# Cyberpunk Victoria:
# The Credibility of Computers and the First Digital Revolution (1848-1883)

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**Abstract:**

*British capitalism was a knowledge economy that lived on reliable numerical information. We argue that human computers and the algorithms they used played a vital intermediation role and supported the growth of the British capital market, because they resolved digital information asymmetries. The hero of our tale is the Institute of Actuaries, the professional organization of human computers, created in 1848, and we argue, the ancestor of modern financial computing. It was put together to address fears that calculations might be manipulated. It led the development of sophisticated formulae for the calculation of interest rates (returns) of complex financial products. Given the lack of an archive, we demonstrate the computers' role as financial intermediaries by identifying their imprint on the production of data by a prominent numerical factory, the* Investor's Monthly Manual*, a companion publication of the* Economist*. Our study underscores the import of digital mechanization and the relevance of human cybernetics to the development of financial capitalism.*

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**INTRODUCTION**

'Steampunk' is a retro-futuristic science fiction specialty that incorporates technology, politics and aesthetics inspired by the nineteenth century. In *The difference engine*, a novel by William Gibson and Bruce Sterling which is credited for having popularized the genre, the authors imagine an alternative Victorian era sparked by successful implementation of Charles Babbage's computer, which would have left the drawing board where it remained in fact to be actually implemented, leading to the dawn of the information age, one century ahead of schedule.[1] In this article, we suggest that the nineteenth century did in fact witness a numerical revolution and the birth of an early form of cybernetics, which have been thus far overlooked. Speaking of 'cybernetics' in a nineteenth century will seem strange and deserves an explanation. As we show, the digital machinery that was developed at that point exploited human powers. It led to the formatting of human calculators who came to be known actually as 'computers.' This formatting and mechanization was achieved through the subjection of human computers to algorithms which controlled deviations in individual behavior and as a result, enhanced the quality of the digital output. In other words, the following article is the story of the cyber world that developed instead of the fictitious steampunk universe envisioned by Gibson and Sterling.

The making of this early cybernetic universe is in fact a story of the deepening of financial capitalism. The nineteenth century digital revolution occurred where computing power was most needed – in the capital market. It is not surprising that the capital market should have been an early consumer of information technology: It is well-known, for instance, that finance was the first client of newly created telegraphic systems, whose cables ended up in stock exchanges initially. More precisely, our central contention is that the deepening of the British financial system rested on the creation of a powerful computing machinery, which is yet to be explored, the present paper offering a first foray and proof of concept. In fact, we argue that computing systems and the individual computers which composed them were financial intermediaries because they helped resolve information asymmetries. By enabling comparison across securities, financial computation helped produce a shared understanding, without which arbitrage would be very difficult and trading would lack liquidity. Access to congruent computation methods did enable traders in the

[1] Gibson and Sterling, *Difference engine*.

financial market to see eye-to-eye. Liquid trading ended up facilitating the process of origination and distribution of securities as well as, we argue, financial innovation. In clear, the history of the development of digital techniques and the history of the capital market are complements. From this vantage point, it is probably not coincidental that Babbage grew up in a family of stockbrokers, his father having been a funding proprietor of the new London stock exchange in 1801, and that he grew up surrounded with financial calculus.

In this paper, we argue that the question of the credibility of computations was at the center of the transformations that occurred. As we show, the human machines in charge of the financial calculations that underpinned the growth Victorian capital market were members of the emerging actuarial profession. Traditionally, the historical literature relates the making of the actuarial profession to the business of life insurance, but life insurance was only one portion of the British financial system and in fact a rather small one, especially at the beginning. As we show, however, the *problems* that actuarial knowledge preoccupied itself with – cash-flows streams and their present value, which involved the reduction of complicated security to a single point in time – provided natural templates for a variety of debt instruments and as a result, the techniques that enabled to determine the bottom line of a life insurance office came handy to address many real-life problems of the capital market. In particular, the 'financial engineering' skills of British actuaries could readily be harnessed to calculate yields on 'new' instruments and the transparency did help make them comparable with predecessors.

Thinking of computers from the vantage point of their contribution to the resolution of information asymmetries in the capital market also provides a way to conceptualize the specific problems of governmentality which they raised. Because they are part of the information system, computers and computations are susceptible of becoming an instrument of exploitation: In modern language, they run the risk of being 'hacked.' One group of traders may take advantage of superior knowledge to exploit others. From this danger, real or imagined, grows the need for computers to be subjected to rules, in short to be governed. In fact, the reason why actuaries became the digital intermediaries in the British capital market was that they developed a governance regime. This interpretation gives agency to the Institute of Actuaries, created 1848, whose main goal was to ensure uniformity of results in computations performed independently by individual actuaries. The Institute did promote digital solutions and what is more, made them credible by subjecting the members of the Institute to the resulting procedures. Members benefitted from the certification of the Institute but had to abide by its norms. Being algorithms, those norms or rules mechanized human computers by mechanizing computations. Through training of aspiring actuaries, the Institute was tasked with 'uploading' the algorithms on the human machines it groomed, examined, then dispatched each year to the four corners of the City. This led to the propagation of an actuarial gospel, made more attractive to end users by warranted perception that it protected against manipulation.

Because of a lack of direct primary sources, itself the result of a tendency of business archives to obliterate technical material at the expense of such sources such as business correspondence, the Victorian cyberpunk universe is a lost world. However, it has survived through traces, in printed contemporary publications debating alternative algorithms, in archival documents describing how the computer licensing system put together by the Institute of Actuaries operated, and most importantly perhaps, in the 'DNA' imprints which are revealed through forensic examination of contemporary numerical material. As we demonstrate, exploration of these sources does reveal the long reach of the actuarial profession inside Victorian finance and investment. We do this through a case study examining the descent of the famous yield tables, which the *Investor's Monthly Manual*, a popular companion publication of the *Economist*, started putting out in 1883. The existence of the numbers is well-known but their meaning has escaped explanation so far.[2] Yet, as we discovered when we managed to crack open the *IMM* interest rate code, the data in question can be mapped onto the formulae and algorithms the actuarial profession had developed in the previous quarter of a century. In other words, our case study demonstrates the historical leadership of the actuarial profession (and in particular, of the Institute) in organizing and propagating interest rate knowledge.

The paper narrates our foray. By contextualizing the *IMM*'s innovation, we get to describe the main stakeholders, the problems and the solutions. The descent of the *IMM* numbers is the story of the rise of a government of computers. As we demonstrate, a significant driver of this governmentalization was financial scandals. These provided successive occasions to expand control over computers. In practice, the sequence may be

[2] Thanks to the generous efforts of William Goetzmann and K. Geert Rouwenhorst, the *IMM* data at large (1869–1929), including the famous yields (1879–1929), has been extracted, put into spreadsheets and posted online, facilitating quantitative work; See it at https://som.yale.edu/.

likened to a typical regulatory cycle: Financial scandals inspired a 'policy' response. In the instance, they inspired the emergence and deepening of digital techniques. Each ensuing crisis or scandal became an opportunity to tighten the grip, which meant to further standardize human computers. Little by little our modern machines were evolved from this substratum, through gradual adjustment of human bodies and especially, human minds.[3]

The case study we consider brings to the fore these mechanics by unpacking the interactions between actuarial science and the expansion of the capital market. Actuaries provided at the beginning a high-end service for wealthy buyers and sellers with greater needs for accuracy and the means to pay for tailored solutions. But with the rise of the British middleclass, concerns over digital exploitation multiplied. This became manifest when a parliamentary investigation, the Select Committee of 1875, tasked with examining possible contractor abuse following a resounding government debt crash raised doubts over financial structuring techniques, which, it was surmised, had taken advantage of digital opacity and created exploitive financial products. As this had happened in an 'under-governed' numerical territory, the response was the colonization the territory in question by the Institute of Actuaries, through provision of new techniques. Stronger assumptions than had been considered acceptable before were made legitimate by the need to fend off abuse. Another response came from the media. The *IMM* belonged to the *Economist*, which was at the forefront of the crusade to protect outsiders against insider abuse. This was why it ended up designing an affordable, run-of-the-mill, version of the actuarial state of the art. The *IMM* became a big data center that did spout actuarial calculations to the tune of upward of 500 per month. The computing system was informed by actuarial theorems that enabled to develop cost-effective routines.

The perspective this paper provided in this paper on Victorian finance and on financial history more generally, is new. Of course, the importance of mathematics in laying out the foundations of modern capitalism has been discussed before, and Fernand Braudel speaks of the need to not underestimate 'the amount of knowledge necessary to acquire,' emphasizing especially interest rate calculations. But this point has been made principally in the context of the Commercial Revolution of the late middle ages and for the early modern period. Previous scholars have discussed the role of the annuity contract and the rise of

[3] See Taylor, *Boardroom scandal*, which emphasizes the centrality of financial scandals in the evolution of British capitalism in the nineteenth century.

commercial arithmetic.[4] The nineteenth century has not yet been analysed under this light and as a result, the knowledge dynamics that underpinned the era are terra incognita.[5] What is more, our novel emphasis on the role of computing as an intermediation or brokerage technique provides an interpretation of the intertwined development of capitalism and calculus that has not been proposed previously.

But before we start with the story properly speaking, we need to state more precisely where it differs from previous research. To begin, the manner in which we approach the actuarial profession differs from that by leading cultural historians such as Timothy Alborn, who has published extensively on the history of actuaries and life insurance. Alborn also identifies actuaries along with other knowledge groups as providers of what he calls real-world expertise.[6] However, as his subsequent reference synthesis shows, he does not emphasize the role of the actuarial profession in the nineteenth century as a digital government nor its vital importance, beyond insurance, to finance at large. In fact, Alborn's synthesis is silent on the amount of energy actuaries spent on deriving financial theorems and on the financial derivative products these theorems made possible. In other words, we suggest that actuaries played in finance a role far more important than conventionally admitted by the best authorities.[7]

Another contribution worth emphasizing is Theodore M. Porter, a historian who has studied the function fulfilled by precision in modern societies. Porter refers to concerns regarding information manipulation as a key driver and source of the demand for 'objectivity.' In fact, he analyses the professionalization of actuaries as one instance of such 'technologies of distance' enabling to secure objectivity.[8] These technologies, he suggests, would have resulted from the need to establish credibility in the face of 'flagging trust in individuals,' a theme that echoes closely the discussion in this paper. But Porter is not interested in elaborating the economic logic at work and even less by doing this in economic

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[4] Braudel, *Civilisation matérielle*, p. 360; See also Sanford, *Short history of mathematics*; Zemon-Davis, 'Sixteenth-century French arithmetics'; Lewin and de Valois, 'History of actuarial tables'; Goetzmann, 'Fibonacci'; Deringer, '"It was their business to know"'. The French experience in the nineteenth century has attracted few contributions. See Jovanovic, 'Economic instruments' and Jovanovic, 'Was there a "vernacular science of financial markets"'; Theocharis, 'The Journal des Actuaires Français'.

[5] Janette Rutterford's exploration of equity valuation technics in the 19th and 20th century constitutes an exception. Rutterford, 'From dividend yield'.

[6] Alborn, 'The other economists'.

[7] Alborn, *Regulated lives*.

[8] Porter, 'Quantification and the accounting ideal'; Porter, *Trust in numbers*; Porter, 'Precision and trust'.

terms, and in fact, he spends quite some time denying the import of economics. For him, the 'history of objectivity is a political history'.[9] We do not deny the importance of political factors, *au contraire*, since after all our story begins in the British Parliament. But we argue that the making of the digital infrastructure of British capitalism is a valid object of classic economic history that can be addressed with 'conventional' tools, especially of business, industrial, and labor history. In fact, this paper may be read as laying out the ground for a political economy of objectivity, rooted in an analysis of the intermediation function which knowledge institutions perform for the capital market.

Finally, at the other end of the disciplinary spectrum, our approach differs from previous financial economists and economic historians. For instance, in a classic paper, which in fact partly draws on the works of Victorian actuaries, Hawawini and Vora survey the long-run evolution of methods to calculate yields.[10] But their approach fails to identify the nature of many of the formulae used at the time and as a result, it misconstrues the project of contemporaries. In particular, misreading the language of the time, they describe these formulae as 'approximations' when in fact they were the update functions of algorithms, which enabled to achieve *complete* precision. In other words, as we shall see, precision was essential to nineteenth century actuaries, in fact to an extent that is astonishing and deserves to be interpreted. A similar problem undermines the empirical study of government bonds by Mauro, Sussman and Yafeh, which conveys the view of a digitally backward nineteenth century.[11] Dealing with those very bonds whose yield the *IMM* did calculate with the luxurious precision we shall document, they claim incorrectly that 'the formulae for exact calculation of yields on [such bonds] were only developed in the middle of the twentieth century, and their application often requires the use of calculators and computers.'[12] They also allude to cognitive strategies that would have led investors to interpret all bonds as if they had been perpetuities because this made the problem tractable for our nineteenth century simpletons. But this is not at all what happened as we proceed to explain.

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[9] Porter, 'Precision and trust', p. 192; Porter, 'Quantification and the accounting ideal', p. 647.
[10] Hawawini and Vora, 'Yield approximations', is reprinted in Poitras and Jovanovic, *Pioneers of financial economics, vol. 2*. See also their collection of reprints, Hawawini and Vora, *History of interest*, which includes Sutton's classic article discussed in this paper.
[11] Mauro et al., *Emerging markets.*
[12] Ibid., p. 41.

**SECTION I. THE PROBLEM OF REDEMPTION**

In June 1879, the editors of the *Investor's Monthly Manual*, decided to supplement their financial tables documenting hundreds of individual investment securities, with a new feature. The *Manual* would now report a measure of the return or 'yield' investors could expect from purchasing individual securities. This yield was computed crudely, as the dividend or coupon produced in the previous year, expressed in percentage of the price of the security. This was a mediocre indicator, as the editors of the journal knew fully well and emphasized in a caveat: The fixed income securities monitored by the *Manual* were structured in creative ways that rendered the measure often inadequate. The caveat warned readers against resulting biases, identifying in particular the case of 'redemption drawings' as potentially treacherous. Under this arrangement, frequent among foreign government securities, reimbursement of capital occurred through lotteries. When the serial number of an individual bond was drawn, the bond was 'redeemed at par' – reimbursed at face value.

But because face value and market price differed from one another, the investor contemplated, depending on circumstances, a significant gain or loss. Yet, as the journal warned, no allowance was made for this element in the reported yields. It was strange to single out this particular problem, because foreign government loans represented a fraction only of the securities the *Manual* tracked. In fact, the *IMM* yields failed to control in general for the impact of the reimbursement of loans at maturity and of course, the crude method they were using was just as misleading for corporate bonds with a finite reimbursement horizon as it was for foreign government bonds and their strange lotteries. Even more intriguing was the fact that the disclaimer, regularly reprinted afterwards, did not manage to soothe readers, quite the opposite. The journal was deluged with angry mail from users complaining about the scandalous flaws in the *IMM* data. The journal tried to deflect criticism but the confrontation continued until the editors finally gave in, and in January 1883, announced the adoption of a new reporting system which would take into account the redemption mechanism. In modern language the journal had begun documenting 'yields-to-maturity' and it would continue to do this well into the twentieth century.

