Making Economics More Useful: How Technological Eclecticism Could Help

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"Modern engineers are seen as taking over their knowledge from scientists and, by some occasionally dramatic but probably intellectually uninteresting process, using this knowledge to fashion material artifacts… Engineers know from experience that this view is untrue… my career as a research engineer and teacher has been spent producing and organizing knowledge that scientists for the most part do not address."

Walter Vincenti (1990): *What Engineers Know and How They Know It.*

Economists who favor policies derived from scientific propositions often say little about how this might be accomplished. Milton Friedman's influential 1953 essay for instance asserts that "positive" economics—the scientific side—must precede any "normative" policy prescriptions.[1] Whatever our goals, he argues, we cannot make sensible policy choices if we can't reliably predict their consequences. Furthermore, after asserting the priority of scientific economic propositions, Friedman devotes the rest of his essay to their nature and verification, saying nothing about how scientific propositions map into specific policies or how we might evaluate the effectiveness of these policies.

But in engineering and medicine, scientific understanding does not always come first. Important advances, from steam engines to vaccinations, have preceded knowledge of the underlying laws of nature.[2] And even when science leads, as in the development of transistor radios and MRIs, useful technologies do not mechanically follow. Scientific "propositions" and technological "prescriptions," to use Joel Mokyr's categories, have distinctive features.[3] As Walter Vincenti argues, "technology, though it may apply science, is not the same as or entirely applied science."[4] Crucially, technology is almost invariably more complex than the science it might incorporate, and the development of technological knowledge reflects this complexity: Developers eclectically combine many techniques to test the performance of alternative designs. Moreover, test results are typically suggestive rather than decisive, complementing but not replacing judgments and hunches. (See Table 1).

In these pages I argue that good economic practice also requires complex recipes selected through eclectic combinations of tests and judgment. And, to "show" and not just "tell," I provide an illustrative example of using simulations to evaluate and legitimize regulatory choices that affect the extension of credit.

Notable earlier work on the connection of economics and technology includes Scott Dulman's 1989 account of railroad engineers' development of Discounted Cash Flow (DCF) techniques, Alvin Roth's "The Economist as Engineer,"[5] and John Kay and Mervyn King's efforts to apply the practical problem solving approach of engineers to economics.[6]

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1 Milton Friedman (1953), *Essays in Positive Economics*, Chicago: University of Chicago Press.

2 Recounting Lawrence Henderson's quip that "until 1850, the steam engine did more for science than science did for the steam engine," physicist Malcolm Longair writes that James Watt's 1765 invention of a condenser, made in the course of repairing a steam engine, "led to the underpinning of the whole of thermodynamics." See page 223 of Malcolm S. Longair (2003), *Theoretical Concepts in Physics: An Alternative View of Theoretical Reasoning in Physics* (Second edition). Cambridge: Cambridge University Press.

3 Joel Mokyr (2002), *The Gifts of Athena: Historical Origins of the Knowledge Economy*, Princeton: Princeton University Press.

4 See page 4 of Walter G. Vincenti (1990), *What Engineers Know and How They Know It: Analytical Studies from Aeronautical History*, Baltimore: Johns Hopkins University Press.

5 Alvin E. Roth (2002), "The Economist as Engineer: Game Theory, Experimentation, and Computation as Tools for Design Economics. *Econometrica*, 70(4), 1341-1378. https://doi.org/10.1111/1468-0262.00335.

6 John A. Kay and Mervyn A. King (2020), *Radical Uncertainty: Decision-Making Beyond the Numbers* (First edition), New York: W. W. Norton and Company.

Table 1
Differences in idealized knowledge and tests

Science	Technology
Universal, concisely specified propositions	Complex recipes designed for specific circumstances and purposes
Objective and decisive (as per community consensus)	Eclectic combinations producing suggestive results

My interest in the technology-economics connection is part of a broader, ongoing study of the nature and development of knowledge in practical fields such as engineering, medicine, and business. That broader study examines several activities and tasks undertaken, such as goal setting, conjecture, testing and evaluation, codification, and communication; the multifarious techniques used; and the risks of rigid adherence to scientific methodologies.[7] Here I focus more narrowly on testing and evaluation and on the use of simulations.

Outline. The main sections of this paper:
1. Examine differences between science and technology (outlined in Table 1).
2. Argue that the scientific goals and methods of disciplinary economics constrain its practical utility in evaluating new policy combinations.
3. Show how simulations can ease these constraints by facilitating reasoned collaborative judgments.
4. Provide an illustrative example of a simulation model designed to evaluate the joint effects of policies that affect credit extension.
5. Describe the outputs of the simulation and their practical policy implications.

Differences in Science and Technology

Scientific knowledge and tests

Scientific communities favor concise, universal propositions like Newton's second law of motion (and Einstein's law of mass-energy equivalence,) whose truth values they can objectively verify to each other's satisfaction.[8] Sometimes, observations of natural outcomes, such as planetary orbits, provide an adequate basis for satisfactory verification. Often, however, verifying general propositions requires an artificially constructed apparatus. Galileo's falling body experiments sought to unnaturally isolate the effect of gravity from other forces such as friction.[9] Similarly, Boyle's celebrated 17th century pump "ma[d]e accessible and manifest the invisible, and normally insensible, effects of the air."[10] And, unlike the scientific propositions themselves, the experimental apparatuses can be highly elaborate. Boyle's air pump, constructed with the assistance of Robert Hooke was, for its time, an engineering feat.

Using an artificial apparatus—and often indirect proxies for the variables of interest—requires scientific communities to agree on what evidence supports or warrants the rejection of a proposition. Even the acceptance of observations of natural phenomena requires a consensus. Galileo's skeptical contemporaries had no compelling reason to trust that the moons of Jupiter he tried to show them through his telescope really existed.[11]

Complexity of technical recipes

Technologies—"technical recipes" in Carliss Baldwin's evocative metaphor[12]—cannot be reduced to concisely codified, universal propositions. Requiring surgeons to wash their hands is a striking exception; and even hand washing is just one step in a surgical procedure. Typically, several factors make useful technical recipes and their development complex.

Technical recipes must solve myriad technical problems. For instance, Sir George Cayley enunciated the principle of fixed-wing flight–that propelling a rigid surface through the resistance of air could produce an upward force ("lift")–in 1809.[13] The then revolutionary idea "freed designers from the previous impractical notion of flapping wings."[14] Yet, it took nearly a century for the first controlled flight of a

7 See Amar Bhidé (2020). "Note on Productive Knowledge," Harvard Business School Working Paper No. 21-010. https://dx.doi.org/10.2139/ssrn.3666503.

8 Although scientific fields can vary considerably science advances with "general statements of steadily increasing explanatory power" according to zoologist Peter Medawar (Peter B. Medawar (1982), *Pluto's Republic*, Oxford: Oxford University Press.), that "annihilate" the need to know particular facts. "Biology before Darwin was almost all facts," writes Medawar but now is "over the hump." Generality also seems to affect status. August Comte, considered the first modern philosopher of science, arranged the sciences "in the order of generality of the principles they establish[ed] (see page 8 of Frank H. Knight (1921), *Risk, Uncertainty, and Profit*, Boston: Houghton Mifflin). And in common usage, the more general a proposition, the more "scientific" it is regarded to be. For instance, Friedrich Hayek contrasts scientific knowledge of "general rules" with "knowledge of the particular circumstances of time and place" in his 1945 essay: Friedrich Hayek (1945), "The Use of Knowledge in Society," *American Economic Review*, 35(4), 519-530.

