merely reflect the paltry data on young male Swiss lives. Data on survival to an earlier year – say 1800 or so – would allow for a much better exploration of this possibility, since many more of the older males lives were presumably still extant then.

I also attempted to discern the age-dependence of the degree of Swiss-related enhancement in the hopes of seeing evidence that some ages of Swiss lives were more selected than others. I did this by introducing a family of Swiss-age interaction dummies. The data were minimal enough, however, that the introduction of these extra dummy variables resulted in no significant coefficients – not even ξ. Perhaps with analogous data from 1777 (and, to a lesser extent, 1773) this would be a feasibly exploration.

5.2 The 1808 Act Sinking Fund Life-Annuities

As discussed in section 4.2, the pricing of the life-annuities issued by the British government in the years after 1808 was quite sophisticated. I have located tables of prices of these life-annuities by age. The prices also depend on the price of 3% consols – i.e. on the interest rate[34]. Prices were constant until 1829[35].

A sample of a portion of these tables appears below:

Age	When the Price of Stock is 50 and under 51					
	For £100 Stock			Avg. Rate For £100 Money		
	l.	s.	d.	l.	s.	d.
35	4	5	0	8	8	3
36	4	6	0	8	10	3
37	4	7	0	8	12	3
38	4	8	0	8	14	2
39	4	9	0	8	16	2

Table VIII: Prices of Life Annuities, 1808. Source: [3]

To interpret the tables, note again that the price of stock implicitly gives the interest rate. The stock being referred to is a perpetuity paying a dividend of £3 per year – or a "3% consol." Under the assumption that this dividend is payable one year from the present, and each year thereafter, the interest rate r can be inferred from the price of the stock P, in £ s, by the simple relation $P = 3/r$. Some simple computations show that the ratio of the "average rate for £100 money" to the "rate for £100 stock" in the preceding table is equal to 50.5 for each age[36], which yields an obvious interpretation for the entries in this column.

These tables suggest that the amount of a life annuity yielded by redeeming £100 worth of stock was invariant over a small range of prices[37] (e.g. from 50 to 51 above.) As such, when computing the money

[32] This is hardly surprising, given that there were only 3 Swiss females and 9 Swiss males in class II.

[33] Which is not necessarily the most natural thing to do here, given that the Swiss sub-population is not concentrated at the same mean values as the population as a whole.

[34] Section 21 of the Act states

> Life Annuities are exempt from all Taxes, except such as Dividends of Consolidated or Reduced Bank Annuities are liable to, and are deemed to be Personal Estate [3].

This removes the complication of differential tax treatment – so the relevant interest rates are the same for the annuities and the consols.

An open question is as to the exact timing of the payments. It is clear when the annuity payments are made, but not when the consol payments are. I ignore this here.

[35] See Murphy [27], and as corroborating evidence, note that the tables from the original act in 1808 and from a publication of rates in 1812 agree down to the pence [3] [15].

[36] Up to rounding, and using the fact that there were 12 pence in a shilling, 20 shillings to a pound.

[37] Indeed, they more than suggest it: at every stock price and every age, the size of the purchased annuity is an even number of shillings. Furthermore, this makes sense, given that until 1817, life-annuities could not be purchased for cash.

price of the annuities at particular interest rates, I used the stock-price of annuities from the table, and I used the price corresponding with the desired interest rate to compute the exact money price at that interest rate.

As discussed above, the price of life-annuities in terms of consols was designed to be actuarially fair, in accordance with the Northampton mortality table. To verify that this was indeed the mortality table used, I used the Northampton mortality table[38] and the published prices to compute EPDVs by age for several interest rates (6%, 5.5%, 5%, 4.5%, and 4%). My calculation shows a small discount of 2-4% – i.e. slight overpricing of the life-annuities relative to the actuarially fair price[39]. But there is no clear pattern by age or interest rate, strongly indicating that it was indeed this table – or a very similar one – that was used to price the annuities. A plot of these EPDVs for interest rates of 6% and 4% appears in figure 9.

