Introduction: From “Economics *as* Engineering” to “Economics *and* Engineering”

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The Transformation of Economics into an Engineering Science: From Analogies to Interactions

In recent years, economists, who in the past had mostly insisted on their discipline’s strength as a rigorous social science, have turned to its larger role in transforming society. As early as 2002, Alvin Roth, the Stanford-educated economist who received the Nobel memorial prize in 2012, has claimed that members of his community should think of themselves as engineers rather than scientists. By this he meant that they should not be interested solely in the making of theoretical models but also in confronting these models with the complexities of real-life situations, which is what engineering is allegedly about. He pointed to the rise of the new subfield of market design, which he had helped develop, as characteristic of an engineer’s stance and provided several examples of engineering practices applied to economics: the design of labor clearinghouses—such as the entry-level labor market for American physicians—and that of the Federal Communications Commission spectrum auctions (Roth 2002).

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More recently, the development economist and MIT scholar Esther Duflo, another recent Nobel awardee, built on Roth's (2002) and Abhijit Banerjee's (2007: chap. 3) contributions and reiterated the need for economists to venture outside academe. But she went further and introduced, in addition to the engineer, a new character: that of the plumber. For her, while scientists attempt to seek epistemic truths using theoretical models and engineers design the machine through which these models can be translated into policy devices, plumbers are the ones who are responsible for making that machine work. For instance, while economic scientists have shown that school vouchers help improve the education level of a population, it is the role of economic engineers to design a voucher system and an incentive structure that helps encourage the use of vouchers. In their turn, economic plumbers are the ones who will work with the population in order to make sure that those vouchers will be addressed to those, situated in a particular environment, who need them the most (Duflo 2017).

For both Roth and Duflo, engineering is the practice of designing policy interventions that requires a certain degree of tinkering in the application of preexisting theoretical models in order to adapt them to real-life practicalities. For them, the engineering and scientific aspects of economics complement each other. By contrast, the macroeconomist Gregory Mankiw (2006: 29) identifies a tension between science and engineering, contrasting two depictions of economics: that of a scientific endeavor, according to which "economists formulate theories with mathematical precision, collect huge data sets on individual and aggregate behavior, and exploit the most sophisticated statistical techniques to reach empirical judgments that are free of bias and ideology (or so we like to think)," with that of engineering. After all, "God put macroeconomists on earth not to propose and test elegant theories but to solve practical problems." Mankiw uses this dichotomy as a foil for him to appraise the development of macroeconomics and to indict new classical macroeconomics as a science while praising the engineering stance of New Keynesian macroeconomics. For him, while the rational expectation theory and calibration techniques conceived by Robert Lucas, Edward Prescott, and their allies exhibit the rigor of science, New Keynesian economics, while less accurate from a scientific standpoint, has the advantage of being easily amenable to policymaking. To gain relevance for policy purposes, therefore, economics as engineering needs to momentarily stray from scientific accuracy.

While Roth, Duflo, and Mankiw located the engineer's attitude at the policymaking level, other economists stationed it at the theoretical model building. Speaking of his "neoclassical growth model," the macroeconomist Robert Solow told our colleague Verena Halsmayer (2014: 241) that it could be considered engineering "in the design sense." What Solow meant was that this model could be conceived as a sort of prototype for more complex measuring devices, subject to simple manipulation, which enables "the modeler-economist to enter a new, unexplored, world" (241). In that case, the engineering aspect is enhanced by the fact that Solow's own institution, MIT, is an engineering school and that the model was partly intended as a pedagogical device for the students, most of whom were future engineers.[1] Solow's model is not the only macroeconomic device that was built using engineering techniques. In fact, as Esther-Mirjam Sent (1997) has shown, all branches of postwar macroeconomics have been using them. New classical macroeconomics emerged from the appropriation by Lucas et al. of Richard Bellman's dynamic programming and Kálmán filtering (Judy Klein and Marcel Boumans, in this volume, develop and qualify the history of this appropriation). These economists may well believe that they helped their field become a *science*, yet they did so using *engineering* mathematics.

