Pricing the Future in the Seventeenth Century: Calculating Technologies in Competition

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WILLIAM DERINGER

ABSTRACT: Time is money. But how much? What is money in the future worth to you today? This question of "present value" arises in myriad economic activities, from valuing financial securities to real estate transactions to governmental cost-benefit analysis—even the economics of climate change. In modern capitalist practice, one calculation offers the only "rational" way to answer: compound-interest discounting. In the early modern period, though, economic actors used at least two alternative calculating technologies for thinking about present value, including a vernacular technique called years purchase and discounting by simple interest. All of these calculations had different strengths and affordances, and none was unquestionably better or more "rational" than the others at the time. The history of technology offers distinct resources for understanding such technological competitions, and thus for understanding the emergence of modern economic temporality.

Few aphorisms seem more characteristic of capitalism than the equation "time is money." Although that equation was given its most famous expression by a North American—Benjamin Franklin in his 1748 *Advice to a Young Tradesman*—it was a formula that, to a large degree, was first written in early modern Europe.[1] During that period, Europeans came to new

1. On Franklin and the "emotive core of modern capitalism," see Sophus Reinert, "The Way to Wealth."

understandings of the relationship between wealth and time, and began to experience time itself differently. Increasingly "industrious" working people reconfigured how time was spent within their households, reducing leisure hours to support a growing desire for consumer goods.[2] Early industrial capitalists saw there was value to be generated in controlling the minutes within the workplace, and by the turn of the nineteenth century this drive for "work discipline" led to an ever more rigid temporal experience for workers.[3] No less than the ticking of the clock, new paper technologies of commerce and finance reshaped economic time. This was especially evident in the British Isles—the primary focus of this article—where around 1700 a burgeoning trade in printed financial prices and business news encouraged journalists not only to fashion systematic records of the past but to venture "forward-looking statements" about the future.[4] Merchants and financiers developed novel strategies for finding order in such chaotic commercial data, laying the foundations of modern "time series" analysis.[5] During Britain's "financial revolution," abstract mechanisms of public and private credit transported units of economic value across increasingly grand expanses of time.[6] Obligations became formalized in paper instruments—bills of exchange, government annuities, lottery tickets, joint-stock shares—which made the economic future into moveable wealth in the present.

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To a great degree, the history of capitalist time can be told as a story about how time became more regular, measurable, regimented, uniform—even time far off in the future.[7] Every minute came to be counted because every minute counted for the bottom line. But we should not assume that the development of modern economic time was in any way straightforward, foreordained, or without conflict.[8] In fact, early modern people had

2. Jan De Vries, "The Industrial and Industrious Revolutions." For a contrary view, see Gregory Clark and Ysbrand Van Der Werf, "Work in Progress?"

3. E. P. Thompson, "Time, Work-Discipline, and Industrial Capitalism." See also: Hans-Joachim Voth, "Time and Work"; Luchien Karsten, *Globalization and Time*, esp. 6 and chaps. 3–5.

4. Larry Neal, *The Rise of Financial Capitalism*, chap. 2; Miles Ogborn, *Indian Ink*, chap. 5; Will Slauter, "Forward-Looking Statements."

5. Judy L. Klein, *Statistical Visions in Time*, chaps. 2–3.

6. On the transformation of credit in early modern Britain, see Carl Wennerlind, *Casualties of Credit*. On Britain's "financial revolution" more generally, see in particular P. G. M. Dickson, *The Financial Revolution in England*; John Brewer, *The Sinews of Power*; Henry Roseveare, *The Financial Revolution*; Anne L. Murphy, *The Origins of English Financial Markets*.

7. On new attitudes toward the future and predictability, especially in the eighteenth century, see Edward M. Jennings, "The Consequences of Prediction"; William Max Nelson, "Weapon of Time"; Jan Golinski, *British Weather*, chap. 3; Slauter, "Forward-Looking Statements." On recent historiographical interest in the "future," see David C. Engerman, "Introduction."

8. See, for example, Michael J. Sauter, "Clockwatchers and Stargazers"; Tony Claydon, "Daily News."

many different ways to relate value to time and present to future. This becomes especially evident if we look to the calculations through which contemporaries made economic decisions. This article looks at one exemplary computational problem—the "present value" of future property—which forced financiers, landowners, and administrators in the seventeenth century to reckon with the shape of economic time. As it turns out, the future was a hotly contested topic in the early modern past.

The problem of present value asks how much an amount of property to be exchanged in the future ought to be worth today. For example: What would you be willing to pay today for $100—more appropriately, £100—if you were only to receive that £100 in fifty years? Intuitively, the present value ought to be some amount smaller than the future value; almost no one would agree to trade £100 today for £100 in fifty years. The question is exactly how much less one ought to pay today for the greater future sum. A slightly more complicated, though very common, version of the problem asks how much one would pay up front for a stream of income in the future—imagine a bond or a rental property that promised to pay £100 every year for ten years, fifty years, even in "perpetuity." It was a problem that cropped up in many different venues in the early modern age: putting a price on real estate, assigning a value to government annuities, or examining whether a public debt might be justified by future tax revenues. Present value calculations did more than show that "time is money." They said exactly how much. Those calculations literally put a price on the future.