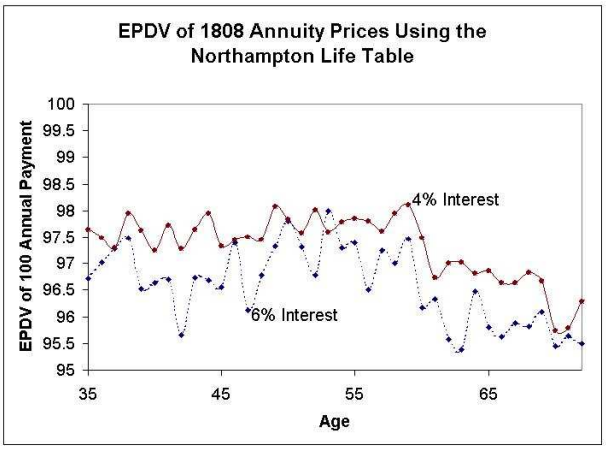

Figure 9: Source: [8] and [15]

In 1823, John Finlaison, who was later to become government actuary, used data from past life-contingent debt issues to construct a new table of mortality [14]. It was this work that led Parliament to conclude that they needed to revamp their life-annuity pricing policies. For a brief period in 1828, the issue of life-annuities ceased, and it was re-started (after much debate) in 1829 with prices based on Finlaison's newly developed tables. Of particular note in these tables was the development of gender-specific mortality rates and, hence, life-annuity pricing. In figures 10 and 11, I plot Finlaison's male and female mortality rates by age and the cumulative probability of life (i.e. the probability of reaching any given age, assuming the individual was alive at age 3), and compare it with the same for the Northampton tables[40].

Figures 10 and 11 indicate that using the Northampton tables led to a substantial undervaluation of life-annuities. It is also clear that there was a selection incentive in favor of women buying annuities from 1808 to 1829 – a proposition that we will soon examine in greater detail. What is not clear from these figures is whether the use of the Northampton tables provided a substantial room for selection on age[41]. It is therefore instructive to com-

[38] Printed in [8, page 559].

[39] Some of this can be attributed to the clause that "one fourth part of the annuity is always payable after the death of the nominee" [13, page 17]. This clause was designed to ensure proper reporting of the deceased. I have not, at present, included this item in my calculations, but it would presumably have two effects: first, it would lead to an increase in the EPDV at all ages by some amount below 2.5%. Second, it would lead to a greater increase at the older ages. Inspection of figure 9 shows that these effects would move the tables even closer towards exact accord with the Northampton mortality tables.

[40] These are from the columns marked with an (a) in [14, pages 66-69]. That these are the correct columns to use is implied by the heading titles "Original Observations in Jan. 1923, by which the New Annuities are computed." This is also corroborated by the table on page 64 of [13].

It should also be noted that there appears to be a typo in these tables. The tables claim to indicate mortality numbers out of 1000 lives, but even a cursory examination reveals that they are supposed to be out of 10000.

[41] Were individuals allowed to purchase annuities on the lives of individuals below the age of about 8, figure 10 does appear to provide some room for selection on age, but the minimum age of purchase was 35 and then 21 (in 1817). At older ages, the figures are un-informative.