9 See page 223 of Nancy Cartwright (2007), *Hunting Causes and Using Them: Approaches in Philosophy and Economics*, Cambridge: Cambridge University Press.

10 See page 98 of Steven Shapin (1996), *The Scientific Revolution*, Chicago: University of Chicago Press.

11 Op. cit., Shapin 1996 p. 72.

12 See Carliss Y. Baldwin, (2018), "Design Rules, Volume 2: How Technology Shapes Organizations: Chapter 7, The Value Structure of Technologies, Part 2: Technical and Strategic Bottlenecks as Guides for Action," (*Harvard Business School Research Paper Series* No. 19-042)

13 https://www.centennialofflight.net/essay/Prehistory/Cayley/PH2.htm.

14 Op. cit., page 208 Vincenti, 1990.

powered, heavier-than-air aircraft—when the Wright Flyer flew 200 feet in December 17, 1903 because the practical implementation of Cayley's principle required solving numerous problems and sub-problems of designing wings, airframes, propellers, and flight controls. Designs incorporating the solutions were inevitably complex and epistemically heterogenous: they drew on concisely codified science, detailed engineering know-how, and tacit craft knowledge.

Satisfying several objectives under a range of circumstances contributes to complexity. For example, design objectives for aircraft typically include specifications for "performance" (e.g., for speed, range, fuel efficiency and payload capacity) and for "flying qualities" (the ease and precision with which pilots can control an aircraft). Designs must also permit safe landings and takeoffs under conditions of limited visibility, rain or snow and extreme heat and cold, and withstand lightning and bird strikes in flight. Therefore, where feasible, designs include shields to protect artifacts from external vagaries.[15] Computers, for instance, have casings to protect their delicate electronic innards, and designs of the plants manufacturing the innards include enclosures to control variations in temperature and exclude dust particles inside the plant.[16]

Eclectic testing of complex recipes

Complexity of recipes makes their testing complex. Recipes for hard boiled eggs may be developed through a simple "vary time, test firmness" sequence. But chefs developing recipes for French omelets that can be stuffed with a variety of ingredients whose qualities span a variety of dimensions cannot rely on simple tests. Rather, developers of complex recipes use an eclectic combination of tests.

Such multifarious combinations have a profoundly different character from decisive experiments undertaken to test binary truth values of concise scientific propositions—although technologists and scientists may use the same instruments and techniques such as microscopes, spectrometers, and, as we will see, computerized simulations.[17] Initial tests of new designs might try to establish the basic principles. Modern drug development, for instance, typically starts with tests to identify "targets" to disrupt the progression of a disease. Subsequent tests progressively narrow possible recipes, balancing expected accuracy against cost and speed. For instance, drug development normally starts with relatively cheap and quick *in vitro* tests of potentially therapeutic molecules and then proceeds through increasingly costly and time-consuming *in vivo* tests, experiments on animals, and finally human trials. Similarly, in Vincenti's 1990 case study, theoretical calculations of propeller designs made at negligible marginal cost and low-cost wind experiments on scaled down propellers in wind tunnels preceded tests of a smaller number of full-scale models.[18]

Role of judgment

Tests to narrow and select recipes produce more ambiguous results than scientific tests designed to verify sharply defined propositions. The ambiguities in turn dictate subjective judgments about suggestive results. For example, the first heart lung machines were initially tested on dogs and then used in operations on critically ill patients. Although mortality rates were high, published reports included the assessment that the heart-lung machine had functioned well, encouraging its further use and development. Pharmaceutical testing spans lab and animal experiments and human trials that require total out-of-pocket costs of over $400 million per new drug approved.[19] The FDA regulates the trials to maximize scientific validity; yet for those drugs that do not demonstrably fail the trials, it is the FDA's expert panels who finally judge safety, efficacy, and appropriate "indications."

Judgments play a similarly pivotal role in choosing which tests to use. For instance, quicker and cheaper software simulations have replaced physical models in the design of bridges and buildings. Medical researchers are switching from laboratory rats and mice to zebra fish: the fish breed

15 See Paul Nightingale (2004), "Technological Capabilities, Invisible Infrastructure and the Un-Social Construction of Predictability: The Overlooked Fixed Costs of Useful Research," *Research Policy*, 33(9), 1259-1284. https://doi.org/10.1016/j.respol.2004.08.008; and Richard R. Nelson (2008), "Factors Affecting the Power of Technological Paradigms," *Industrial and Corporate Change*, 17(3), 485-497. https://doi.org/10.1093/icc/dtn010.

16 Recipes must also include instructions about sequence—the steps through which a dish is cooked. In contrast, scientific knowledge often focuses on equilibrium states and tendencies (op. cit., Knight 1921 p. 17). And, technical recipes are themselves dynamic: Feedback effects and exogenous changes also preclude the timelessness that science aspires to. For instance, the evolution of drug resistant bacteria, patent expirations, and new biosynthesis techniques can spur the redesign of antibiotic molecules.

17 Classic decisive tests include Newton's prism experiment showing that white light comprises many colors and Pasteur's flask experiment refuting the spontaneous generation of microbes.

18 The later stage tests may not validate earlier findings. Theoretical calculations of propeller performance deviated significantly from the results of wind-tunnel experiments on scaled down models which in turn did not closely match results from full scale models. Similarly, in medical research, animal experiments do not reliably predict what happens in humans. For example, the "Vineberg procedure" to treat coronary disease which had been refined and tested on dogs proved ineffective in humans. Conversely, contrast agents which were dangerous when inserted into the coronary arteries of dogs were accidentally discovered to be safe for humans, paving the way for cardio-angiography. See Amar Bhidé, Srikant Datar, and Fabio Villa (2019), "Coronary Artery Bypass Grafting: Case Histories of Significant Medical Advances, "SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3427408.

19 Joseph A. DiMasi, Ronald W. Hansen, and Henry G. Grabowski (2003), "The Price of Innovation: New Estimates of Drug Development Costs," *Journal of Health Economics*, 22(2), 151-185. https://doi.org/10.1016/S0167-6296(02)00126-1.

more quickly and are easier to care for, while their cell-physiology is like that of humans, making the fish a suitable model for many human diseases.[20] Developers of consumer goods on the other hand now increasingly favor more laborious "ethnographic" research over traditional market surveys and interviews.[21] And adoption of new tests usually turns on judgments. Zebra fish may be demonstrably cheaper, but their reliability for testing new treatments of human disease is based on fallible inference. Likewise, the increasing use of ethnographic research is based on *prima facia* plausibility and some success stories.

Technologists have more leeway to exercise such judgments than scientists, who tend to be constrained by the testing conventions of their communities. For instance, some architects prefer traditional physical models to evaluate building designs over cheaper, faster, and now more popular computer simulations. Some developers with unusual confidence and authority, notably Steve Jobs, may rely on their instincts instead of market research. Others may favor "on-line" beta testing and trial and error and "learning by doing" experimentation to ex-ante, "off-line" tests. Technologists' tests are therefore more eclectic than scientists' tests; there is also greater diversity of the combinations used.