Just like the bills of exchange and price currents and factory clocks that helped fashion modern capitalist temporality, present value calculations were technologies. The general introduction to the seminal 1987 volume on *The Social Construction of Technological Systems* distinguishes "three layers of meaning" for the concept of technology: physical objects or artifacts; activities or processes; and "know-how."[9] Calculations can be understood as technologies in all three of these senses. First, while calculations are not inherently physical, they are often manifest in physical form. They are encoded in tables, "ready reckoning" books, and calculating machines of all kinds, from slide rules and calculating cylinders to electronic pocket calculators and algorithmic trading platforms.[10] Computational formulas, like those used to calculate present value, are the software that guide these instruments of economic thinking. Calculations are also "hard-wired" into countless material, legal, and institutional mechanisms that structure economic life—in contracts, mortgages, insurance policies, retirement plans,

9. Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems*, "General Introduction," xlii.

10. For exemplary financial calculating machines, see Peggy A. Kidwell, "Elizur Wright's Arithmeter"; Science Museum Group, "McFarlane calculating cylinder, c.1835," Science Museum Group Collection Online, http://collection.sciencemuseum.org.uk/objects/co60367, accessed 1 May 2017. Kristina Peterson, "Wall Street's Cult Calculator."

tax returns, and so on. Second, calculations are activities. They do not exist in some abstract space of economic rationality. Calculating takes time and it takes work, human and machine. Consequently, calculations have constraints just like other technological processes. Factors like cost, speed, complexity, fragility, and user-friendliness matter in deciding what calculations are useful and viable in certain contexts. Third—and perhaps most obviously—calculations constitute a critical form of technical knowledge. But as in other technological contexts, knowing how to calculate requires more than just knowing the explicit formulas that are written down in textbooks. Calculators need to build up experiential know-how about how calculations fit together, when they ought to be applied, and what it takes to make them "work."[11]

Scholars in a variety of domains have come to recognize that economic calculations can be understood as technologies. Accounting scholars have long been interested in the history of techniques like double-entry bookkeeping. A particularly vibrant strain of critical accounting research, heavily informed by the theoretical perspectives of Michel Foucault, has emphasized how accounting and related "calculative practices" function as "technologies of governance."[12] Further, economists and economic historians have taken an interest in the historical development of foundational financial technologies, including computational innovations like compound-interest discounting and age-related pricing for annuities. This historical-technological perspective is exemplified by a 2005 volume on *The Origins of Value*, edited by two scholars from the International Center for Finance at the Yale School of Management. The volume is rich with historical detail and economic insight, although as the volume's subtitle—"the financial innovations that created modern capital markets"—suggests, economists' perspective on financial innovation can smack of technological determinism.[13] Finally, the technological dimensions of economic calculations have garnered mounting attention from scholars in the "social studies of finance" (SSF), an emergent interdisciplinary field of inquiry at the junction of economic sociology, economic anthropology, and STS. For scholars in SSF, calculations constitute vital "market devices," the "mater-

11. For two illuminating examples of the messy work of economic calculation in practice—in nineteenth-century life insurance and twenty-first-century electricity trading—see Timothy Alborn, *Regulated Lives*, 121–27; Canay Özden-Schilling, "The Infrastructure of Markets."

12. This literature is abundant, but to begin, see Nikolas Rose and Peter Miller, "Political Power beyond the State," 183; Peter Miller and Christopher Napier, "Genealogies of Calculation"; Peter Miller, "Governing by Numbers." For a recent example of how this literature has been extended in other scholarly settings, see Cris Shore and Susan Wright, "Audit Culture Revisited." For a different kind of study of the long history of accounting as a technology of governance, see Jacob Soll, *The Reckoning*.

13. William N. Goetzmann and K. Geert Rouwenhorst, eds., *The Origins of Value*; Goetzmann, "Fibonacci"; James Poterba, "Annuities."

ial and discursive assemblages that intervene in the construction of markets." Critically, SSF scholars like Michel Callon and Donald MacKenzie—both of whom made formative contributions to social studies of science and technology before turning their attention to markets—have shown that calculating technologies do not simply represent economic truths but "perform" the economy itself. The most successful calculations, like the Black-Scholes-Merton model for pricing options, might even be able to reshape the economic world in their own image.[14]

Despite this diversity of scholarly interest in the technological dimensions of economic calculations, there is still much to be learned about capitalism by looking at economic calculations using the interpretive tools of the history of technology. The social studies of finance literature has been predominantly grounded in synchronic sociological and anthropological research. Those SSF studies that do explore change over time tend not to look much earlier than the beginning of the twentieth century.[15] Yet many of the essential and enduring devices in modern capitalist life emerged centuries ago and took shape over long periods. Historians of technology are particularly well equipped to understand these long-term, complex, and contingent stories. In particular, the history of technology reveals that the creation, growth, and dominance of technologies are open-ended processes, irreducible to any single cause or master narrative. Which technologies succeed and fail cannot be predetermined based on some *a priori* definition of what makes a "superior"—more useful, powerful, efficient, rational—technology.