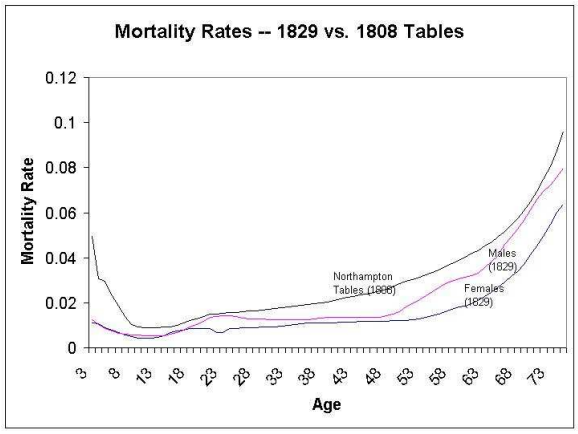

Figure 10: Source: see text

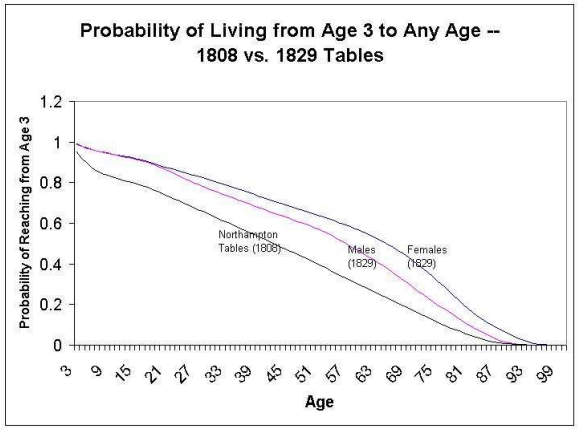

Figure 11: Source: see text

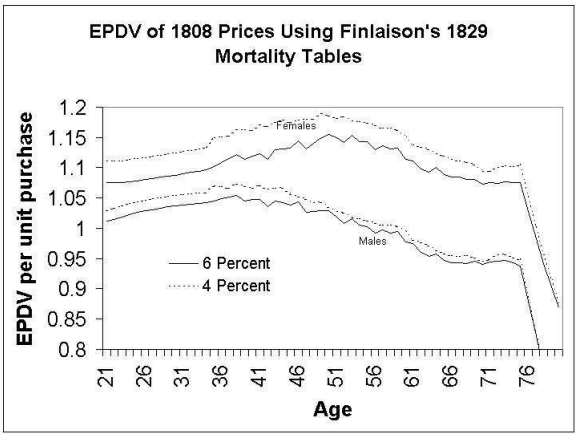

Figure 12: Source: see text

pute the EPDV of life-annuities using the pricing from the 1808 Act and Finaison's tables. A plot of the EPDVs at various interest rates appears in figure 12[42].

Figure 12 reveals several interesting facts about the 1808-1828 annuity pricing scheme. First, it is clear that life-annuities are unambiguously a good "investment," in present value terms, from the point of view of male purchasers under about 55 and female purchasers under about 75. Second, if price-based speculation-by-selection by a person informed of the Finlaison's mortality tables were taking place, we would expect to see a clustering of female nominees around 50 years old. Third, the constant price for life-annuities at ages above 75 leads to a rapid drop-off of the EPDV at older ages, so we would expect to see comparatively few nominees much above 75 (this third observation is not, of course, particular to Finlaison's tables.)

[42]For simplicity, I have assumed in constructing this figure that payments occurred yearly as opposed to half-yearly.

In this computation, I wished to include ages from 21 to 34, even though I have no explicit data on the pricing at these ages. Given the evidence presented in figure 9 and the knowledge that pricing of life-annuities was not amended until 1829, I was able to infer these prices from the Northampton mortality tables.

Before proceeding, it is useful to distinguish two types of selection. I will refer to these as 'self-selection' and 'speculation,' respectively. To the first: individuals may wish to purchase life-annuities on their own life (or on the life of a closely related individual such as a child or wife) in order to provide an income stream with an insurance component – e.g. to provide a guaranteed source of income for a widow or to insure oneself against running out of resources before death. By 'self-selection' I mean that individuals considering whether to purchase a life-annuity for this purpose will be more likely to choose to do so if the EPDV of that annuity is higher. On the other hand, an individual may wish to purchase a life-annuity on some life (not necessarily closely related to his or her own) as a pure financial investment. By 'speculation' I mean that individuals purchasing life-annuities for this purpose will carefully select the *lives* they choose to nominate so as to yield the greatest EPDV. Hence 'self-selection' occurs when the decisions of those individuals who are contemplating the purchase of life-annuities on *particular* lives are sensitive to the pricing on *those* lives; in contrast, 'speculation' occurs when the life *chosen* depends on the pricing of *all* types of lives. It is clear that the two types of selection can co-exist, and it may be difficult to distinguish empirically between the two.

There are at least three places in the history of this class of life-annuity issues to look for numerical evidence of selection: (1) gender selection before 1828, (2) age selection before 1828, and (3) age-selection after 1828. Keeping in mind that both types of selection can co-exist, it is natural to think that (1) and (2) are most likely to provide examples of self-selection, while (3) is better suited to an examination of speculation.

To examine (1)-(3), I have located two sources of data. First, I have found a digest of reports presented to parliament after 1799 [25]. It contains a distribution, separately by age and gender, of the purchasers of life-annuities between 1808 and 1832. This appears in table IX. Second, I have data on the distribution of purchase age and age of death for the 1808-1856 annuitant nominees, broken down by 'selected' and 'non-selected' status. This will be discussed below.