The anxieties summoned among the investing public by a problem of redemption in an age of evaporating religious faith are a bizarre but ultimately fruitful point of entry into the subject of financial calculus. In fact, to understand the reasons for the reaction of readers and controversy we must go back about 10 to 15 years in time, during the 1860s and the

1870s, a time when the British stock exchange was booming. One of its most active sections of the stock exchange was the foreign government debt market. Foreign states desirous to borrow turned *en masse* to the London stock exchange where they met financial expertise and between 1860 and 1875, more than 100 long term foreign government bonds were concocted.[13] The boom came to a head somewhere between 1872 and 1873. The trigger was the Honduran 'ship railway' scandal, which erupted in May 1872, when the Honduras government attempted to launch a staggering 15 million pounds loan, for a mind-blowing three-track across the Isthmus that would lift steamers from one Ocean and drop them in the other, ostensibly redirecting the routes of commerce. The loan came under attack from representatives of creditors of Honduras who feared dilution and from the media who claimed that numbers in the prospectus were doctored. The loan was withdrawn. Declining investor morale was amplified by a monetary crisis which led the Bank of England to raise interest rates, triggering a shift out of foreign debt.[14]

The sovereign debt crash that that ensued and the instances of malpractice it ostensibly exposed provided background for Trollope's *The way we live now*. Literally written in the wake of the ship railway scandal and released in installments from February 1874, it portrayed a reckless insider, Melmotte, pulling the levers of the stock exchange to promote a railway 'from Salt Lake City to Vera Cruz' at the expense of outside investors.[15] By the time *The Way We Live Now* was released in book format, Parliament had appointed a committee to investigate the multiplying charges of contractor abuse. The result was the Select Committee on Loans to Foreign States, which sat in the Spring of 1875. Led by Henry James, it looked for culprits and found many. The *Report* published in July 1875 concluded that there had been rampant manipulation. For instance, underwriters had secretly charged fat fees, concealing true riskiness from public view. They had hidden the actual amounts subscribed, turning failed issues into apparent successes. Finally, forward sales had puffed up securities.

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[13] Classic references include Jenks, *Migration of British capital* and Landes, *Bankers and pashas*.
[14] Marichal, *Century of debt crises*, p. 102; Flandreau, *Anthropologists*, pp. 237 ff.; Miranda, 'Small money, big problems'.
[15] Trollope, *The way we live now*.

Among the charges, one concerned the redemption modalities of loans.[16] At the time, the boilerplate for foreign government bonds involved a reimbursement system or ‘amortization’ that was operated through lottery drawings. The lottery was carried out with the help of machines similar to the one shown on figure 1, which contained individual bond serial numbers. If a bond serial number came up, it was reimbursed to the holder.[17] Now, when bonds were issued significantly below par (that is, below their reimbursement price), the mechanism created opportunities for lottery gains. This was discussed by the Select Committee in the case of the infamous Honduras issues (that had taken place before the aborted ship railway loan), such as the Honduras loan of 1870: Issued at £80, and with a par value of £100, it enabled the holder to contemplate a gain of 25 per cent (=(100-80)/80).

Some witnesses before the Select Committee claimed that the prospect of such gains had produced a ‘hot-house’ effect.[18] Evidence appeared to support the view that issuers exploited the lottery system to pump up issues. The Secretary of the Corporation of Foreign Bondholders who had led the charge on the ship railway pointed out that the contractors for the Honduras loan of 1870 had announced, only a few months after the subscription was closed, two extraordinary drawings. It was implied that this was meant to give artificial support to the market.[19] Members of the Select Committee were persuaded, not least because bond-tied lotteries had been prohibited in Britain since 1826. It was felt that the redemption by drawing were trying to resurrect this wretched system; In the *Report*, the lawmakers attacked this ‘lottery scheme’ whose ‘operation [had] undoubtedly tended to increase speculation, until it has become gambling, in these loans.’ They recommended a

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[16] The question of drawings at par first surfaced on March 11 during the interview of Samuel Herman de Zoete, Chairman of the London Stock Exchange (Q.251). See also Q.444, Q.2340, Q.2852, Q.4840, Q.5212; We estimate (based on the analysis of 105 prospectuses) that about 80% of the government loans issued in London between 1860 and 1875 were reimbursed by a lottery system. Another mode of reimbursement (representing 14% of the total) which did not entail the lottery system consisted in purchasing in the market the amount to be retired, though even in this case a lottery was used when the price of loans was above par. A small minority were perpetuities (about 6% of the total). We could not identify the redemption modality for 8 of those 105 loans.

[17] A slightly later technical description is provided in Arch. BNP Paribas 73AH491, 1891.

[18] See for example Lionel Cohen: ‘You issue a loan at 50 *l.* or 60 *l.* and draw it back the next year at 100 *l.*; that appears to me very much like the lottery which is prohibited in this country, and if it were possible, lotteries being one of the things which the law deems to come within its reach, to say that a loan was issued under 80 *l.*, should not be redeemable with a premium above 25 per cent. on its value, there is no doubt that that would check in some way the introduction of hot-house loans. That adds to the gambling element a great deal.’ (S. C. on Loans to Foreign States, P.P. 1875, XI, Q.5212, pp. 237–8).

[19]Interview of Hyde Clarke, Ibid., QQ.612–31, p. 31. The extra drawings were announced in the *IMM*, 1 April 1871, p. 98. (See also *IMM*, 27 May 1871, p. 166 for confirmation).

ban on drawings or at least their prohibition 'until after the expiration of 18 months from the payment of the last instalment' so as to take away from contractors the power to excite the public. In their view, had such a provision existed at the time of the foreign debt boom, this would have checked 'gambling transactions.'[20]

While it is quite possible that either appetite for risk or Allais-like asymmetries between valuation of losses and gains did lift prices, it is unlikely that the effect on prices was very large. The gains from being drawn were limited, not comparable at all to the large prizes that could be won in eighteenth century bond-related state lotteries. In the case of the Honduras loan of 1870, the probability of being drawn in the current year was 3 per cent for a 25 per cent gain only.[21] In fact, as so often, the conspiracy theories that emerged after the crash involved a lot of exaggeration. The economist Robert Lucas Nash would argue soon after, that high yield foreign government bonds had not performed so poorly in the end, and that with some diversification, investors could do quite well.[22] An early investment trust, the Foreign & Colonial, launched in 1868, demonstrated the point. Its portfolio, which included a small portion of Honduras bonds, delivered solid returns from diversification. But the moment had fixated exploitation fantasies. It did not help that those who tried to argue otherwise were stakeholders of the boom: Financiers who, having been involved in the loans, could be easily disposed of as having blatant conflicts of interest.[23]

An important channel for the propagation of anxieties was the media. James Taylor has shown how in the British capital market, established newspapers fulfilled a gatekeeping function assisting their readers with general directions and offering pointed words of caution on the more egregious cases.[24] In fact, some prominent journals such as the *Economist*, had

[20] S. C. on Loans to Foreign States (P.P. 1875, XI), p. xlix.
[21] As a result, the expected gain on a £80 loan (which had to be fully paid before the first lottery) was 0.6. The standard error was 3.4, the ratio between the standard error and the mean value of the loan was 0.04, and the skewness was 5.5. Drawing on the case of British lottery loans, Velde, 'Lottery loans', reports evidence consistent with cumulative prospect theory (asymmetrical valuations of gains and losses). Investors paid up to three times for the advantage (but the instruments he considers entailed considerably greater maximum gains). Even if Honduras investors had paid triple for the gain, the price increase would have been below £2. This could not drive prices off the chart.
[22] Nash, *A short inquiry*.
[23] This included men such as James Barclay, the broker in charge of the Honduras loan of 1870; When asked whether 'those drawings strengthen the market?' Barclay replied 'I do not think the drawing had any effect on the market.' (S. C. on Loans to Foreign States, P.P. 1875, XI, Q.2852); Another was Carlos Gutierrez, envoy of the Honduras government in London at the time of the issues; See Gutierrez, *Loans to foreign states*, pp. 31–2; For a recent defense of the 'Honduran view', see Miranda, 'Small money, big problems'.
[24] Taylor, 'Privacy, publicity, and reputation'; Taylor, 'Financial crises'. Bignon and Flandreau, 'Economics of badmouthing', theorize the gatekeeping function of the media and discuss the predator-prey relation.

played a key role in the debacle and in the events leading up to it.[25] According to a doctrine articulated by Herbert Spencer, an early sub-editor of the journal, exposure was a powerful weapon, that served to police the capital market[26]. As lending expanded in the 1860s, the new editor Walter Bagehot started cautioning investors against the perils of lending to foreign states and especially focused on misleading statements in prospectuses.[27] In May 25, 1872, the journal made a decisive contribution to the all-out attack against the Honduras ship railway by checking the numbers in the prospectus against British statistics sources. As they found, the amount of trade through Cape Horn – which the project was meant to capture – had been seriously inflated.[28]

As the Select Committee was still sitting, Walter Bagehot theorized its revelations as an insider-outsider problem.[29] He spoke of a 'gang of operators' inside the stock exchange seeking to take advantage of outside investors.[30] The point was driven home when a few months later, Bagehot turned the *Economist* into an investigative newspaper, attempting an estimation of the profits the promoters of the Honduras loan realized at the expense of outside investors.[31] Ordinary investors became weary of eccentric structuring of loans. In the newspaper-reading public, 'drawings' and 'redemption at par' became synonymous to 'financial fraud.'[32] More than 10 years later, the *Economist* would still mobilize the arguments of the Select Committee's *Report* to go after new securities. In an article entitled 'Disguised lottery loans', published in June 1886, it came down on an Argentine loan for containing the infamous amortization clause. The article did provide lengthy quotes from the Select Committee *Report* whose condemnation of the drawing system 'will hardly have been forgotten by our readers.'[33] It was hardly surprising, therefore, that when Robert Harry Inglis Palgrave, new editor of the *Economist*, first introduced in the *Manual* new columns with

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[25] Grant, *Bagehot*.
[26] Spencer, 'Morals of trade'.
[27] Not all established journals behaved that way. On the conflicts of interest of the editor of the city article for *The Times*, Marmaduke B. Sampson, see Kynaston, *The City of London*, pp. 267–9; Flandreau, *Anthropologists*, pp. 85–9 and pp. 234–43.
[28] 'The Honduras ship railway loan', *Economist*, 25 May 1872.
[29] 'Why the Stock Exchange Is Likely to Have More and Greater Frauds in It Than Any Other Market.' *Economist*, 27 March 1875, p. 361.
[30] *Economist*, 24 April 1875.
[31] *Economist*, 'M. Gutierrez', 7 Aug. 1875; *Economist*, 'The Report On Foreign Loans', 14 Aug. 1875. *Economist*, 'How Much Profit Was Made By The Operators In The Honduras Loans?', 25 Sept. 1875.
[32] *The Times*, 18 May 18, 1875.
[33] *Economist*, 'Disguised Lottery Loans', 5 June 1886.

yield computations that glossed over those numerical trappings the journal made its trademark to expose, they were greeted with a barrage of hostility.

**SECTION II. RISE OF THE COMPUTERS**

One professional group which was following the Select Committee inquiry with particular attention was the actuaries. The claim that redemption drawings had been an invitation to speculators was coming right within their remit, which consisted in extracting the yield from financial products structured in all kinds of ways. In fact, they had played a leading role in the boom. The reason is that their computations fulfilled a vital function in the capital market by enabling to resolve information asymmetries through their ability to render securities comparable with one another: Attacks on incongruous financial engineering, to the extent that it had been inspired by actuaries, entailed a reputational risk for the profession.

Traditionally, the development of actuarial science has been related to the rise of life insurance and to the production of supporting tools such as life tables which helped to price policies.[34] In this perspective, the work of the actuary is understood as consisting in assessing solvency and setting premium for life insurance offices. But the mathematical techniques that were mobilized for such tasks had import way beyond the specific problems that preoccupied life insurance offices. Assessing the sustainability of insurance offices involved the transformation of future cashflows in present values and compound interest. Of course, the same techniques could be used to determine the yield (and thus inform the pricing) of the large variety of fixed income securities that were traded on the capital market. This overlap between actuarial knowledge and finance was a distinct trait of nineteenth century British capitalism: The century opened with the publication by a member of the London stock exchange, of what was arguably the first general treatise of mathematical finance, namely Francis Baily's *Doctrine of interest and annuities*.[35] It ended with the President of the Institute of Actuaries, T.E. Young, urging in 1896 aspiring computers to develop a solid command of 'Finance' because 'mastery of financial questions [had] assumed an imperative supremacy' for the profession.[36] In between, the term 'actuary'

[34] Alborn, *Regulated lives*.
[35] For a discussion of the significance of Baily's contribution, see Mokyr, *Enlightened economy*, p. 231.
[36] Young, 'Nature and history of actuarial work'.

had come to bear a broad meaning, in fact referring to mathematicians involved in the business of finance, including but not limited to life-insurance.[37]

In fact, the focus of Baily's classic treatise provides a powerful illustration of the manner in which the specific interests of actuarial science and of finance writ large dovetailed. Baily was a member of the London Stock Exchange, heavily involved in the life of the market (he had contributed to writing its first *Rules and Regulations*). On the other hand, the *Treatise* dealt with the determination of the interest rate on 'annuities', as the name suggests, financial instruments that paid a fixed amount for a given number of years. In other words, annuities were essentially pensions, explaining their importance for life insurance. But many other financial contracts used this template. As shown by Kopf, their use dated back all the way to the middle ages.[38] In early modern Britain, annuities were used extensively to structure land rental contracts.[39] Many debentures traded in the London stock exchange also adopted the same shape. After surveying these varied uses, Baily concluded in the preface of his *Treatise* that the determination of the yield on annuities was a problem whose resolution had wide significance, and 'assuredly acquires a degree of importance which it never before aspired to.'[40]

The practical determination of the yield on an annuity mobilized numerical techniques because there was no closed-form analytical solution.[41] Scarce computing time encouraged the development of efficient methods. In the late seventeenth and eighteenth century, direct formulae, which substituted for the true value an approximation, had been developed concomitantly with algorithms, which aimed by contrast at determining the exact interest rate iteratively. Baily did break new ground by designing a powerful algorithm, which would be celebrated by nineteenth century actuaries as foundational because of its fast convergence. As a result, the *Doctrine* can be seen as having ushered in the preference for algorithms as the default method to calculate the yields on annuities. In the words of a knowledgeable observer, in the wake of the late eighteenth century advances, it had become possible to determine the solution of the annuity problem 'to a degree of exactness

[37] Walford, 'Actuary'.
[38] Kopf, 'Early history of the annuity'.
[39] Bellhouse, *Leases for lives*.
[40] Baily, *Doctrine of interest*, pp. iii–iv.
[41] Goetzmann, 'Fibonacci'.

abundantly sufficient for any useful purpose by one substitution [that is, iteration] only.'[42] As for the kind of precision that could be contemplated with the new methods, it was described by Baily as 0.0001 basis point.[43]

In the first half of the nineteenth century, the contours of the actuarial profession remained in flux, though the social value of the function they fulfilled was fully recognized.[44] In fact, actuaries did not form a defined professional group but rather a network of individuals tied to one another by common questions and methods. The predominant path for becoming an actuary was through a form of apprenticeship with an established practitioner. In terms of their employment, actuaries could be salaried by life insurance offices or work as consultants. Consulting work seems to have defined the default for the elite, who could deploy its talent in the eclectic problems submitted to them. The case of Benjamin Gompertz, like Baily a stockbroker, but also the part-time actuary of the Alliance British & Foreign Life Assurance Co. provides an illustration. In this context, there were also many self-proclaimed actuaries. As Charles Babbage, actuary of the Protector Life Assurance Society of London at the same time he was developing his Difference Engine lamented: 'The degree of knowledge possessed by persons so situated at the different institutions is exceedingly various, passing through all degrees, from the most superficial acquirements, derived merely from the routine of an office, up to the most profound knowledge of the subject.'[45]

The concerns created by this context were heightened with the passage of the Joint Stock Companies Act 1844, which led to widespread anxieties regarding possible exploitations of the capital market. By providing for the unobstructed formation of companies, the Act led to a wave of incorporations.[46] The life insurance industry bucked the

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[42] Milne, *A treatise*, pp. 686-7. That one iteration did suffice has been mixed up by Hawawini and Vora, 'Yield approximations', with the fact that contemporaries used 'approximations,' in part because in the language of the time, to describe an algorithm, it was spoken of a method that resolved the problem by (successive) 'approximations.'

[43] Baily, *Doctrine of interest*, p. 129.

[44] Cornelius Walford dates the officialization of the profession in 1819, when John Finlaison (future president of the Institute of Actuaries) was appointed 'actuary to the Commissioners of the National Debt' and when, the same year, the Friendly Societies Act imposed on the British mutual aid societies to have their tables 'approved by two persons at least, known to be professional actuaries, or persons skilled in calculation.' See Walford, 'Actuary'.