Practical Limitations of Economic Science

Scientific orientation of goals and methods

Disciplinary economics, which D. Wade Hands distinguishes from "ersatz economics, Better Business Bureau economics, or folk economics," has long favored scientific knowledge and inquiry. The first sentence of Frank Knight's 1921 classic, *Risk, Uncertainty and Profit*, [22] tells us that economics is "the only one of the social sciences which has aspired to the distinction of an exact science" like physics.[23] And like physicists, economic scientists prize propositions that transcend specific circumstances. Knight asserted that "the very conception of an exact science involves abstraction" while Friedman argued that an "important" hypothesis "'explains' much" by abstracting "crucial elements from the mass of detailed and complex circumstances." Nowadays, writes Nancy Cartwright, "modeling by the construction of analogue economies is a widespread technique." The models, popularized by and closely associated with Nobel Laureate Robert Lucas, "have only a few agents with few options and only a narrow range of both causes and effects is admitted." The goal is to "isolate [a] process; to study it in a setting where nothing else is going on that might affect the outcome as well."[24]

Disciplinary economists, like other scientists, value decisive verification to each other's satisfaction. And, as in other scientific communities, standards for verification evolve. In 1874, John Stuart Mill categorized economics as an *a priori* deductive science.[25] Later, Frank Knight, referred to economists as "empiricists" in the sense of "holding that all general truths or axioms are ultimately inductions from experience."[26] Mill and Knight also saw theories predicting "tendencies" that might be confounded by extraneous factors without refuting the theory proposed.[27] Rather, their main criteria for validity was whether the initial premises conformed to experience and whether tendencies deduced logically followed.

Deductive theorizing is now almost invariably mathematical.[28] This enables verifying the internal consistency of elaborate analogue models (mentioned above) in which everything is fully and precisely specified. Meanwhile "empiricism" has also changed from the use of personal experience as the starting point for causal theories to testing predicted outcomes as Friedman advocated in 1953 and using sophisticated econometric methods to exclude the effects of extraneous factors and spurious correlations.

Limitations of deductive theories

According to Lucas, analogue models that produce "statements of verifiable [deductive] fact" can serve "as laboratories

20 University of Alabama at Birmingham (July 19, 2016). "Zebrafish's Growing Impact on Medical Research," *Science Daily*, Retrieved November 22, 2017 from www.sciencedaily.com/releases/2016/07/160719161816.html.

21 Christian Madsbjerg and Mikkel B. Rasmussen (2014), "An Anthropologist Walks into a Bar," *Harvard Business Review*, 81-88.

22 Frank H. Knight (1921), *Risk, Uncertainty, and Profit*, Boston: Houghton Mifflin.

23 In 1968, the Swedish central bank endowed the "Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel." None of the other Nobel prizes include "science" in their name and indeed physics and chemistry awards periodically recognize instruments and artifacts that, like the Boyle-Hooke air pump, mark significant engineering achievement. For example, Arthur Ashkin shared a Nobel Prize in Physics in 2018 for developing "optical tweezers" and all three Chemistry prize winners in 2019 were recognized for developing lithium-ion batteries.

24 Even economists who study institutions abstract away from the particulars. Seminal papers on transaction costs (e.g., Ronald H. Coase (1937), "The Nature of the Firm," *Economica*, 4(16), 386-405. https://doi.org/10.1111/j.1468-0335.1937.tb00002.x) or legal origins (e.g., Rafael La Porta, Florencio Lopez-de-Silanes, Andrei Shleifer, Robert W. Vishny (1998), "Law and Finance," *Journal of Political Economy*, 106(6), 1113-1155. https://doi.org/10.1086/250042) utilize broad categories such as "firms" and "markets" and "civil law" and "common law" systems. Elinor Ostrom's case-study-based heuristics for solving commons problems stand out in their exceptional attention to specific institutional circumstances.

25 John Stuart Mill (1874), "On the Definition of Political Economy; and on the Method of Investigation Proper to It," in *Essays on Some Unsettled Questions of Political Economy*. Retrieved from http://www.econlib.org/library/Mill/mlUQP5.html.

26 Op. cit., Knight 1921 p. 8.

27 Specifically, Mill defined economics as a science concerned solely with the conduct of man *"as a being who desires to possess wealth"* and that "predicts only such of the phenomena of the social state as take place in consequence of the pursuit of such wealth." But because people had other desires, the predictions could not be clearly observed.

28 Belying Knight's prediction that "mathematical economics…seems likely to remain little more than a cult (op. cit., Knight 1921 p. 14)."

in which policies that would be prohibitively expensive to experiment with in actual economies can be tested out at lower costs." Artificial conditions are not deficiencies; as Lucas observes, "Any model that is well enough articulated to give clear answers to the questions we put to it will necessarily be artificial, abstract, patently 'unreal'."[29]

Cartwright agrees that analogue models can have practical utility. For example, it may be helpful for policymakers to learn from Christopher Pissarides's model[30] how skill loss can make unemployment persistent, even if factors excluded from the model offset this tendency. Nonetheless, three reasons warrant caution about relying just on analogue and other such deductive models to evaluate new policy recipes.

First, although the number of agents, options, causes, and effects admitted in the models are few, "the list of assumptions specifying exactly what the analogue economy is like is very long."[31] The Pissarides skill-loss model "contains some 16 assumptions and that for just the first of six increasingly complex economies that he describes."[32] And we cannot know whether the tendency of interest—say, the persistence of unemployment—stems from the causal mechanisms the model seeks to isolate or from the many incidental or auxiliary assumptions used to make the model deductively verifiable. We may therefore learn little about tendencies outside the analogue economy. Additionally, modeling requires "special talents and special training," potentially excluding contributions from "different kinds of thinkers who may provide different kinds of detailed understanding of how economies can and do work."[33]

A second problem with the practical application of deductive models arises from aggregation that obscures important parts of the whole. Central bank economists for instance now rely heavily on models in which everyone produces and consumes the same thing. But, as Mervyn King pointed out in a July 2017 lecture at the National Bureau of Economic Research, policies to sustain demand for consumption as a whole can injure producers of goods exposed to international competition. Similarly, before 2008, the U.S. Federal Reserve's model did not have a financial sector and thus did not consider the risks of its collapse.[34]

A third problem pertains to the difficulty of combining the results of models that admit "only a narrow range of both causes and effects." An airplane designer can use Newton's laws of motion and fluid flow equations to estimate separately the forces of gravity, lift, and drag and then cumulate their overall effect using vector addition. Similar procedures do not exist in economics. Therefore, one model may help estimate the effect of easing monetary policy and a different model may provide estimates of the effects of increasing capital requirements for banks. But adding up the two estimates does not provide a useful prediction of the overall outcome.

More complex models might ameliorate the second and third problems. For instance, models might distinguish between tradables and untradables, between services and manufacturing, and include a banking sector and bank capital requirements. But greater complexity would require more incidental assumptions, making it harder to isolate tendencies of interest to policymakers. Or they might fail to yield unique solutions and therefore sacrifice the "statements of verifiable fact" valued by Lucas.