This is no less true for calculations, as the history of present value in the early modern period shows. It was not always clear that the problem of present value ought to be solved in one specific way. In fact, in the 1600s, there were at least three viable calculating technologies available: a vernacular years purchase technique, simple-interest discounting, and compound-interest discounting. I argue that these three different approaches to present value are best understood as competing technologies with distinct advantages and drawbacks, rather than right-or-wrong answers to a technical question or more-or-less "rational" approaches to economic decision-making. As with other well-studied cases of technological competition, like keyboard layout or video cassette platforms, it was not that

14. Fabien Muniesa, Yuval Millo, and Michel Callon, "An Introduction to Market Devices," 2. For an introduction to SSF, see Michel Callon, Yuval Millo, and Fabien Muniesa, *Market Devices*; Trevor Pinch and Richard Swedberg, eds., *Living in a Material World*; Donald MacKenzie, *Material Markets*. On "performativity," see especially Callon, "Embededness"; Callon, "What Does It Mean"; MacKenzie, *An Engine, Not a Camera*; Donald MacKenzie, Fabian Muniesa, Lucia Siu, eds., *Do Economists Make Markets?*

15. For examples of SSF literature that emphasize historical change, see MacKenzie, *An Engine, Not a Camera*; Alex Preda, *Framing Finance*; Martha Poon, "What Lenders See."

obvious at the time which technology was going to triumph.[16] In the early modern past, it was an open question which computational tools would be used to build the economic future.

For the majority of early modern Britons who encountered the question of present value, the most familiar version of the problem came from pricing land. The value of a piece of agricultural property was commonly described in terms of its annual rental income. But when land was bought, sold, or mortgaged, parties needed some way to render the present value of that annual income stream into a single number. The standard way was simply to multiply the annual income by a multiplier referred to as the years purchase, a customary metric that reflected the relative value of all land in a region. For example, if a property in Essex promised £100 annually in rents, and land in Essex was understood to be worth sixteen years purchase (*y.p.*) at the time, the monetary price for that plot would be £1,600. The technique and terminology of years purchase were well entrenched by the early sixteenth century and likely in use much earlier. In 1539, for example, the British Crown established an official policy mandating that any monastic lands that were sold be valued at twenty times their annual income, or twenty years purchase.[17] The logic of years purchase likely developed out of vernacular practices for negotiating land deals, as illustrated by a didactic poem (ca. 1500) uncovered by historian J. D. Alsop.[18] The poem is written down in an eclectic manuscript notebook, though its form suggests it "was originally composed for easier oral transmission."[19] The poem provided a checklist for buyers to consider before purchasing land and articulated a standard for how to measure a property's fair value.[20] The closing couplet read: "And if yu wise prchessor be /

16. Technological competition has been a topic of interest across the social sciences, notably among economists and economic historians. See Paul David, "CLIO and the Economics of QWERTY"; W. Brian Arthur, "Competing Technologies"; S. J. Liebowitz and Stephen E. Margolis, "The Fable of the Keys"; Michael A. Cusumano, Yiorgos Mylonadis, and Richard S. Rosenbloom, "Strategic Maneuvering"; S. J. Liebowitz and Stephen E. Margolis, "Path Dependence"; Sangin Park, "Quantitative Analysis of Network Externalities"; Tanjim Hossain and John Morgan, "The Quest for QWERTY."

17. H. J. Habbakuk, "The Market for Monastic Property." The earliest citation for this usage of "purchase" in the *Oxford English Dictionary* is from 1571, by Scottish bishop and diarist John Leslie, though Leslie's language suggests the practice was well established by then. See "purchase, n.," *Oxford English Dictionary*, 3rd ed. (Oxford, UK: Oxford University Press, 2007), online at www.oed.com; *The Bannatyne Miscellany*, vol. 3, 132.

18. J. D. Alsop, "Late Medieval Guide." The original manuscript is located at Trinity College, Cambridge, MS 0.2.53, fol. 24.

19. Alsop, "Late Medieval Guide," 161.

20. On the peculiarities of the "feudal" model of English land tenure, see A. W. B. Simpson, *History of the Land Law*, chaps. 1, 3. On changes in legal and cultural attitudes toward land in the seventeenth and eighteenth centuries, see H. J. Habbakuk, *Marriage, Debt, and the Estates System*, vii; G. E. Aylmer, "Meaning and Definition of 'Property'"; Andrew McRae, "To Know One's Own."

in x [ten] yere day yu shalt agayne yr money se."[21] In other words, the shrewd purchaser aimed to make back his original purchase price in rents in ten years. It is easy to imagine how such practical mnemonics gave rise to the more robust computational tool of years purchase. Economic historians have accumulated an extensive collection of data on years purchase quotations in land deals, pointing out that by the seventeenth century Englishmen generally assumed land prices to be anchored at a natural maximum of twenty years purchase.[22]