[45] Babbage, *Comparative view*, pp. xi–xii; On Babbage's relations with the actuarial industry, see Campbell-Kelly, 'Charles Babbage'; Wilson, 'Babbage among the insurers'.

[46] On the Act of 1844 see e.g. Harris, *Industrialising english law*; Taylor, *Boardroom scandal*.

trend: Between 1844 and 1848, 56 new offices were created. Some bursted immediately and the fateful term 'bubble' was proffered.[47] One concern was that new companies might find incompetent or worse, pliable calculators to vouch for unscrupulous policies that would undercut established businesses. Actuaries complained of a lack of consideration from company directors and reported attempts by latter to bully the former. Henry W. Porter told the story of the board of an insurance company that had 'not only acted perfectly in opposition to the most proper advice of their actuary, but also ridiculed the prominence, phrenologically speaking, of his organ of caution.'[48]

Responses included the emergence of a brand of muckraking journalism to coordinate attacks against identified abusers and the circulation of lists of respectable actuaries and companies. Alborn discusses the case of Hooper Hartnoll's *Post Magazine*, which developed as a kind of monitor of the industry.[49] There were also calls for regulation: In the 1850s a pamphlet war led to a thorough Parliamentary investigation, chaired by James Wilson, founder of the *Economist*, but in the end no definite recommendation was provided.[50] A fundamental development for the industry with long run consequences occurred in 1848, when the Institute of Actuaries was created and tasked with the responsibility to contain the looming 'tragedy of the commons.'[51] The most salient change brought in by the creation of the Institute was the creation of an examination prospective actuaries had to pass to prove their worth and secure the coveted label. The examination was means to the end: Its aim, enshrined in the association's Constitution, was to ensure that 'none but those duly qualified […] should be entitled to practice the profession.'[52]

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[47] See the 'Table of the number of companies existing, established, and discontinued during the last half-century' in Deuchar, 'The progress', p. 163.
[48] Porter, 'On some points', p. 108.
[49] Alborn, *Regulated lives*, p. 59.
[50] S. C. on Assurance Associations (P.P. 1852/3, XXI).
[51] On the creation of the Institute of Actuaries, see: Simmonds, *The Institute of Actuaries*, and Dennett, *Mind over data*; For a similar point, see Porter, *Trust in numbers*, and Porter, 'Precision and trust'. The effect of professionalization on trust is emphasized by Abbott, *System of professions*.
[52] 'The Institute of Actuaries,' *Journal of the Institute of Actuaries*, 13 (1867), pp. 392, 1867; *Constitution and laws of the Institute of Actuaries of Great Britain and Ireland* (1850), Art. 40, p. 25: 'The Council, at their first meeting subsequent to the Annual General Meeting, shall appoint two Fellows, an Official Associate, and an Honorary Member, or in lieu of the last, a third Fellow, as Examiners whose duty it shall be to examine candidates for certificates of competency in accordance with a plan to be approved by the Council.' Subsequent reforms of the examination were typically legitimized as contributing 'to the great object for which the Institute was organized, viz., the elevation of the status and character of the profession.' See 'The Institute of Actuaries', *Assurance Magazine*, 2 (1852), p. 195.

Established actuaries who were to be the first to bear the consequences of a reputational crisis and might have had self-interested motives, too, in preventing competition had provided the initial impulse for the creation of the Institute. But very soon, the innovation developed its own momentum. A majority of members did support the open expansion of the insurance business, which ultimately benefitted them collectively. Rather than restricting entry, they wanted to organize the market and indeed, the reform would pave the way for a spectacular increase in the number of actuaries. In fact, the development of a community was seen as a way to leverage solutions developed individually: Innovations, if turned into best practice, could be propagated and the market size, increased. This invited a 'research and development' function, the second major achievement of the Institute. It was materialized with the launch of a journal. Created in 1851, the *Journal of the Institute of Actuaries* (initially *Assurance Magazine*) mostly published the papers of the society's members, sometimes followed by minutes of discussions that had taken place after the presentation.[53]

During its first years of existence, the Institute expended significant efforts in accumulating reputational capital. This reflects the centrality of prestige for the profession a crucial feature to support its intermediation function. Emulating the fashion in which nationhood was invented in the nineteenth century, leading actuaries turned themselves into historians, archivists and collectors. A narrative of the origins of actuarial mathematics was constructed, the discipline tracing its root to glorious figures such as the Dutch John de Witt, Isaac Newton and Edmond Halley.[54] The mathematician Augustus De Morgan, a committed fellow traveler of the new organization (and the teacher of Bagehot at the University College), provided the first historical account of the evolution of algorithms for resolving the annuity problem.[55] He secured the transfer to the Institute of Baily's 'actuarial' papers. He also mined Baily's correspondence where he discovered a hitherto unpublished

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[53] Two other actuarial societies were created soon after the Institute: The Actuaries' Club in late 1848, and the Edinburgh-based Faculty of Actuaries in 1856. The first, which never gathered more than a dozen actuaries and acted more as a trade association than as a scientific society, was absorbed by the Institute in 1884. See Recknell, *Actuaries' Club*. The second was the product of the decision by the Scottish members of the Institute to form their own society (Davidson, *History of the Faculty of Actuaries*). The Institute, which was over the nineteenth century on average four times as large in membership as its Scottish equivalent, always maintained close ties with the Faculty, and both eventually merged in 2010, to form the currently existing Institute and Faculty of Actuaries.

[54] Hendricks, 'Contributions to the history of insurance'; De Morgan, 'Account of a correspondence'; De Morgan, 'On the determination'.

[55] De Morgan, 'On the determination'.

algorithm's update function to extract the yield from the annuity problem, due to George Barrett, a Baily protégé.[56] Upon examination, Barrett's formula was found to have extraordinary numerical powers, being superior in fact to the update function in Baily's *Doctrine of interest*. It was integrated into the corpus of actuarial science, taught to students and subsequently further improved upon.[57] The Institute's *Journal* became the site where the vibrant new-old science showcased its advances.

While this happened and *because* this happened, the capital market kept complexifying. In order to accommodate the expanding needs of borrowers and lenders, new financial instruments were created. Digital developers endeavored to concoct ever more powerful algorithms and tables to solve for the yield of the new products in cost-effective ways. Against this backdrop, actuarial calculus became an instrument whereby financial deepening was achieved. Because actuaries could dissipate numerical information asymmetries, they became essentially digital brokers, delivering a vital service for the capital market. By covering the grid of financial products with their formulae, they produced the digital infrastructure for the ongoing wave of financial expansion. The process walked in the footsteps of Baily's *Doctrine*, whose agenda of algorithm-based, precision-minded solutions it borrowed.

Two financial products, both being fixed income securities, gained rapid traction during those years. In the first arrangement, known as 'terminable loans,' full reimbursement of the lender occurred at maturity. Foreign and colonial railway companies that borrowed in London in the 1850s made extensive use of this template.[58] Under this arrangement, money was saved by the borrower and invested each year in a 'sinking fund' held in trust and the principal was eventually reimbursed from the sinking fund. There was initially no admitted general method to determine the yield on such instruments though of course a good calculator could come up with a numerical solution, if only through brute force calculation. But the rapid spread of this form of borrowing soon triggered an actuarial response: In 1855, an anonymous actuary signing 'M' published in the *Journal* an algorithm to calculate the

[56] De Morgan, 'Account of a correspondence'.
[57] MacLauchlan, 'On the formulas'; Hardy, 'On the rate of interest'.
[58] This was in contrast to British railway companies which mainly issued perpetual bonds.

exact yield on terminable loans.[59] We suggest that the innovation might in fact have contributed to further encourage the propagation of this redemption method.

On the other hand, there was the lottery system discussed previously. It came itself in two incarnations. The main variant followed the so-called 'accumulative' template. As explained in greater detail later, the mechanism consisted in directing towards the reimbursement of the loan the savings on interest payments on previously reimbursed bonds. The system kept the total annual outpayment constant, pretty much as in a modern mortgage. This meant that the loan, beyond the glitter of its mesmerizing drawings, was really for the borrower a straight derivative of the old-fashioned annuity. As a result, the cost of such loans could be calculated with the help of conventional algorithms, explaining why further efforts were made at the time to improve on the formulae provided by Baily and Barrett, leading to publications in the *Journal*. The other variant kept the amortization factor constant so that the total outpayment decreased over time (since less and less interest had to be paid). This was a numerical complication but in 1868 actuary Peter Gray, a leader of the Institute, seized the opportunity of a public controversy in the *Times*, whose moot point was whether an Austrian loan using this template had been usurious or not, to provide a method and exact solution.[60] Gray's complex algorithm was soon superseded by the elegant approach developed in 1874 by William Makeham, another member of the Institute.[61] Actuaries also worked towards constructing granular tables, from which quality initial values could be selected.[62] Of course, not all features were successfully priced. An example was the option for the borrower to repay at any point in time, though even there, efforts were made that led to forays in option theory. It should also be noted that no general formula exists today for pricing such a feature.[63] Appendix 1 provides a guide or 'map', in the form of a flow

[59] M., 'On the means of approximating'.

[60] 'A Broker' *The Times*, 30 Nov. 1865; 'An Actuary' *The Times*, 4 Dec. 1865; Gray, 'On the rate of interest'; Gray, 'Further considerations'.

[61] Makeham, 'On the solution'. The latest edition (as of 2019) of the Institute's official textbook on the topic of financial mathematics – one of the so-called Core Technical subjects that students need to master to become certified actuaries – devotes a generous portion of its chapter on 'The Valuation of Securities' to exposing, proving, and presenting the 'attractiveness' of Makeham's formula; see Garrett, *Introduction to the mathematics*, p. 134.

[62] Oakes, *Loans payable by drawings*, provides tables dealing with loans redeemable at maturity; Oakes, *Tables of compound interest*, provides a classic compound interest and annuity table with high granularity (eights of percentage points).

[63] Another case that could not be handled except under strong assumptions was when amortization could take the shape of purchases in the open market. The classic article by Lefèvre, 'Physiologie et mécanique sociales', which pioneered option theory was published in the French younger sibling of the *Journal of the Institute of*

chart, associating to each redemption modality the nineteenth century state-of-the-art yield-to-maturity actuarial formula and when it was developed.

As evidenced from the language of the articles and the discussions that followed the presentation of the papers, the members of the Institute were focused on best practice, which they sought to propagate. The approach may be described as divided in two steps. The first step was concerned with establishing, for each security, an orthodox standard for yield extraction. It aimed at complete exactitude. Once this was done, the focus changed to devising more cost-effective ways to go about the calculation. All kinds of numerical stratagems could be developed at that point. Of course, there was a fundamental complementarity between the orthodox solutions and the stratagems, since command of the former enabled one to gauge the validity of the latter. Deep numerical knowledge involved mastery of both registers. Ultimately, the Institute's role as custodian of precision was what carried the brand of the profession. Against this backdrop, the enemy was the (rebellious) individual element. In 1875 one Andrew Baden, a reputed actuary, caused a scandal at the Institute by speaking against algorithms as 'more or less intricate formulas' and advocating instead the 'unscientific' use of a trial and error method. Baden argued that, in fact, he had acquired a 'tact in guessing' that enabled him to essentially divine solutions. During the heated conversation that ensued, his colleagues sought to have Baden admit that his guesswork had been informed by the fine granularity tables of the tables he used. With evident relief, the chairman concluded that Baden had merely exploited 'knowledge previously obtained' enabling him to derive 'by intuition what was the result of his formula.'[64]

Accordingly, the formatting of the human became a chief goal of the Institute. In fact, some of the advances accomplished during these years, such as the design by Makeham of his celebrated formula, ought to be cast in this light: Unlike Gray's method, which left significant room for computer improvisation, Makeham formula guided him step by step, thus ensuring that two different organic machines would reach the exact same result. In fact, a glimpse of the sort of individual which the Institute aspired to create may be garnered

*Actuaries*, the *Journal des Actuaires*, which began publication in the early 1870s (Theocharis, 'The Journal des Actuaires Français'). For a discussion of Lefèvre, see Jovanovic, 'Economic Instruments'. There are interesting echoes between the story told here and the one in MacKenzie, *An Engine, not a Camera*.

[64] See Sutton, 'On the rate of interest', pp. 95–97.

from a visit a German gentleman paid to the Institute of Actuaries in 1850, which was commented abundantly in the financial press. For an entire evening, Herr Daze dazzled the society of computers assembled in the Society's premises, now returning the cube of 457 'almost instantaneously' (95,443,993), now dividing a number by another consisting of two or three figures, 'without any apparent intermediate process', now giving in the blink of an eye the factors of 7,421 (41 and 181). As the press summarized, Daze was an 'extraordinary calculator.'[65]

From there the Institute's strenuous efforts at exerting control upon individuals, the principal tool being the examination: The aim was to ensure that the latest programs that were designed by the research and development function would be installed on the latest machines. Teaching became a predominant function. Initially, only a reading list in mathematical finance was provided to guide aspiring actuaries in the preparation of the certificate, but in 1872, a fully-fledged course had to be attended.[66] The lectures were entrusted to William Sutton, the actuary of the London & Provincial Law Assurance Co. and a rising star of the actuarial profession, who was latter to become president of the Institute.[67] The course led to the production of a textbook, the actual ancestor of the modern textbook still taught today.[68] The combination of the examination and textbook enabled to weed out objectionable methods which were marked for extinction. They would disappear from want of cultivation, though the reality was always more complex. Suggestive of the organization's growing influence was its ability to tighten the screw over admissions: Our calculations show the admission rate dropped over time, from 89 per cent in 1851–5 to 35 per cent in 1876–80.[69]

These developments were not the abstract games of detached scientists but methods meant to bring pressure to bear on the real world. As a result, the financial tide of the 1860s and early 1870s lifted the boats of the actuarial profession. As digital intermediaries, both

[65] ''The Gazette', *Economist*, 6 July 1850, p. 748, drawing from the *Globe*.
[66] 'The Institute of Actuaries', *The Journal of the Institute of Actuaries and Assurance Magazine*, 17 (1872), p. 146.
[67] In 1888–90; As a result of his seniority, Sutton came to occupy prestigious positions in public offices traditionally reserved to prominent actuaries, such as actuary to the Friendly Societies' Central Office and actuarial advisor to the Board of Trade. Unfortunately, relatively little is known of this important character. For elements on Sutton's career, see Caverly and Bankes, *Leading insurance men*, p. 188.
[68] Sutton, *Institute of Actuaries' text-book*; Garrett, *Introduction to the mathematics*.
[69] Authors' calculations from the Institute reports: 1851–5: 89%; 1856–60 85%; 1861–5: 56%; 1866–70: 44%; 1871–5: 46%; 1876–80: 35%; 1881–5: 44%.

the rank-and-file and the elite of the profession were increasingly called in. Market participants routinely sought out actuarial advice. Because this expansion of the capital market had been their objective from the first, the computers were happy to respond in kind, corralling talent from the professional classes towards the certificate. Young men realized that lucrative careers were to be had in the new branch. This was reflected by the fact that, despite more trying examinations, the number of actuaries admitted expanded: At the peak of the financial mania (1871–5) a total of 168 new actuaries were sworn in. This was an all-time high that would only be reached again in the late 1880s.[70] Wherever we look, whether towards the London stock exchange where they could serve as partners in stockbroker firms, towards banks hiring them as managers, towards building societies employing them as consultants, or towards leading accountancy firms which they contributed to create, the actuaries are ubiquitous in the British capital market.[71] Of course, they were also involved in the foreign government debt boom. According to contemporary testimony, loan contractors turned to them to know the cost under various structuring scenarios and used the numbers for decision-making.[72]

A significant development was the involvement of actuaries at the forefront of financial innovation. This was nothing new. The role of actuarial science in structuring financial products in the eighteenth century is attested by Cramer.[73] Likewise, Baily had relied on the prestige conferred by his treatise, to promote life insurance companies.[74] But in the mid-nineteenth century, the scale exploded. In particular, actuaries were involved in figuring out the so-called ‘finance companies’ that were created at an extraordinary rate during the 1860s. The term covered a wide range of institutions that used the statute for joint stock companies to avoid the constraints from incorporation as banks. These creatures ranged from what would be called today ‘shadow banks’, to money market funds, to investment trusts, and they were behind the credit boom that had contributed to the expansion of the market for foreign government debt. This involvement in finance companies was natural

[70] There were 153 new actuaries in 1851–55, 97 in 1856–60, 132 in 1861–5, 130 in 1866–70, 168 in 1871–5, 126 in 1876–80, and 162 in 1881–5. Authors calculations from annual reports.
[71] On links with the stock exchange see Pearse Chope, *Devonian year book*, pp. 19–20. On actuaries in building societies, see Matthews et al., *Priesthood of industry*, pp. 22–3. On Edwin Waterhouse an actuary who was a founder of Price Waterhouse and Co, see Waterhouse, *Memoirs*, p. 73.
[72] Sutton, ‘On the rate of interest’, p. 95.
[73] Cramer, ‘Les trente demoiselles’.
[74] Baily, *An account*.

because comparing income streams on the asset and liability side and determining the amount of buffer capital was an actuary's job. The techniques could also objectivize financial benefits, in the end encouraging both innovation and distribution among those circles that admitted actuarial computations. What was more, insurance companies were saddled with large amounts of financial wealth which their officers had to invest with a predicted time-profile.[75] In other words, an ecological relation existed.