	Age					
Year	21-34	35-39	40-44	45-49	50-54	55-59
1808		5	13	26	35	43
1809		14	26	31	61	67
1810		10	14	22	45	45
1811		3	7	18	40	34
1812		2	9	11	18	42
1813		8	7	25	36	51
1814		7	11	15	43	44
1815		10	17	22	29	28
1816		11	19	15	50	52
1817	2	15	40	67	96	132
1818	19	18	31	44	78	86
1819	12	12	17	32	49	62
1820	13	12	17	39	87	66
1821	9	15	29	48	91	82
1822	21	24	50	87	115	121
1823	432	252	204	135	143	108
1824	29	29	36	34	69	73
1825	19	27	28	44	60	51
1826	25	26	39	70	92	101
1827	24	18	40	58	100	104
1828	11	12	28	31	56	51
1829	4	4	7	7	18	14
1830	26	13	39	43	75	94
1831	29	14	14	25	48	57
1832	15	11	14	23	46	50

Year	60-64	65-69	70-74	75-79	80+	All
1808	46	31	27	18	0	2192
1809	63	65	43	10	1	2383
1810	48	37	21	14	1	2203
1811	38	31	25	9	1	2131
1812	44	31	24	12	1	2131
1813	54	34	30	23	2	2251
1814	67	50	28	16	4	2284
1815	35	32	27	14	1	2154
1816	62	58	41	15	3	2339
1817	131	79	49	24	3	2768
1818	95	70	47	21	2	2587
1819	61	63	39	18	3	2392
1820	72	66	38	17	7	2478
1821	77	61	45	20	3	2530
1822	121	101	64	25	4	2899
1823	124	83	55	23	5	3705
1824	74	60	46	17	2	2511
1825	59	58	40	9	3	2404
1826	100	56	60	16	3	2668
1827	95	79	44	23	2	2682
1828	54	29	18	11	0	2252
1829	10	7	7	2	6	1955
1830	112	97	61	28	33	2843
1831	63	52	39	30	38	2530
1832	70	42	37	74	30	2601

Table IX: Numbers of Life-Annuities Purchased by Age. Source [25, page 214][43]

There are at least four important things to note about table IX. First, the 21-34 age category does indeed appear in its proper year: 1817. Second, there is a clear break in 1829, coinciding with the shut-down of sales and re-calibration of prices. Third, there is a substantial increase in the number of very old lives from 1829 on. Fourth, there is an anomalous number of purchases and – among those – young-life nominees in 1823. These four observations are more obvious in figures 13 and 14.

I have attempted to determine the cause of the fourth of these. The only reference to it that I have found is in a footnote to the table with the original

[43] What appears to be missing from this table is the nominees aged 15-21, who were admitted in 1829 [27, page 5].

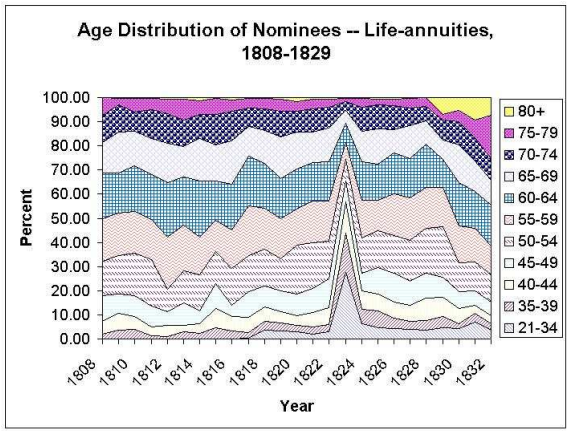

Figure 13: Source: [25, page 214]

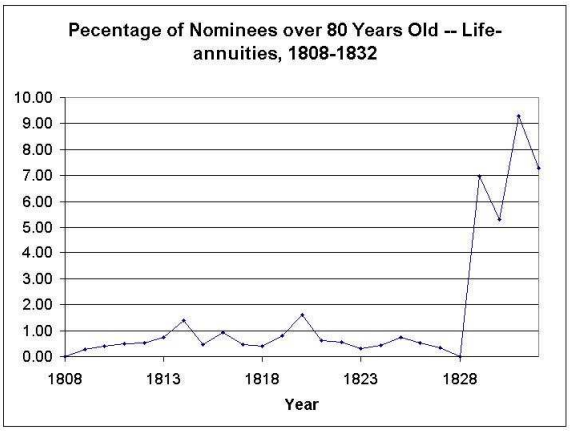

Figure 14: Source: [25, page 214]

data:

> The most striking feature... is the larger number of Young Lives admitted in 1823... [this] was doubtless occasioned by the 5%s paid off in that year... [25, page 214].

This is not particularly enlightening, but it may indicate that holders of 5% consols were required to sell them in 1823, perhaps only for life-annuities. In any event, lacking more information on this clear outlier to the pattern, 1832 will be dropped out of all future considerations.