Not only practitioners but also historians of the discipline have addressed this engineering characterization of economics. Writing for a history of social science audience and building on the *HOPE* volume she had coedited with Malcolm Rutherford in 1998, Mary Morgan provided an account of the development of twentieth-century economics as that of an engineering science, arguing that it implied two things: first, that economics "came to rely on a certain precision of representation of the economic world, along with techniques of quantitative investigation and exact analysis that were alien to the experience of nineteenth-century of economics"; second, that it is "best characterized as a science of applications and implies a technical art, one that relies on tacit knowledge and decidedly human input" (Morgan 2003: 276).[2]

Michel Armatte (2010) expanded on Morgan's argument and wrote a book-length depiction of the transformation of political economy into an

1. Economics was a compulsory subject for all MIT undergraduates, even those who were not enrolled in a social science program.

2. In fact, Morgan was not the first historian of economics to use the "economics as engineering" analogy. In his 1979 presidential address to the History of Economics Society, Craufurd Goodwin (1980: 619), then editor of this journal, wrote: "If economists do insist on taking models for the development of their subject from elsewhere rather than constructing new ones, a closer analogy than the physical sciences may be engineering. Much of what economists do is more comparable to the designing and fabricating of structures for social use than to the laboratory work of the physicist."

engineering science, covering several national experiences and various subfields—from econometrics to environmental economics. In his account, "economics as engineering" is characterized by the development of a unified body of doctrine (neoclassical economics), a new way of using evidence (quantitative and mathematical), the inclusion of economic theory into a socioeconomic environment (a new management of economic activities), and the rise of a new kind of economic expertise (in think tanks and other institutions).

While the economics as engineering analogy seems to work well as a backdrop to articulate a relatively cohesive narrative about the discipline's development, it also undermines some of the actual tensions that have existed between economics and engineering in that period. In the article mentioned above, Sent (1997: 277) summed it up by writing that "while economists attempted to develop scientific knowledge . . . engineers are practical people who are concerned with getting specific jobs done and who seek satisfactory solutions in the face of complexities and uncertainties. Engineers are known to use trial-and-error empiricisms and rule-of-thumb techniques that could not be generalized to a wide range of problems."

Most of these accounts of economics as engineering, whether written from an economist's or a historian's perspective, share a number of common traits: they point to the fact that the depiction of economics as a science leaves aside some important practical aspects involved in the application of economic knowledge to real-life situations; the necessity to have recourse to tinkering and trial-and-error procedures, both in modeling practices and in the use of these models for policy purposes; the characterization of economic issues as necessitating complex computational processes; and, more generally, the characterization of the economy as a machine. However, there is room for deeper scrutiny. For instance, while Roth characterizes the transformation of economics into an engineering science as a relatively recent—post-1980s—feature of the discipline, Morgan and Armatte locate that transformation at the turn of the twentieth century. Also, while Roth and Mankiw circumscribe the engineering attitude to certain aspects of the discipline, that of policymaking and market design, others consider the analogy as a more general take on economics. More important, what is more often left aside is the actual interaction between economists and engineers. How did the latter react to economists' appropriation of their tools, and were they themselves interested in taking into account economic knowledge as part of their professional activities?[3] This points to the fact that economics *as* engineering, taken as an analogy, while insightful, may not be the best way to grasp or assess, from a historical standpoint, the presumed transformation of economics into an engineering science. To do this, we might turn instead to the history of economics *and* engineering: accounts of how these two types of knowledge—and the communities who produce them—have interacted in various institutional and national contexts.

Historicizing "Economics and Engineering": A *HOPE* Conference

The encounters between economics and engineering have been seldom documented in the existing historical literature, yet there are hints that these interactions may have been more significant than is currently acknowledged. Besides modern macroeconomics, one instantiation most familiar to historians of economics is the contribution by mid-nineteenth-century French engineers to the development of what would be later termed "microeconomics."[4] Robert Ekelund and Robert Hébert have argued on many occasions (most notably Ekelund and Hébert 1999) that Jules Dupuit, an engineer at the École des Ponts et Chaussées, should be considered the founder of neoclassical economics. However, because they look at past engineering from the perspective of modern economics, reading Dupuit's writings in search of evidence of antecedents to contemporary economic verities, the authors do not say much about the context in which the practices of French engineers occurred and their relation to the existing economists' community. On the other hand, when we move away from the economist's perspective and look at the literature in engineering, there is ample evidence that economic matters have constituted an object of interest for engineers since the end of the nineteenth century, mostly at the educational level—the "engineering economics" class that was compulsory in most US engineering programs (see Bix, this volume). After World War II, some engineers, like Arnold Tustin and A. W. Phillips, began to be interested in analyzing the economy as a mechanical system, inventing paper tools and physical devices to do so (see Klein, this volume). Some of

3. While pointing to these divergences between economists and engineers, Sent (1997) does not really attempt to put them in historical perspective.