The years purchase heuristic was remarkably flexible. While most common as a means of assessing perpetual property like outright landownership, it also provided a loose framework for evaluating property owned for temporary periods. If rent-bearing land cost twenty *y.p.* to own outright at a given moment, it could be deduced that a long-term fixed lease for that property might be worth some intermediate fraction. Evidence from an arithmetic textbook in 1628, for example, suggests that twenty-one-year leases generally sold for seven to eight *y.p.*, or about 40 percent of the price for "freehold" ownership.[23] A 1667 guidebook on purchasing and buying real estate explained that "leases for lives," which lasted for the lifetime of one or more lessees, usually went for seven *y.p.*, but explained that the skilled bargainer ought to adjust that figure for the health of the leaseholder. (The text asked "Whether he be aged or sickly? if so, his life may be valued at five or six years purchase.")[24] Such instructions show how years purchase provided users with an adaptable tool for rendering a range of economic factors—in this case, the health of a leaseholder—into a numerical judgment about present value. Users could adjust to different circumstances by flexing the multiplier up or down by a few years. Furthermore, years purchase provided a basic language for talking about any form of property that paid out predictably over time, not just land. For example, the price of financial securities was commonly quoted in those terms, as shown by a 1540 law that priced government annuities at seven years purchase.[25]

The technology of years purchase provided a useful quantitative framework for transacting business, but it did not provide unique, authoritative "answers" about present value. Critically, it did not dictate a specific mathematical relationship between equivalent income streams held for different numbers of years.[26] Such an indeterminate approach was not always desir-

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21. That is: "And if you [a] wise purchaser be, in ten years [to the] day shall again your money see." Alsop, "Late Medieval Guide," 164.

22. H. J. Habbakuk, "The Long-Term Rate of Interest," 28–29; Christopher Clay, "The Price of Freehold Land"; Robert C. Allen, "The Price of Freehold Land."

23. Lewin, "Compound Interest," 433–44; Allen, "Price of Freehold Land," 34, provides a useful table of average land prices across the seventeenth and eighteenth centuries.

24. Primatt, *City and Country Purchaser*, 21. On the history of such "pattern books" on real estate, see William C. Baer, "Institution of Residential Investment."

25. Ian Hacking, *Emergence of Probability*, 112

26. For example, assuming land prices for outright ownership were 20 *y.p.*, the years

able, particularly when faced with more intricate mercantile transactions or especially sensitive matters of government finance. A more mathematically precise way to "discount" future property was to determine the amount one needed to save today—with interest—to accrue the future sum by a given date. Different pictures of the future emerged depending on the assumptions about that interest, in particular whether it was to be simple or compound. Discounting by simple interest was common in both private commerce and public finance in early modern Europe. Italian merchants in the fifteenth century, for instance, typically used simple interest in reckoning how to divide the profits of commercial partnerships in which members invested capital at different times, as described in the popular 1478 "Treviso Arithmetic."[27] In the mid-1570s the financial accountants to the cash-strapped Spanish king Philip II used simple-interest discounting at a 9 percent rate in analyzing the present value of future hearth taxes owed by the subject Kingdom of Naples.[28] Among the practical textbooks in mercantile arithmetic that proliferated in English in the seventeenth century, authors often gave more attention to the mathematics of simple than compound interest, including the use of simple interest to solve present value or "rebate" problems. Indicative were *Webster's Tables*, by William Webster, which went through five different editions between 1629 and 1647 and, until the fifth and last edition, devoted the vast majority of its pages to simple-interest mathematics.[29]

The method of simple-interest discounting offered more rigor than years purchase yet remained quite easy to handle when applied to common economic deals. Calculating the present value of a single sum in a future period was relatively straightforward arithmetically, requiring at most one division and one multiplication operation.[30] Critically, it also did not require imagining that one earned "interest upon interest." At a time when there were moral and legal injunctions against "usury" and moneylending was tightly regulated, this was no small matter.[31]

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purchase method alone did not precisely state what a temporary lease for, say, 21 years ought to be worth—7 was the standard benchmark, but the years purchase technique did not say why it could not be worth 5 or 14 years purchase instead (so long as it was less than 20). According to a compound-interest discounting approach, by comparison, land at 20 years purchase implied an effective interest rate of 5 percent, which suggested a 21-year lease ought to be worth 12.8 years purchase.

27. Geoffrey Poitras, *Early History of Financial Economics*, 156–60. On the Treviso Arithmetic, see Frank Swetz, *Capitalism and Arithmetic*.

28. John A. Marino, "Creative Accounting."

29. See, for example, William Webster, *Webster's Tables*, 2nd ed.

30. Assuming simple interest, the present value of a monetary sum p in t years at interest rate r is $x=p/(1+rt)$. By that logic, £100 to be earned one year in the future is worth about £95.23, assuming 5 percent interest; in 10, £66.67; in 99 years, £16.81.