Marshall [25] also has data on numbers of purchases each year by gender[44]. This appears in table X below.

[44]Unfortunately, he does not provide a table by age and gender simultaneously, so I do not have gender-specific age breakdowns.

	Of all Ages			Of all Ages	
Year	Male	Female	Year	Male	Female
1808	83	161	1821	147	333
1809	118	263	1822	226	507
1810	73	184	1823	438	1127
1811	72	134	1824	147	322
1812	68	126	1825	110	288
1813	89	181	1826	174	414
1814	74	211	1827	159	428
1815	60	155	1828	90	211
1816	98	228	1829	47	39
1817	206	432	1830	248	373
1818	144	367	1831	158	251
1819	95	273	1832	208	204
1820	131	303			

Table X: Numbers of Life-Annuities Purchased by Gender. Source [25, page 214]

The key observation concerning table X is the apparent increase in the male-female ratio after 1829. This is more easily seen in figure 15.

Tables IX and X and figures 13, 14, and 15 provide some preliminary evidence on (1)-(3): the three places we are looking for evidence of selection.

To (1), figure 15 shows clear evidence of a preferential nomination of females over males before 1829. We might be tempted to infer that this preferential nomination was due to the greater EPDV for women, and thus evidence of self-selection (or speculation.) However, it may have been that women were preferentially nominated because of the insurance characteristics of the life-annuities, which may have been

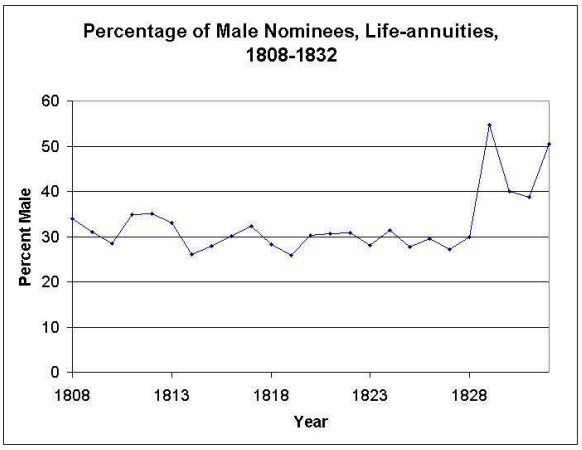

Figure 15: Source: [25, page 214]

more important for females. As such, the pre-1829 male-female ratio does not provide *any* evidence of selection in and of itself. But the clear structural break in the male-female ratio exactly at the time of the change in pricing in 1829 *does* provide this evidence – and rather convincingly. Indeed, a two-proportion Z-test on hypothesis that the fraction of males before and after the 1829 break are equal has a z-score of over 10 ($P < 10^{-26}$) in a 1-tailed test.

It is also interesting to note that a 1-proportion Z-test clearly rejects ($P = 10^{-5}$) the hypothesis that the proportion of males is 0.5 after 1829. This suggests that that there was a pre-1829 selection-induced demand in favor of females, and that this was in addition to a higher demand for female nominees even in the absence of selection effects[45].

To (2), there appears to be no evidence of selection by age in figure 13. If selection by age *were* occurring, we would expect to see nominees predominantly in the 30-60 age range as per figure 12. The peak of the distribution of nominees occurs between ages 60-64, however, and almost half of the nominees were above 60. We can certainly rule out *complete* speculation. Similarly, if the demand for life-annuities was independent of age, we can also rule out the possibility that the only cause for variation by age is the EPDV of that age. Nevertheless, it is reasonable to suppose that the insurance-demand for annuities increases with age – at least to a point – and therefore we cannot rule out the possibility of self-selection mixed with this increasing demand.

To (3), there *does* seem to be evidence of speculation by age after 1828, as indicated by the discussion in section 4.2. It *is* clear from figure 14 that there was a jump in the proportion of nominated lives above 80 years of age in 1829[46]. To see why this speculation was *able* to occur, recall that the life-table constructed by Finlaison was based on past annuitants. Hence, the older lives which Finlaison observed were, by and large, nominated at young ages. As such, they would tend to have higher mortality than a newly selected healthy older life. This possibility was discussed by John Finlaison [13, pages 61-63]. So there was the means and the know-how to engage in the selection of older lives. Murphy, in his 1939 address [27] relays a quotation from John Francis in 1853 asserting that a number of speculators had purchased annuities on the lives of old Scotsmen, and given their local clergymen and surgeons funding enough to make sure their "investments" stayed alive.