Evidence of a powerful tendency of the elite of the Institute to assist the process of financial innovation by acting as financial consultants is attested by Cornelius Walford's *Insurance Cyclopædia*, the glossary of the actuarial profession. In a detailed entry entitled 'Actuaries, Consulting' he speaks of 'actuaries of known reputation' who derive a 'very considerable income from a species of chamber practice, quite apart from the conduct of the business of any particular office with which they may be associated.' He goes on emphasizing that the role has come to encompass advice to guide investment, because 'most persons over-estimate the values of [certain] investments when not acting under competent advice.'[76] As an examination of individual cases reveals, many of these actuaries of known reputation not only advised but also became themselves originators of finance companies. Charles Jellicoe, a senior figure of the Institute is featured as 'consulting actuary' for a well-known finance company, the Australian, Mortgage, Land & Finance Co., created 1863. Arthur Scratchley, a very active member of the Institute, helped design the first 'investment trusts,' and produced an influential theorizing of the industry.[77] Many other members of the Institute of Actuaries became founders or managers of finance companies. William Sutton Gover (no connection with the other William Sutton) founded in 1857 the Equitable Investment, a quasi-bank, which was itself tied to the British Equitable Assurance Co. of which Sutton Gover was manager. C.J. Thicke founded a pioneer finance company, the British Mutual Investment Loan & Discount Co., in 1857. Stephan Henry Emmens presided the Mutual Society Trust, created 1872.[78] It would be easy to go on.

[75] Bailey, 'On the principles'.
[76] Walford, 'Actuaries, Consulting', p. 26.
[77] Scratchley, *On average investment trusts*.
[78] The link between actuaries and finance companies is captured, for instance, by the fact that Hartnoll's *Post Magazine*, which by the mid-1850s was the de facto official almanack of the actuarial profession, started in 1857 documenting what it called 'Loan, Investment, Discount and Deposit Companies' (p. 51). The feature was discontinued in 1884, but it attests strongly of the cross-pollination role of actuaries.

But when the crash came, and revelations were made suggesting that complexity had been used as an exploitive instrument, this close involvement of actuaries with the sell-side of the market became a concern. Optics suggested they had been accomplices or at least the hand-maid of abuse. In the case of foreign government loans, it was observed by Sutton that the interest rate calculations actuaries had communicated to contractors had seldom made it to the investing public. Our independent examination of a government debt issues covering the period 1860–75 showed that indeed, indication of yields in prospectuses were exceptional.[79] Of course, wealthy investors had the means to secure the intelligence. An account by William Sutton identifies the very top of the wealth distribution – individuals capable of making purchase orders worth £100,000 to £150,000 – as typically wanting to know 'the exact penny' because for them, Sutton suggests, such differences amounted to large gains or losses.[80] It is known also that private banks had access to the required skills. To give but one example, William Newmarch, a Fellow of the Institute, served as the secretary of the Globe Insurance Co. before becoming manager at Glyn's, a position he occupied for 19 years.[81] The manipulation problem arose for the middling classes. Actuarial services were beyond the reach of ordinary investors who, as a result, risked being left out. In the end, 'complex' products had been issued which only wealthy investors (with actuaries at their elbow) could fully figure out. In the toxic climate created by the revelations of the Select Committee, this could pass for professional duplicity.[82]

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[79] Our own examination of the evidence supports this. Out of 105 foreign loan prospectuses we examined covering most of the sovereign debt issues of the period, we found only three in which the yield was printed.
[80] See for instance Sutton's discussion of the demand side in Sutton, 'On the rate of interest', p. 96: 'I agree with Mr. Baden that in most questions of this kind the people asking for information do want the exact penny, the reason, as stated by our Chairman, being that the amounts dealt in are very large; and I am informed that even private individuals will sometimes take £ 100,000 or £ 150,000 worth of stock. Banks and stockbrokers frequently have inquiries made by their clients as to what rate of interest such and such an investment will yield. Indeed it would seem that private investors are getting as much interested in the matter as financiers.' A penny is 0.004 pound; For conversion in today's (2020) pound, Eh.Net's WeasuringWorth translates £100,000 of 1875 pounds into a range of £1.36 to £2.79 million using CPI/RPI, and £1.11 million to £2.83 million. When using the GDP deflator.
[81] *Economist*, 25 March 1882, p. 343; The French Rothschilds famously employed Henri Lefèvre who is credited for having later developed option theory.
[82] Looking at the period 1860–75, and focusing on loans whose primary market was London: The Chilean loan of 1866, the Dutch Indies loan of 1869 and the Turkish loan of March 1869. We also came across the discussion of an Imperial Ottoman loan 6%, 1865, issued in Paris, where the interest rate was given including redemption (see *The Times*, Dec. 19, 1865). As Sutton (1875, p. 96) admitted, he had seen 'many prospectuses, but very few in which the actual rate of interest is put in.'

**SECTION III. SEEING LIKE AN INSURANCE COMPANY**

At issue, in fact, was the broadening of the London capital market to new, structurally less-informed investing classes. This involved the creation of a level-playing field. From this vantage point, the crisis was an opportunity for actuaries. The digital scandal that exposed the vulnerability of a mode of structuring loans to manipulation simultaneously elevated the arcane calculation of yields to the status of *cause célèbre*. The manner in which this was dealt with illustrates the logic we discussed in the introduction: A system update was produced and uploaded on the computers. It took the shape of a paper by William Sutton, the figurehead of the actuarial curriculum, presented in the Institute's premises on April 26, 1875 and published a few months later in the *Journal*.[83] The paper came down forcefully against drawings accusing them of being intentionally deceptive. It advocated a new standardized procedure to calculate yields. In the future, individual computers would have to abide by the update. In clear, the resolution of information asymmetries in the market place and the control over computers were the two sides of the same coin.

In order to demonstrate this, we need now delve more closely into the specific problem which the foreign government loans scandal exposed. We have explained that during the 1850s and 1860s, actuaries had striven to expand the digital grid to cover new financial products. In fact, the grid had a small chink when it came to redemption drawings. It is not that the knowledge necessary to form an idea of the yield for such loans was missing. As we mentioned already, methods had been developed to determine the cost to the borrower. In the predominant mode of drawing known as the 'accumulative' system for instance, we said that the new financial product boiled down to the familiar annuities. This was because under this arrangement, the amount amortized was increased each year from the interest savings on already amortized bonds so that as a result, the total outpayment (interest and amortization) was constant. Figure 2 illustrates this mechanism in the case of the Japanese loan of 1873. This rendered calculation of the interest cost trivial, since it could be done with the familiar algorithms that served to deal with annuities. Likewise, as we said, special methods had been developed by Gray and perfected by Makeham to determine the interest cost of securities amortized by constant drawings.

[83] Sutton, 'On the rate of interest'.

But these were methods that informed the sell-side of the market only because, for the borrower, the element of chance disappeared. Borrower only faced deterministic, known annual lump-sum payments. But what about the flesh and blood individual investor? If she held only a few of those securities, the apocryphal spinster was subjected to chance. She might be reimbursed immediately or twenty years later and the performance would vary a lot. As the actuary Peter Gray put it: 'The rate realized on each bond will depend on the period at which it is paid off.'[84] Against this backdrop, what should actuaries tell her? Up to the Select Committee and the publication of Sutton's piece, British actuaries were reluctant to give clients a single return.[85] Evidence suggests that the attitude was informed by an innate understanding of the concept of risk appetite. Gray for instance, interpreted his own hesitation by the fact that risk takers might value more the possibility of large financial gains.[86] Given this, actuaries communicated to clients a menu of yields (analogous to the 'payoff matrix' found in modern treatments of the theory of choice under uncertainty). An example, shown in figure 3, is taken from Gray.[87]

The outcome was problematic with respect to the specific anxieties the Select Committee had aroused. For a level playing field to exist in a laissez-faire world, all investors should be able to afford purchasing the payoff matrix. But of course, it was unlikely that middle-class or 'outside' investors would do it. A solution was to develop a standard, that is, identify a relevant number, which could be exhibited. Sutton's solution theorized a suggested average, that drew on an analogy with life insurance companies. Since offices valued contingent revenues at their mathematical expectation, it was 'reasonable' to do the same for drawings. Of course, the foundation for this solution was the prestige enjoyed by

[84] Gray, 'On the rate of interest', pp. 99–100; Gray, 'Further considerations'.

[85] As a result of this, actuaries thought of inferring the value of being drawn from the market, through the creation of a drawing insurance system. As Hardy explained 'if you take [the cost of insuring bonds being drawn] off, it will give you the interest rate' (See the discussion printed in Sutton, 'On the rate of interest', p. 95). This brings us again to the connections between actuaries and the finance companies of the 1860s. Actuaries followed and perhaps inspired efforts by financiers to set-up drawing insurance schemes. Under one arrangement discussed by Cornelius Walford, in 1866, a company had taken up the idea and purchased from individuals the right to the benefit of being drawn (Sutton, 'On the rate of interest', p. 95).

[86] In his language, 'it is quite conceivable that this element of uncertainty— embracing as it does the possibility of a very large return on the sum invested— may act with no small effect as a lure on minds of a certain constitution.' (Gray, 'On the rate of interest', p. 100).

[87] Gray, 'Further considerations', pp. 188–9. A more rudimentary variant is G. F. Hardy who described his own policy as to 'always [give] two rates. I say, 'You will get so much if the bond is paid [i.e. drawn], and so much if it is not'. See Sutton, 'On the rate of interest', p. 95; Scratchley, *On average investment trusts*, p. 140; Glen, *Actuarial science*, p. 49.

life insurance companies as reputable knowledge brokers. With this approach, which amounted to postulating risk neutrality, the revenue to the lender was identical to the cost to the borrower, because the probability of being drawn in a given year was identical to the fraction of the loan that would be drawn that year, a proposition Sutton took care of proving mathematically. In the end, the tried-and-tested annuity formulae were relevant to determine the yield to investors as well.[88]

Having done this, Sutton undertook a forensic examination of 37 foreign government loans issued during the 'mania', including the scandalous ones. His yield results, computed with the help of what was at the time the most recognized algorithms to determine the yield on an annuity (viz. Baily, Barrett and the more recent one by MacLauchlan) were compared to the yield seen by 'naïve' investors. Sutton defined them as individuals who would have been blind-sighted by redemption drawings. They would have measured performance only by comparing the dividend with the price paid to acquire the security, and as a result, would have neglected to factor in the value of drawings. As results demonstrated, 'naïve' yields were always below what Sutton described as his 'true' yields. For instance, the Honduras loan of 1870 showed a 'naïve' yield of 12.5 per cent, while Sutton's method gave 13.9518 per cent, or a spread of about 150 basis points. Sutton's conclusion was that the drawings system had misled investors into thinking that loans structured in this manner were less risky than they were in fact. It had helped 'conceal […] the actual terms on which the loan is obtained.' Had investors been enabled to figure the 'extravagant terms offered in some cases' this would have 'acted as a caution.'[89]

The exposé is intriguing. Not only does it contain an early formulation of the Rational Expectations Hypothesis, but, from the more specific vantage point of our story, it does interpret the government debt crisis as a product of deception, rather than speculation. This is in fact the opposite of the view of the Select Committee, which claimed that the lottery element had been exaggerated by investors, a source of speculative excitement. At the same time, there was something ludicrous in Sutton's conspiracy theory for it was not exactly as if the ploy had successfully concealed the risk. Whether it is set at 12.5 per cent or 14 per cent,

[88] As Sutton put it, an investor might 'fairly reckon' that her bonds would be 'drawn for repayment year by year in the proportion the total amount of them bore to the total amount of the loan.' (Sutton, 'On the rate of interest', pp. 85–7).
[89] Sutton, 'On the rate of interest', p. 78.

the high-yield nature of the proposition spoke for itself.[90] What is more, the concept of naïve investor which Sutton championed was problematic. Predictably, publishers had stepped into the numerical breach and popular tables informed ordinary investors of the value of drawings. A successful product whose success is attested by contemporary praise and its several reprints, was the tables of stockbroker W. T. F. M. Ingall.[91] They provided a correction of the 'naïve' yield. The trick consisted in adjusting the yield by the expected value of being drawn in the forthcoming year. This was of course not grounded in the soundest actuarial practice but it did the job. For instance, Ingall's correction set the actuarial yield for the Honduras loan of 1870 at 13.4 per cent, fairly close to Sutton's 14 per cent. Whoever were those naïve investors Sutton had in mind, they must have been so numerically destitute that they could not even buy their copy of Ingall.[92]

These remarks help us see what was the ultimate objective of Sutton's intervention. It had to do with territory: Sutton sought to reclaim from competitors such as Ingall a ground which had been imperfectly colonized, owing to the actuaries' own hesitations. If the profession wanted to expand its rule as information broker in the capital market, it had to transcend the views of the purists, especially when they stood in the way of industrialized solutions. The former discretionary element (the table), was now replaced by an algorithm. At the cost of more demanding assumption, it would become possible to distil risk and return in but one statistic. This underscores the nature of the economic trade-offs out of which the scientific advance was born. Of course, as mentioned, since Sutton was both the head of teaching at the Institute and the author of the textbook (where the relevant

[90] Another perplexing observation is that, as we indicated, until the crisis of 1872–3, most sovereign loans were redeemed via an accumulative sinking fund rather than via the alternative constant annual amortization. But the science required for constant annual amortization, was more recent and heavier to mobilize. And so, the majority of the abusive loans had adopted the more transparent method.  If deception was the objective, the more opaque form ought to have been preferred. We also note that, other things being equal (amount borrowed, coupon and maturity), loans redeemed via constant amortization had a higher cost than loans redeemed via an accumulative sinking fund (because of the fact that the amortization flow of the former was higher in the early years and thus worth more overall, in virtue of the discounting factor). The Honduras loan of 1870 did cost 13.96%, but it would have cost 14.9% had constant amortization been chosen.

[91] Ingall, *Tables of drawings*.

