Adverse Selection and Redistribution in the Irish Tontines of 1773, 1775, and 1777

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Abstract

We construct and analyze a new data set on the mortality experience of the nominees of the 1773, 1775, and 1777 Irish Tontines. The active participation of Genevan speculators in these Irish tontines has been well documented. We use our new data to quantify the extent to which these nominees were longer-lived and the financial consequences of that enhanced longevity. The Genevan nominees were indeed notably longer-lived than non-Genevan nominees—particularly so for the 50 nominees selected by a Genevan investment syndicate. Their enhanced longevity had only trivial consequences for the Irish government issuer, but it led to significant redistributional from non-Genevan to Genevan investors. We highlight the implications of this across-group redistribution for modern proposals to introduce tontine-like elements into modern retirement pensions.

Keywords: Historical annuities; Pension reform; Life-contingent debt finance

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1 Introduction

Economists have long recognized the value that defined benefit pensions and life annuities provide in insuring retirees against the idiosyncratic risk of outliving their resources (viz Yaari, 1965; Davidoff et al. 2005). Pensions and life annuities also protect retirees from aggregate longevity risk by effectively offloading this risk onto annuity providers. Providers' limited ability to hedge their exposure to this aggregate risk (Blake, 1999) can both cause higher pricing (Brown and Orszag, 2006) and raise the probability of default risk, particularly for underfunded state and local pensions (Forman and Sabin, 2014).

In contrast to a traditional life annuity or defined benefit pension, which pays a regular, guaranteed income stream to an annuitant for the remainder of his or her life, a tontine is a financial product that pays a regular, guaranteed sum to a *pool* of subscribers—a sum which is then divided up among the surviving members of that pool. A number of scholars and practitioners have recently proposed incorporating tontines or tontine-like products features into pension and annuity products on the grounds that tontines mitigate providers' exposure to aggregate longevity risk and can thereby improve pricing and limit default risk. These including Piggott et al. (2005), Rotemberg (2009), Forman and Sabin (2014), Newfield (2014), Milevsky and Salisbury (2015), and, most notably, Milevsky (2015) in his book *King William's Tontine: Why the Retirement Annuity of the Future Should Resemble Its Past*.

The aggregate-longevity risk-hedging benefits of tontines are most easily seen from the point of view of the party responsible for providing the regular income stream. Consider, for example, a cohort of newly retired 65-year-old individuals "locking in" a pension for the remainder of their lives, and consider a government with a fixed sum of resources R set aside to fund these pension payments. Suppose first that, as in the U.S. Social Security system, the government pays a pension in the form of a life annuity: it promises each individuals a fixed annual income for as long as that individual remains alive, with the magnitude of the annual income calibrated so that the expected discounted cost equals R. In this case, the government is fully exposed to aggregate mortality risk: if the cohort turns out to have significantly lower mortality than expected, then the provider will see their annual pension payment outlays rise more or less immediately, and the cost of providing the pensions will greatly exceed R.

Contrast that with the case of a pure tontine, where the government earmarks a regular annual payment to the entire *cohort* of individuals, and, each year, divides that annual payment up among the surviving members of that cohort. In this case, the government is minimally exposed to aggregate mortality risk. It is true that, if the cohort turns out to be longer-lived than expected, the government will be responsible for making additional expected payments, but *all* of these extra payments will occur some forty or more years in the future, after the last member of the cohort was originally expected to decease. At a 5% discount rate (e.g.) the provider will be on the hook for no more than an additional 15% of R in payments—as $(1.05)^{-40} \approx 15\%$, so the extra payments in the post 40-year tail would have a present value of 15% if death was completely eliminated and the provider owed constant tontine payments forever.

The fact that tontines provide an effective hedge for aggregate mortality risk from the point of view of an annuity or pension provider such as a government does not necessarily make them desirable, of course. Indeed, relative to a traditional pension annuity, a tontine exposes the pension recipients—who may have less ability to bear it—to greater aggregate longevity risk. We use the unique historical "experiment" to discuss (and, in this historical case, to quantify) another potential drawback to tontine schemes: tontine pools may introduce redistributive risks caused by the potential for group-specific longevity shocks. For example, the small mortality improvements experienced by lower earners relative to high earners in the U.S. during the 20th century (National Academies, 2015) would have effectively redistributed (more) resources from low to high earners if they were participating in the same tontine-based pension scheme.

As we discuss in Section 3, the public sector use of both tontines and traditional annuities was common in early modern Europe. Milevsky (2014), for example, examines King William's Tontine of 1693—the earliest use of public-sector life-contingent debt in Great Britain—which involved using *both* types of products to raise funds. Our paper uses a newly compiled data set from a under-studied historical tontine scheme to explore the hedging benefits and distributional risks of tontines.

Specifically, we compile and analyze a new data set on the Irish tontines of 1773, 1775, and 1777. These have been discussed in earlier literature, notably by Gautier (1951) and Jennings and Trout (1983), but without the benefit micro-data we have gathered from several archival sources. We have a complete list of all lives nominated for these tontines, their age at the time of nomination, their domicile, and substantial but—because of imperfect record-keeping—incomplete information on their death dates. These data allow us to make precise computations of the mortality experience of different sub-groups of participants in these tontines and, for the first time, precise estimates of the financial returns to investments therein.

As discussed in Gautier (1951) and Jennings and Trout (1983), Genevan bankers subscribed heavily to these Irish tontines. These bankers took advantage of the fact that, like most life-contingent debts issued in early modern Europe, the owner of the tontine income stream did not have to have an insurable interest in the nominee on whose life the tontine payments were contingent. Indeed, as discussed in Cramer (1946), these Genevan bankers had reportedly mastered the art of picking particularly long-lived nominees through extensive participation as investors in the French life-contingent debt studied by Weir (1989) and Velde and Weir (1992).

We first use our micro-data to show that Genevan nominees indeed had mortality rates significantly below those of the non-Genevan nominees, confirming some rough calculations in Jennings and Trout (1983) and Gautier (1951). Second, we are able to compare the longevity of the 50 nominees identified in Gautier (from the records of a Genevan investment syndicate) with the longevity of other Genevan nominees. We find that the syndicate appears to have been markedly more skillful in selecting high-return nominees.

Third, our data allow us to decompose longevity enhancements into two components: a component attributable to the better age and gender "selection" by Genevan nominees, and a component attributable to selection of nominees with lower gender- and age-conditional mortality rates. We find—contra the thrust of earlier work on these tontines—that most or all of the enhanced longevity can be attributed to lower age- and gender-conditional mortality.

Finally, we provide a precise quantitative assessment of the enhancement of financial returns earned by the nominators of Genevan nominees. We show that, in tontine issue where the Genevan presence was most notable, the syndicated Genevan nominees earned, on average, an 8.5% higher rate of return than did the non-Genevan nominees. Importantly, however, the cost *to the Irish government* of raising funds was essentially unaffected by the presence of Genevan bankers.

These findings suggest that adverse selection was quantitatively important in this life-contingent debt-issue—mirroring Rothschild's (2009) findings for the British Life Annuities of 1808-1850. Unlike Rothschild's study however—which documented significant gains by speculative investors in government-issued life annuities at the expense of the British Government—the tontine structure of the Irish life-contingent debt successfully insulated the issuing government from the costs of this selection; the costs of adverse selection were borne *within* the nominee pool by the investors with less adversely-selected nominees.

In other words, relative to the roughly-contemporaneous traditional government-provided annuities, tontine annuities effectively hedged aggregate longevity risk. This hedge did not come costlessly, however: the presence of a sub-group of nominees—the Genevans—with significantly enhanced longevity led to non-trivial *distributional* consequences.

Our paper proceeds as follows. In Section 2, we use a simple analytical model to clarify the important aggregate-mortality-hedging differences between tontines and life annuities. In Section 3, we describe the Irish tontines and the construction of our data set. In Sections 4 and 5, we analyze these data. In the former, we test for the extent and patterns of longevity enhancements among Genevan nominees. In the latter, we estimate the financial and distributional implications of these longevity differences. Section 6 concludes and offers a back-of-the-envelope calculation of the potential magnitude of the distributional risks associated with converting the U.S. Social Security system to a tontine scheme, the details of which appear in a technical appendix.

2 A Simple Model of Tontines vs Life Annuities

This section uses a highly stylized model to illustrate the significant hedging benefits of tontines versus traditional annuities. It then minimally tweaks the model to illustrate the potential distributional risks associated with tontines versus traditional annuities.