31. Over the seventeenth century, lending at interest became increasingly tolerated as a moral matter, in both Britain and its overseas colonies. But Parliament closely regulated maximum interest rates as a matter of public economic welfare, reducing the

Yet simple-interest discounting also had some potentially significant mathematical limitations, particularly when extended to more complex transactions like the valuation of annuities.[32] One of the period's most theoretically inclined financial mathematicians, the early Royal Society fellow John Collins, exerted considerable energy toward developing a robust mathematics of present value using the logic of simple interest.[33] Collins's 1685 text, *The Doctrine of Decimal Arithmetick, Simple Interest, &c. As Also of Compound Interest and Annuities*, began with an extended discussion of how to carry out both "forbearance" (future value of a present sum) and "rebate" (present value of a future sum) problems with simple interest. It went on to contemplate whether it might be possible to "Aequate"—calculate the present value of—"an Annuity, at Simple Interest."[34] Collins acknowledged a key technical challenge: to use simple interest to value an annuity, an accurate and efficient method was needed to find the sum of a harmonic or "musical" series, namely a series that "adds Fractions that have a constant Numerator, and an Arithmetical Progression for their Denominators."[35]

Compared to the analogous problem for compound interest—which required summing a geometric series—summing a harmonic series turned out to be remarkably vexing mathematically. The "great mathematical gossip and magpie" Collins spent decades trying to find a solution to the problem, querying his remarkable network of mathematical correspondents, including Isaac Newton, for help.[36] In 1668 Collins wrote to his confidant and Royal Society secretary Henry Oldenburg for assistance in tracking down a book by Danish mathematician Erasmus Bartholin that "perchance handles

maximum allowed lending rate on three separate occasions between 1624 and 1714. Legal restrictions on interest remained until 1854. See Norman L. Jones, *God and the Moneylenders*; Norman L. Jones, "Usury"; Peter Temin and Hans-Joachim Voth, "Interest Rate Restrictions"; Mark Valeri, *Heavenly Merchandize*, 134–57.

32. In the early modern period, annuities referred to a general class of financial bargains in which one party paid an up-front sum and in turn received a consistent, fixed return for some period in the future (usually a stated number of years or the length of one or more persons' lives). Annuities had a long history as a mechanism of government finance in the small medieval states of Italy, Germany, and the Low Countries. See John H. Munro, "Medieval Origins"; Edwin W. Kopf, "Early History of the Annuity"; Hacking, *Emergence of Probability*, chap. 13; Poterba, "Annuities."

33. On Collins, see William Letwin, *Origins of Scientific Economics*, chap. 4; Helena M. Pycior, *Symbols, Numbers, and Geometric Entanglements*, chap. 3.

34. John Collins, *Doctrine of Decimal Arithmetick*, 7.

35. Assuming simple interest at r, an annuity which pays out p annually for n years is worth $\sum_{t=1}^{n} p/(1+rt)$, which is a series of fractions with constant numerator (p) and denominators in arithmetic progression ($1+r$, $1+2r$, $1+3r$, etc.). Critically, infinite harmonic series diverge (that is, become infinitely large), a fact that had been proven by French mathematician Nicole Oresme in the fourteenth century but was not widely known in the seventeenth century. Because harmonic series diverge, it is not theoretically possible to use simple-interest discounting to value perpetual annuities, because the value assigned would be infinite.

36. A. Rupert Hall and Marie Boas Hall, eds. and trans., *Correspondence of Henry Oldenburg*, 9: xxvii.

the Musicall Progression."[37] The "Musicall Progression" was more than just a theoretical curiosity for Collins, formerly a ship's purser in the Venetian trade and an on-and-off state administrator, who throughout his career was deeply interested in how cutting-edge mathematical research could be brought to bear on commercial practicalities.[38] Yet his efforts were largely for naught. In his 1685 text, the only answer he could give on the harmonic series problem was to direct readers to a work by the Bolognese mathematician Pietro Mengoli, which Collins admitted he had never read.[39]

Collins was keenly aware of the state of the art in both mathematical research and commercial practice. The fact that he remained so occupied with the problem of harmonic summations shows that, through his lifetime, simple-interest discounting was seen as a potentially viable approach to calculating present value.[40] Nonetheless, there had long been calculators in Europe who felt that compound—not simple—interest offered the most sensible way to think about the value of the future.[41] Compound-interest discounting implied that the present value of future property declined exponentially the further out in time you went. One critical effect of this technology was that it put an extremely small price on the very distant future. But this exponential pattern also made it easy to apply compound-interest discounting to streams of future income like annuities, due to the mathematical properties of geometric series.[42] Mediterranean merchant-

37. Collins to Oldenburg, [December ?] 1668, in Hall and Hall, eds., *Correspondence of Henry Oldenburg*, 5: 212.

38. It is also possible that Collins was interested in the development of simple-interest mathematics for specific legal reasons. In 1665 he had added a specific section to his textbook on merchants' accounts on "a Question of Mortgage stated according to Simple Interest, such as the Courts of Equity do allow." Though I have been unable to corroborate this explanation, it seems reasonable to suppose that English equity courts might have only allowed simple-interest reasoning in adjudicating disputes over the value of future property. See "Collins, John," in "Birch's Biographical Notes," f. 336.

39. Collins, *Doctrine of Decimal Arithmetick*, 8. Mengoli is credited with rediscovering (after Oresme) that the harmonic series diverges. On Mengoli, see A. Natucci, "Mengoli, Pietro."