4. Since that time, an important feature of the engineering curriculum in France is the strong background in mathematics. Not surprisingly, there has been a long tradition of studying the French engineers turned economists as originating a branch of mathematical economics. For a panorama of this literature, see Mosca 1998.

these attempts have been addressed in the existing literature (see, for instance, Morgan 2012 on the Phillips machine), but, on the whole, not much is known about the extent to which they actually participated in the transformation of economics or the reasons they failed to do so.

There also exist contributions standing outside disciplinary history that can be interpreted as implicit accounts of the interaction between engineering and economics (among other social sciences). Guy Alchon's (1985) history of planning in the 1920s depicts how social scientists collaborated with business managers in the creation of an American branch of planning, which the author labels "technocratic progressivism" (see also Layton 1986). The thought collective he describes associates institutionalist economists like Wesley Mitchell and Taylorites like the engineer Morris L. Cooke, who would later head the Rural Electrification Administration under President Franklin D. Roosevelt's legislature. Likewise, Erickson et al. (2013) told the story of how the Cold War transformed rationality, first seen as a human faculty associated with the enlightenment to its modern algorithmic, formal, and mechanistic version. Their narrative situates that change at the crossroads between engineering, operations research, economics, management, psychology, and the political sciences. In a quite similar vein, William Thomas's (2015) account of the sciences of policy in Britain and the United States during the twentieth century tells the story of how the nascent disciplines of operations research and management science—both neighboring to economics in some way—were grounded in military planning and engineering practices. All those contributions evoke economics knowledge to some extent, but because the economics discipline is not at the center of their narrative, not much is said about disciplinary exchanges between engineering and economics and how the latter has been transformed in the process.

Finally, several works in the history of engineering have sought to portray American engineers' conflicted relation to techno-capitalism over the past century. David Noble (1977) depicts their transformation into business managers during the first decades of the twentieth century, pointing to their role in the rise and defense of corporate capitalism. On the other hand, Matthew Wisnioski's (2012) study of engineering in the 1960s analyzes the debates among engineers during a period where technology ceased to be seen as an engine of liberation and progress. In response to this challenge, engineers became "socio-technologists" who would help society adjust to technological change. These stories do not specifically address economics as a discipline, yet they deal with the engineers' various visions of the economic system and their take on subjects such as growth and sustainability.

Although fragmentary, the preceding elements were enough for us to think that a more systematic investigation into the economics-engineering nexus would constitute a useful addition to the history of both disciplines. Under the patronage of the Center for the History of Political Economy and Duke University Press, we invited an eclectic group of historians of economics, historians of science, and engineering studies scholars to write papers on this topic. The resulting conference was held April 5–6, 2019, in the Breedlove Conference Room of the Perkins Library at Duke University. The present volume collects most of the papers that were presented there, with a foreword by the engineering scholar David Blockley and closing comments by the researcher responsible for drawing our interest in this topic in the first place, Mary Morgan.

Identifying the Economics-Engineering Nexus: The Historiographical Challenge

We may not need to properly define "economics" and "engineering" in order to retrace the history of their relation in the twentieth century. Yet, because we need to start somewhere, we must at least identify the sites where economics and engineering knowledge are produced and the communities that produce them. Traditionally, historians of economics have studied the sort of economics that has been produced within academe and whose output is mostly found in treatises or scientific articles—but the practice turn has challenged this and opened up what we understand by economics (see Boumans and Duarte 2019). The question of whether economics taken in that sense is a unified field is subject to debate (see, for instance, Davis 2019), but at least when considered from an academic perspective, it is one discipline, and a relatively structured one—with journal rankings, *JEL* codes, and so on.