In these stylized models, there are many individuals i, each with a time-independent mortality hazard $(1 - s_i)$. A government with a discount rate of $\delta = 1/(1+r)$ is considering offering one of two products. The first is a life annuity, which will pay a constant real income stream of y at a price normalized to 1. The second is a tontine, with shares again normalized to a price of 1, which will pay out a total income of Nz each year, where N is the number of individuals in the tontine pool. The government cannot distinguish individuals, and believes that each has some time-independent mortality hazard $(1 - \hat{s})$. Given this belief, it prices the two products in order to break even, in expectation:

$$y = \left(\sum_{t=1}^{\infty} \delta^t \hat{s}^t \right)^{-1} \tag{1}$$

and

$$z = \left(\sum_{t=1}^{\infty} \delta^t \left(1 - (1 - \hat{s}^t)^N \right) \right)^{-1}. \tag{2}$$

If the government's belief about the survival hazard $\hat{s}$ is correct, then the government breaks even at these prices. If the true mortality hazard s_i is lower than $\hat{s}$ for some or all of the nominees, the government will lose money in expectation: it charges a price 1 for the income stream y or z, when, to break even, it should have been charging a price $p > 1$ (or, equivalently, offering a lower payout stream at a unit price).

Figure 1 plots the magnitude $(p-1)/p$ of the government losses in the case of a uniform-across-nominee mortality reduction. Specifically, it considers the special case

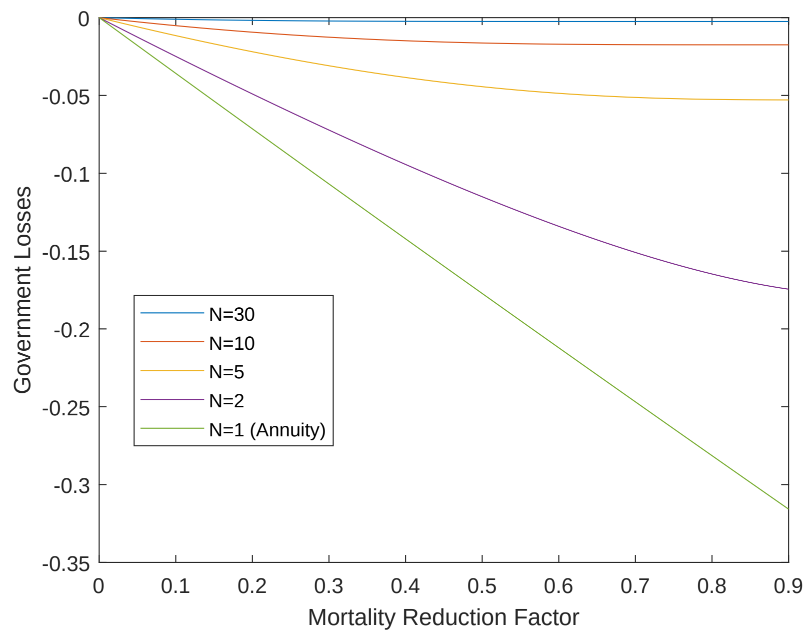

Figure 1: Government losses (actuarially fair price - actual price)/(actuarially fair price) as a function of a uniform mortality reduction by a factor α for tontine pools of various sizes. Assumptions: baseline mortality $(1 - \hat{s}) = 1/40$, interest rate $r = 5\%$.

where, for all i, $(1 - s_i) = (1 - \alpha)(1 - \hat{s})$ for some mortality reduction factor $\alpha \in [0, 1]$. It plots the losses, as a function of α, for tontine pools of various sizes N (with $N = 1$ corresponding to an ordinary life annuity). The figure assumes an interest rate of $r = 5\%$, and a baseline survival hazard of $\hat{s} = 39/40$, corresponding to a life expectancy of 40 years.

Figure 1 shows that the government losses rise rapidly with the mortality reduction factor α for an annuity, with a 20% mortality reduction corresponding with more than a 7% loss. Government losses are much smaller for even modest-sized tontines. For a tontine pool as small as 5, losses barely exceed 5% even for a 90% mortality reduction. For a tontine pool with 30 members, government losses barely register at all. This is because, under our simple assumptions, an $N = 30$ tontine pool is effectively a perpetuity: there is a 99.63% chance that one of its members will live for 70 or more years; and with an interest rate of 5%, less than 3.3% of a perpetuity's present value is attributable to the "beyond 70 years" tail.

Next, consider instead an *uneven* reduction in the mortality hazard. Specifically, suppose that *half* of the nominee population (the "long-lived" types) has mortality hazard $(1 - s_i) = (1 - \alpha)(1 - \hat{s})$ for some $\alpha \in [0, 1]$, while the other half (the "short-lived" types) has unreduced mortality $1 - s_i = 1 - \hat{s}$. Figure 2 plots the actuarial effects of this mor-

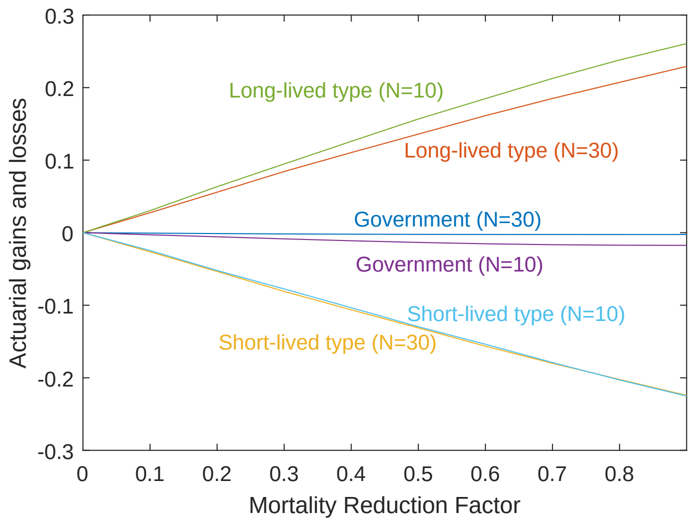

Figure 2: Percent changes in present-discounted value for tontine pool members caused by an unexpected mortality reduction for half of the nominee population (the "long-lived" types) holding the mortality of the the other half (the "short-lived" types) fixed. Assumptions: baseline mortality $(1 - \hat{s}) = 1/40$, interest rate $r = 5\%$.

tality reduction for tontine pools of size $N = 10$ and $N = 30$. In particular, it plots both the associated government losses—which, per figure 1, are modest for all α—as well as the expected present discounted value gains accruing to the high-longevity types and the expected present discounted value losses borne by the low-longevity types. The figure clearly shows that the *across-type* effects swamp the effects on the government at all levels of α: the primary effects of mortality changes in tontine pools are distributional.

Figure 3 plots the welfare losses to short-lived types caused by unexpected mortality reductions to *other* members of their tontine pool. Specifically, it considers a tontine with 15 short-lived types with baseline mortality $1 - \hat{s} = 1/40$ and 15 long-lived with mortality $1 - s_i = (1 - \alpha)(1 - \hat{s})$ for various mortality reduction factors α, and it assumes that individuals are von Neumann-Morgenstern expected utility maximizers with time-additive constant-relative risk aversion utility functions with a risk aversion parameter of $\gamma = 2$ (i.e., $V = \sum_{t=1}^{\infty} \hat{s}^t u(c_t)$ with $u(x) = x^{1-\gamma}/(1-\gamma)$ for $\gamma = 2$). For any given α, we use Monte Carlo simulations to compute the expected utility of the short-lived types. We then compute the "equivalent variation:" the percentage reduction in the annual tontine dividend that would result in an equal expected utility if the long-lived types had

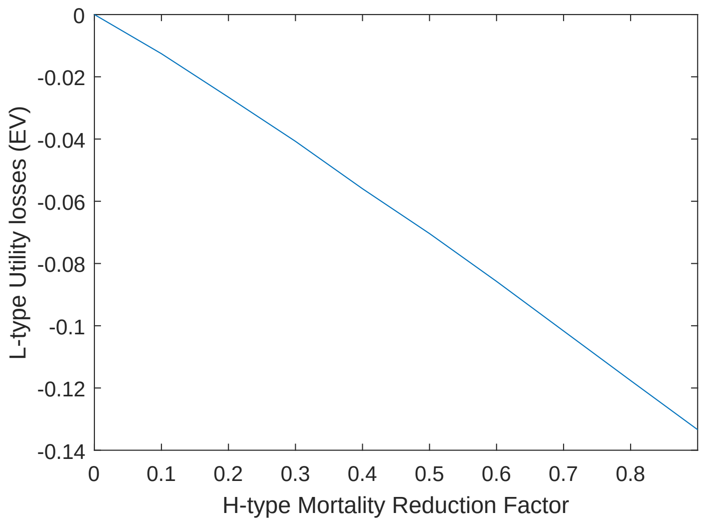

Figure 3: Welfare losses to short-lived types caused by an unanticipated reduction in the mortality of the long-lived half of nominees in a tontine pool of size $N = 30$. Losses are computed as the expected-utility-equivalent uniform percentage reduction in annual tontine dividends under the uniform baseline mortality. Assumptions: 15 "long-lived" and 15 "short-lived" nominees; baseline mortality $(1 - \hat{s}) = 1/40$; interest rate $r = 5\%$; constant relative risk aversion of 2.

maintained their baseline mortality $1 - s_i = 1 - \hat{s}$.[1] The potential losses are sizable: a 35% reduction in H-type mortality is welfare equivalent to about a 5% decrease in the tontine payment.

We now turn to the data from the Irish tontines to illustrate the extent to which these same effects played out as a result of selection-on-lives by the Genevan finance community.