Limitations of econometric and experimental tests

Econometric techniques used to verify causal tendencies through natural experiments and difference in difference testing also have scientific aims that limit their practical utility. They can help verify tendencies outside artificially constructed economies. But econometric tests, like physical experiments, require many assumptions that conform to conventions chosen to coordinate scientific inquiry rather than for their practical utility. Econometric models also follow the scientific convention of focusing on a few abstracted constructs. The practical problems of suppressed detail and of adding the effects of multiple tendencies to evaluate complex recipes therefore remains. Moreover, many important policy choices are naturally novel (think about quantitative easing in the U.S. and Europe and privatization in transitional economies); therefore, suitable natural experiments and control groups may not be available to investigate even the general tendencies affecting these choices.

In principle, Randomized Controlled Trials (RCTs) can test novel policy combinations. But in practice, according

29 See pages 271-272 of Robert E. Lucas (1981), *Studies in Business-Cycle Theory*, Cambridge: MIT Press.

30 See Christopher A. Pissarides, "Loss of Skill During Unemployment and the Persistence of Employment Shocks," *The Quarterly Journal of Economics*, Volume 107, Issue 4, November 1992, Pages 1371-1391, = https://doi.org/10.2307/2118392.

31 Op. cit., Cartwright 2007 p. 226.

32 Op. cit., Cartwright 2007 p. 228.

33 Op cit., Cartwright 2007 p. 234. Unverifiable auxiliary assumptions also connect hypotheses to observations and experimental results in the physical sciences. Therefore, scientific falsifiability inevitably requires conventions to justify its procedures, as Karl Popper—the best-known champion of falsifiability—pointed out. See D. Wade Hands (2001), *Reflection Without Rules: Economic Methodology and Contemporary Science Theory*, Cambridge: Cambridge University Press.

34 In contrast, engineers are expected to take seriously the risks of failure of minor components, such O-rings in rockets, and treat the whole only as resilient as its most vulnerable part. In economic science, theorizing (and empirical verification) requires extensive aggregating and abstracting, as mentioned. Kremer's (1993) O-ring theory of economic development itself analyzes highly abstracted constructs. See Michael Kremer (1993),"The O-Ring Theory of Economic Development," *The Quarterly Journal of Economics*, 108(3), 551-575. https://doi.org/10.2307/2118400.

to Angus Deaton and Nancy Cartwright, "RCT results can serve science but are weak ground for inferring 'what works.'"[35] Efforts to mirror the norms of natural science experiments apparently limit utility. The efficacy of policy interventions—as in engineering and medicine—can depend a great deal on how their constituent ingredients are combined: one combination of the same ingredients can produce spectacular results while another combination can utterly flop. But the cost and time needed for RCTs will typically permit the testing of only a few possible combinations.

Critics of RCTs of surgical innovations have long highlighted the problem of variants. For instance, heart surgeon Jack Love questioned the value of randomized trials of bypass operations, and other evolving procedures, noting that surgical operations were "rarely introduced as fully defined, easily reproducible techniques."[36] Rather, they came as "principles for solving particular problems" that could be implemented in a wide variety of ways. For instance, more than 200 specific procedural combinations could be used for the same general principle of heart valve replacement.

Using Simulations to Support Policy Judgments

Risks of unilateral and siloed judgments

In practice, policymakers (including those on leave from economics departments) often rely on subjective judgments—choosing "narratives" as Kay and King put it—that go beyond standard equilibrium models and empirical tests.[37] But opaque or ad hoc judgments—the Federal Reserve's qualitative stress tests of large banks or protracted quantitative easing for instance—can expose policymakers to allegations of caprice or favoritism and undermine their legitimacy and public standing. In other instances, regulators avoid the vector addition problem by focusing on narrow remits. But siloed choices can produce intractable misalignments; like omelets made from bad recipes, basic inconsistencies cannot be repaired, although the alignment of approximately congruent policies can be iteratively improved. Eclectic "technological" combinations of tests and contextual judgments that help policymakers reduce the risks of compromised legitimacy and inconsistency therefore warrant consideration.

Simple imitation of engineering or medical practices is clearly impossible. Wind tunnel experiments and rapid prototyping with foam models are infeasible in economic domains. Conversely, there may be a greater role for collectivized judgment through a dialectical, collaborative—or even formally adversarial—process that integrates consideration of prior cases and precedents with numerical data. Such evaluations are routine in judicial, legislative, and business decisions. But instead of comparing a broad set of possibilities, I focus next on how computerized simulations can support collaborative judgments about novel recipes.

Simulations as collaboration tools

As mentioned, simulation software is now widely used in engineering as a low-cost substitute for physical models to evaluate new designs. Simulation tools available for practical economic applications have also vastly improved. Many hedge funds, for instance, use sophisticated Monte Carlo simulations for pricing assets and managing portfolio risks. And virtually all businesses use spreadsheet simulations, not closed-form equilibrium models, to evaluate and plan projects.

The widespread use of spreadsheet simulations likely reflects multiple benefits that offset the limitations. As with most physical artifacts, several choices (about for instance pricing, advertising, compensation, and borrowing) combine with external factors (such as demand, wages and interest rates) to produce many consequential outcomes (such as profits, cash flows, and shares of strategically important markets). Spreadsheets provide a convenient way to model and display how multiple choices might map into multiple outcomes, mitigating the "vector addition" problem mentioned earlier.

The models are, however, entirely "deductive," and their premises invariably speculative. Spreadsheets require specifying many individual functional relationships (e.g., how consumers respond to prices and advertising) whose structural forms and parameter values are not easily observable and highly context specific. Their value lies in conveniently projecting what happens under different guesstimates. Even models with questionable guesstimates—and wide ranges of outcomes, as exemplified by William Sahlman's discounted cash flow calculations[38]—can serve as "conversation pieces" for discussions that may improve and confer more legiti-

35 Angus Deaton and Nancy Cartwright (2018),"Understanding and Misunderstanding Randomized Controlled Trials," *Randomized Controlled Trials and Evidence-Based Policy: A Multidisciplinary Dialogue*, 210, 2-21. https://doi.org/10.1016/j.socscimed.2017.12.005.

36 Jack W. Love (1975), "Drugs and Operations: Some Important Differences," *JAMA*, 232(1), 37. https://doi.org/10.1001/jama.1975.03250010019016.

37 John A. Kay and Mervyn A. King (2020), *Radical Uncertainty: Decision-Making Beyond the Numbers* (First edition), New York: W. W. Norton and Company.

38 William A. Sahlman (1990), "A Cautionary Tale About Discounted Cash Flow Analysis," *Harvard Business School Division of Research Working Paper No. 90-069*.

macy on judgments than would purely verbal reasoning. The discussion and legitimacy are especially valuable in pooling diverse expertise and opinions to evaluate large irreversible investments undertaken by professionally managed organizations—even though the reliability of the spreadsheet projections is obviously low.