40. In the 1730s, Swiss mathematician Leonhard Euler would eventually develop useful formulas for calculating sums of finite terms of a harmonic series. See Morris Kline, *Mathematical Thought*, 2: 436–37, 449–50.

41. Assuming compound interest, the present value of £p in t years, with an r rate of interest: $p/(1+r)^t$. By that logic, for example, £100 to be earned one year in the future is worth about £95.23, assuming 5 percent interest; in 10, £61.39; in 99 years, £0.80. By comparison, compound-interest discounting places a much lower price on property in the very distant future than simple-interest discounting does, assuming the same interest rate. (Assuming a 5 percent interest rate, the present value of £100 in 99 years is £16.81 using simple-interest discounting, versus only £0.80 using compound-interest discounting.)

42. The formula giving the present value of x units annually from year 1 to year t, assuming an interest rate of r, is $\sum_{t=1}^{n} p/(1+r)^t = (p/r)(1-(1+r)^{-n})$. Assuming 5 percent interest, an annuity that pays £100 a year for 10 years is worth about £772; for 50 years, £1,826; for 99 years, £1,985.

mathematicians had explored the arithmetical implications of compound interest since the medieval period. Perhaps the earliest formulation of compound-interest discounting came in the 1202 *Liber Abaci* (Book of the Abacus) of Leonardo of Pisa, commonly known as Fibonacci. The *Liber Abaci* offered a distinctly commercial logic for understanding the value of passing time—what Fibonacci called the "method of trips," which likened each interest-bearing time period to a new voyage by a merchant traveling between two trading posts.[43] Subsequent compound-interest calculations appeared in the work of the Florentine merchant-politician Francesco Pegolotti (c. 1340), the Lyonnais mathematician Nicolas Chuquet (1484), and the accounting pioneer Luca Pacioli (1494), while early compound-interest tables appeared in Jean Trenchant's 1566 *L'Arithmétique*. A more systematic explanation of the exponential approach emerged courtesy of the Flemish engineer and polymath Simon Stevin, who published the first tables for compound-interest discounting in 1582.[44]

Amid the vibrant culture of practical mathematics that developed in early modern London, private arithmetic instructors advertised compound interest among the many skills they could teach at least as early as 1590.[45] Systematic instruction in compound-interest discounting began in English with Richard Witt's 1613 *Arithmeticall Questions: Touching the Buying or Exchange of Annuities.*[46] The text included multiple different tables or "breviats" showing the effects of compound interest on £1 at different interest rates from 5 to 10 percent. It also provided narrative instructions for how to solve practical problems using the tables, offering a series of fifteen modular "Directions" that could be combined to calculate a range of different unknowns. While the mathematics Witt described was hardly new, the intricate algorithmic computations he laid out were not easy, either. His method did not seem to catch on especially quickly, except among a few boosters. In a 1634 textbook, *Compound Interest and Annuities*, "mariner and Practitioner in the Mathematiques" William Purser of Bristol reflected with exasperation on the refusal of his contemporaries to adopt the logic of compound interest.[47] Purser tried to make compound-interest discounting more conceptually rigorous and user-friendly. He explained that, mathematically, the present value of yearly annuity payments followed the rules of "continued proportion, or as it is most usually called *Geometricall*

43. Goetzmann, "Fibonacci," esp. 134–36.

44. On the history of compound-interest calculations, see G. W. Smith, "Brief History of Interest Calculations"; Michael E. Scorgie, "Evolution of the Application of Present Value"; Poitras, *Early History*, chap. 5.

45. See *Such as Are Desirous*. On practical mathematics in early modern London, see E. G. R. Taylor, *Mathematical Practitioners*; Deborah Harkness, *The Jewel House*, chap. 3.

46. R[ichard] W[itt], *Arithmeticall Questions*. On Witt, see C. G. Lewin, "An Early Book"; Lewin, "Compound Interest", 423–38; Poitras, *Early History*, 169–75.

47. William Purser, *Compound Interest and Annuities*.

Progression.[48] Subsequent sections of his text outlined the basic operation of geometric series, provided extensive numerical tables, and introduced a helpful zigzag template that showed readers how to set up the necessary calculations using the "rule of three," the most fundamental skill in early modern mathematical practice.[49]

Purser's treatise was in part a piece of mathematical propaganda, seeking to promote as well as to explain compound-interest discounting. He felt the "certaine and infallible general Theoremes" he formulated ought to apply quite widely, particularly to the analysis of land. He believed his methods were especially useful for addressing the class of land bargains known as "reversions," in which real property was held by one owner but was expected to revert to another in the future (for example, because of fixed-term leases or inheritance). But Purser was also realistic that his way of pricing the future was hardly standard. After over eighty pages of dense tables and instructions, he admitted: "I find that neither of these tables, nor any other are wholly agreeable to the custome of these times in this cause, for men in these things are more ruled thereby, than by Art." Purser suggested a couple of different factors behind this customary resistance to thinking exponentially. Most obviously, the calculations strained the mathematical talents of all but the most numerate individuals. But the opposition went even deeper; contemporaries were simply uncomfortable thinking about economic time in that way. There was something strange, even fanciful, about the assumption of regular, compounding returns that underlay Purser's methods. He noted, for example, how confusing it might be to apply the logic of compound interest to contingent property like a house. Though it might earn regular rents and therefore act much like an annuity, a house required expensive ongoing repairs and brought greater "danger of casualty," both of which complicated the matter of valuation. Purser further noted that the prices on annuities in the marketplace did not conform to his mathematical models. Specifically, long-term annuities (those that promised to pay out for long periods, like several decades) were valued too highly when compared to their short-term counterparts. "The cause," Purser explained, "is I conceive, because when men have an assurance of their estates for many years, they are the willinger to take lesse gaines."[50] Early modern Englishmen were willing to pay a relative premium for the security of a long-term return, a feeling about economic time that Purser's tables simply did not reflect.