3 Historical Background and Data

Tontines were proposed as a source of public funds by Lorenzo Tonti, an expatriate Neapolitan who secured a position in the court of the French King in the 1650s (Hendriks, 1861). Tonti's proposal was carried out by King Louis XIV in 1689, and a total of 15 tontine issues were undertaken by the governments of Britain and France over the subsequent

[1]Because the short-lived types have exogenous mortality, we can treat utility in the "dead" states as any constant. Note that a similar exercise would not be possible for the long-lived types without taking a stand on the "value" of being alive vs. dead – i.e., the value of longevity improvements themselves.

century (viz Weir (1989) who, along with Jennings and Trout (1982), is excellent an source for additional historical details).

This paper focuses exclusively on the Irish tontines of 1773, 1775, and 1777. These tontines were the most successful of all of the tontine issues on the British isles. They raised a total of over £7 million—or over £850,000 in current terms.[2] Each of the Irish Tontine issues were were divided into three classes: Class 1 consisted of nominees over 40, class 2 of nominees between 20 and 39, and class 3 of nominees under 20. All allowed nominees of either gender. Each share cost £100, the equivalent of approximately £12,000 or £150,000 using price or wage indexing (www.measuringworth.com). Multiple shares could be taken out on a given nominee's life. For the 1773 and 1775 issues, each share carried a 6% dividend rate—with the exception of the 1773, class 1 issue, which carried a 6.5% dividend rate. In 1777, the dividend rate was 7.5%.

There was no requirement of an "insurable interest" for investing in one the Irish tontines: As with most life-contingent debt issues in early modern Europe (viz Rothschild, 2009), there was no requirement for the party receiving the tontine payments to have had any relation whatsoever to the nominee upon whose life those payments were contingent. This made the tontine issues perfect opportunities for speculative investments—most notably by those in the Genevan banking community who had recently been actively investing in French life-contingent debt (Cramer, 1946). Indeed, as discussed in Jennings and Trout (1983), the Genevan banking community was, in the early 1770s, actively developing and exploiting the so-called "Geneva formula" which involved an investor or syndicate purchasing life-contingent debt on multiple lives, and then pooling and securitizing the resulting income stream. There is both direct and anecdotal evidence that the Genevan community engaged in just such a scheme in at least the 1777 Irish Tontine.

Gautier (1951) discusses the presence of 50 nominees in the 1777 who were explicitly part of a syndicate.[3] Jennings and Trout (1983) use some limited observations of nominee mortality to argue that these 50 nominees were significantly longer lived than the other nominees. They claim, in particular, that the 32 of these 50 nominees survived until 1837, as compared with only 461 out of 1091 overall. They also compare the nominees to (then) contemporary life tables, and argue they were longer lived than those tables would have suggested.

[2]This calculation was done using MeasuringWorth's purchasing power calculator (MeasuringWorth, 2017) to convert 1777 U.K. £ into 2017 U.K. £. Shares were purchased in Irish £, which traded at approximate parity with British £ at the time. Indeed, the Payment Books indicate that in 1826 the Irish tontine dividend payments were converted from Irish to British £ at a rate of .926 British £/Irish £.

[3]For a first-hand account of the actions of this syndicate, see a letter therefrom on pp. 15-16 of the 1813 Report from the Committee on the Tontine Annuities of Ireland, 1773, &c

Owing to their limited access to data, neither Gautier (1951) nor Jennings and Trout (1983) attempt to further quantify the relative mortality of these nominees and the many other Genevan nominees. In particular, while both papers speculate about the high returns presumably earned by the Genevan nominees, neither has the necessary data to quantify these returns. Moreover, neither paper looks at the 1773 and 1775 tontines, which also had a non-zero Genevan presence.

We assemble a comprehensive data set using several archival primary sources in the National Archives in London which allows us to dig deeper into these issues.

Our first primary data source is a set of three "nominee books" documenting the details of the original lives nominated for the three waves of the tontine (Clements, 1775, 1777, 1779). These Nominee Books provide a detailed profile of the nominees at the time they were nominated for the tontine, notably the nominee names, their country of residence, their age, their gender, and the amount subscribed on their lives (number of £100 shares). Hand written notes of death dates were added to this book over time, as were forfeiture dates for the nominees who failed to claim payments for three consecutive years; since the financial gains from claiming dividends were substantial, these forfeitures likely to reflect unrecorded deaths in most cases, and, for the subsequent analysis, we treat a forfeiture in year t as a death in year $t-3$.

Unfortunately, the death and forfeiture records in the Nominee book are extremely incomplete: the majority of nominees have neither a death date nor a forfeiture date recorded.

Our second major source is a nearly-complete set of "payment books" documenting the period from December, 1802 until the termination of the tontines (U.K. Parliament, 1802, 1830, and 1852). Each page of the payment books provides a given semi-annual payment. They report, in particular, two key pieces of information: a list of newly deceased or forfeited shares, and the "extra" dividend paid out to surviving shares as a result of these and earlier deaths and forfeitures.[4]

The payment books are remarkably complete, but there are, nevertheless, three types of omission therefrom. First, the payment books only begin in 1802—when British Parliament took over administration from Irish Parliament. So data from the 1773-1802 period are lacking. Second, the payment book recordings for each class cease when the last nom-

[4]The precise accounting works as follows. First, they compute a total "redundancy" in the accounts. This consists of any carried over redundancy, plus all of 6%/2, 6.5%/2, or 7.5%/2 dividend payments that *would* have accrued to the shares which have already "fallen" through forfeiture or death. Second, the resulting redundancy is then divvied up evenly among the remaining shares to determine an "extra" payment that shareholders receive in addition to their initial 6%/2, 6.5%/2, or 7.5%/2 payment. Typically, round numbers are used for this extra payment, which results in a modest remaining redundancy, which then carries over to the next semi-annual payment period.

inee dies—so the death of the final nominee is not recorded. Third, they are missing for one year between Christmas 1850 and Midsummer 1851. Across all 9 class-year issues, the payment books identify approximately 75% of the death (or forfeiture) dates of the lives initially nominated (a total of 2701 of the 3558).

We are able to partially fill in approximately one-forth of these missing data using other sources—most prominently the nominee books. Specifically, the nominee books can be used to identify the death ages of all of the last-to-die nominees missing from the end of the payment books and the death or forfeiture dates of a number of individuals who presumably appeared in the missing 1850 and 1851 books for several nominees from the 1773 class 3, 1775 class 2 and 3, and 1777 class 2 and 3 issues. They also contain a sub-set of death ages for those who died prior to 1802, but only in the 1777 class 1 (where the data are complete) and 1777 class 3 nominee books (which is about half-complete in the pre-payment-book data). So it is only for these two latter issues that we have *any* data on death ages prior to 1802 (with the exception of a small number of nominees reported in the first payment book who died a few years prior to 1802).

We also make modest use of four supplementary sources. First, Gautier (1951) reports the death dates for all 50 of the Genevan syndicate nominees discussed above—one of which appeared in neither of our two main data sources. The data from Gautier are otherwise consistent to within 1 year (in all but one 2-year case) with our main data sources.

Second, the House of Commons issued a report in 1811 (Committee on the Tontine Annuities, 1811) which contains a comprehensive list of all nominees from all three tontine issues who were certified to be living in December, 1810.[5] We used this 1810 data to corroborate the data from other sources, and we find virtually perfect agreement. Across all 9 class-year tontine issues, we identified only four nominees who were certified to be alive in 1810 and for whom we could not identify a death date from the payment or nominee books. We presume these individuals to have died in 1851—i.e., that they appeared in the one missing year of payment books.

Third, Marie Antoinette, whose 1793 death date is well known, was among the nominees lacking a recorded death date. We manually add this death date.[6]

[5] A similar 1830 report (Committee on the Tontine Annuities, 1830) contains a comprehensive list of all nominees who received their half-yearly tontine payment in early 1830. This is less useful, as a large number of subscribers appear not to have collected this payment by the time the report was constructed, but who remained in the pool, collecting payments thereafter. Presumably, these nominees collected their 1830 payment at a later date. Regardless, the 1830 report is not comprehensive enough to be useful.

[6] There is also a set Register Books (Irish Tontine Leger Session, 1773 and 1775 and Irish Tontine Leger Session 1777) which record a subset of nominees, all of whom died or forfeited after the start of the payment book data. We used these to spot check some nominee and payment book data book data, but otherwise did not employ it.

Fourth and finally, we searched for still-missing names from the 1777 class 3 Tontine issue on two online genenology data aggregators (familysearch.org and acestry.org) and identified two additional matches: Hester Paulina Lushington (died 1795) and Thomas Pack (died 1786).

Table 1 summarizes the sources of death dates and the missing data. It also reports the percentage of "deaths" which were recorded as forfeitures.