In the public sector, spending agencies use spreadsheets to evaluate infrastructure projects. Bank regulators and bank compliance officers use simulations in Internal Rating Based (IRB) calculations of bank capital requirements; regulators also use Monte Carlo simulations to monitor the trading and systemic risks of hedge funds; and, in 2010 the European Commission formalized SYMBOL (Systemic Model for Banking Originated Losses) simulations as the standard for testing proposed financial regulations and rules, including deposit insurance schemes, bank capital requirements, and financial transaction taxes.

Published research on simulations

Some of these regulatory initiatives have produced scholarly and semi-scholarly research publications. Many regulators and their consultants who work on simulations have PhDs in economics—and some have faculty appointments in economic departments. And unlike private companies who worry about confidentiality, regulatory agencies often encourage the publication of staff papers, books, and journal articles.

(*My Applied Economics* article lists several publications by European and U.S. regulators.)

These studies have antecedents in research from the 1950s when Allen Newell and Herbert Simon "conceived the idea that the right way to study problem-solving was to simulate it with computer programs."[39] By 1960, simulation had gained sufficient traction for the *American Economic Review* to publish a symposium on its use in economics, with contributions by Martin Shubik, Guy Orcutt, and Geoffrey Clarkson and Herbert Simon.[40] Richard Nelson and Sidney Winter used computer simulations to model innovation and explicate their evolutionary theory of economic change.[41]

But it would not be unfair to say that simulations, and especially their practical applications, fall outside the disciplinary mainstream. PhD coursework in economics (which Hands uses as a criterion for demarcating the discipline) rarely includes learning about simulation software. In contrast, spreadsheet simulations are routinely used to teach quantitative analysis in all graduate and undergraduate business programs. And engineering students learn to use more advanced simulation tools, such as Matlab, Python, and SimPy, through lectures, textbooks, and course-projects.[42]

Simulations are likewise now rarely seen in leading journals in economics and finance, possibly because simulations cannot easily satisfy scientific standards for generalizability and replicability. Moreover, disciplinary economists doing scientific research predominantly use—and have previously used—simulations to investigate concise general propositions, not multifaceted contextual prescriptions. Simulations typically used in scholarly economic research are thus analogous to simulations used to design experiments in high-energy physics and biologists' evolutionary models rather than simulations used by engineers to design bridges and buildings.[43]

Controversial popularity of field experiments

RCTs have attracted much greater support and controversy. The U.S. Congress initiated regulatory use of randomized trials in 1962 when it authorized the FDA to secure "substantial evidence" of efficacy to approve new drugs. Over time, the FDA required randomized multi-center trials "with clear, prospectively determined clinical and statistical analytic criteria."[44] The U.S. government used trials to evaluate economic policies in the late 1960s and 1970s when it "sponsored four large-scale social experiments to measure individuals' responses to different levels of benefits and tax rates."[45]

Starting in the 1990s, RCTs "transformed development economics" as the 2019 Nobel Prize in Economic Science announcement noted. According to Oxford economist Lant Pritchett, "there are now literally thousands of published RCTs, with dozens of studies on conditional cash transfers, on micro-finance, and literally hundreds of studies

39 The Nobel Prize (2019), Herbert A. Simon - Biographical. Retrieved from https://www.nobelprize.org/prizes/economic-sciences/1978/simon/biographical/.

40 Mary S. Morgan (2004), "Simulation: The Birth of a Technology to Create 'Evidence' in Economics," *Revue d'histoire Des Sciences*, 339-375. Retrieved from Persée http://www.persee.fr.

41 Richard R. Nelson and Sidney G. Winter (1982), *An Evolutionary Theory of Economic Change*, Cambridge: The Belknap Press of Harvard University Press.

42 See, for example, Barry L. Nelson (2013), *Foundations and Methods of Stochastic Simulation: A First Course*, New York: Springer.

43 See, for example, Thorbjørn Knudsen, Daniel A. Levinthal, and Sidney G. Winter (2017), "Systematic Differences and Random Rates: Reconciling Gibrat's Law with Firm Differences," *Strategy Science*, 2(2), 111-120; and Santiago Bazdresch, Robert J. Kahn, and Toni M. Whited, (2017), "Estimating and Testing Dynamic Corporate Finance Models," *The Review of Financial Studies*, 31(1), 322-361. https://doi.org/10.1093/rfs/hhx080 exemplify recent scientific use.

44 See, page 12 of Food and Drug Administration (1998), "Guidance for Industry: Providing Clinical Evidence of Effectiveness for Human Drugs and Biological Products," Retrieved from https://www.fda.gov/media/71655/download.

45 See, page 1 of Alicia H. Munnell (Ed.), (1986), *Lessons from the Income Maintenance Experiments*, Federal Reserve Bank of Boston.

of boutique interventions in water, sanitation, education, health [and] business training."[46] Pritchett questions their actual impact, however, and a recent study has reported that the budget for "a classic RCT is between $500,000 and $1,500,000, and each RCT often generates just one published research paper."[47] Moreover, whatever their cost-effectiveness, scientific RCTs can only provide a starting point for complex recipes, as I suggested earlier.[48]

I will now illustrate how simulations—which we can think of as cheap "virtual" experiments—can be used to help evaluate policy recipes through the example of rules that affect how lenders screen loan applicants. Unlike scientific simulations and RCTs, this illustration does not seek to validate or refute general propositions. It also does not propose specific prescriptions, whose efficacy, as with most practical recipes, will depend on circumstances of time and place. Rather, the example illustrates how low-cost simulations can support judgments about combinations whose complexity and novelty limit what decision makers can learn just from theoretical models, econometric studies, and RCTs.

My aim is analogous to showing how spreadsheets can help design programs to launch new products rather than to produce scientific propositions about new product launches. And consistent with this limited purpose, my simulations make illustrative assumptions about "input" functions and numerical values and produce "outputs" intended merely to exemplify how simulation results can facilitate discussion and judgment. The illustration does not, however, target an imaginary gap in evaluations of policy outcomes, as we will next see.

Simulation Model

Policies affecting credit screening

Lenders routinely seek to screen out unscrupulous or overconfident borrowers using categorical markers, statistical models, and information about individual applicants. Regulatory choices in turn affect lenders' choices about the nature and extent of their screening. For instance, anti-discrimination laws in the U.S. forbid lenders from using borrowers' postal codes to screen loan applications and, as described in articles I published recently, promote strict reliance on credit bureau scores by increasing the regulatory risks of securing more detailed information. European rules in contrast do not prohibit rejections based on postal codes, and new rules now encourage lenders to secure detailed information by making lenders liable for loans carelessly made to borrowers who fail to repay.

Regulators also have indirect influence. Perhaps most important, increasing capital requirements is believed to encourage more careful screening. At the same time, however, promoting competition between lenders can limit their willingness and capacity to pay for information about borrowers—or possibly spur more efficient screening.

Assessing the overall effect of these policy combinations is however difficult. One recent review suggests that while policies that encourage lenders to secure more information will tend to reduce rates and losses, the effect on the quantity of lending is ambiguous.[49] And the "vector addition" problem mentioned earlier makes it difficult to assess disparate combinations—how might for instance changing capital requirements and antitrust rules along with information requirements affect loan rates and volumes? Similarly, as also mentioned, new policy combinations increase potential errors produced by applying empirical results drawn from historical data. And verbal reasoning alone does not take us far.