Purser acknowledged that his exponential view was not going to take the commercial world by storm all of a sudden. As a result, he made delib-

48. Purser, *Compound Interest*, 2.

49. See, for example, Purser, *Compound Interest and Annuities*, 38. On the rule of three, see Caitlin Rosenthal's contribution in this volume and Michael Baxandall, *Painting and Experience*, 95–102; Klein, *Statistical Visions*, 25–34; Goetzmann, "Fibonacci," 130–32.

50. Purser, *Compound Interest*, 82–83.

erate efforts in his textbook to connect his compound-interest computations to alternative techniques for valuing the future. One section showed how to convert between the years purchase and compound-interest discounting technologies. According to Purser, the years purchase assigned to a piece of perpetual property was simply the reciprocal of the interest-rate used to value it.[51] He made a further concession to those who preferred thinking about the future in terms of simple, rather than compound, interest, concluding with a begrudging chapter on how to value certain kinds of simple annuities at 8 percent simple interest.[52] Purser's brand of exponential arithmetic desperately needed defending, and in 1634 it was far from clear whether he would succeed.

This would continue to be the case through the seventeenth century. Financiers and mathematical writers regularly juggled competing approaches to present value, often while complaining that their preferred system had not yet come to prevail. Exemplary was Samuel Morland's *The Doctrine of Interest, Both Simple & Compound*, published in 1679. That text's introduction lamented the problems that were caused by the fact that his contemporaries still used multiple different technologies for calculating interest. Morland was especially worried that unscrupulous agents were committing "manifold abuses . . . by selling according to one Rate of *Interest*, and Buying by another, and so confounding together *Simple* and *Compound Interest*, as it makes most for the advantage of the Money Merchant." Yet Morland did his own part to perpetuate the multiplicity of calculations. His text, like Collins's, contained extensive tables and instructions for both simple and compound approaches. It even provided a side-by-side comparison, showing the effects of each technique on the valuation of annuities of different lengths (figs. 1–2). While he made it clear that he preferred the compound approach, what seemed to bother him most was simply the lack of a single standard. "The truth is, it is as great pity that there should be two so different Calculations of *Interest*," he wrote, "as that there should be so many different *Weights* and *Measures*." For Morland, it seemed the choice between different calculating technologies was less a matter of truth or rationality than a matter of convention, like choosing standardized units of measure.[53]

51. Purser, *Compound Interest*, 17. According to Purser, to say that a piece of land was worth "20 years purchase" was the same as using Purser's compound-interest techniques using 5 percent as your chosen interest rate; 16 years purchase implied 6.25 percent, and so forth. Mathematically, this is a consequence of the formula for the present value of an annuity using compound-interest discounting: $(p/r)(1-(1+r)^{-n})$ (see note 42 above). Allowing n to approach infinity, the "discount factor" $(1+r)^{-n}$ approaches zero, and the formula for present value reduces to p/r.

52. Purser, *Compound Interest*, [viii], 88–92.

53. Morland, "Introduction," *The Doctrine of Interest*, section on "Reflections upon Simple and Compound Interest" (unpaginated).
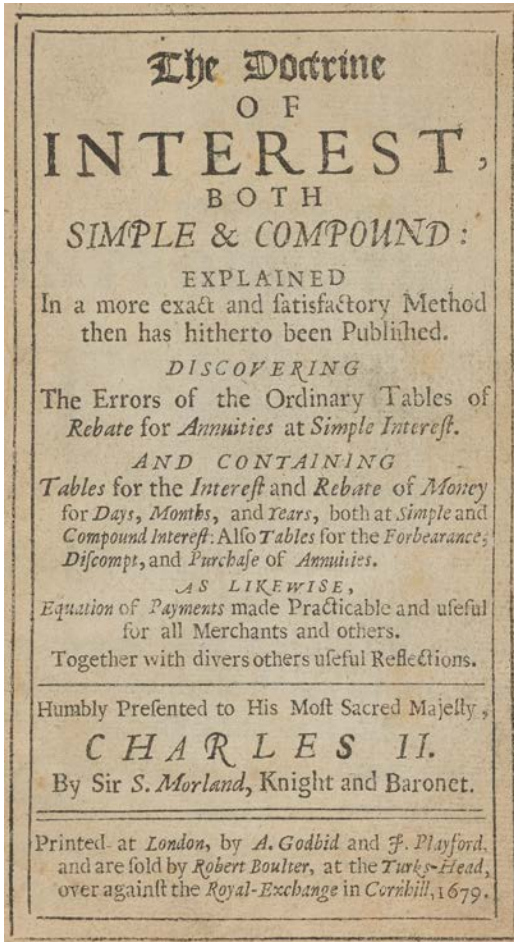
FIG. 1 S[amuel] Morland's *The Doctrine of Interest, Both Simple & Compound* (London: Printed for A. Godbid and J. Playford, 1679). (Source: Courtesy of the History of Science Collection, John Hay Library, Brown University)