[92] We also note that of the four foreign loan prospectuses containing an indication of yield, Sutton's 'method' enabled us to come within a ballpark of the figure in the prospectus. The prospectus of the Dutch Indies loan of 1869 mentioned 'nearly 5.25%' and Sutton's method gave 5.23% de yield (*The Times*, 12 Dec. 1869). The Ottoman 6% (issued in Paris and discussed in *The Times* (19 Dec. 1865) was announced as yielding 'about 11.75%' and Sutton's method gives 11.78%. In both cases, the coincidence is perfect and this implies that the method was not novel in any fundamental sense. For the other two loans, for which one had unusual features and the other a much shorter term than what was usual for this class of securities, we have not been able to identify with full certainty the method mobilized.

passages of his 1875 article would be reproduced word for word), resistance was futile.[93] If the question came up at the exam, as happened in 1881, the candidates were expected to treat redemption drawings as if they were annuities and to calculate their yield accordingly.[94] The influence of Sutton's also snowballed because of the centrality of the Institute as a knowledge leader: Later competing textbooks would closely emulate his approach and even lift the notations. The new algorithm, in other words, was now running full steam on human machines.[95]

## SECTION IV. NOBLESSE OBLIGE

With this development, a collision course had been created with yet another development, the rise of the financial press. As we have said, prominent journals, such as the *Economist*, were involved in financial gatekeeping, and, what is more, they had drummed up the digital drama. We have already emphasized the role the *Economist* played in bringing down the Honduras ship railway loan in 1872. As part of this gatekeeping function, major outlets also started providing financial data. The *Economist* had been a leader. In 1863, faced with competitors seeking to penetrate the market for financial news on the back of the credit boom, Walter Bagehot decided to launch the *Investor's Monthly Manual* as a monthly supplement. The intention was to tie readers to the *Economist* group, the *IMM* covering statistical reference material while the *Economist* would get into specifics. The *Manual* could be bundled with the weekly sister publication or purchased separately.[96] Taken together, the two publications were meant to be a powerful source of information.[97]

The austere and voluminous tables of the *IMM* covered a wide array of securities, traded both on the LSE and on provincial stock exchanges, as well as a few instruments that appear to have been dealt over-the-counter.[98] Initially, the tables gave readers prices (both latest

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[93] Sutton, *Institute of Actuaries' Text-Book*, p. 133.
[94] See examination questions in *Journal of the Institute of Actuaries and Assurance Magazine*, 23 (1881), pp. 68–70, questions 5 and 21; and 24 (1883), p. 141, questions 6.
[95] See King, 'Theory of finance', p. 217; Glen, *Actuarial science*, p. 52.
[96] For a discussion of the media boom and its entanglement with foreign loans, see Meszaros, 'The Corporation of Foreign Bondholders'. Other journals created during the period included the *Money Market Review*, and the *Bullionist*. Porter, '"A Trusted Guide of the investing public"', counts 19 British periodicals specializing on money and finance in 1874, rising to 32 in 1884 and 50 in 1894.
[97] Grant, *Bagehot*, p. 285. For a description of what the *Economist* thought the IMM should be, see *Economist*, 15 Oct. 1864, p. 1.
[98] In fact, a significant fraction of the securities covered by the IMM were not traded in London. As Leslie Hannah explains 'The IMM cannot generally be equated with the LSE. In its early years, it measured something

and recent), dividend amounts, capital outstanding, details on reimbursement and the like. To retain its edge, the *IMM* kept diversifying content. New features were added over time: In January 1865, it started including information regarding shareholder and bondholder meetings. In early 1871, it introduced a narrative of the main events of the month. It was against this backdrop that the tabulation of yields appeared for the first time in June 1879.[99]

Until that point, the journal had only supplied a large, 1-page table entitled 'Table for Investors' which could be used to form an idea of yields. Readers would read information on the dividend and price in the columns of the *Manual*, then use the table to figure the yield. The function of such tables, whose origin can be traced to the eighteenth century, was to help users compare securities that yielded different coupons.[100] For example, a security purchased at £50 and promising a yearly coupon of £2, was understood to be roughly 'similar' to one yielding of £3 and costing £75 because both would yield the same return in the next year or about 4 per cent (because 4 per cent=2/50=3/75). Of course, this was a crude measure and it was not actuarially correct since it only considered the short run. Despite the rudimentary character of the method, the Manual's table enabled the reader from the comfort of her armchair, to secure a direct comparison of fairly heterogeneous securities, even if they had different characteristics, and even if they were traded on different financial platforms.

The feature introduced in June 1879 was only marginally more capacious in that it purported to do for the reader the first stage of the work without her having to strain her eyes. The new feature did pre-calculate the yield (for all securities) according to the same basic logic. The resulting numbers were, if one will, the 'naïve' yields which Sutton had stigmatized. Of course, the editors of the *IMM* were fully aware of the progresses of

approaching the whole national market, covering about one-half more by value than all the LSE official list's corporate securities; By 1929, the situation had reversed: the official list alone was nearly half as high again as the value of IMM corporate securities.' (Hannah, 'The London stock exchange', p. 1353).

[99] A word of comparison with financial yearbooks such as Mihill Slaughter's *Railway Intelligence* (1849–79), Henry Burdett's *Burdett's Official Intelligence* (1882–98) subsequently *Stock Exchange Official Intellige*nce (1899–1933), and Skinner's *Stock Exchange Official Year Book* founded 1875, later called *Stock Exchange Year Book*, and merged with Burdett in 1934 (see Hannah, 'The London stock exchange', for discussion of these sources). What the *IMM* did must be differentiated from what the yearbooks did, in that not only did they differ by frequency (monthly versus annual versus) and coverage (for the *IMM* a selection of stocks not limited to the London stock exchange, but the London stock exchange for the annuals), but the *IMM* alone busied itself with computing yields.

[100] See for instance, *IMM*, 31 Aug. 1872, p. 272. The table spanned the £10 to £300 range (security prices) and from £1 to £20 (coupons). For earlier tables, see for instance in Mortimer, *Every man*.

actuarial calculus and of the limitations of their solution. In no place did the journal claim that their yields were the true actuarial yield of the security.[101] The limited value of the measure was emphasized by a caveat, printed when the feature was introduced and reprinted again and again afterwards. As we said, it did single out redemption by drawings as a source of distortion: 'The yield to the buyer, the journal warned, has been calculated without making any allowance […] for the value of redemption drawings, which form an additional item of prospective profit [or loss] to investors.'[102] Obviously, the editors of the *IMM* knew that the readers would have the findings of the Select Committee in mind.

That this did not produce the desired effect makes also perfect sense given the expanded reach of actuarial ideas. The *IMM* was catering to that public for which anxieties about manipulated numbers ought to have been paramount. Such readers would worry about the digital problem, ask their money manager and receive confirmation that there was an issue. The fact that a number of brokers employed actuaries as we have said, suggests that a number of clients would be aware of the matter. Logically, therefore, individual investors sent protests and some financial intermediaries complained, too, probably because they were caught between clients to whom they had given some figures and those numbers the *IMM* reported. This was the case of Grahames, Crum & Spens, a Glasgow firm, which advertised itself as 'stockbroker and chartered accountant' and whose partners would later play a significant role in the Investment Trusts movement. They wrote to take issue with the scandalous case of an Indian loan whose true actuarial yield would be something like 3£ 2s, not at all the 3£ 16s 2d the *IMM* reported (3.1 per cent versus 3.8 per cent).[103]

This prompted the journal to publish a long article in November 1881 entitled 'Redemption at Par' reiterating their ground. They were perfectly aware of the problems arising from ignoring maturity, but on the other hand, taking into account redemption was a can of worms. What was more, the case of government loans was only the tip of the iceberg. Most other financial instruments tracked by the *Manual* would require correction as well. This was altogether a large, implausible engagement. When it would be eventually

[101] The header of the new column made it crystal clear. It read 'Last two dividends yield investor at latest price…', which of course was not the same thing as saying 'Security does yield...'. See *IMM*, 30 June 1879, p. 192; *IMM*, 31 Jan. 1883, p. 2.
[102] *IMM*, 30 June 1879, p. 192; They also mentioned that they did not control for 'accrued dividend,' the effect which a looming dividend has on price.
[103] *IMM*, 26 Nov. 1881, p. 491; Bassett, *Men of note*, p. 203.

implemented, in January 1883, it would be spoken of a 'Herculean task.'[104] This explains why the journal initially pushed back, dumping on readers a do-it-yourself correction, in fact the method already used in Ingall's tables ten years earlier. As we saw, it consisted in adjusting the yield by the effect of being drawn next year. Mercurially, the *IMM* emphasized that this computation mobilized data readers would find in the journal's own columns.[105] The next month, another article showed how to do it in practice.[106]

The pacifier failed to soothe the nerves of grousers. The default installation of the dozens of newly minted actuaries the Institute now released each year in the City included, not only Sutton's method but the diverse algorithms that could indeed handle the full diversity of redemption techniques. At that point there were about 450 self-identified members of the Institute of Actuaries working not only in life offices but, as indicated, with the stock exchange, banks, investment funds and accounting firms as consulting actuaries or in other capacities. And as we saw, there were many defrocked actuaries too, who had moved to other businesses but knew the relevant techniques. Between 1875 and 1882, the exams of the Institute were sat more than 300 times, and 118 new students passed (Authors' calculation, from the annual reports of the Institute of Actuaries). 1882 was also the year Sutton's textbook was released. Because of the actuarial diaspora, it reached beyond the actuarial profession. In fact, some 'translators' worked to propagate the actuarial gospel into vulgar tongue.[107] It was not possible for a data outlet such as the *IMM*, advertising itself as a 'work of constant reference among the moneyed classes', to keep promoting back-of-the-envelope calculations pilfered from popular tables.[108] At some point in 1882, the *IMM* threw in the towel, explaining why in January 1883, a completely revamped calculation system was launched. The article that introduced the change recanted the previous method. It was now charging that 'it has always been apparent where future redemption at par has to be taken into account, that the return to the investor upon the two last dividend payments has been open to material qualification.'[109] The new yields controlled for redemption, as reflected by

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[104] The Economist, *The Economist: a centenary volume*, pp. 126–127.
[105] *IMM*, 26 Nov. 1881, p. 491. The amount in circulation was reported under 'Amounts of Loan Unredeemed.' Drawings were recapitulated in the *IMM*'s 'Notice and reports.' The price was given in the column 'Last Business Done' and the parity was in the column 'Par.'
[106] 'The amount of Value of Some Coming Drawings', *IMM,* 31 Dec. 1881, p. 546.
[107] Maddison, *On the stock exchange*, p. 265 ff.
[108] *IMM,* 29 April 1882, p. 145.
[109] See *IMM*, 31 Jan. 1883, p. 2, 'The Alterations Introduced in the Present Number.'

the changed header of the yield column, formerly 'Last two div[idends] Yield to Investor at Latest Price' but now 'Yield to Investor at Latest Price, Redemp[tion] Included' (See figure 4).[110]

**SECTION V. THE WAY WE COUNT NOW**

The ambitious change shows the reach of the actuarial gospel. As we discovered, it was not just that the journal followed the actuarial best practice: In fact, cutting-edge actuarial expertise had been harnessed to *design* the new program, enabling the journal to navigate the contradictory imperatives of adequacy with the state of the art and cost-efficiency. How the expertise had been communicated is not known but Robert Harry Inglis Palgrave, the editor who piloted the recasting, had extensive connections with the profession.[111] He was a banker and an economist versed into interest rate policy, which of course meant that he was in contact with actuaries. More pointedly, he was an auditor for the Universal Life Assurance Society. This put him in contact with its actuary, Frederick Hendricks, a founding member of the Institute of Actuaries who also became a contributor to the *Economist*. It might have been through Hendricks or through any of the influential members of the Institute such as Arthur H. Bailey or Thomas Bond Sprague with whom Palgrave rubbed shoulders at the London Statistical Society, that the *IMM* secured the advice.[112]

In truth, this deep influence of the actuarial profession in designing the *IMM* program may escape cursory examination, explaining previous misinterpretations. We discovered its DNA almost fortuitously, by pondering the journal's verbal description of the new protocol.[113] It spoke of calculating the value of redemption as the capital gain or loss which, if compounded over the lifetime of the bond, would return the gain or loss from redemption

[110] The similar header for the 'British, Colonial and Foreign Railway' column was kept in its old form ('last two dividends yield investors at latest price'), even as the mode of calculation was changed, as the IMM indicated. We interpret this as further proof that the bulk of anxieties had focused on the case of government loans. See e.g. *IMM*, 31 Jan. 1900.

[111] Palgrave, *An analysis of the transactions*. On Palgrave, see Howe, 'Palgrave'; Palgrave succeeded Bagehot in 1877 jointly with C. Lathbury, then alone after 1881 and resigned in 1883. On Palgrave in the Universal Life, see the company's prospectus, in Supplement to the *Economist*, 'Commercial History and Review of 1882,' 51 (Feb. 1883), p. 5; It is perhaps not coincidental that Walter Bagehot had studied mathematics at the University of London under the mathematician and IoA fellow traveler Augustus De Morgan (Grant, *Bagehot*, pp. 16–7).

[112] On the overlap between Victorian economists, statisticians and professional actuaries, see Alborn, 'The other economists', and Alborn, 'Victorian actuaries'. See 'List of Fellows', in *Statistical Society (Founded 1834), Corrected to 1st January 1883*, 1883, pp. 8–42.

[113] See 'The Alterations Introduced in the Present Number', *IMM*, 31 Jan. 1883, p. 2.

at par. Although the *Manual* does not give any source for this method, its smacks of the present value calculations actuaries relied upon. We thus embarked on an exploration of possible candidates in the contemporary literature. To that end we first transcribed the formula algebraically, then looked for a positive match. As we discovered, the model for the *IMM*'s formula was in fact the update function published by 'M' in 1855, which at the time (and for quite some time to go) still represented the actuarial state of the art.[114] As indicated, it enabled to determine the yield on debentures reimbursable at par at maturity.[115] We also discovered that the *IMM* had been shown how to cut down the number of iterations. Using the coupon/price ratio as starting value for the algorithm worked miraculous well. In the end, the calculation boiled down to applying a simple formula plus reading an actuarial table.[116]

Use of M's formula as the default was logical because as just said it applied to debentures reimbursable at maturity, a preferred template for corporate bonds and foreign railway companies, which as Table 1 shows, represented about 80 per cent of the securities the *IMM* monitored. It was also becoming the main way to structure the debts of British colonies. But it remained that not all securities were debentures repayable at maturity. The drawing system still predominated among foreign government loans. In other words, a large part of the foreign loans documented by the *IMM*, representing 20 per cent of the securities

[114] See app. 2 for a derivation and proof of equivalence.

[115] Sutton, *Institute of Actuaries' Text-Book*, pp. 92–3, 'formula E1', and again p. 134; See also Todhunter, *Institute of Actuaries' Text-book*, p. 115.