In spite of this strong circumstantial evidence, the jump in the proportion of octogenarians is *not* sufficient evidence to conclude that speculation was occurring. To see why not, recall that the EPDV of life-annuities fell of extremely rapidly with age above the age of 75 until 1829 – as indicated by figure 12. Because prices were re-calibrated to be more fair for older lives, the jump older lives in 1829 may therefore represent nothing more than self-selection: perhaps older lives had wanted these annuities before, but found them to be such a bad deal that they refrained from purchasing them.

To distinguish between the competing hypotheses of speculation and self-selection as the cause of the surge in older nominees in 1829, we turn to a second source of data on these life-annuitants. Alexander Glen Finlaison [13, writing in 1860] has data on all of the life-annuitants from the 1808-1850 life-annuity

[45] Assuming, of course, that Finaison's tables are correct – or at least believed to be correct by annuity buyers.

[46] A Z-test for the equality of proportion of octogenarians before and after 1829 yields the absurdly high z-score of 19.6.

sales. According to Finlaison, only 675 of the 16,812 lives in these data were explicitly purchased by "parties who speculated in life annuities." As for the rest, "the great bulk... are the investments of... persons who nominate their own lives for the tenure of the annuity" [13, page 14]. Finlaison divides these 675 'selected' lives into two classes: 322 "very old lives" (over 73) and 343 old lives (between 58 and 73.) The former, he claims, were mostly purchased shortly after 1829, while the later were sent in groups by city life-insurance offices. Lacking additional references and concrete facts on this matter, it would be unwise to take Finlaison's claims about the small speculative presence at par-value. It would seem that for administrative reasons and for proper incentives there would be strong cause for speculators to arrange for its nominees to purchase annuities in their own names, and to have a side contract designed to transfer the payments back to themselves. The mere lack of *explicit* nomination by a third party does not rule out the possibility of speculation. Nevertheless, the 675 'selected' lives – and particularly the 322 'very old lives' *are* of some great interest to us. If we can show that the mortality rate of these 322 lives was significantly lower than the mortality rate from Finlaison's tables, we will have strengthened the evidence in favor of speculation[47]. The data Finlaison provides is not ideally suited for this purpose. It appears in table XI below. This table show the number of the selected lives that entered at each age and the number who died at each age. This is subdivided into two classes: those who were nominated before the age of 84, and those who were nominated afterwards.

[47] To strengthen it even further, we would like to show that the mortality rate of these 322 lives was significantly lower than the mortality rate of the other 'very old' lives in the data nominated after 1829. Unfortunately, the form of the data provide by Finlaison does not allow this to occur. He tabulates, as of 1856, (a) how many individuals, in total, were nominated at each age, (b) how many individuals, in total, had died at each age, and, (c) how many individuals, in total, were still alive at each age. Because the non-selected lives are not broken down by age, many of the older lives captured in this sort of data were nominated at young ages. So these data do not allow us to separately identify the post-1829 self-selected (but not 'speculative') older lives.

	Class I		Class II	
Age	Entered	Dead	Entered	Dead
73	6	0	-	-
74	4	0	-	-
75	14	1	-	-
76	24	2	-	-
77	50	8	-	-
78	54	12	-	-
79	65	9	-	-
80	47	27	-	-
81	21	29	-	-
82	2	21	-	-
83	1	29	-	-
84	1	20	-	-
85	-	18	1	0
86	-	17	6	1
87	-	16	7	0
88	-	20	8	3
89	-	12	5	8
90	-	15	4	4
91	-	8	2	1
92	-	6	1	1
93	-	5	0	7
94	-	4	0	4
95	-	4	0	1
96	-	1	0	1
97	-	2	0	2
98	-	1	0	1
99	-	0	-	-
100	-	0	-	-
101	-	1	-	-

Table XI: "Selected Lives" of Life Annuitants from 1808-1856" Source: [13, page 89]

Lacking the matching of death ages with birth ages, it is difficult to easily determine if this distribution of death ages is consistent with Finlaison's mortality table. To get a rough idea, we can easily compute the total number of years lived (after nomination) by the nominees of each of the two classes (1839 and 122, respectively), and compare it with the expected number of years that a group of individuals with the indicated starting age profile would live according to Finlaison's mortality table (1502 and 63, respectively.) This *seems* to indicate successful selection; but are these numbers significantly different, or could they be due to random fluctuations?