Year:	1773			1775			1777			
Class:	1	2	3	1	2	3	1	2	3	Total
Payment Book	39	178	551	63	154	505	102	243	866	2701
Other Source	0	0	11	0	2	14	45	5	131	206
Total	84	230	705	115	203	663	147	320	1091	3558
% Missing	54	23	20	45	23	22	0	23	9	18
% Forfeitures	0	1	6	0	1	8	10	5	13	-

Table 1: Sources of Death Data

We are particularly interested in comparing the longevity experience—and hence financial returns—of Genevan nominees with those of the non-Genevans. Insofar as the Genevan nominees had relatively greater longevity, we are further interested in knowing the extent to which these longevity enhancements can be attributed to better selection of ages and genders versus better selection of lives *conditional on age and gender*.

Tables 2-5 provide summary statistics on the numbers and basic demographics of the Genevan and non-Genevan nominees in the various tontine issues. Each table breaks out the number of nominees, the number of shares, and the gender and age breakdown by Genevan vs Other residential status at the time of nomination. In class 3 of the 1777 tontine, the table further breaks down the number by "Gautier" and "Other Genevan" status—since the 50 nominees identified in Gautier (1951) as being nominated by an investment syndicate represent a identifiably distinct group. This distinctness is clear from the demographics: the Gautier 50 were all female, they had a significantly lower age than did both the other Genevan nominees and the non-Genevan nominees, and the number of shares per nominee was significantly higher than any other group in any tontine issue. There is some suggestive evidence from table 3 that the Genevan nominees in class 3 of the 1775 issue were selected, at least partially, by investors using a similar strategy: they are predominantly female and much younger in comparison with non-Genevan nominees, but they only have about one share per nominee, and they are still a modest presence in the overall tontine pool. By contrast, the Genevan nominees in other classes and years—including the non-Gautier Genevans in 1777 class 3—are not predominantly female or are not younger than the non-Genevan nominees and had few shares per nominee.

In keeping with the fact that the posted annual dividend per share was independent of class[7], the vast majority of nominees in all three years were in class 3.

	Class 1		Class 2		Class 3	
	Genevan	Other	Genevan	Other	Genevan	Other
Nominees	2	82	8	222	21	684
Shares	2	270	18	663	22	1675
% Female	0.0	54.9	37.5	62.2	52.4	60.1
Mean Age (Female)	-	44.4	21.0	27.0	9.7	8.4
Mean Age (Male)	42.5	44.9	26.2	26.6	9.3	8.5

Table 2: Summary Statistics: 1773 Irish Tontines

	Class 1		Class 2		Class 3	
	Genevan	Other	Genevan	Other	Genevan	Other
Nominees	25	90	12	191	39	624
Shares	26	179	13	382	56	1093
% Female	0.0	58.9	25.0	62.3	76.9	59.8
Mean Age (Female)	-	45.3	22.0	27.2	4.8	8.6
Mean Age (Male)	41.0	44.0	22.1	28.3	4.2	7.8

Table 3: Summary Statistics: 1775 Irish Tontines

	Class 1		Class 2		Class 3		
		Non-		Non-	Genevan		Non-
	Genevan	Genevan	Genevan	Genevan	Gautier	Others	Genevan
Nominees	28	119	40	280	50	138	903
Shares	34	175	50	453	710	191	1375
% Female	7.1	51.3	52.5	61.4	100.0	44.9	57.0
Mean Age (F)	42.0	44.6	22.2	26.8	3.4	6.0	8.4
Mean Age (M)	42.4	43.9	22.5	26.9	-	5.5	8.2

Table 4: Summary Statistics: 1777 Irish Tontines

Figure 4 plots the distribution of ages for the three groups of nominees in the largest and most interesting of the tontines: the 1777 class 3 issue. The Gautier 50 are clearly carefully selected, in terms of demographics, with all ages roughly uniform between 1 and 5, and no nominees older than 7. In contrast, both the other Genevan nominees and the non-Genevan nominees have long tails extending into the upper ages of the class.

[7]The higher 6.5% dividend for the 1773 class 1 issue may have been implemented because some of the initial nominees died after purchasing shares but before the payments commenced.

	Class 1		Class 2		Class 3		
	G'van	Other	G'van	Other	Gautier	Other G'van	Other
Nominees	28	119	40	280	50	138	903
Shares	34	175	50	453	710	191	1375
% Female	7.1	51.3	52.5	61.4	100.0	44.9	57.0
Mean Age (Female)	42.0	44.6	22.2	26.8	3.4	6.0	8.4
Mean Age (Male)	42.4	43.9	22.5	26.9	-	5.5	8.2

Table 5: Summary Statistics: 1777 Irish Tontines

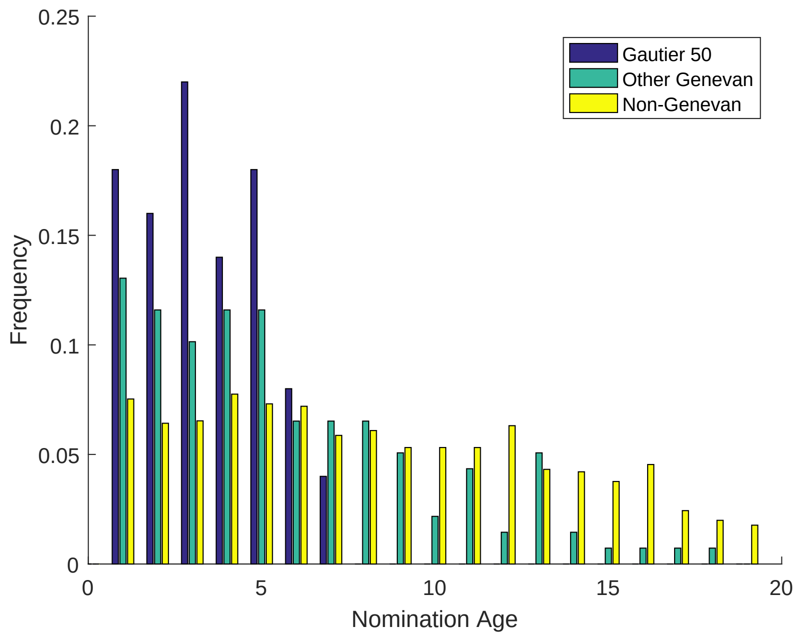

Figure 4: Distribution of ages of the 1777 class 3 nominees.

The demographic differences visible in Figure 4 clearly corroborate the anecdotal evidence in Gautier (1951) and others about the Genevan syndicate was actively selecting lives on the basis of *observable* characteristics (age and gender) in pursuit of high financial returns. Anecdotally (see Jennings and Trout (1983)), they were also actively selecting on the basis of *unobservable* (to us) characteristics. In the next two sections, we attempt to quantify the extent to which they were successful in selecting more favorable nominees, and the extent to which this success is attributable to selection on observable versus unobservable characteristics.

4 Non-parametric Tests for Differential Selection

This section formally tests for longevity differences between different groups of nominees in the various tontine issues. We run tests for differences among different subsets of nonminees—e.g., the Gautier 50 versus the non-Genevan nominees or the Gautier 50 versus the other Genevan nominees. For the sake of concreteness, however, our discussion proceeds in terms of comparisons the longevity of Genevan (G) and non-Genevan (NG) nominees.

We run three types of tests. The first test is for whether the typical G nominee died in a later year than the typical NG nominee. When the answer is yes (as it is, and strongly so, for the 1777 class 3 tontine), there are two conceptually distinct reasons: the G nominees may have been longer-lived because of a distribution of ages and genders that was more conducive to longer lives, or else (or in addition) they may have been longer-lived because of a better longevity experience for nominees of a given age and gender. The second and third tests we discuss separately test for evidence of mortality differences due to these two distinct reasons.

A challenge we face in conducting these tests is our lack of a complete set of death dates. Before describing how we address this incomplete data problem, we first describe a closely related set of tests we could run with a complete data (as we have for the 1777 class 1 issue). To that end, suppose that we have all death dates, and note that a natural test statistic is the then-readily-computable difference D between the mean death dates for G and NG nominees.

The distribution of D under the null hypothesis of "no longevity differences" can be found by computing the value of the test statistic under each possible permutation of G versus NG status for each nominee. More precisely, note that computing the difference in mean death dates only requires knowing the death date d_i and domicile $h_i \in \{G, NG\}$ of each nominee and, under the null-hypothesis of "no longevity differences", it is equally probable to have observed $\{(d_i, h_i)\}_{i \in I}$ and $\{(d_i, h_{P(i)})\}_{i \in I}$ for any given permutation $P(i)$ of I. For each such $P(i)$ we can compute the difference in mean death ages $\tilde{D}_P$. We compute a p-value for a nonparametric test for longevity differences by comparing the *actually observed* mean death age difference with the distribution across $P(\cdot)$ of the $\tilde{D}_P$.