[116] See 'The Alterations Introduced in the Present Number', *IMM*, 31 Jan. 1883, p. 2. The matter dovetailed with another question that was captivating actuaries at the time, and we suspect that the two developments were related, though we cannot establish it beyond showing circumstantial evidence. Actuaries debated a distinction between the 'accumulative rate' (the rate at which the sinking fund created for the eventual reimbursement of the creditor accumulates) and the 'remunerative rate' (the return of the security). It had been first introduced in 1850 by Peter Hardy (Hardy, 'On the values of annuities') and in 1877, mining engineer Henry Davis Hoskold published a book, written with the help of actuary Peter Gray, harnessing the distinction to deal with yield calculations on mine or colliery debentures (Hoskold, *Engineer's valuing assistant*). Mines and collieries were usually very risky and their yields were accordingly higher than the rate of return of a sinking fund invested in safe assets. A question arose as to whether it was correct to postulate, as was conventionally done, that reimbursements to the sinking fund (the accumulative rate) accumulated at the rate of return of the project (remunerative rate). The result was that the equation expressing the present value of debentures while distinguishing between the two concepts led to a formula for the yield solution that was formally identical to the one used by the *IMM*. This formula was well-known at the time and is presented in Sutton's textbook, as a special case of the more general debenture formula (Sutton, *Institute of Actuaries' text-book*, p. 134). In 1881, Herbert Johnson published a set of tables (the first of its kind) that returned the yield of such debentures as a function of the coupon, the maturity, and the rate at which the sinking fund was assumed to be accumulating (Johnson, *Investment tables*). If one fed the coupon/price as the rate at which the sinking fund was assumed to be accumulating, the table returned the yield-to-maturity which the *IMM* was after. We speculate that the emergence of such convenient tools further contributed to the obsolescence of the older way of reporting.

the *IMM* monitored involved lotteries and the 'accumulative' system which mobilized Sutton's method. This raises the question of the manner in which the *IMM* did manage to put the calculation of actuarial yields for this group within the remit of M's formula. Here again, the answer is that the editors mobilized actuarial insight. As they explained, the subterfuge used was to assume that everything happened as if all future drawings would take place at one unique 'average' date. This artificial horizon, known to actuaries as the 'probable epoch' was defined as the year when one-half of the loan would have been repaid. The editors of the *IMM* gave the example of the Japanese 7 per cent loan of 1873, which matured in 1898. Since half of the bonds in circulation in January 1883 would have been drawn by 1892, the security was just like 'a seven per cent loan absolutely repayable ten years hence.'[117]

The probable epoch was originally a rule of thumb, a vernacular technique used by stockbrokers in the London stock exchange.[118] In public, actuaries had reservations because the approximation had inherent instabilities. Purists such as Gray cautioned against it, stating that it was 'entitled to but little confidence.' Sutton discussed it as well, admitting that it was 'in actual use' but warning that it was 'clearly incorrect in theory and in practice it gives results wide off the mark.'[119] In private however, they knew that the tactic belonged to those valuable stratagems that cut computing costs. For some ranges of parameters, they could work rather well in fact. Sutton gave a mathematical formula for accurate calculation of the probable epoch from the parameters of the loan, an indirect recognition of its reach.[120] As long as the horizon of the bond was long enough, the distortion was minimal as can be shown for, instance, in the Japanese 7 per cent loan of 1873, for which the error term from using the probable epoch rather than Sutton's formula was initially negligible.[121] In the

[117] See 'The Alterations Introduced in the Present Number', *IMM*, 31 Jan. 1883, p. 2. Likewise, in 'Redemption at Par' (*IMM*, 26 Nov. 26, 1881), it is declared about the Argentine Public Works, which had still 11 years to go, that one might use as de facto maturity ''seven years, by which date *one-half* of the at present outstanding bonds will have been redeemed' (italics in original).
[118] See for instance the analysis of the 1865 Austrian loan by 'A Broker' (*The Times*, 30 Nov. 1865).
[119] Gray, 'On the rate of interest', pp. 187–188; Sutton, 'On the rate of interest', p. 83–4; Sutton, *Institute of Actuaries' Text-Book*, pp. 129–31.
[120] Sutton, 'On the rate of interest', p. 83; and Sutton, *Institute of Actuaries' Text-Book*, p. 130; Actuaries even distilled a baby sister, an improvement on the probable epoch, known as the 'epoch of mean probability,' a weighted average of drawing dates; It was due to French actuaries F. Vintéjoux and Jacques de Reinach (Vintéjoux and de Reinach, *Formules et tables*, pp. 34–6; Sutton, 'On the rate of interest', p. 84).
[121] Authors' calculations.

end, with the help of the probable epoch, lottery bonds and other loans gradually amortized could be placed under the orbit of M's method, enabling industrialization of the procedure.

**SECTION VI. EMPIRICAL EVIDENCE**

The previous description lends itself naturally to empirical verification. One would like to know such things as whether the *IMM* did as advertised and if it did, whether its industrialized method fared well compared to the actuarial state of the art. This can be determined by replicating with the help of a computer the operations we understand the *Manual* performed by hand, and by comparing the results with the yields reported in the *IMM* tables. Initially, we envisioned a large-scale reconstruction of the primary dataset used by the *IMM* (the input) and a systematic assessment of the actuarial yields that the journal printed (the output).

Gradually however, we realized that while the logic of this blueprint is straightforward, it is difficult to implement rigorously. For instance, the *IMM* did not indicate the structuring group to which individual securities belonged. As a result, the reader is forced to make herself the determinations security by security from evidence in the *IMM* columns, which is not always easy. Using stock exchange annuals such as *Burdett's* which provide language that facilitate interpretation is not enough because many securities in the *IMM* are not in *Burdett's*.[122] In fact, we found that it is often the case that for want of a complete command of sign-posts in the financial language of the time, misinterpretations can arise. An 'sinking fund' may refer either to an actual fund under trust or 'metaphorically' to an amortization procedure through drawings. When our command of the lingo improved, we started realizing that the *IMM* itself was not immune from the problem. More than once, they made errors themselves, which they eventually corrected, possibly following reader complaints.[123]

What we did instead is focus on a sample of randomly picked securities and examine more specifically what happened between December 1882 and January 1883, when the regime change took place. To that end, we drew 45 fixed income long term securities, including 15 government loans, 15 foreign railway debentures and 15 municipality loans. For each, we collected information on financial characteristics as well as the yield reported in

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[122] Hannah, 'The London stock exchange'.

[123] For instance, the Mauritius 6% 1865 was calculated by the *IMM* as a lottery loan in Jan. 1883. It was in fact a loan redeemable at maturity. The correction took place in Feb. 1883.

the *IMM* columns. We use this data to discuss our previous claims regarding the significance of the regime change and the properties of the *IMM*'s computing strategy. In particular, we want to show that the *IMM* did implement the program it described. What is more, we show that this program closely emulated the 'technological frontier' set by the Institute of Actuaries.

Figure 5.a shows that until December 1882, the *IMM* simply calculated yields by dividing the dividend by the price of the security, exactly as it explained. This is demonstrated by the perfect alignment of the yield reported by the *IMM* on the numbers implied by this formula. Next, figure 5.b shows what happened in January 1883. As indicated, the *IMM* switched to a new program, harnessing M's 1855 formula. We replicated the same technique and the figure compares the yields reported by the *IMM* to the yields resulting from the application of M's formula. As already stated, M's formula is the update function of an algorithm, and we applied it in the manner suggested in contemporary sources, using the dividend-price ratio as starting value. The figure demonstrates the near perfect alignment of *IMM* numbers on yields calculated using M's formula. We interpret the minor departures that are nonetheless observed as a result of the fact that, the IMM's figures having been calculated by hand, they mobilized computational tricks and could not be as precise as the counterpart we derive, which exploits the power of a spreadsheet. Finally, driving the point home, figure 5.c underscores this time the *difference* between the old and the new methods. The transformation of January 1883 was anything but immaterial.

We now move to the quality of the process adopted by the *Manual*. Figure 5.d shows the relation between what we define as the actuarial state of the art and the *IMM*'s approach. The actuarial state of the art is operationalized through implementation, for each security-class, of the best available method with enough iterations of the preferred algorithm so that an exact solution be generated.[124] For loans redeemed at maturity, M's method is used as previously but with more iterations. For lottery loans, it consists in relying on Sutton's method (and thus doing away with the probable epoch). In other words the actuarial state of the art is a computation-heavy benchmark which we use to assess the quality of the computation-light alternative adopted by the *IMM*. Figure 5.d demonstrates the quality of the numerical strategy adopted by the *IMM*. Unsurprisingly, the main distortions occur for

[124] We define the threshold following Baily, *Doctrine of interest*, p. 129.

government loans which, being lotteries, required calculation of the probable epoch, an additional source of distortions. This underscores the reasons for the actuaries' concerns with the probable epoch, but at the same time, the distortions are shown to be not too considerable. Finally, figure 5.e shows how well the *IMM* numbers align with the actuarial state of the art. This does demonstrate that, not only did actuarial logic rule, but approximations, informed by actuarial knowledge, were close to the benchmark.

**SECTION VII. INSIDE THE DATA FACTORY**

The production of yield numbers did consolidate the position of the *IMM* as a major data center and pilar of the capital market. It was a logical development because in fact, over time, the *IMM* had accumulated the resources which proved necessary to the success of the new endeavor. Since its launch in 1863, the journal had been gathering the primary input that was necessary to feed the yield calculations. In order to document the securities it tracked, it had collated and organized extensive primary documentation, including the prospectuses, and had routinized mechanisms for the collation of asset prices probably by developing its own information sources in the market. Taken together, this was vital material for the new endeavor, because the basic parameters to calculate the yields were now at hand. The journal's experience with tabulations also meant that there was a labor force capable of handling the tasks. In other words, the *IMM* had a head start. This helps explain why it fell upon it to develop this function. Other journals did not have the knowledge or infrastructure. Likewise, actuaries, with their small-scale shops, were ill-equipped to mobilize the scale economies. By contrast the *IMM*, with already access to a clientele of subscribers, was perfectly positioned to reach into the mass market for numbers. This explains why in the end, actuaries had proved willing to cooperate with the design of a new product, which secured their rule by proxy and burnished their shield since it did abide by their methods, without really taking business away.

Available evidence on the operation of the *IMM*'s yield factory, fragmentary and indirect as it is, speaks of a high degree of division of labor. In its efforts to minimize costs, the journal ended up pursuing essentially of pre-Taylorian logic. The *IMM*'s well-known 'spread-sheets' offer an illustration. Because this was before the advent of the linotype, compositors had to prepare the plates manually, character by character, from letters and numbers drawn from separate compartments. This was a source of errors and was labor consuming, too. To limit the risk of errors and control costs, the printing plates for the tables, including line and column headings, were kept intact from one month to the next (as persistence of display over time and appearance of slightly worn-out characters demonstrate). Only new contents were updated. The personnel responsible for organizing the data communicated the material to the typographers, who would dispose the new numbers in their proper location. But as a result, this also became the source of errors. For instance, because interest rates were reported as pound, shilling and pence per cent, efforts to limit changes led to update only the shilling and pennies. As a result, if a 'pound' error had cropped up, it tended to persist.

From the point of view of cost minimization, one of the great tractions of the adaptation of M's formula was the division of labor it permitted, which in turn enabled to replace expensive actuarial labor with more basic computational work. In fact, examining M's formula enables to reconstruct the detail of the production process: For each fixed income security tracked by the journal, preparers only needed to identify three parameter values: The coupon, the 'bonus' from being reimbursed (this was the difference between the par and the latest price), and the maturity. Once these three elements had been determined, calculators could apply the formula. This involved, first, the determination of a simple ratio, the proportional capital gain or loss at redemption. With the help of an actuarial table they would next determine the value that would accumulate into this figure; The rest of the formula was then applied, involving a few simple operations, all in all, two divisions, one addition, one multiplication, and one subtraction. Only simple numerical skills were required. The output (the yield result) was communicated to the type-setter. This was repeated, month after month, several hundred times.

Ironically, the import of actuarial methods as a system of labor rationalization is nowhere more visible in fact, than in the manner in which glitches would occur. We realized this when we began to notice strange, systematic departures, initially absent but growing over time, between what the *IMM* ought to have been calculating had it followed the assigned program and what it reported in practice. Biases were especially serious for the case of government loans. Figure 6.a illustrates the phenomenon in the case of the Japanese 7 per cent loan of 1873. As can be seen, the yield reported by the *IMM* differed increasingly from the yield that ought to have been reported. A significant spread emerged, eventually as large as 100 basis points. This discrepancy caused us a lot of head-scratching until we figured the cause.

In the operationalization of M's formula, only one parameter was susceptible to faulty interpretation, the famous 'probable epoch' and this was where problems cropped up. To show this, we did reverse the calculation. Taking as given the yield printed in the columns of the *IMM*, we determined the maturity *IMM* calculators were using.[125] Figure 6.b shows the result, along with two possible measures of the probable epoch, the correct one and an incorrect alternative, consisting in the horizon at which the loan would be entirely reimbursed: This alternative implies that calculators mixed up the actual maturity with the probable epoch. As can be seen, the clerks in charge of feeding the algorithm were not sure which one they ought to have been using. They alternated between the two until they settled with the incorrect one. Essentially, they kept mixing up lotteries with bonds redeemable at maturity. Three other government loans chosen randomly were subjected to the same treatment and revealed the same pattern: An inconsistent use of the probable epoch in the 1880s, followed by the complete doing away with the method from the late 1880s onwards.[126]

One would like to know the reasons for this error, which also reveals a failure of quality control: Cost-cutting causing a degradation of monitoring, the de facto monopoly position of the *IMM* encouraging complacency, the response of overwhelmed and confused employees, who 'scarcely slept at all in the hectic interval between the end of each month and the appearance of each new number'?[127] As already suggested, errors and inconsistencies are not unusual in the *Manual*.[128] But the glitch induced by the faulty probable epoch is striking in that it speaks of the machinery behind. The calculator operating on the flawed input was not unlike Charlie Chaplin in *Modern Times*, a digital operator overwhelmed in a data factory, screwing one bolt after the other as they came his way, with a limited visibility on

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[125] Given the formula used by the *IMM* (see app. 2), the horizon used implicitly by the *IMM* can be written as $n = \log\left(\frac{\mathrm{kj}}{p}\left(\frac{1}{pi-j}\right)+1\right)/\log\left(1+\frac{\mathrm{j}}{p}\right)$. (On the meaning the symbols, see app. 1).

[126] The loans were: New south Wales 5% loan of 1868, New Zealand consol. 5% of 1868, Cape of Good Hope 4% 1881; Details available on request.

[127] The Economist, *The Economist*, pp. 126–7.

[128] A characteristic problem we encountered in the primary data for instance, was the tendency of the reported 'outstanding amount' of loans repayable by drawings to move in erratic ways. While by definition the amount outstanding of such loans can only go down, they occasionally drifted upward before being called back to their correct path. For example, in Dec. 1885, the outstanding amount of the Danubian 7% loan of 1864 was reported to be equal to £270,700 but £231,400 the preceding December, which is absurd. This is even more puzzling because this stock data is inconsistent with the 'flow' data, on drawings amounts reported in the 'Notices and Reports' section, which by contrast was generally correct. For example, it correctly indicated that £66,300 of the Danubian loan had been drawn during the year 1885 (*IMM*, 31 Dec. 1885, p. 655). We note that the mistake concerning the 'outstanding amount' was eventually corrected in June 1886.

what he was doing. The factory was on auto-pilot, processing an incorrect input in a sophisticated algorithm, the error itself, in the end, rigorously actuarial.

**CONCLUSIONS: DEUS EX MACHINA**

The findings of this paper place us at a significant distance from modern assumptions found in the work of some economic historians as quoted in the introduction, who imagine contemporary investors as digital simpletons and suggest that the lack of 'modern' formulae and 'modern' computers did set tight cognitive constraints. Against this view, we argue that it is more interesting to take a deep look at the economics of computation, and more correct to speak of a digital revolution happening in the mid-nineteenth century, one that led to the rise of the human computer, a capital market intermediary. It fell upon 'Cyberpunk Victoria' to develop the first prototype: The kind of machine that the era called for, looked up to and identified with was a digital *Übermensch*, an organic computer. That a previous digital formatting of the financial world occurred at this point in time may also explain why, when computers first appeared 'everywhere' in the 1970s and 1980s, they did not show up in productivity statistics, a mystery known as Gordon's paradox. Our suggested resolution is that computers had already been around for quite a while.

A separate question, and one with which we did not deal with in this paper is that of the effect which the methods developed at the time, and the human formatting they caused, had on the pricing of financial securities. This is a legitimate question, which some will surely and legitimately ask, and it is informed by our findings. For instance, what 'model' did contemporary investors use to determine yields and as a result, to price bonds? If, as economists believe, marginal investors rather than average investors get to price assets, then this paper might be taken as making a strong case for the use of yield-to-maturities, and more generally for employing techniques that control for redemption. That is, if one wants to mimic the sort of operations that are consistent with the conscience of the time. But as the *Economist* soon remarked and emphasized, subjecting the diverse securities of individual borrowers to this kind of numerical treatment produced curiosities. The different securities of a same borrowers had sometimes heteroclite returns. In the exact same manner a grand style Chicago economist, the Victorian journal disposed of the anomalies as forgone arbitrage opportunities, urging readers to study them 'for their own benefit.'[129]

Another interesting door our paper opens is the departure it offers from behavioral finance. Some economists have recently suggested to engage with rationality in the market place from a cognitive and psychological vantage point which, they suggest, can be approached through human experimentation. In the alternative picture we offer, which exploits instead the historical record, room is provided for considering the anima of the financial system. The story of the rise of interest rate calculations told here is a systemic one and indeed, the emerging conscience of the market was rooted in concerns over self-preservation – ensuring its own survival and growth as a system. The consciousness was collective, not individual, it was a cognitive order that is better informed by looking at transaction costs and explaining the making of the digital rhizome than by placing electrodes on the brain of undergraduate students and showing them images of chocolate bars. Cyber Victoria was a multiheaded machine: If anything, it's Coase, not Thaler.