On the other hand, while there certainly exists engineering knowledge produced within academe, in engineering schools and departments, it is just a small part of what engineering is about. Blockley (2010) observes that engineering includes many subdisciplines, noting that in the UK alone there are more than thirty different professional institutions that qualify engineers. In his foreword to this volume, he seeks less to define engineering than to characterize it in opposition to science: whereas science is about "knowing," engineering is about "doing" things, that is designing and/or building a device—not necessarily a physical one—in order to satisfy human needs, those of a client, for instance. But while in the traditional conception of science, knowledge is created at an abstract level and then "applied" to solve practical problems, in engineering knowledge creation occurs as the by-product of practice itself (see also Vincenti 1990).[5] This horizontal character of engineering, as opposed to the more vertical nature of applied science, must be taken into account when we analyze knowledge transfer from engineering to economics. To do this, we must first ask ourselves what sort of engineering we are talking about—mechanical engineering, civil engineering, chemical engineering, electrical engineering, systems engineering—and, second, look outside academe. For instance, when we analyze the use of "engineering mathematics" in modern macroeconomics, we need to take into account that engineering mathematics itself has a history and that it may have evolved in accordance with the set of practical issues in which it was grounded. Borrowing one's mathematics from control engineering or from information engineering will therefore produce different sorts of macroeconomic knowledge (see Boumans, this volume).

Reciprocally, the more we study the relation between economics and engineering the more we realize that our traditional vision of economics as, first and foremost, an academic discipline might itself be unsatisfying. Admittedly, economists mostly identify themselves as academics. In the United States, even economists who act as experts for governments, businesses, and other sorts of nonacademic institutions draw their legitimacy for doing so from their success in a highly competitive academic environment (Fourcade 2009). The so-called applied turn in economics did not really compromise the discipline's academic anchorage. The typical applied economist may occasionally venture outside the university, but doing so is not a necessary condition to define one as an applied economist because most of her activities (the analysis of natural and controlled experiments and the building of databases, for instance) take place in the confines of the research center (Backhouse and Cherrier 2017).

However, when we move to the study of economics and engineering, we come up with a reversed situation. While there are occasional instances

5. The notion of applied science has been a controversial one among historians of technology and on characterizing engineering as such (see Alexander 2012). Besides, the reasoning style and the knowledge engineers produce possess elements that cannot be reduced to verbal descriptions and, thus, depend on a mental process that is visual and nonverbal, according to Eugene Ferguson (1992).

when economists have absorbed engineering knowledge without having to do fieldwork, most of the engineering-economics nexus is located outside academe, and, at times, it does not even involve the sort of professionals we commonly identify as "economists." In other terms, the history of that nexus cannot be fully grasped without having a fairly extensive view of what economics is. Therefore, it is no wonder that many contributions in this volume do not deal with academic economics, or when they do so, they examine their practices in nonacademic settings. For instance, rather than studying "price theory," Daniel Breslau's and Guillaume Yon's respective chapters deal with "pricing," a practice that relates only partly to theory, although it quite unintentionally ended up producing knowledge that the economics profession has come to identify as part of its own canon (the Ramsey-Boiteux pricing, for instance).

Seen from the perspective of engineering history rather than the history of economics, there are two main reasons why historicizing the economics-engineering nexus is particularly challenging. The first is that engineering has evolved to display "extreme diversity of . . . jobs and realizations" that has clear national traits, as the engineering historian Antoine Picon (2004: 422) argued:

> Engineering looks more like a continent marked by striking contrasts than like a unified field. On this continent, no self-evident link seems to exist between the organization of the profession and the various activities engineers are involved in. In this context, it may be tempting either to define the engineer through his social identity and aspirations or to limit oneself to a relatively narrow domain of technological expertise.

The second reason is that engineers have attempted, since the Renaissance, to ground their practice on science and at the same time to distance themselves from "down-to-earth practitioners" (Picon 2004: 429), which implies that there is "some kind of intermediate know-how" between "the formalized knowledge that can be traced through courses and treatises, and the everyday decisions made by engineers" (424). As a consequence, Picon argues, the temptation is "to define the engineers through a certain kind of rational argumentation, either in design or in decision-making" (429).

While this could sound like music to the ears of economists, the historically contingent notion of rationality and of efficiency in engineering has sharp contrasts to those in economics that came with the widespread acceptance of Lionel Robbins's definition of economics.[6] Rationality in

6. Roger Backhouse and Steve Medema (2009) discuss the acceptance of Robbins's definition.

engineering "appears primarily as a guideline for action," revealing itself "primarily through the concrete practice of design, technological development and decision-making rather than in purely discursive structures" (Picon 2004: 429).[7] Picon then argues that "contrary to a long tradition in the social sciences, when confronted with science and above all technology, rational behavior cannot be separated from the objectives it aims at" (429–30), to conclude:

> This constant interaction means that rationality is not synonymous with a crystal-clear attitude consisting in the determination of the most appropriate means towards an end, whatever it is. In other words, rationality cannot be reduced to a sort of calculation. Ends and means do not follow similar paths. They are often somewhat contradictory. Their interaction is synonymous with perturbations that transforms rationality into something more muddy, so to say, than what one might expect a priori.
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> Another reason for this muddy nature lies in the fact that the engineer's rationality is not a pure individual conduct. It emerges in a context of interaction with other partners. Beside the other engineers, it has to take into account the existence of entrepreneurs and workers, even if it tries to set its own agenda. Rather than the result of a solitary exercise of the mind, rationality is the product of interaction, communication, and conflict. (430)

Both Picon (2004) and Blockley (this volume) call attention to the fact that efficiency, or fitness for purpose, means to have a good representation of what matters in the physical world (given that engineers typically see themselves as mediators between nature and man). So both efficiency and rationality are central concerns to engineering and to economics, but they became understood very differently in those areas. Paying attention to the actual interactions of engineering and economics requires, therefore, handling historiographical challenges that are not minor.

The Economics-Engineering Nexus Delivered

As its title suggests, the structure of this volume is tripartite. The contributions focus on the relation between economists and engineers within specific institutions, or on the way tools traveled from one area to the other, or

7. Picon (2004: 429) highlights that "rationality is not to be confused with logic at large. Contrary to logic, rationality is permeated by all sorts of historically determined factors like the representations of nature and man that prevail in a given society."

on how the engineering-economics relation operated in specific national cultures. Of course, these three aspects are necessarily interrelated, and several contributions ended up addressing them together.

Our volume, accordingly, starts, in part 1, with three chapters on interactions between economics and engineering knowledge in specific types of institutions. The set of institutions covered in Amy Bix's contribution is the American engineering school in the first half of the twentieth century. Showing that there is more to economics education intended for future engineers than Paul Samuelson's *Economics*, she analyzes how economic concerns were present in the engineering profession since the late nineteenth century, focusing especially on the attempt by the Society for the Promotion of Engineering Education to counter the widespread claim that engineers were deemed responsible for "technological unemployment" during the Great Depression. It is in that context that engineering educators developed their own version of economics knowledge and spread it through textbooks and courses, coming up with the subfield of "engineering economics."

While dealing with the same period of time, Thomas Stapleford's chapter explores economics and engineering knowledge developed not in academe but in private businesses. Depicting Malcolm Rorty's work for American Telephone & Telegraph Company, he argues that some of the distinct features of telephone engineering created opportunities for the interaction between economists and engineers, especially when it came to choosing the optimal amount of investment to respond to the demand. Trained as an electrical and mechanical engineer, Rorty helped develop market forecasting techniques and wrote about economics on the occasion of debates over the public ownership of utilities. Focusing on Rorty is interesting also because he, unbeknownst to most historians of economics, was one of the founders of the National Bureau of Economic Research with Wesley Mitchell. And yet, Rorty was only one engineer among a handful whose work for telephone companies contributed to the development of operations research and management science during World War II.

The last chapter in part 1, by Béatrice Cherrier and Aurélien Saïdi, is also the only one in this volume that deals with a particular place, Stanford University. Home of many self-professed "economic engineers" like Roth, David Kreps, Paul Milgrom, and Robert Wilson, Stanford has a long history of cross-fertilization between economics and engineering tools, merging economic modeling with statistics, optimal control, and game theory. None of those research programs, however, are specific to

Stanford. What is specific is how they were combined and infused with an entrepreneurial spirit later exhibited by Roth and the like. However, it was never a straightforward story, especially as economics was not considered an important force at Stanford until relatively recently and was scattered through many different and at times competing departments and schools there: the economics department and, most important for our purposes, the engineering department and the Graduate School of Business.