We can similarly use a version of the test statistic D to test for the presence of longevity differences due *only* to differences in age and gender across the G and NG group. We do this by strongly maintaining the assumption that there are *no* differences conditional on age and gender. Under this maintained assumption, any permutation of h_i *within* each (age,gender) cell is equally probable: the particular data set $\{(d_i, h_i)\}_{i \in I}$ is *assumed* to be a random draw from the set of all possible data sets $\{d_i, h_{Q(i)}\}_{i \in I}$, where $Q(\cdot)$ varies across all possible within (age,gender)-cell-permutations of nominees. A p-value for the test of mortality differences due to differences in the age and gender distributions across the G and NG groups can thus be found computing the p-values for a basic test of mortality differences (from the preceding paragraph) for each of the notional data sets $\{d_i, h_{Q(i)}\}$ and averaging. Equivalently, we can compute the probability that the $\tilde{D}_Q$ associated with a randomly selected age-and-gender-conditional permutation of death ages $Q(\cdot)$ will exceed the $\tilde{D}_P$ associated with a randomly selected unconditional permutation $P(\cdot)$.

Finally, we can use D to test for the presence of longevity differences due *only* to differences in age-and-gender-conditional mortality by comparing the *actually observed* D with the distribution of mean age differences $\tilde{D}_Q$ across all within-(age,gender)-cell-permutations $Q(\cdot)$. This exercise holds fixed the age and gender distributions for the G and NG nominees and and asks what the likelihood of seeing a mean death year gap as large as D by random chance under the null hypothesis that there is no relationship between d_i and h_i in all $(age, gender)$ cells.

Tests based on the difference in mean death dates are natural, but it is just as easy to analogous tests based on differences in *median* death dates: we simply use the Wilcoxon rank-sum test statistic (viz Mann and Whitney (1947)) instead of the difference in mean death dates—and compute the analogous permutation-based p-values for this statistic. The major advantage of using this Wilcoxon test statistic is that it can also be applied to the 8 tontine issues for which we have incomplete death data. Recall that in 7 of the tontine issues we have *no* data from prior to 1802, when the payment books started. For each nominee in these data sets, we have an *ordinal* "death date"—equal to the actual death date if it occurred after 1802 and equal to "before 1802" otherwise. Since the Wilcoxon test statistic only relies on ordinal rankings, we can apply the Wilcoxon-statistic-based approach directly to these data sets (effectively treating any two "before 1802" observations as tied.) We can similarly apply this approach to the 1777 class 3 tontine issue by effectively dropping all death observations prior to 1802 and re-coding them as "before 1802".[8]

Table 6 reports the results of these tests for the 1773 and 1775 tontine issues, and table 7 reports the results of various of these tests for the 1777 tontine issues. In all cases, we re-

[8]One way to think about this "data dropping" exercise is that we run our tests using only the payments book data. An alternative way to think about it is as a taking a conservative approach: we throw out the data from before 1802 and effectively impose that the death distributions *conditional on dying before 1802* are equal across the two groups. This obviates any concerns about systematic differences in recording errors in the pre-1802 period but of course biases us against finding any longevity differences insofar as they manifest prior to 1802. We revisit and relax this conservative assumption in the next section.

port the one-tailed p-value associated with the permutation- and Wilcoxon statistic-based tests described above. For example, the first column of the tables reports the probability that the Wilcoxon statistic computed from the observed data would be exceeded by the Wilcoxon statistic that would obtain for an alternative data set with a randomly chosen permutation of the observed G and NG status across all nominees.

These unconditional tests strongly that Genevan nominees were, in a number of subpopulations, longer-lived than the other nominees. The evidence is particularly strong for 1775 class 3, 1773 class 1 and especially within 1777 class 3.[9] Moreover, *within* the 1777 class 3 pool, the 50 syndicated nominees appear to have been long-lived even relative to the other Genevan nominees, who in turn appear to have been longer-lived than the non-Genevan nominees.

The second column of Tables 6 and 7 reports the results of the test for differences in longevity driven by "selection on observables", i.e., due to differences in the gender and ages of the nominees in the two groups. There is little evidence of such differences. In contrast, the third column of table 7 provides strong evidence of age- and gender-conditional differences in longevity between the Gautier 50 nominees and the other nominees (both Genevan and non-Genevan).

Taken together, this suggests that the overall longevity differences for the 1777 class 3 nominees were driven mostly by age- and gender-conditional longevity differences. That is, they appear to be driven more by selection of favorable lives for any *given demographics* rather than selection of favorable demographics. This is somewhat surprising in light of the emphasis placed on these demographic selection variables in the prior literature, notably Cramer (1946) and Jennings and Trout (1983).

4.1 Possible explanations

We view the preceding results as strongly indicative of the greater longevity of the Genevan nominees in general and the Genevan syndicate nominees in particular. A natural interpretation of this is in terms of *adverse selection*: the Genevan nominees were adversely selected from the point of view of other nominees and the government.

As is typically the case in testing for adverse selection, however, it is impossible to disentangle adverse selection from moral hazard (viz Chiappori and Salanie, 2000). There are at least two possible sources of moral hazard. First, the Genevan nominees could have been longer-lived because investors spent money and attention looking after their

[9]The 1773 class 1 pool is notable, as there were only two Genevan nominees in the pool—but those nominees were the third and 12th longest lived nominees among the 84 nominees.

	Overall	Across Age/Gender	Within Age/Gender
1773 Class 1	0.01	0.46	0.05
1773 Class 2	0.21	0.50	0.20
1773 Class 3	0.52	0.60	0.37
1775 Class 1	0.44	0.73	0.12
1775 Class 2	0.09	0.05	0.84
1775 Class 3	0.01	0.24	0.07

Table 6: Wilcoxon Rank-Sum Tests, Genevan vs Non-Genevan, 1773 and 1775 tontines. Each cell contains the p-value associated with a (one-tailed) Wilcoxon Rank-Sum-based test of the hypothesis that Genevan and Non-Genevan nominees have the same longevity. Column 1 contains unconditional tests for differences in longevity. Column 2 tests for the presence of longevity differences driven by differences in nomination-age and gender composition of Genevan and Non-Genevan nominees. Column 3 tests for the presence of longevity differences driven by differences in nomination-age- and gender-conditional longevity differences. See text for details.

	Overall	Across Age/Gender	Within Age/Gender
Class 1 Genevan vs Non-Genevan	0.19	0.58	0.10
Class 2 Genevan vs Non-Genevan	0.07	0.19	0.41
Class 3 Gautier vs Other-Genevan	0.00	0.20	0.03
Class 3 Genevan vs Non-Genevan	0.00	0.16	0.01
Class 3 Gautier vs Non-Genevan	0.00	0.11	0.00
Class 3 Other-Genevan vs Non-Genevan	0.02	0.32	0.09

Table 7: Wilcoxon Rank-Sum Tests 1777 tontines. Each cell contains the p-value associated with a (one-tailed) Wilcoxon Rank-Sum-based test of the hypothesis that two populations have the same longevity. See table 6 and text for details.

heath—as seems entirely plausible given the discussion in Jennings and Trout (1983). Second, as discussed by Milevsky (2014) in the context of the King William Tontine of 1693, there could have been (differential) *fraud*, due, for example, to false certifications of "alive" status. Jennings and Trout (1983) indicate that at least the 50 nominees listed in Gautier were local celebrities in Geneva, which makes this latter interpretation somewhat less plausible in the Irish tontines than in Milevsky's context.

Assuming that differences indeed reflect selection rather than moral hazard effects, it is also natural to interpret these results as evidence that the Genevan nominators were better at selecting low-mortality nominees. This is consistent with the anecdotal evidence reported by Jennings and Trout and others that Genevans were *skilled* at identifying long-lived nominees. In principle, it could also reflect greater longevity in Genevan at this time—but this could only explain the differences between the Genevan nominees in general and the other nominees, not the clearly higher longevity of the Gautier 50 nominees relative to the other Genevan nominees.[10]

5 Distributional Effects of Differential Selection

The results of the preceding section indicate that the most interesting of the tontine issues—from the point of view of the Genevan presence— was the 1777 class 3 tontine. We focus on that tontine henceforth (though see Appendix B for a discussion of the 1777 class 1 tontine—the other issue for which we have death data prior to 1802). In the preceding section, we conservatively ignored all data from the incomplete pre-1802 period. In this section, we use this earlier data by making a natural—but ultimately only imperfectly verifiable—identifying assumption about the process by which some death dates were recorded, and others not. This identifying assumption allows us to calculate the investment returns for the tontine investors and sub-groups thereof.

To illustrate this assumption, we start by demonstrating how we can use it to compute the difference in mean death years between various sub-groups of nominees in the 1777 class 3 tontine. We then perform two related exercises that get at the central question of the paper: how profitable was the Genevan speculation? First, we estimate the average internal rate of return for each of three sub-groups of nominees: the non-syndicate Genevan nominees, the Non-Genevan nominees, and for the 1777 class 3 tontine, the syndicated Gautier 50 nominees. Second, we use a counterfactual simulation to estimate how much of this gap can be attributed to better age and gender selection among Genevan nominees, and how much is instead due to longer-lived Genevans *conditional on age and gender*.

5.1 Estimating mean death years

Recall that we have complete death year data from the Payment books from 1802 on. For the 1777 class 3 tontine, we also have partial but non-trivial data from other sources from before 1802 (the vast majority of which come from the Nominee books).