To answer this question I ran a simulation. Using Finlaison's mortality table, and the initial distribution of lives in each of the two classes, I simulated 10,000 death-distributions. I then computed the total number of years lived (after purchase) by each of these 10,000 simulated distributions, and plotted the distribution of these total years. This distribution, for class I, is plotted below in figure 16; it is approximately normal, with a sample mean of 1501.86 and a standard deviation of 65.84. Under the null hypothesis that the mortality of these class I 'selected' annuitants follows Finlaison's tables a number of total years lived as large as 1839 is an *extremely* unlikely result ($z = 5.12, P = 1.5 \times 10^{-7}$).

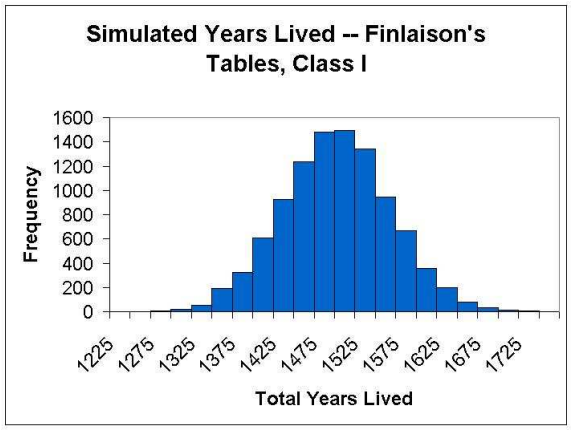

Figure 16: Source: [25, page 214]

Similarly, the sample mean and sample standard deviation for the class II simulation were 62.96 and 11.18, respectively. Observing an actual total number of years as high as 122 under the null hypothesis that class II 'selected' lives follow Finlaison's mortality table is even more unlikely ($z = 5.28, P = 6.3 \times 10^{-8}$).

In spite of this overwhelming evidence of selection, note that we still lack hard evidence that this was 'speculation' rather than 'self-selection.' To reach this conclusion, we would need to look at data on the death distribution of older lives which were not 'speculative' (according to Finlaison's definition.)

6 Conclusions

From the late 15th century through the middle of the 19th century, Holland, Britain, and France made use of life-annuities and tontines for borrowing purposes. The pricing of these life-contingencies often provided different rates of return depending on the age and gender of the nominated lives. There was therefore ample opportunity for selection in the nomination process. The degree to which governments and investors recognized and suffered from or exploited this opportunity has been much discussed. There is a preponderance of supposition and circumstantial evidence that, as this period passed, investors became more and savvy, and therefore more able to take advantage of governmental mis-pricing.

This paper has presented some of the first hard numerical evidence to shed light on the degree to which selection occurred – particularly in the context of the British life-annuity issues associated with sinking fund in the early nineteenth century. Selection effects were found to be quite powerful therein: when pricing policies changed with respect to age and gender, the makeup of the annuitant pool changed dramatically. A broad class of buyers clearly understood the selection opportunities.

This paper has also presented the first quantitative analysis on the effectiveness of "speculation" in these markets (that the author is aware of.) It presented numerical evidence that the Swiss lives involved in the Irish tontine of 1775 were carefully and successfully selected to an impressive degree: calculations presented in section 5.1 show that the Swiss lives selected were as much as 50% more likely to survive until 1830 – *after* accounting for age and gender.

The primary data tapped in this paper covers only two of the large number of life-annuity issues of the 17th, 18th, and 19th centuries. Further research into primary data sources will shed even more light on the degree to which purchasers were able to and did select nominees over the course of this time period – and hence illuminate the degree of intellectual development of a broadly conceived "investor class" over the course of this crucial time-period. At the same time, a more thorough investigation of Swiss[48] "speculation" in life-contingent debt could be undertaken easily upon the location of comparable data for any of a number of the other debt-issues. This would, in its turn, illuminate the degree to which an analytically sophisticated "elite" group of investors was able to use their superior mathematical skills to take advantage of investment opportunities. These two, taken together, have potential to provide historical insight into the contemporary dichotomy between the unprecedentedly broad "investor class" and the modern-

[48] And other savvy financiers such as the Dutch in the British life-annuities of the 1740s.

day hyper-analytical"investment elite." It is this author's hope that the present work will inspire future research along these lines.

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