Yet after 2008, policymakers have made significant changes on several fronts. As mentioned, European regulators have increased penalties for careless credit extension but have also sought to increase competition between lenders, thereby potentially reducing their capacity to pay for more screening. In the U.S., regulators have increased "know your borrower" requirements, but to a lesser degree than in Europe. At the same time, U.S. regulators have "gold-plated" internationally agreed-on capital requirements. How these new policy combinations are likely to affect lending is therefore not just a hypothetical question.[50]

The effect of policy combinations on securitization also remains unexamined. In recent articles, I proposed that U.S. rules discouraging lenders from collecting detailed

46 Lant Pritchett (2020), "Randomizing Development: Method or Madness?" In Florent Bédécarrats, Isabelle Guérin, and François Roubaud (Eds.), *Randomized Control Trials in the Field of Development: A Critical Perspective*, Oxford: Oxford University Press.

47 Florent Bédécarrats, Isabelle Guérin, and Francois Roubaud, (2020), *Randomized Control Trials in the Field of Development: A Critical Perspective*, Oxford: Oxford University Press.

48 For instance, the Prize Committee for the Economics Nobel praised the 2019 winners for RCTs showing that distributing more textbooks without better teaching did not improve student learning and that paying bonuses reduced teacher absenteeism, when attendance was monitored by cameras. Such demonstrations may provide valuable general cautions about the importance of complements and incentives; but reminders to buy eggs and butter doesn't tell cooks how to make tasty omelets. And policy recipes have to match specific circumstances: Studies of paying U.S. professors bonuses (with CCTV monitoring) to reduce their absenteeism might fail Institutional Review Board scrutiny. But million-dollar RCTs can screen just a few of many possible combinations for fit with their targeted circumstances.

49 Raymond Fisman, Daniel Paravisini, and Vikrant Vig (2017), "Cultural Proximity and Loan Outcomes," *American Economic Review*, 107(2), 457-492. https://doi.org/10.1257/aer.20120942.

50 SYMBOL simulation protocols could be used to assess the combinations but have not. Simulations studies sponsored by regulatory agencies have apparently focused more on specific interventions, such as capital requirements and deposit insurance, rather than their "combinations" (such as increased capital requirements plus more pro-competition rules). In particular, simulations appear not to have investigated combinations that include rules requiring or discouraging lenders from collecting information about borrowers. They also seem to focus more on systemic risks rather than routine lending effects.

information actually facilitate the exceptionally high degree of securitization: I pointed out that, as lenders' ignorance about their borrowers increases, investors' concerns about information asymmetries actually decline, although overall, defaults by borrowers increase. And reducing "lemons" risks increases the demand for "pooled" securities, provided borrowers in the pool pay interest rates that are commensurate with the higher defaults produced by less informed lending.[51] If this hypothesis is correct, European efforts to raise securitization to U.S. levels without imposing similar limits on lenders' information are unlikely to succeed.

But capital requirements on loans held to maturity also encourage securitization.[52] Could tougher capital requirements, rather than less severe information asymmetry problems, account for the exceptionally high securitization of credit in the U.S.? If so, European policymakers could plausibly expect to boost securitization while also encouraging lenders to secure more information about borrowers (by raising capital requirements). This possibility has not been researched either through simulations or traditional equilibrium models and econometrics.

Main features

My simulations show that under illustrative assumptions, combining rules requiring in-depth credit analyses of borrowers with tougher antitrust rules will: (1) increase interest rates; 2) reduce loan volumes; and (3) severely discourage securitization. The simulations also provide indicative "guesstimates" about magnitudes, again under illustrative assumptions.

Like economist Joe Bain's "structure-conduct-performance" paradigm, my model does not contain "policy" variables (see Table 2).[53] Rather, as in the Bain model, it can help generate plausible hypotheses about how policies that likely affect "structure" and "conduct" variables could alter lending "performance."

I make two simplifying assumptions about the two "conduct" variables. I assume that lenders incur the same expenditures to screen all the loan applications they receive, denoted by the variable *InfoCost* and expressed as a proportion of loan applications. For instance, if lenders spend $5 to screen $100 of loan applications, *InfoCost* will equal 0.05. Similarly, I assume that lenders offer all applicants they categorize as creditworthy loans at the same *PrimeRate* and all other applicants' loans at the same *NonPrimeRate*.

Alternatives and complements

Like all simulations, my model, implemented through a software program called *Mathematica*, starts with a mathematical representation of variables and assumptions about their parameters. And including many variables, which allows examination of policy combinations, precludes unique analytical solutions. And because, like "business" spreadsheets, my simulations are entirely deductive exercises, using different mathematical representations or making different numerical assumptions would change the results. Moreover, the complexity of multi-variate simulations poses expository challenges.

But practical applications of closed form equilibrium models, which in principle produce unique, unambiguous solutions, cannot avoid these problems. For instance, Black-Sholes-Merton option pricing models produce results that are highly sensitive to unverifiable, subjective assumptions about the volatility of the prices of the underlying securities.[54] Moreover, for many users of option pricing models, the mathematics can be "off-putting," making crucial auxiliary assumptions opaque to the users.[55]

Yet, Black-Sholes-Merton option pricing models play an important practical role by providing a common "vocabulary" to traders and their managers, who may have different views about future volatilities. The vocabulary in turn enables more objective discussions that, as mentioned earlier, give legitimacy to judgments made and can help rule out some utterly implausible options. My illustrative simulation similarly seeks to support discussions about policy combinations that cannot be evaluated with closed form equilibrium models.

Unlike axiomatically based option pricing models, my simulations do reflect ad hoc choices of salient variables, functional forms, and numerical values. But implementing the simulation in *Mathematica* allows analysts to easily change the variables, functions, and numerical values to reflect their judgments about conditions in specific credit

51 Amar Bhidé (2017), "Formulaic Transparency: The Hidden Enabler of Exceptional U.S. Securitization," *Journal of Applied Corporate Finance*, 29(4), 96-111. https://doi.org/10.1111/jacf.12265 and Amar Bhidé (2020). "Symmetric ignorance: The cost of anonymous lemons" *European Financial Management*. https://doi.org/10.1111/eufm.12298.

52 Ben S. Bernanke and Cara S. Lown (1991), "The Credit Crunch," *Brookings Papers on Economic Activity*, 1991(2), 205-247. https://doi.org/10.2307/2534592.

53 Joe S. Bain, (1959), *Industrial Organization*, New York: Wiley.

54 These cannot be reliably inferred from historical prices. For instance, as I pointed out over a decade ago, there is no theoretical basis for using 30-day prices rather than 90-day prices to calculate historical volatility and historical volatilities can be unreliable predictors of future volatilities.