We assume that *conditional on* gender, age, any nomination sub-group (i.e., Gautier, Other Genevan, or Non-Genvan), the recording of pre-1802 death dates was random. Under the assumption, the *recorded* death dates within any (gender,age,sub-group)-"bin"

[10] The OECD report "How was life?" (van Zanden et al, 2014) reports similar life expectancy at birth in 1820 for Ireland and Switzerland and notably higher life exepctancy at birth in the U.K. however. There do not appear to be good mortality estimates for Geneva (or Switzerland more generally) in the late 1700s.

is a consistent estimate of the distribution of death dates for the unrecorded death dates, and we can therefore use these recorded dates to randomly "fill in" the unknown death dates.

While the validity of this identifying assumption is ultimately unverifiable, Figure 5 provides some evidence that it is plausible. It compares the distribution of death years for the pre-1802 non-payment book death observations to a theoretical distribution that would have obtained from the *entire* subset of the nominees who died prior to the commencement of the payment books—a theoretical distribution computed by using the Carlisle life tables (Milne, 1815), a widely used, approximately contemporary life table derived from observations in Carlisle, England, between 1779 and 1787. If nominee deaths that occurred later in the 1779 to 1802 period were systematically more likely to be recorded than deaths in the mid 1780s, then Figure 5 would indicate a upward trend in the observed death dates relative to the predicted death dates. We see no such pattern. Indeed: the observed distribution is broadly consistent with the Carlisle predictions—except during the first 4-5 years of the tontine issue, which is plausibly attributable to simple adverse selection (as nobody would nominate a currently-unhealthy life).[11]

Our imputation procedure for the 1777 class 3 issue runs as follows. First, we start with the original data set (or, when we bootstrap for standard errors, a bootstrapped sample of the entire original data set, which includes all nominees with missing death dates). Second, for each nominee i within this sample with a *missing* death date, we identify all the set J of all other nominees who: (a) have the same age and gender and are in the same sub-group (e.g., non-Genevan, Gautier 50, or other Genevan); and (b) have a recorded death date prior to 1802. We then randomly select a member $j \in J$ and set i's death date equal to j's death date.[12]

For each such random imputation, we can compute the mean death year for the nominees of the various sub-groups. The first line of Table 8 reports a average of the mean death years across the possible imputations of death years (computed by Monte Carlo simulation). Standard errors in the second line of the table are computed by bootstrapping.

[11] Moreover, note that even if there was relative under-recording in the early years, it would have to be differential between Genevan and non-Genevan populations to pose problems for our identifying assumption.

[12] In a few cases, the set J is empty for Genevan nominees. In those cases, we instead choose from the set J' of non-Genevan nominees with the same age and gender, which is conservative since it effectively equalizes mortality across all sub-groups for these bins. In a few cases, bootstrapping leads to a situation where both J and J' are empty. In these cases, we randomly assign a death date from among all of the death dates in that time window. Our results do not depend substantively on the details of the imputation in these rare cases.

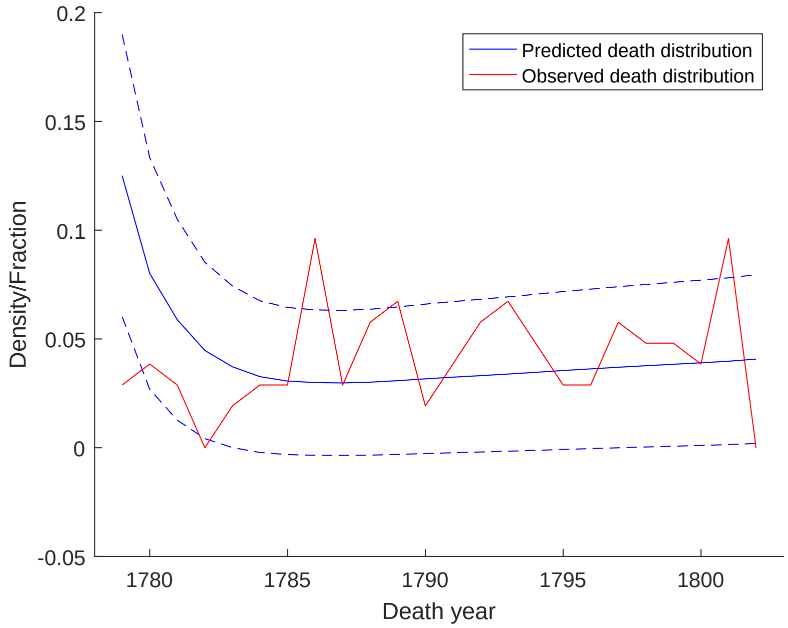

Figure 5: Testing the plausibility of the "random recording error" identifying assumption. The jagged line shows the death date distribution for the 106 of the 200 nominees in the 1773 class 3 tontine who died prior to 1802 and who do not appear in the payment books. The solid line (and associated 2-σ error bars) shows the Carlisle-life-table-predicted distribution of death dates for the entire 200 nominees.

These results are consistent with the tests for longevity difference test in Table 7. In particular, we see that the Gautier 50 nominees lived the longest (on average 60 years after payments began in 1779) followed by the other Genevans (51 years). The non-Genevans (46 years). The standard errors suggest—and formal tests, not reported here confirm—that the differences between the Gautier 50 and the non-Genevan and Other Genevan nominees is highly statistically significant, while the difference between the Other Genevan nominees and the non-Genevan nominees is marginally statistically significant.

The third line of Table 8 runs the same exercise under the maintained assumption that *conditional* on age and gender, all sub-groups of nominee have the same longevity. In particular, it implements this by randomly permuting group membership status with each (age,gender) cell prior to running the death age imputation and computing the mean death year of each group. Because this mechanically equalizes the average mean death age within each (age,gender) cell across all sub-groups, any remaining differences are due only to differences in the distributions of nominees across ages for the sub-groups—i.e.,

	Non Genevan	All Genevan	Gautier 50	Other Genevan	All Nominees
Mean Death Year	1825.22	1832.06	1838.77	1829.63	1826.40
Std. Dev	0.85	1.58	2.93	1.88	0.77
Mean Death Year (Conditionally = Mortality)	1826.36	1828.43	1831.54	1827.30	1826.72
Std. Dev	0.35	1.48	3.00	1.80	0.18

Table 8: Mean death years for various sub-classes of nominee in the 1777 Class 3 Tontine. Mean death year with conditionally equalized mortality computes the mean death year when imposing equal mortality within each (nomination-age,gender) cell, so that any remaining differences are attributable to differences in selection on observable age and gender.

to "selection on observables." Again consistent with Table 7, line three of Table 8 indicates that equalizing mortality does not change the order of longevities, but differences across sub-groups are no longer statistically significant at conventional levels; there is no strong evidence that the longevity differences in the first line are due to better selection of an age and gender by Genevans.

5.2 Baseline non-parametric estimates of the returns gap

We next use the same imputation procedure to compute the *profitability* of the various sub-groups of nominees. In particular, any given imputation of the missing death ages yields a notional data set with a full set of deaths. We can use these to compute the semi-annual dividend payments, and hence the *realized* profitability of any given nominee or group of nominees. We summarize this profitability via the internal rate of return (IRR)—i.e., the constant annual rate of return that would make a £100 investment return exactly £100 in present value for a given subgroup.[13]

Table 9 reports the results. The first two lines of Table 9 reports the IRRs for various sub-groups. The first line uses the *realized* semi-annual dividends recorded in the Payment books from 1802 on and imputes the pre-1802 dividends from the number of living individuals. The second line imputes all semi-annual dividends from the number of individuals alive at each half-year. Reassuringly, these two lines are close to identical.[14] Only

[13]For comparability with the 7.5% annual per share dividend, which was paid in semi-annual 3.75% dividends, we compute the semi-annual internal rate of return $IRR_{\frac{1}{2}}$ and report $2 \times IRR_{\frac{1}{2}}$. Of course, the true annualized IRR is instead $(1 + IRR_{\frac{1}{2}})^2 - 1$, which is modestly higher—but by the same token, the true "effective" annual dividend rate is greater than 7.5% because dividends are paid semi-annually.

[14]What minor differences exist are attributable to two factors. First, the imputed dividends use the recorded death dates, but these death dates were not always known immediately—and the dividends due

the second line—with imputed dividends—is sensible for boostrapping standard errors (since a different sample of nominees would end up with a different set of survivors and hence dividends). These bootstrapped standard errors are reported in the third line.

Again consistent with Tables 8 and 7, the Gautier nominees had the highest rate of return and the non-Genevans the lowest—the gap between the rates of return was slightly more than 8.5% (i.e., $(7.89 - 7.27)/7.27$)—with the Other Genevans having an intermediate IRR indistinguishable from the overall IRR for the entire tontine of 7.49%.

The overall average IRR for the tontine is also interpretable as the effective cost of funds for the Irish government. Observe that this cost of funds is very close to the originally posted tontine dividend of 7.5% and, per the standard error in line 3, invariant across bootstrapped samples. These observations starkly illustrate a key point raised in Section 2: from the point of view of the Irish government, the tontine was effectively a riskless perpetuity,[15] and essentially *all* of the mortality risk from the tontine was borne by the nominees themselves.