Finally, there will be readers interested in the question of knowing whether the *IMM* yield data is 'reliable' or not, whether its 'biases' are serious or not and whether they can safely feed the *IMM* interest rate 'output' to their programs. We wish to remind them that the *IMM* data, including and especially the glitches, carries perhaps even more powerful lessons than those that can be gleaned by their exploitation. This circles back to the point emphasized at the beginning when we emphasized the tight connection we see between the rise of computers in the Age of Victoria and the problem of information asymmetries. The reason for the historical rise of computers was their peculiar ability to resolve information asymmetries: This claim illuminates the deep affinity, still at work and even accelerating in modern times, between capitalist accumulation and the accumulation of computing power. Today, a significant portion of trading is intermediated by machines. But the digitization of finance started long ago and for the same reasons that ensure its continued hold today. From that vantage point, our paper has captured the companion rise of a 'digital class' and more generally of data-driven capitalism to which the *IMM* project belonged. In the end, everything gets redeemed.

[129] 'Curiosities in the market prices of similar investments', *Economist*, 6 Oct. 1883, pp. 1163–4. There is an obvious echo between this question and the one considered in modern studies of performativity; See for instance the influential study by MacKenzie, *An engine, not a camera*.

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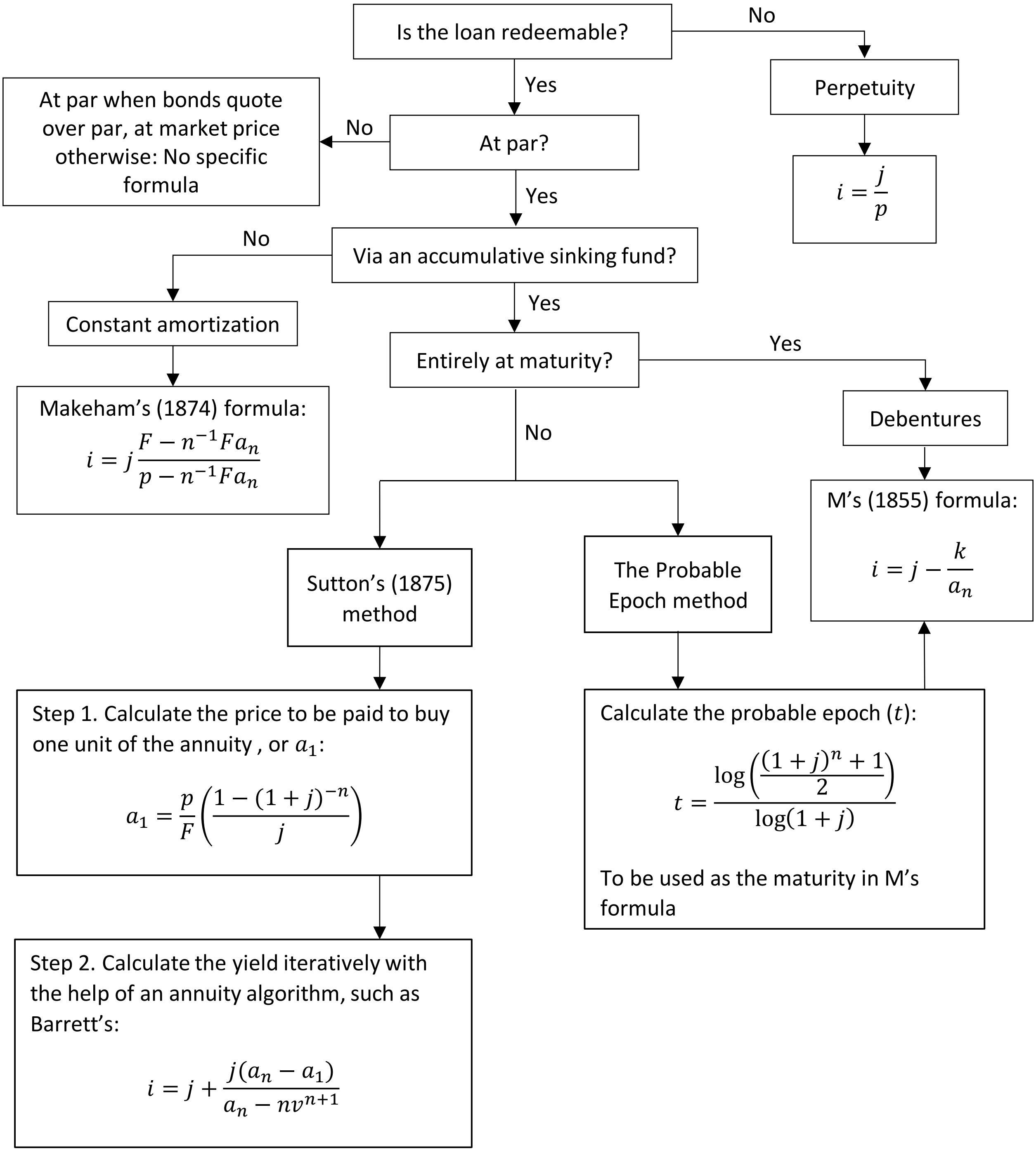
## Appendix 1. Redemption Modalities and the Actuarial State-of-the-Art Yield-to-Maturity Computation Methods: A Flow Chart




Notations: $i$ the yield, $j$ the coupon, $p$ the market price of the bonds, $k$ the discount or premium on the bonds (the difference between the market price and the face value), $n$ the maturity, and $F$ the face value of the bonds, $v$ the present value of £1 due in 1 year (that is, $(1+i)^{-1}$), and finally $a_n$, the present value of a stream of £1 per year for $n$ years, or, expressed algebraically: $a_n = \frac{1-(1+i)^{-n}}{i}$. This value was to be found by looking into an annuity table (which tabulated this function), such as Oakes, *Tables of compound interest*.

## Appendix 2. The *IMM*'s Formula and its Actuarial Underpinnings: A Proof

The verbal instructions given by the *IMM* in January 1883, as they introduced the new yield feature, can be reformulated as follows: First, find a pound value which, accumulated at a rate equivalent to the ratio of coupon over price, for a period equivalent to the remaining maturity of the loan (or to the probable epoch for sovereign loans), would produce an amount equal to the premium or discount on the bonds (i.e., the difference between their market price and their par value). Second, to divide the pound value thus found by the market price of the bonds, in order to find the 'capital return' of the bond. Third, to add (subtract) the capital return to the ratio of coupon over price, for bonds which traded below (above) par. The rate thus found was meant to represent the yield, effect of redemption included. Those three steps, expressed algebraically, give the following formula:

$$i = \frac{j}{p} + \frac{k}{s_n p} \tag{1}$$

With $i$ the yield, $j$ the coupon, $p$ the market price of the bonds, $k$ the discount or premium on the bonds (the difference between the market price and the face value), and, last, $s_n$, the future value of £1 per annuum accumulating at a rate $x$, for a period $n$ corresponding to the maturity of the loan (or to the probable epoch for sovereign bonds):

$$s_n = \frac{(1+x)^n - 1}{x} \tag{2}$$

Given that the *IMM* assumed the sinking fund to be accumulating at a rate equal to coupon/price, we have in this case $x = j/p$. Had the editors wished to attain yet a greater degree of precision, they ought to have taken $x = i$, and solve (1) iteratively.
Isolating $k$ in equation (1) (and assuming the par value to be unity) results in the following expression:

$$k = (i - j)\frac{1}{s_n^{-1} + i} \tag{3}$$

This is equation corresponds to the classical expression of the value of a debenture's premium (or discount), found in actuarial textbooks, such as Sutton's (*Institute of Actuaries' text-book*, p. 134). By replacing $s_n^{-1}$ in (3) by its expression as a function of $a_n$ (that is, by replacing $s_n^{-1}$ by $a_n^{-1} - i$, see on this relation Sutton, *Institute of Actuaries' text-book*, p. 30), and by isolating $i$, we have:

$$i = j - \frac{k}{a_n} \quad (4)$$

With $a_n$, the present value of a stream of £1 per year for $n$ years, or, expressed algebraically: $a_n = \frac{1-(1+i)^{-n}}{i}$. Equation (4) corresponds to the formula to calculate iteratively the yield-to-maturity of a security redeemable at maturity, found in M's article ('On the means of approximating', p. 55), and latter reproduced in actuarial textbooks (Todhunter, *Institute of Actuaries' text-book*, p. 115).

**Appendix 3. Data**

The bonds we used in the various exercises were selected randomly, among a population with desirable characteristics. That is, we only admitted, in the universe from which those securities were drawn, bonds which differed from their par value by at least 5%, in order to exclude those which offered only marginal redemption gains or losses. The reason is that first, this was precisely where the IMM's method made a difference. In other words, we wanted to magnify the distortions between alternative methods so as to be able to identify them. Moreover, given the British railway companies' exclusive reliance on irredeemable securities, the railway bonds were here exclusively taken within the foreign and colonial section of this market.

The 15 government loans are: Anglo-Dutch Russian 5% 1864; Anglo-Dutch Russian 5% 1866; Argentine 6% 1881; Buenos Ayres 6% 1873; Cape of Good Hope 6% 1861; Cape of Good Hope 4% 1881; Danubian 7% 1864; Danubian 8% 1867; Greek 5% 1881; Hungarian 5% 1871; Hungarian 5% 1873; Japanese 7% 1873; New south Wales 5% 1868; New Zealand 5% Consol 1868-72; Trinidad 5% 1872.

The 15 railway loans are: Baltimore and Ohio 6% 1895; Baltimore and Ohio 6% 1902; Brazil Imp. Cen. Bahia 6% 1909; Eastern of Mass. 6% 1906; Havana Railways 1rst Mortgage 7%; Illinois Central Railroad 5% 1905; Louisville and Nashville 6% Sterling 200l bonds 1902; Midland of Canada 5% 1908; New York, Pennsylvania & Ontario 6%; Ohio 6% 1910; Panama Railroad 7% 1897; Pennsylvania Gen. Mort. 6% Sterling 1910; Philadelphia & Erie 6% Gen. Mortgage; United N. Jersey 1894 6%; United N. Jersey Central 6% 1901.

The 15 municipal loans are: Auckland City Consolidated 6% 1930; Boston City 5% 1902; Brisbane 5% 1891; Christchurch 6% District Drainage 1926; Dunedin 6% 1906; Hobart Town 5% 1930; Lond. City (Ontario) Water works 6% 1898; Middlesbro' 4,25% 1908; New York City 6% 1896; Ottawa 6% 1895; Ottawa 6% 1904; Quebec City 6% 1893; Timaru 7% 1910; Wanganui 6% 1905; Wellington Nw Z. 6% 1907.

Table 1: Number of Redeemable Bonds Tabulated Each Month by the *IMM* (1870-1900)

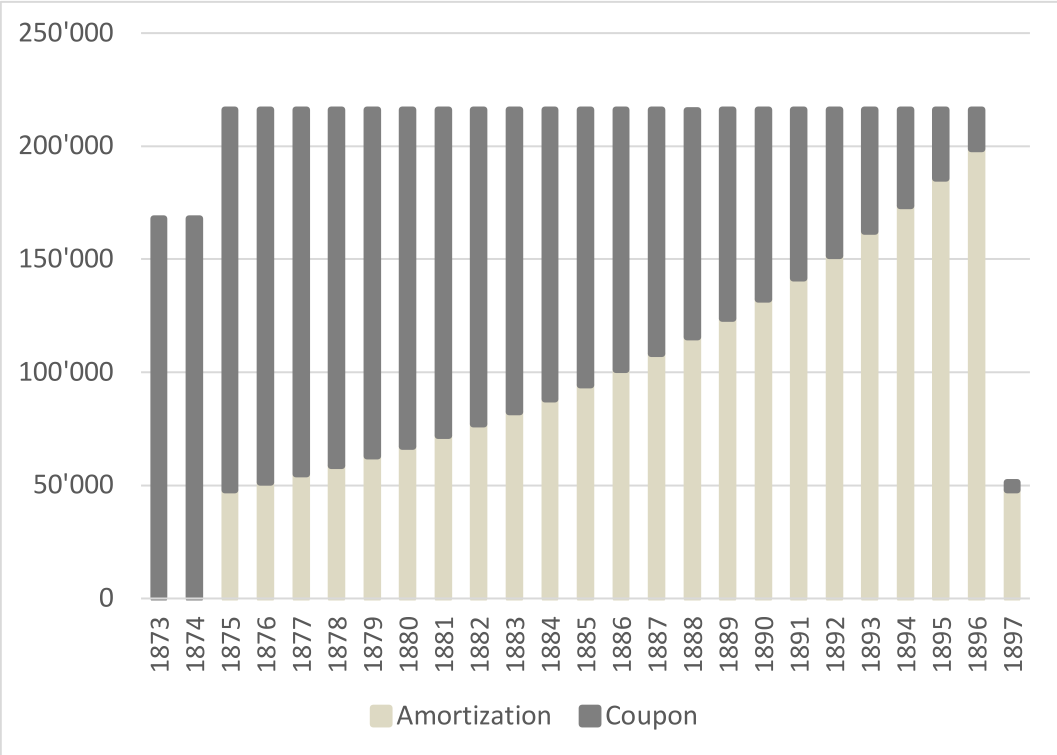
| | 01-1870 | 01-1880 | 01-1890 | 01-1900 |
|---|---|---|---|---|
| British, Colonial and Foreign Gov'nt Loans | 198 | 250 | 247 | 276 |
| Colonial and Foreign Railways Loans | 95 | 179 | 286 | 312 |
| Municipal Loans | -- | 55 | 134 | 166 |
| Total | 293 | 484 | 667 | 754 |

Source: authors, from *IMM* issues. The number of British, Colonial and Foreign Government Loans is from the eponymous section from the *IMM*, from which we deducted the irredeemable British securities and the shares (such as British Consols and Bank of England stocks). The number of redeemable railway loans was obtained by identifying individually redeemable loans from the list in the *IMM*'s "British, Colonial and Foreign Railways" section. The latter combined stocks (shares, both British and foreign), perpetual debentures (British railway companies), and terminable debentures. We removed the shares and the perpetual debentures. The total number of railway securities, before removal, are: 837 (01-1870), 702 (01-1880), 838 (01-1890) and 905 (01-1900).

Figure 1. A Drawing Machine for the Redemption of Bonds

Source: Photo taken by authors, Banque de Paris et des Pays-Bas Archive, 2011.

Figure 2. Breakdown of amortization and coupon in the case of an accumulative sinking fund: Japanese 7% Loan of 1873: Unit: £



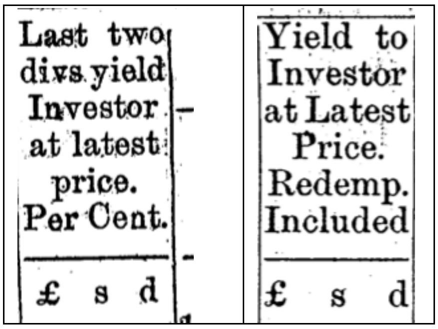

Source: Authors' computations, from various sources; As was frequent, the loan was terminated in the middle of a year. As explained by Sutton (1875, pp. 86-88), this was handled in practice by rounding up.

Figure 3. Gray's Lottery Table: Interest Rate Performance for Investors According to Drawing Date of the Austrian loan of 1865

| n. | Half-yearly Rate per Cent. | Error. | Annual Rate per Cent. |
|---|---|---|---|
| 5 | 11·221 | + ·0088 | 23·700 |
| 25 | 4·708 | + ·0008 | 9·635 |
| 45 | 4·062 | − ·0022 | 8·288 |
| 65 | 3·849 | − ·0019 | 7·845 |
| 78 | 3·783 | − ·0055 | 7·709 |
| Limit | 3·678 | | 7·490 |

Source: Gray (1868b), p. 189. The chosen mode of reporting tabulated the performance as a function of the date of the drawing (n is the horizon when one is drawn, for instance, if one is drawn after 25 years, the annual performance is 9.635). Note: The Austrian loan of 1865 was amortized through constant drawings.