In the seventeenth century, therefore, at least three substantively different computational technologies existed for pricing the economic future. At moments, these competing calculations came into direct conflict, as on the eve of the Anglo-Scottish Union in 1706. In that year, contemporary politicians and pamphleteers debated a proposed monetary "Equivalent" that was to be paid up front by the English government to Scottish stakeholders in exchange for accepting higher future tax rates. In the course of discussions about the Equivalent, different calculators used all three techniques in trying to figure out what future Scottish taxes ought to be worth

FIG. 2 Table, from S[amuel] Morland, *The Doctrine of Interest, Both Simple & Compound* (London: Printed for A. Godbid and J. Playford, 1679). The table compares the present value of an annuity for 10 to 100 years, assuming 6 percent interest, calculated according to simple-interest discounting and compound-interest discounting. Note also that Morland labeled the calculations using the language of "years purchase." This table thus bore the marks of all three contemporary techniques for calculating present value. (Source: Courtesy of the History of Science Collection, John Hay Library, Brown University)

in the present.[54] The three different calculating technologies imagined the economic connection between present and future in different terms, whether it was how many years of rents were needed to recoup the purchase price for land or the compounding profits to be made on successive commercial "trips." Each computational technology had pros and cons.

54. On the "Equivalent" as a controversy about present value, see Crawford Spence, "Accounting for the Dissolution of a Nation-State"; Deringer, "Calculated Values," chap. 2.

The traditional years purchase heuristic was simple, quick, and widely understood, and could be applied to various bargains by simply adding or subtracting years from known benchmarks. Yet it lacked rigor and specificity. Simple-interest discounting boasted improved precision, remained relatively easy to use in many common transactions, and avoided the moral and conceptual complications that came with "interest upon interest." Yet the mathematical quandary of the harmonic series frustrated attempts to extend simple-interest logic to annuities. Compound-interest discounting was the most mathematically powerful and adaptable thanks to the computational convenience of geometric series. Yet it required substantial mathematical competence to use at all and challenged basic contemporary intuitions about commerce, value, and time.

Ultimately, the compound-interest view of Fibonacci, Witt, and Purser won out. Exponential discounting has become endemic throughout modern capitalist practice, from the valuation of financial securities and actuarial science, to corporate capital expenditure decisions and government cost-benefit analyses, even to planning for global climate change.[55] In the economic orthodoxy of the twentieth century, exponential discounting became an essential part of what it meant to be rational.[56] To explain how and why compound-interest discounting triumphed must remain a question for another time—but I will hypothesize that conquest was largely complete in Britain by 1730. Simply to recognize, though, that serious alternatives once existed helps us to "denaturalize" one of the most essential devices in modern capitalism.

Viewing seventeenth-century contests over present value as a technological competition prompts a range of provocative questions about the history of economic reasoning and the emergence of capitalism. How did exponential discounting become consolidated as an essential component in the configuration of modern capitalist markets? Can the triumph of exponential discounting be seen as an example of technological "lock-in"? What role did "network effects," the benefits users gained from others using a particular technology, play in the ultimate ascendance of the compound-interest view? As it turns out, compound-interest discounting is probably not the method that best reflects how people instinctually feel about the future, even today. Behavioral economists have shown that individuals rarely exhibit strictly exponential preferences when asked to choose between differing amounts of "future" money in experiments.

55. For a small sampling of the literature on the use of exponential discounting and its history in finance, business, and governance, see John R. Graham and Campbell R. Harvey, "Theory and Practice"; James C. Robinson, "Philosophical Origins"; Hal R. Varian, "Recalculating the Costs."

56. On the history and present state of economic scholarship on present value, see Shane Frederick, George Loewenstein, and Ted O'Donoghue, "Time Discounting."

Rather, they often perceive the future "hyperbolically"—following a pattern arguably closer to early modern simple-interest discounting models.[57] Did William Purser's approach win because it best reflected economic realities in his day, or did it win because the economic world came to look more and more like Purser's model? Was compound-interest discounting "performative," in that it reshaped the economic world in its own image? In the end, did the "best" calculating technology win, or as Samuel Morland hinted, was the choice of technologies more a matter of convention, like the choice of standardized weights and measures? When it comes to economic calculation, what defines "best"?

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57. Foundational in this line of inquiry is Richard Thaler, "Some Empirical Evidence on Dynamic Inconsistency." For a review of the literature, see Frederick, Loewenstein, and O'Donoghue, "Time Discounting," 360–62; see esp. 360, n.13 on the use of functions of the form ($p/(1+rt)$) to model humans' tendency toward "hyperbolic discounting."

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