	Non-Genevan	All Genevan	Gautier 50	Non-Gautier Genevan	All Nominees
Payment Book Dividends	7.22%	7.81%	7.89%	7.51%	7.47%
Imputed Dividends	7.27	7.81	7.89	7.49	7.49
Std. Dev	0.06	0.08	0.10	0.16	0.00
Equalized Mortality	7.41	7.61	7.66	7.41	7.49
Std. Dev	0.07	0.10	0.14	0.18	0.00

Table 9: Unconditional and (nomination-age,gender)-conditional rates **internal rates of return** (annualized, percent) for various sub-populations of the 1777 class 3 Irish Tontine

5.3 Testing and decomposing return gaps

The standard errors in Table 9 suggest that differences in IRR are statistically significant. We formally test this in Table 10 using a permutation-based test that mirrors the test described in Section 4 and reported in Table 7. Specifically, we first run a large number of

to someone who failed to collect a semi-annual dividend but who was not yet known to be dead were held back until the death was known. Second, dividends paid out in a given half-year appear to have been computed in a slightly different fashion than the simple calculation conducted in the imputed-dividends exercise that we do. In particular, nominees received their £3.5 per share "due" dividend each half year. Dividends "due" to shares that had already fallen accrued to a "redundancy" account, from which an evenly rounded "bonus" dividend was paid to each surviving share. Because these bonus payments were evenly rounded, the redundancy account carried a modest balance from period to period.

[15]The last member died in 1871, 91 semi-annual payments after payments commenced. At an interest rate of 7.5%, the present value of the post 1871 "tail" of a perpetuity amounts to approximately 0.12% of its initial value.

"baseline" draws using the baseline data set but imputing the missing death dates, as described above. Second, we run a large number of "equalized-mortality" draws which first mechanically equalize the longevity across all groups by randomly permuting the group status across *all* nominees. We then compute the fraction f of times a randomly chosen "baseline" draw" exceeds a randomly chosen "equalized-mortality" draw. Under the null hypothesis of equal longevity, any one of the permutation-based draws is *ex-ante* equally likely, so this fraction f is interpretable as the p-value associated with the observed sample under an equal-mortality null hypothesis.

These p-values are reported in the first column of Table 10. They indicate that the difference between Genevans in general (and the syndicated Genevans in particular) and the non-Genevans is highly statistically significant ($p \approx .001$). The evidence for return differences between the non-syndicated Genevans and non-Genevans ($p = 0.054$) and between the non-syndicated and syndicated Genevans ($p = 0.099$) is more equivocal.

	Overall	Across-Age/Gender	Within Age/Gender
Genevan − Non-Genevan	0.000	0.225	0.007
Gautier 50 − Non-Genevan	0.001	0.210	0.011
Other Genevan − Non-Genevan	0.054	0.501	0.063
Gautier 50 − Other Genevan	0.085	0.253	0.308

Table 10: Significance tests for differences in rates of return for various sub-populations in the 1777 Class 3 Irish Tontine. Elements are based on three independent simulated draws on the data: (i) a "baseline" draw which randomly imputes the missing 94 death years but otherwise maintains the baseline data set; (ii) a "equal-mortality" draw which randomly permutes sub-population status across all observations and then imputes the missing 94 death years; (iii) a "conditionally-equal-mortality" simulation which randomly permutes sub-population status within each (nomination-age, gender) bin and then imputes the missing 94 death years. The first column reports the probability that the return gap from an equal-mortality draw exceeds the return gap from a baseline draw. The second column reports the probability that the return gap from an equal-mortality draw exceeds the return gap from a conditionally-equal-mortality draw. The third column reports the probability that the return gap from a conditionally-equal-mortality draw exceeds the return gap from a baseline draw.

We next mirror the discussion in Section 4 to test whether the observed differences in financial returns across groups are attributable to the different distribution of ages and genders within the different groups—as illustrated in Table 5 and Figure 4—or if they instead reflect different longevity conditional on age and gender. We follow the same basic approach that led to the tests in columns 2 and 3 of Table 7 for these tests. Specifically, we run a third set of simulated draws "in-between" the "baseline" draws and the "equalized-mortality" draws described two paragraphs above. This intermediate set of draws first randomly permutes the group membership (e.g., G vs NG) ages across all nominees *within* each (age,gender) bin. It then randomly imputes missing death ages. Under the maintained hypothesis that the (age,gender)-conditional mortality rates are equal across all nominees, each of the permutations underlying these draws are equally likely. Comparing the distribution of return gaps across these conditionally-equal-mortality draws with the distribution of return gaps across the fully-equal-mortality draws provides a test of the equality of returns conditional on the *maintained* hypothesis of conditionally equal mortality—i.e., a test of whether the across (age,gender) differences across groups was an important source of return differences.

The second column of Table 10 reports the results of this test. More precisely, it reports the probability that the return gap from a random "equalized-mortality" draw exceeds the return gap from an random "in-between" draw. This is interpretable as the p-value associated with a test of equal-returns conditional on the strongly maintained hypothesis of (nomination-age $\times$ gender)-conditionally equal mortality. The fact that none are significant at conventional levels indicates that there is no strong evidence that return gaps are being driven by differences in the distributions of age and gender across different groups. This is again consistent with the evidence on longevity in the second column of Table 7 (viz the second column, which is built on the same basic permutation-based test).

The third column of Table 10 reports tests for "other part" of the decomposition of overall return gap—i.e., return gap differences attributable differences across groups in (nomination-age $\times$ gender)-conditional longevity differences. Specifically, it reports the probability g that a random "in between" draw exceeds a random "baseline" draw. Since this exercise holds fixed the (age,gender) distribution of each group of nominees, g is interpretable as the p-value associated with a test for difference in returns due to (age,gender)-conditional longevity differences. The low p-values in first two rows of the third column of Table 10 indicate that there is strong evidence that the Genevan nominees and especially the Gautier nominees of a given age and gender were, on average, significantly longer-lived than the non-Genevan nominees.

In summary, although we cannot rule out that the syndicated Genevan nominees may have benefited modestly from better age and gender selections, the data appear to be consistent with *all* of the unconditional return differences being attributable to the lower mortality *conditional* on age and gender. Selection (or perhaps moral hazard) effects for the 1777 class 3 nominees thus appear to be largely driven by differences in higher age- and gender-conditional longevity among Genevan nominees.

6 Conclusions

Our newly developed data set on the nominees of the 1773, the 1775, and, particularly, the 1777 Irish tontines strongly supports earlier contentions that there was a substantial presence of savvy Genevan investors in these tontines. We show that the Genevan nominees were longer lived than the other nominees, and, as a result earned investors on the order of 8% higher lifetime returns on the tontine than investors in non-Genevan nominees. The subset of Genevan nominees known to be nominated by a Genevan syndicate which was investing specifically to earn high returns appears to have earned particularly high returns. In contrast to the anecdotes in the earlier literature, we find that most of the return gap appears to be attributable to higher longevity *conditional on age and gender* as opposed to better selection of ages and genders.

Our case study of these tontines also illustrates a more general principle: tontines are highly effective at hedging government exposure to adverse selection and moral hazard. A government issuing life annuities exposes itself to non-trivial losses if the annuitants are significantly longer lived—as the British government experienced in the early 19th century (Rothschild, 2009). But any adverse selection or moral hazard costs in a government-issued tontine context are born almost entirely by other participants in the tontine.

This observation has important implications for evaluating recent proposals to introduce a tontine element into retirement plans (Milevsky (2014)). On the one hand, implementing such a proposal would have a clear benefit as a hedge against aggregate mortality risk (owing either to adverse selection or medical advances, e.g.). On the other hand, differential mortality improvements across different groups, e.g., between low-income and high-income sub-populations, can expose particular sub-populations to non-trivial extra risk, as compared with standard life-annuity based retirement systems. We can get a sense for the potentially significant magnitude of this distributional risk via a back-of-the-envelope thought experiment in the context of the U.S. Social Security Retirement system.

A growing gap between the longevities of low and high socioeconomic status individuals in the U.S. has been well-documented.[16] In Appendix A, we use projections from Waldron (2007) of the mortality of the 1912 and 1941 birth cohorts to ask what the re-distributional consequences of converting Social Security into an ideal tontine for the 1941 cohort. Specifically, we imagine converting Social Security into an ideal tontine us-

[16] For example, see Pappas et al. (1993), Preston and Elo (1995), and Waldron (2007). See also Waldron (2013), Bound et al. (2014), and National Academies (2015) for analyses of the implications of these trends for the Social Security system.

ing mortality projections that fail to account for differential mortality trends between the 1912 and 1941 cohorts for individuals of above- and below-median earnings. We then compare the re-distribution across these two groups that would have taken place under the ideal tontine relative to a status-quo Social Security. We calculate that moving to a tontine structure would have resulted approximately a 13% larger reduction in the present value of Social Security receipts for the below-median earnings portion cohort (relative to the direct reduction from slower-than-projected longevity improvements).