The second part of the volume deals with tool transfers. Building on many years of historical work on the military's influence on the mathematical social sciences, Judy Klein depicts the "shotgun weddings" between control engineering and applied mathematics that produced techniques eventually used in modern macroeconomics. In some ways, her narrative starts where Stapleford's left off, depicting the association between the engineering of long-distance telecommunication and that of regulators such as thermostats in the production of servomechanisms to control weapons during World War II. The new technologies, using negative feedback loops to enhance a system's stability, were soon extended to human areas such as economics. Both critics and defenders of state intervention to stabilize the economy shaped their discourse using concepts taken from feedback-loop engineering. By the time economists joined, though, a second shotgun wedding had occurred, one between optimization theory and the theory of stochastic processes, which would most notably nurture rational expectations theory in macroeconomics. This is where Marcel Boumans's chapter picks up. His contribution focuses on the macroeconomist Robert Lucas, who developed his models while at the Graduate School of Industrial Administration at the Carnegie Institute of Technology, in the wake of Charles Holt and Herbert Simon's research project on business forecasting and decision-making using engineering methods. Boumans argues that what permitted the rational expectations "revolution" was a shift from control to information engineering. This is not a neutral move: while control engineering depicted a world dominated by human-machine relationships, information engineering described one populated with information-processing robots.

The third chapter in part 2, by William Thomas, revisits a seemingly well-known episode in the history of economics, Kenneth Arrow's 1963 paper on the economics of medical care. While that article, which is considered a staple of information and uncertainty theory, is generally depicted as emanating from theoretical concerns over efficiency and rationality, Thomas connects Arrow's contribution to his research at RAND on military R&D.

There, Arrow developed the view that sequential information gathering could help reduce uncertainty. That work was qualitative and descriptive, emphasizing the tentative and approximate nature of decision-making. This descriptive character also pervaded Arrow's work on health economics. Therefore, Thomas argues that Arrow's place in the history of economic theory should not just be seen through the prism of his pushing for a more formalistic economic theory, as this would undermine the heterogeneous character of his methodology.

The fourth and last chapter on tool transfers, by Chung-Tang Cheng, explored another allegedly engineering-induced economic technique: microanalytic simulation (microsimulation), invented by Guy Orcutt. Cheng argues that Orcutt's approach was influenced by his engineering and physics backgrounds, and describes it as an alternative to the Cowles Commission econometric models. Microsimulation used the engineering of feedback loops, creating a model in which knowledge is derived not only from the study of aggregate data but from analyzing how components in an economic system work with one another and react to external changes. Used as a technique to simulate welfare policies, it became a tool to reengineer society.

The final part of our volume offers three chapters placing the engineering-economics nexus in specific professional practices and/or national contexts. Daniel Breslau's contribution deals with electricity pricing in the United States, depicting the efforts of a group of researchers—electrical engineers and economists—led by the control theorist Fred Schweppe to build an efficient marketplace for wholesale electricity. This followed the demise of the regulated load-following system, in which it was taken for granted that the dispatch of power—and therefore prices—should adjust to the changing demand. Schweppe came up with a new pricing method, called "locational marginal pricing," in which at each location prices are equal to the marginal cost of serving one additional unit of electricity. While this seems to match neoclassical price theory in a perfectly competitive market, Breslau argues that the Schweppe team reached that conclusion not by thinking in terms of deregulated, free markets but by introducing price signals and consumer participation into a self-correcting control scheme. Therefore, he presents a case study of market design where the designers were not the typical Roth-like economists but actual engineers.

The second contribution in this part, by Guillaume Yon, also deals with electricity pricing but in a different context: France in the immediate postwar period. The author presents electricity pricing at the crossroads between engineering, economics, and French politics. Focusing on Marcel Boiteux's work as a civil servant for Electricité de France, the state monopoly, from the late 1940s onward, it presents the development of long-term marginal cost pricing as a calculative technique that did not emanate from economic theory but from an equipment issue. Like in the United States at the same period, the pricing of electricity rested on assumptions about the growth in the load. But in postwar France growth was politically, not technologically induced, as it was a rule devised by the Commissariat général au Plan, the French planning agency, that the production of electricity should double every ten years. In addition to solving this equipment issue, long-term marginal cost pricing had two other roles in the economy: that of providing instructions to the users of electricity so that they would act according to the plan and that of constituting a social contract with the population, in which the burden of large-scale investment would be fairly distributed among citizens.

The final paper of part 3 explores the economics-engineering nexus in Soviet Russia during the post-Stalin era. Ivan Boldyrev studies the work of a group of engineers led by the control engineer Mark Aizerman at the Institute of Control Sciences in Moscow, who ended up developing knowledge in choice theory that, outside Russia, would be considered part of economics. Moving freely from one area to another is what permitted Aizerman and his team to be in contact with "bourgeois" economists in Western countries and develop knowledge that would have been otherwise considered subversive to the authorities.