55 See Donald Mackenzie (2008), *An Engine, Not a Camera: How Financial Models Shape Markets*, Cambridge: MIT Press.

Table 2

Model variables and mapping assumptions

Structure: **Exogenous Conditions** ▶	***Conduct*****:** **Lenders' Choices** ▶	***Performance*****:** **Lending Outcomes**
• Market power of lenders (capacity to charge profit maximizing interest rates) • Proportion of loan applications submitted by creditworthy borrowers • Efficiency of lenders' spending on information collected to screen applicants • Rate sensitivity of loan applicants • Loss incurred by lender per dollar lent to bad borrowers • Capital cushion lenders maintain as buffer against unexpected losses and the cost thereof	• Expenditure on information to select "good" or "prime" borrowers • Interest rate offered on loans to applicants categorized as prime • Interest rate on loans offered to applicants categorized as nonprime	• Loans made and profits earned • Unwarranted approvals and rejections of loan applications (Type I and II errors) • Whether loans securitized
	"Mapping" assumptions: • Modified logit expressions used to specify how: 1) the acceptance of loan offers depends on rates at which lenders offer loans and the rate sensitivity of borrowers, and, 2) the accuracy of screening loan applications depends on amount and efficiency of expenditures incurred on screening • Proportion of false positives—the proportion of creditworthy applicants denied loans—assumed to track overall accuracy	

markets. In contrast, modifying the Black-Scholes-Merton model (or the Pissarides skill-loss model mentioned earlier) without breaking their capacity to produce unique solutions requires extraordinary expertise and skill.

In principle, a spreadsheet would require even less skill to modify than my *Mathematica* model; but in practice, the complexity of a spreadsheet (with the functionality of my simulation) would make changes difficult to implement and audit. Additionally, although using *Mathematica* requires learning the program's syntax, the software has more powerful analytical, computational, and plotting capabilities than spreadsheets. Adding or substituting variables to analyze additional policy combinations is also relatively simple. And *Mathematica* allows easier plotting of more complex possibilities than would spreadsheets.

My model does not, however, include dynamic or interactive effects: borrowers don't learn or change their behavior; competing lenders don't adapt to each other's strategies; and changing the value of one of my structure variables does not affect the value of any other. It also generates end results without indicating the path followed to get there; and paths can be of serious concern to policymakers. But it is hard to imagine any equilibrium or spreadsheet model without similar limitations.

An agent-based model could incorporate some dynamic and interactive effects that my simulations lack and trace paths along which the variables change. But the results of agent-based models can depend on how long the models are run for. The models are also more complex and require more expertise to construct and modify, potentially limiting their transparency and value in discussing and legitimizing policy choices. Agent-based modeling may nevertheless serve as a useful complement or a "next step" to my simpler simulations, much the same way as *in vivo* tests might follow *in vitro* tests in pharmaceutical research or wind tunnels follow simulations in aeronautical design.

Illustrative Plots and Policy Implications

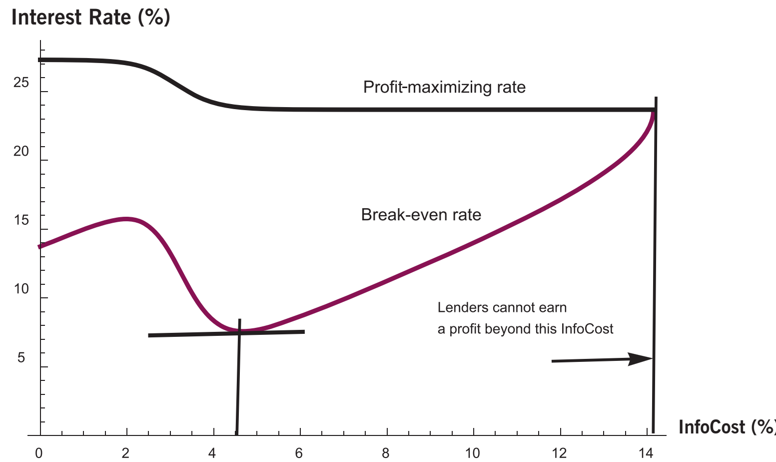
Regulating information and competition

To focus on the joint effects of regulating information and competition on lenders' "conduct" (choices) and thus on lending "performance" (outcomes) I first fix five "structure" (exogenous) variables in the base-case of my simulation model (as described in my prior *Applied Economics* article).

I then compute interest rates as a function of *InfoCost* under two kinds of market structures: 1) monopolistic, when lenders set rates to maximize profit, and 2) highly competitive, when lenders maximize loans by charging "breakeven" interest rates (that allow lenders to avoid losses). Expectedly, as shown in Figure 1, the profit-maximizing interest rate (charged by lenders with market power) is always greater than the break-even rate.

Ideally, we would next want to find an expression or value for the lenders' optimal spending on screening expenditure (*InfoCost),* but the model's complexity makes such a computation impossible. The software can however plot (Figure 2) several lending outcomes—the "performance" variable of potential interest to a policymaker—as a function of the lender's choice of *InfoCost*.

Figure 1
Interest rates as a function of information expenditures



The Figure 2 plots suggest the following relationships between policy goals and combinations of market structure and *InfoCost* policies:

• If regulators want lending to all good borrowers and zero to bad borrowers, their rules should *maximize* competition between lenders and *require* spending of about 5.7% (of the value of the loan applications screened) on *InfoCost*.

• If regulators want "prudent" oligopolist lenders to earn profits (as a cushion for future credit shocks)—but lend nothing to bad borrowers, the rules should *limit* competition but *require* lenders to spend about 5.7% on *InfoCost*.

• If regulators *limit* competition and *do not regulate InfoCost* expenditures, lenders will *choose* 4.5% *InfoCost*, producing a 1% rate of lending mistakes (bad applicants receiving loans and good applicants not receiving loans).

• *Requiring* lenders to spend 4.5% on *InfoCost* while *maximizing* competition will minimize interest rates borrowers pay.

• Requiring lenders to spend *less* than 4.5% on *InfoCost* while *maximizing* competition will increase total lending—and the rates borrowers pay (as compared to unregulated spending on *InfoCosts).*

The plots also suggest that the current U.S. combination of an oligopolistic banking structure with severe restrictions on *InfoCost* has the unintended consequence (compared to the other combinations plotted) of maximizing interest rates borrowers pay, while minimizing good loans and their percentage of loans made. Similarly, current European efforts to increase competition in banking while imposing tough "know your customer" rules may be neutralizing each other, at least in terms of increasing lending: competition reduces interest rates and increases loans made; but high spending on *InfoCost* has the opposite effect.

Non-prime rates and prime securitization

As detailed in the longer *Applied Economics* article, lenders may extend offers at non-prime rates to applicants who they have characterized as "bad," under the expectation that some of these applicants may in fact be creditworthy. But if lenders incur large information expenditures in their initial screening, few good applicants will be left in their "reject" pool. Therefore, as shown in Figure 3, lenders will offer non-prime loans at much higher rates than they offer prime loans; and at high subprime rates, many borrowers will reject loan offers. The plot thus suggests that rules that allow or require high spending on information will severely limit or even eliminate subprime lending.