Introducing tontine elements may have an important role to play in the retirement schemes of the future, particularly for retirement systems run by institutions (unlike the U.S. federal government) for which a large shock to aggregate longevity could induce default. The experience of non-Genevan nominees in the Irish tontines of the 1770s who lost out to Genevan speculators in the Irish tontines of the 1770s points, however, to the importance of taking into account the potential distributional consequences of the tontine structure.

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Appendix A Tontines in Social Security

This Appendix describes a back-of-the-envelope exercise for quantifying the potential distributional risks associated with moving the U.S. Social Security system to a tontine-like system.

The solid lines in Figure 6 plot Waldron's (2007) projections of mortality for the 1912 and 1941 birth year cohorts. Each cohort is broken into two halves: those with Average Indexed Monthly Earnings (AIME) above the median ("high earners"), and those with AIME below the median ("low earners"). These projections show mortality improvements for both high and low earners, but much larger improvements for the high earners. The dashed line in Figure 6 plots a notional mortality curve for the low earners in the 1941 cohort: the mortality that lo earners *would have had* in 1941 if they had experienced the same mortality gains as did the high earners. In other words, the dashed mortality curve is the mortality rate that the low earners in the 1941 cohort would have had if the mortality gap between high and low earners had stayed constant between 1912 and 1941.

Figure 6: The evolution of mortality for Social Security recipients with above and below-median Average Indexed Monthly Earnings (AIME), 1912 and 1941 cohort. The dashed line plots the mortality rate that low-AIME recipients would have had in 1941 if the mortality gap between below- and above-median AIME recipients had remained constant. Authors' computations using data from Waldron, (2007).

Our thought experiment runs as follows. Suppose that, just as the 1941 cohort retired, the Social Security system was converted into a tontine with total payments to the

1941 cohort exactly equal to the projected Social Security payments, as computed using (i) Waldron's estimates of mortality for the top earners and (ii) the "notional" estimates in Figure 6 for the 1941 low earners. Suppose further that Waldron's estimates turn out to be exactly correct for both high and low earners in the 1941 cohort. Then the *realized* income stream for both high- and low- earners will differ from the projected payments (which, by construction, are equal under the baseline Social Security system and the tontine system replacing it). We then want to quantify the redistribution, relative to the projections and the status quo Social Security system that takes place as a result of the incorrect projection. Intuitively speaking, this thought experiment captures the idea of an unanticipated adverse shock to the mortality of low earners in the 1941 cohort relative to the projections—and we are quantifying that shock as the difference between the notional and actual mortality estimates in Figure 6.

To implement this thought experiment, e first estimate the ratio of Social Security payments between high and low earners in the 1941 cohort. Using the AIME distribution for workers newly eligible for retirement benefits in 2007 (See the table equivalent of Chart 4 in Waldron (2012)) and the 2007 formula for converting AIMEs into monthly payments (bend points: \$680 and \$4100), we compute that the typical low-earner received a Social Security payment equal to 0.567 of the typical payment received by high earners. We normalize the annual payment under the baseline (life annuity) Social Security regime to 1 for high earners and 0.567 for low earners. When computing the realized payments under the tontine scheme, we interpret each low-earner has having 0.567 "shares" of the tontine, while the high earners receive 1 shares.

We normalize the number of retirees to 200 (100 high earners and 100 low earners), so that, under the baseline Social Security regime, the pool of retirees will receive a total of \$156.7 in the first year. We then use the actual high-earner and notional low-earner mortality curves for the 1941 cohort (from Figure 6) to impute a share-weighted number of survivors S_a to each age ($a = 66, \cdots, 119$) after retirement. The baseline Social Security system thus anticipates paying a total of $\$156.7 S_a$ to the cohort at age a.

We now imagine that the Social Security system is converted to a tontine paying the cohort $\$156.7 S_a$ at each age a. If the mortality tables being used to compute S_a were correct, this would be the so-called "ideal tontine" or, per Milvesky (2015), "Jared's tontine:" the Social Security system would pay out the same amount under both the baseline life annuity and the new tontine system. But—in our thought experiment—the mortality table is incorrect, and, consequently, the baseline and new systems pay out differently. Indeed, since the low earners experience a mortality shock and a smaller number $\tilde{S}_a$ of share-weighted retirees survive to age a. Under the baseline Social Security regime, each

	Baseline Anticipated	Baseline Realized	Baseline Renormalized	Tontine Anticipated	Tontine Realized
High Earners	13.91	13.91	14.64	13.91	14.73
Low Earners	7.58	6.50	6.85	7.58	6.76

Table 11: Distributional consequences of an unexpected mortality shock. Each cell contains the present value of the (normalized) retirement income stream received by a retiree using a real interest rate of 2%.

retiree receives the same annual payment in all years of retirement and the Social Security system pays out a lower-than-anticipated total of \$156.7$\tilde{S}_a$—strictly less than the fixed \$156.7S_a paid out under the tontine scheme. Conditional on surviving to age a, a high-earner expects to receive a payment of \$$S_a/\tilde{S}_a$ and a low-earner expects to receive \$0.567$S_a/\tilde{S}_a$. Together with the mortality tables, these can be used to compute the present discounted value of the anticipated and realized retirement income streams provided by the Social Security under the baseline and new systems. We use an real interest rate of 2% for these calculations.

Columns 1 and 2 of Table 11 respectively report the anticipated and realized present values for the high and low earners under the baseline life annuity system. Under this system, the low earners receive a negative shock, relative to expectations, as a result of being shorter-lived. The high earners, whose mortality was correctly anticipated, are unaffected. Of course, taken together, this means that the government spends less than anticipated under the Social Security regime. To run a fair "horse race" with the tontine system—which by construction keeps spending constant—column 3 re-normalizes the results from column 2 by proportionally raising the present value for both low earners and high earners to hold spending government constant. This is equivalent to assuming that the government surplus generated by the unanticipated mortality shock is redistributed in proportion to the Social Security payments. A comparison of columns 1 and 3 thus quantifies the amount of pure across-earner redistribution resulting from the mortality shock: the low earners effectively transfer 9.63% ($(7.58 - 6.85)/7.58$) of their present value to high earners (under this assumption about how to account for the government surplus).

Columns 4 and 5 respectively report the anticipated and realized present values for the high and low earners under the tontine system. Because of the way the tontine is constructed, column 4 is identical to column 1. Moreover, because the tontine holds fixed the government spending, there is no need to renormalize column 5. Under the tontine, the mortality shock causes low income individuals to effectively transfer 10.84% ($(7.58 - 6.76)/7.58$) of their present value to high earners—or an additional 13% on top of the

9.63% they already would have transferred under the baseline regime.

Appendix B 1777 Class 1

Computing investment returns for Genevans and non-Genevans is straightforward for the one tontine issue for which we have complete death data: class 1, 1777. Unlike the class 3, 1777 issue discussed in the main text, there is no need to impute any death years: we simply use the complete set to impute the number of nominees (and shares) surviving to each half year and hence the semi-annual dividend to each surviving nominee in each half-year and, from that, the internal rate of return (IRR) for the entire group and subgroups of nominees. We compute standard errors via bootstrapping.

	Non-Genevan	All Genevan	p-value of gap
Imputed Dividends	7.26	7.61	0.328
Std. Dev	0.08	0.32	-
Payment Book Dividends	7.28	7.60	-
Equalized Mortality	7.32	7.38	.447
Std. Dev	0.09	0.44	-

Table 12: Internal rates of return for Genevans and non-Genevans in the 1777 Class 1 Irish Tontine. See Appendix B text for details.

The first line of Table 12 contains the baseline estimate (with standard errors in the second line). It indicates that the 28 Genevan nominees in the 1777 class 3 tontines earned a 4.8% higher rate of return than the non-Genevans (i.e., $(7.61 - 7.26)/7.26$), although the difference is not statistically significant. This is consistent with Table 7, which showed no statistically significant evidence of greater longevity among the Genevan nominees in the 1777 class 1 tontine issue.

The dividends used for computing returns in the first line of Table 12 are imputed from the number of individuals alive at any given moment in time. The third line makes the same computation using the *actual* dividends for the post 1802 period, as recorded in the payment books. Unsurprisingly, this change has no material affect on the IRR estimates—which is important because we need to use imputed dividends to compute standard errors via bootstrapping.

The final two lines of table 12 respectively contain estimates and standard errors for the IRRs with age- and gender-conditionally equalized mortality. As in the main text, we accomplish age- and gender-equalization of mortality by averaging the IRRs over all (age,gender)-conditional permutations of the Genevan vs Non-Genevan status of nominees. Equalizing mortality conditional on age and gender results in virtually identical and statistically indistinguishable estimates of the internal rate of return for the Genevan and non-Genevan nominees: there is absolutely no evidence at all that Genevan nominees in Class 1 were better-selected on the observable age and gender dimensions.

One final note: the average IRR for all nominees is notably lower than the 7.5% posted dividend, in contrast to the estimates for class 3 (viz Table 9). This is because of the higher average age of the class 1 nominees: the last death in class 1 was in 1832, 57 years after the tontine payments began (as opposed to 1871 for class 3, 92 years after the payments began). The class 1 tontine is thus farther from being an effective perpetuity.