Finally, Mary Morgan offers some concluding remarks. Reassessing her initial thesis that economics has transformed into an engineering science during the twentieth century, she now distinguishes between two engineering modes: the engineering design mode and the tool-based engineering mode of problem solving. Drawing on this distinction, she then comments on the articles in this volume.

Building a New Metanarrative or Revisiting Old Ones?

It is not for us to judge whether these contributions, taken together, participate in the making of a new metanarrative in the history of economics.[8] On

8. One of the editors has argued (Giraud 2019) that metanarratives mostly belong to the past of the history of economics discipline and that the best we can do is to qualify and elaborate on already existing ones. Nonetheless, Roy Weintraub (2014: 4) revisited the "narrative approaches to telling the story of how economics changed in the postwar period" to then launch a new one that is important for understanding the rise of MIT economics.

the other hand, it is rather clear that they show that the economists' own metanarrative that their discipline has transformed into an engineering science in the second half the twentieth century cannot be accepted without a few qualifications. Indeed, most of the chapters can be read as evidence that while there were many interactions between economics and engineering knowledge, these exchanges have not always changed the scope and culture of each discipline. In substance, economists and engineers still retain their respective visions of technology and markets. At the risk of oversimplifying, we can say that whereas most engineers consider prices as either parameters or solutions to a problem essentially driven by technological characteristics, most economists see prices as conveying epistemic truths and the markets where they are determined as truth-generating engines.

Likewise, a word like *efficiency*, while used in both disciplines, will take a specific meaning in each of them. For engineers, efficiency is mostly a technical property, whereas for economists it is related to a certain allocation of resources. Of course, there are many ways in which economists and engineers can interact and make use of these concepts to solve practical issues, but it is unlikely they will leave each other with a better mutual understanding of such issues. The same could be said about those disciplines' respective professional attitudes and values. While economists are interested in solving practical economic and social issues, their career advancement is still based on scientific merits, as attested by publications in leading journals, and their sense of accountability regarding the economic and social consequences of the devices they help build is still limited. In other terms, economists' contacts with engineering did not prevent them from going on acting mostly as (applied) scientists.

Whether or not they may offer a new metanarrative, the chapters in this volume at least not only allow for a reconsideration of some of the main existing ones concerning the transformation of economics in the twentieth century but also invite engineering historians to better understand what Picon (2004: 421) presented as a still open-ended issue: what are the relations between engineering history and social history, or "what can we learn through engineering evolution that concerns society and culture at large?" For the side of economics, while the histories of the field's mathematization and more generally of its transformation into a more technical discipline have been mostly considered through the prism of theory (e.g., Weintraub 2002), the story of economics' relation with engineering reminds us that the technical turn also arose from the treatment of practical issues—Thomas's reconstruction of the engineering roots of Arrow's uncertainty and information theory provides compelling evidence of this, and so does Yon's depiction of Boiteux's long-term marginal cost.

Similarly, looking at the involvement of economics with World War II and Cold War military funding not from the viewpoint of its association with "big science" but through the prism of its interacting with engineering offers a fresher look. Whereas the military-industrial complex story is most often interpreted from the perspective of economists as an opportunity to assuage their science envy, Klein's chapter describes how some of these interactions came through the initiative of the engineers, who identified similarities between economics and problems in control engineering they had been used to deal with while participating in the war effort. Additionally, looking through the economics-engineering nexus helps us better understand how Samuelson's famous textbook, *Economics*, which developed a streamlined version of Keynesianism in order to make it fit for future engineers at MIT, should take into account Bix's study of the engineer's side of the story. Finally, looking at the engineering-economics nexus in certain national traditions helps qualify the simple history of the internationalization of economic knowledge. Being an engineer or an economist in France or in the USSR implies a social function that differs from that of US engineers and economists. While exhibiting a neutral and universal character, the knowledge that these people produce is most often embedded in their respective countries' politics.

Like most *HOPE* conference and annual volumes, this one does not seek completion. Instead, our role is to encourage further work. Therefore we hope that the reader will find herself sufficiently stimulated to want to expand the research to other topics and periods of time. One aspect that this volume did not cover and that may be of interest to both historians of economics and STS scholars is the competing views of engineers and economists about technology and, even most important, the environment. More generally, we also hope that this volume will encourage historians of both economics and engineering to move further away from disciplinary history and start considering the extent to which what they perceive as knowledge in their respective fields is in fact jointly produced.

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