The plot also provides an indication of the extent to which differences in U.S. and European rules affect securitization. As mentioned earlier, capital requirements encourage banks to securitize their loans while "lemons" problems hinder securitization. U.S. rules limiting information also work to limit the "lemons" problem hindrance in the following sense: lenders offer loans to all applicants whose credit scores (generated by a credit bureau, rather than the lender) exceed a threshold without any further scrutiny. The lender thus has little information that it might, when given the opportunity, choose to hide from buyers of its securitized loans. In contrast, European rules, which require more

Figure 2

Loans made and profits earned as a function of information expenditures

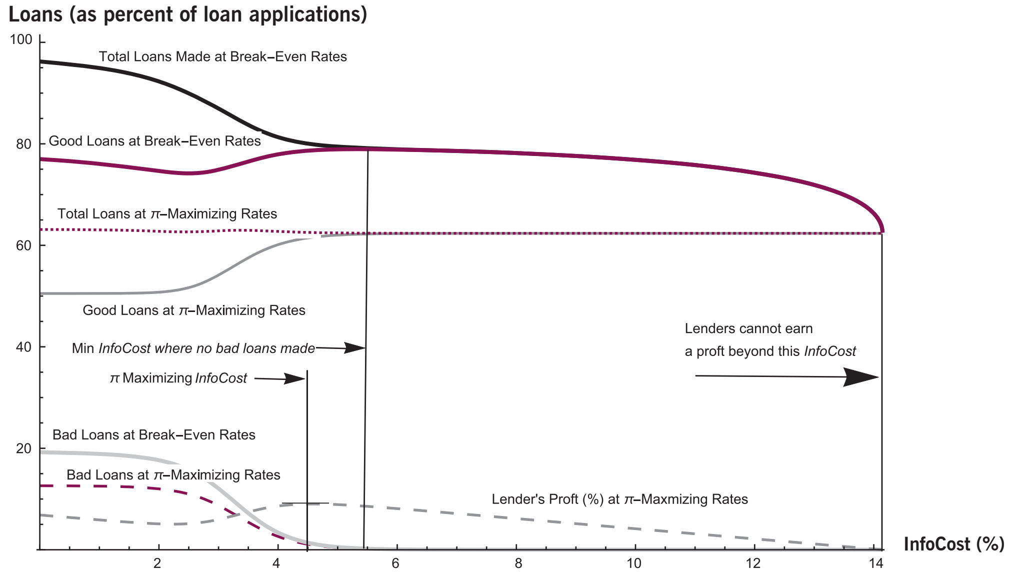
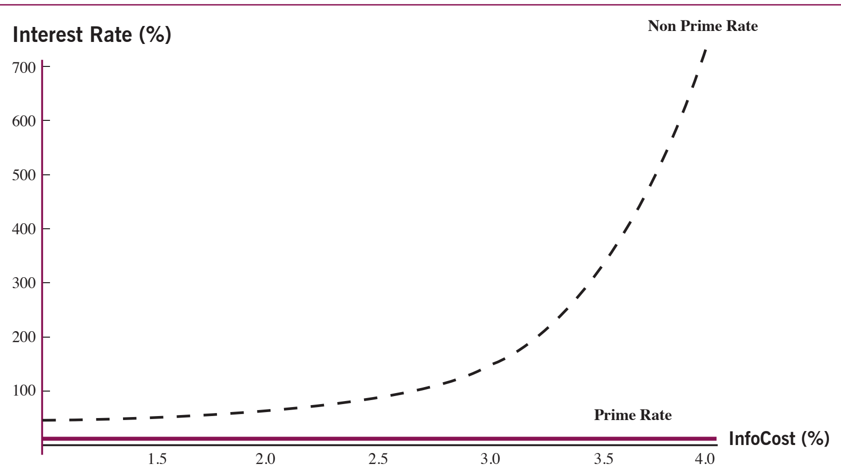


Figure 3

Prime versus non-prime interest rates



Note: Plot for Prime Rate same as in Figure 1 but highly "flattened" because of different Y-axis scale.

information gathering, give European banks the possibility of knowing significantly more than their investors about the creditworthiness of each borrower. This increases investors' concerns that lenders will sell off their bad, non-prime quality loans while keeping their good, prime quality loans. Investors may then demand rates commensurate with the quality of non-prime loans. The higher rates, which the plot suggests can run into triple digits, can severely discourage securitization and overwhelm any plausible capital cost advantage the bank might gain.

Effects of policies affecting other structure variables

My model can provide hypotheses about interventions affecting the structure variables.[56] The hypotheses again depend on

56 Regulators can influence the "structure" variables whose values I had fixed earlier (for the "base-case" Figures 1-3) in several ways. Capital requirements directly affect *CapitalCosts*; rules such as the U.S. Community Reinvestment Act that require lending in economically distressed neighborhoods can potentially reduce *GoodProportion* (the proportion of creditworthy applicants); bankruptcy rules protecting delinquent borrowers can increase *Loss* (by reducing what lenders can recover from defaulted loans) and reduce *RateSensitivity* (by increasing the willingness of borrowers to take on high-interest obligations); and rules to increase competition by reducing borrowers' switching costs

the particular values used in my illustrative example, not what we can expect as universal occurrences or tendencies. And even careful studies of specific circumstances will not yield foolproof estimates of the necessary values. Indeed, a noteworthy generalization suggested by the illustration is that like equilibrium models, simulations cannot by themselves predict the concrete effects of multifaceted policy changes. Novelty and complexity make Knightian uncertainty unavoidable and eclectic techniques and interpretive judgments necessary.

Concluding Comments

Milton Friedman took his distinction between "positive" economic and "normative" ethical questions from a source he identified as John Neville Keynes's "admirable book, *The Scope and Method of Political Economy*." But, while Keynes's 1890 book, like Friedman's later essay, highlighted the problems of confusing the positive and the normative, Keynes also distinguished the positive science of economics from "the system of rules for the attainment of a given end," which he referred to as the "art" of economics.

The art of systematic medicine and engineering has made great advances since the publication of Keynes's book. We can credit an important part of this progress to foundational advances in scientific knowledge, but engineering and medicine have also benefited enormously from efforts to develop technological tools. In economics, however, disciplinary effort has strongly favored systematic science over systematic art.

Alvin Roth's "Economist as Engineer" paper on the development of labor clearing houses that place doctors in their first jobs, auctions of the radio spectrum, and markets for electric power represents an illuminating exception.[57] Economists followed an "engineering approach," Roth writes, that combined game theory, computation and experimentation, and responsibility for details and complications. These efforts and subsequent programs to match students and schools and kidney donors and recipients have produced indisputably significant practical results.

The exceptions may have benefitted from unusual circumstances: game theory that provided an atypically comprehensive conceptual foundation; computational tools and rapid "lab" experiments that enabled the development of design details at a fraction of "field" RCT costs; interactions of users that, like the innards of computers and semiconductor plants, could be shielded from external disturbances; and economists like Roth and Vernon Smith, who, like the Manhattan project's physicists, had extraordinary talents for science, invention, and enterprise.

In an alternative view, techniques for computational experimentation now widely used in medical research have surged ahead. Several other techniques also now support the design of complex artifacts and procedures. Prominent economists, such as Hal Varian at Google, are using and improving the computational and other tools in private companies. But like medieval artisanal knowledge (developed before "open" engineering research), valuable advances made in private companies often remain confidential. Meanwhile, dedication to scientific propositions and methods limits the practical contribution of more "open" disciplinary economics. Valuing practical ends alongside Friedmanite science and tolerating eclectic technological means would give Roth's economist-engineers more scope to advance the common good.

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may reduce *InfoEfficiency* (because lenders now screen applications submitted by non-customers).

57 Ibid, Alvin Roth (2002) "Economist as Engineer."

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