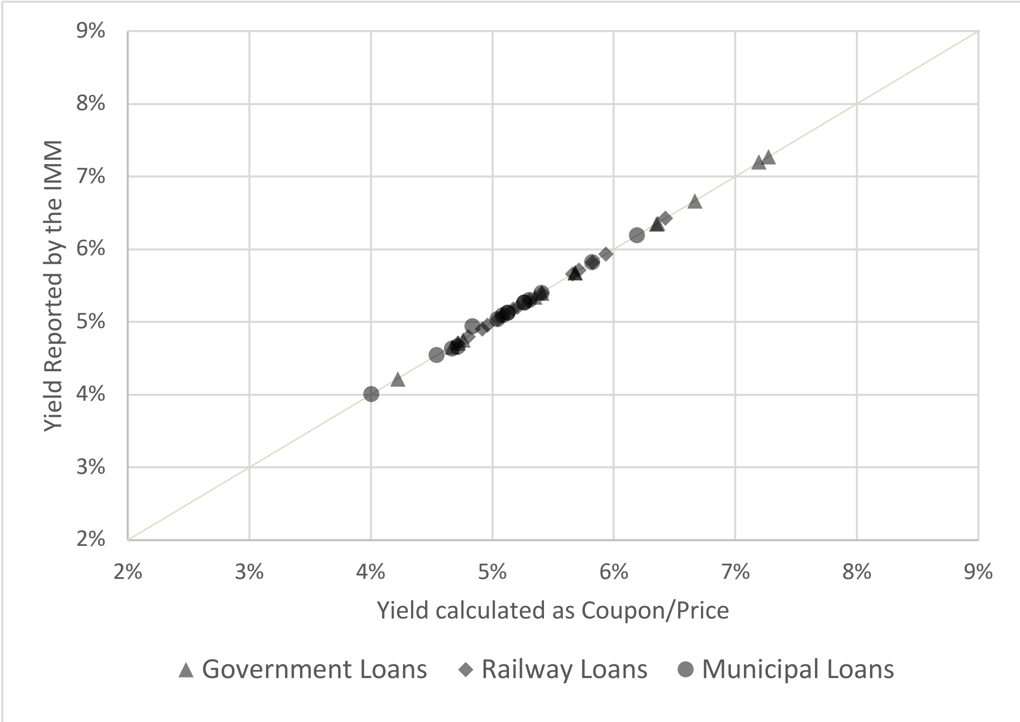
Figure 4. The Old and New Yield Reporting System:
Left (6:1879-12:1882); Right (1:1883-…)



| Last two divs yield Investor at latest price. Per Cent. | Yield to Investor at Latest Price. Redemp. Included |
|---|---|
| £ s d | £ s d |

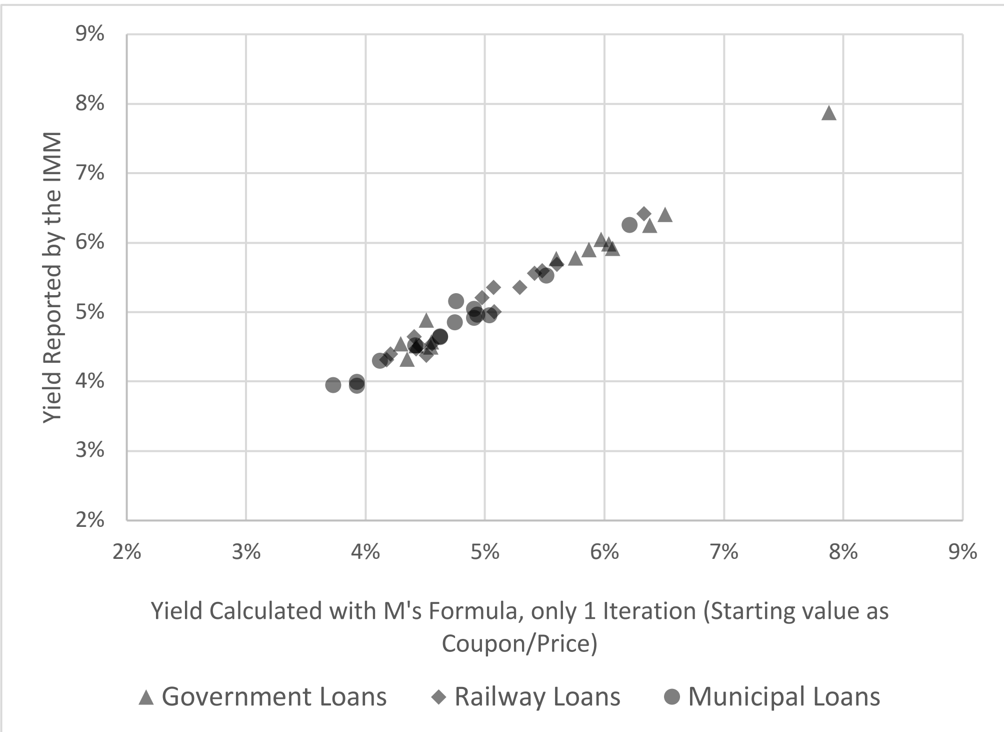
Source: *IMM*, June 1879, January 1883

Figure 5.a: Reporting Coupon/Price Before January 1883



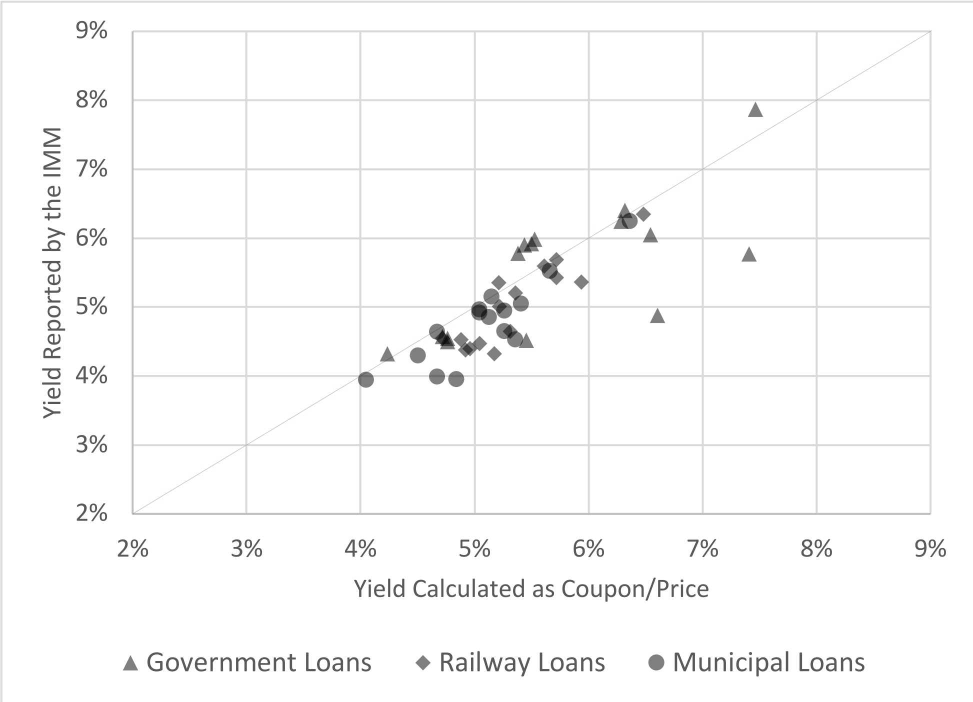

Source: Authors' calculations and *IMM* (December 1882)

Figure 5.b: Reporting Yield-to-Maturity After January 1883



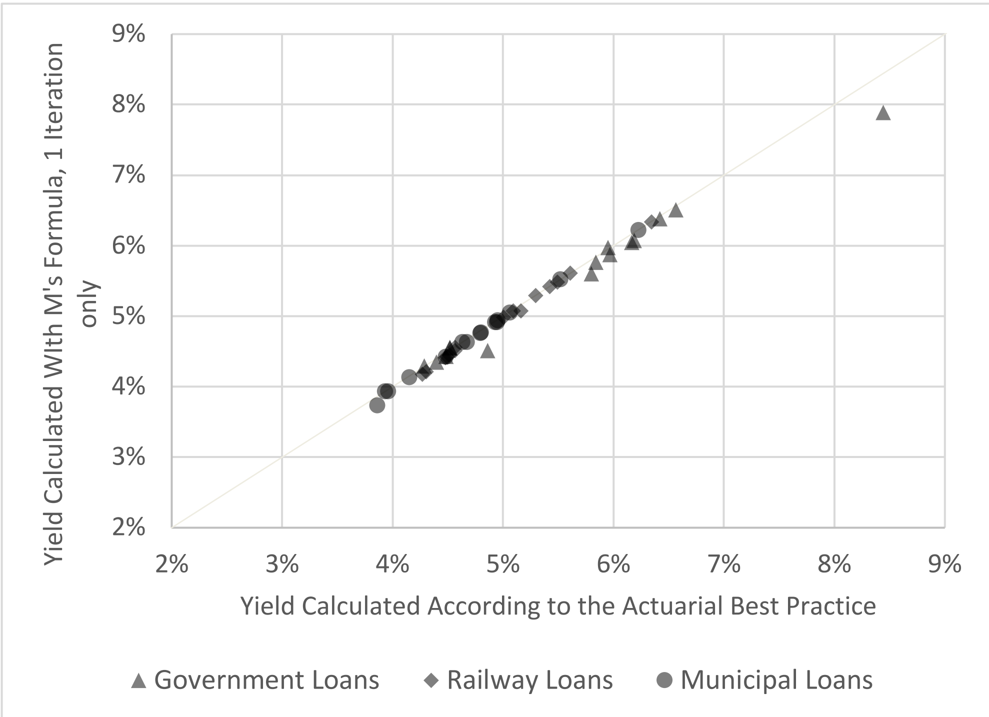

Source: Authors' calculations and *IMM*, see Appendix 3

Figure 5.c: Comparing 'Before' and 'After' January 1883



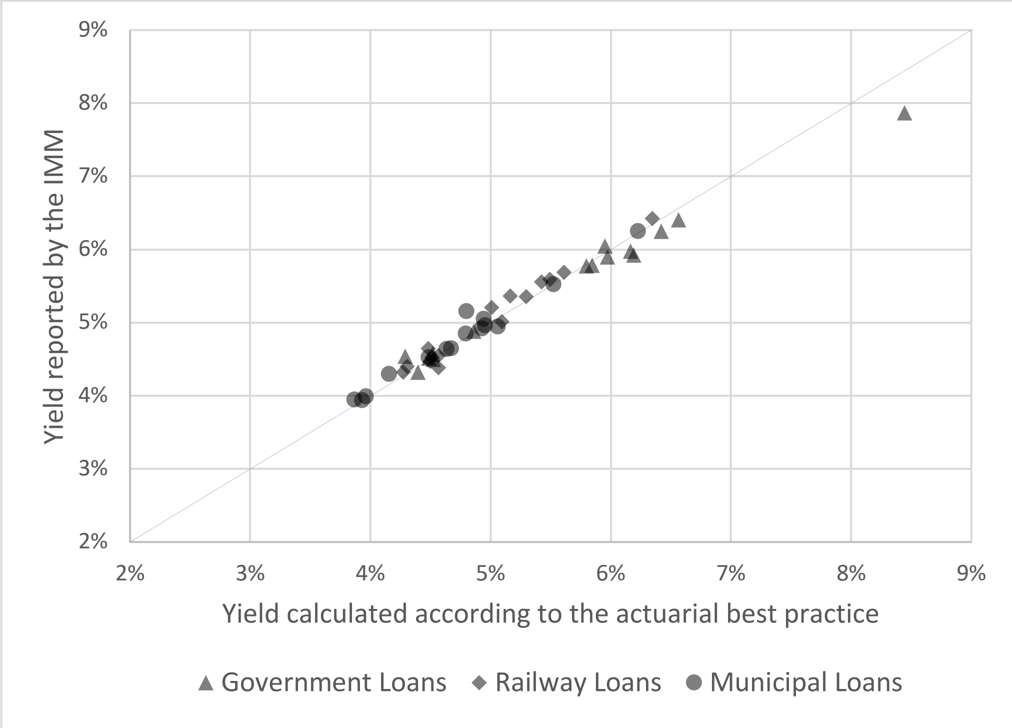

Source: Authors' calculations and *IMM*, see Appendix 3

Figure 5.d: M's Formula and Actuarial Best Practice



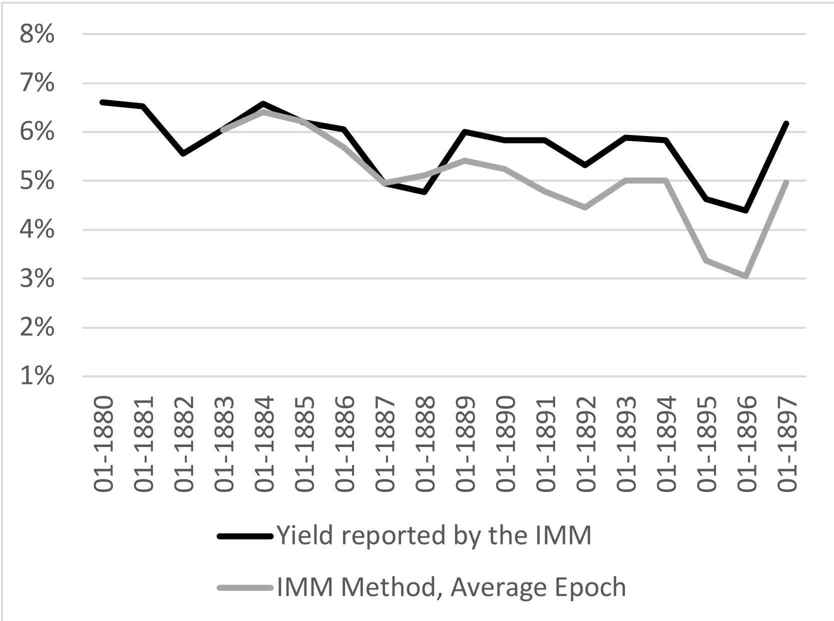

Source: Authors' calculations and *IMM*, see Appendix 3

Figure 5.e: IMM as Actuarial Best Practice



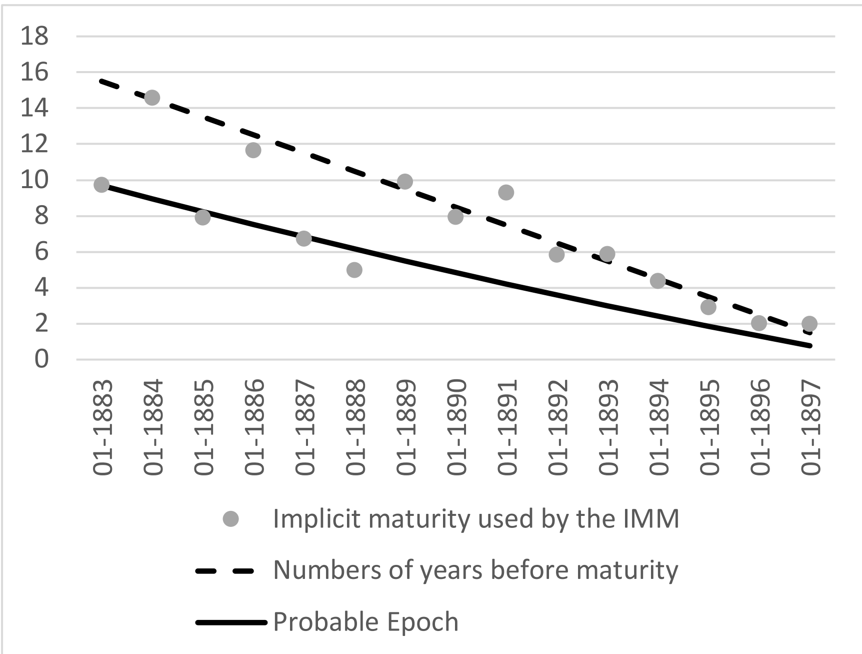

Source: Authors' calculations and *IMM*, see Appendix 3

Figure 6.a: IMM Yields and Yields using the probable epoch method
(Japanese 7% loan of 1873)




Source: Authors' computations, *IMM*

Figure 6.b: Implicit Probable Epoch (in years) Measured by IMM Calculators
(Japanese 7% loan of 1873, 1883-1897)




Source: Authors' computations, *IMM*