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How academic opinion leaders shape scientific ideas: an acknowledgment analysis

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Abstract
In this paper, we examine how a research institution's social structure and the presence of academic opinion leaders shaped the early adoption of a scientific innovation. Our case considers the early engagement of mathematical economists at the Cowles Commission with John von Neumann and Oskar Morgenstern's *Theory of Games and Economic Behavior*. We argue that scholars with administrative leadership functions who were not only scientifically but also organizationally central—in our case Jacob Marschak, the director of research at Cowles—played a crucial role in promoting the early adoption of the *Theory of Games*. We support our argument with a scientometric analysis of all acknowledgments made in 488 papers published from 1944 to 1955 in the two main research paper series at the Cowles Commission. We apply blockmodeling techniques to the acknowledgments network to reconstruct the formal and informal social structure at Cowles at the time. Our case study emphasizes the importance of formal and informal social structures and the research agendas of academic opinion leaders to explain the early engagement with and adoption of innovative scientific ideas. Studies of the early adoption of scientific theories can benefit from complementary perspectives on the role of academic opinion leaders and scientists in explaining theory adoption.

Keywords Acknowledgments analysis · Blockmodeling · Diffusion of scientific theories · History of rational choice theories · History of economics · Academic opinion leaders

Introduction

The history of ideas in science is a history of successes and failures. Philosophers and historians of science have shown that the reasons why some ideas are more successful than others are manifold. Sociologists and historians of science agree that factors responsible for the success of scientific theories stem partly from the social, institutional, cultural, and

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political contexts in which knowledge production takes place. Yet, successes and failures are often assumed to be directly or indirectly related chiefly to the activities and practices undertaken by the scientists and less so to those by administrative staff. This paper complements the common perspective on the role of scientists as primary promoters of scientific ideas. Specifically, we consider the role of administrators and organizational leaders as academic opinion leaders in promoting scientific innovation. We argue that academic opinion leaders can play crucial roles in shaping research agendas and fostering early engagement with novel scientific ideas. Our case study considers the role of academic opinion leaders at the Cowles Commission for Research in Economics between 1944 and 1955 in promoting rational choice theories. We support our argument with a scientometric analysis and show that such leaders played a key role in enabling the adoption of rational choice theories not only as scientists but also in their institutional roles.

The pioneers of rational choice theories were John von Neumann and Oskar Morgenstern. Their book, the *Theory of Games and Economic Behavior* (hereafter *TGEB*) was first published in 1944 and laid the ground for game theory and expected utility theory. Von Neumann and Morgenstern (1944) provided a mathematically rigorous formulation of rational decision-making by introducing the minimax criterion as a rule of behavior in situations of strategic uncertainty. The minimax rule advises rational agents to minimize the maximum loss that they may suffer as an effect of the other player's behavior: of an outcome.[1] The second edition of TGEB, published in 1947, also provided an axiomatic formulation of the principle of expected utility (von Neumann & Morgenstern [1944], 1947). This principle holds that the rational choice in risky situations is that which maximizes an agent's expected utility. Ultimately, both accounts of rational decision-making spread widely across the social and behavioral sciences. However, expected utility theory was adopted among economists much faster than game theory.

In this paper, we examine the conditions under which both accounts of rational decision-making were first adopted to explain the differences between their adoption paths in economics. Von Neumann and Morgenstern's *TGEB* had a powerful impact at the Cowles Commission for Research in Economics. In the 1940s, Cowles was a small but important research institute. It was the stronghold of mathematical economics during the 1940s and 1950s and presented the most important institutional context in which economists applied new mathematical methods to economic problems (Weintraub, 2002). Between the publication of *TGEB* in 1944 and Cowles's move from Chicago to Yale University in 1955, the commission was directed by Jacob Marschak (1943–1948) and Tjalling Koopmans (1948–1955). Housed in the social sciences building of the University of Chicago, it was known for the sophistication of the mathematics and statistics of its research staff.

We address the question of what enabled the early engagement with *TGEB* and the adoption of the expected utility principle and game theory at Cowles. Answering this question is interesting not only because it helps us explain why Cowles scholars initially prioritized the expected utility principle over game theory. It also reveals something more general about the conditions in which innovative ideas are rapidly and widely adopted in science. In the 1940s and 1950s, innovative research abounded in the social sciences (e.g., Isaac, 2010). While there was a natural connection between game theory and the axiomatic formulation of the expected utility principle and economics, these were only two of

[1] Note that von Neumann's (1928) primary contribution was not to offer a rule for advice on rational decision-making but the proof of the minimax theorem (about the early history of game theory, see Dimand & Dimand, 1992; Giocoli, 2003; Leonard, 2010; Mirowski, 2002).

several new methodological tools emerging alongside other approaches, such as cybernetics, for instance (ibid.). More importantly, while both accounts of rationality were related to economics, there were *prima facie* no apparent reasons why economists should prefer the expected utility principle over game theory in those early years. The strategic analysis underlying game theory was a whole new approach to the discipline. And while the problem of decision under uncertainty was well-known in economics the latest since the early twentieth century, economists had never really dealt with it axiomatically. So, at least on the mathematical level, both approaches were technically demanding for the average economist at the time yet equally accessible for mathematically skilled economists at the Cowles Commission.

The early engagement with *TGEB* at Cowles was strongly shaped by Jacob Marschak. This paper shows how Marschak fostered this engagement not only as a key contributor to the axiomatization of the expected utility principle (see, e.g., Moscati, 2019, ch. 10) but also as Cowles's director. His influence in this administrative role contrasts with that of his colleagues, who promoted expected utility theory as scientists. Marschak's role in this process differed structurally from other early adopters who actively engaged in the debate about its usefulness for economics.[2] Both a scientist and an administrative leader, his own research interests and his vision of mathematical economics strongly influenced the research agenda at Cowles. In recognition of his dual function as researcher and administrative leader, we refer to Marschak as an academic opinion leader, a role that is often neglected when we study the early adoption of scientific ideas.

We support our argument with a scientometric analysis, conducting a blockmodel analysis of acknowledgments relations. Increasingly, acknowledgments are recognized as empirical traces of informal social relations that contribute to scientific knowledge production (e.g., Oettl, 2012). However, not many studies are undertaken that use acknowledgment data generally but also in the history of science (for exceptions, see Baccini & Petrovich, 2022; Petrovich, 2021, 2022). In this respect, our paper makes a novel methodological contribution in that it showcases how such acknowledgments analyses can be fruitfully analyzed and interpreted. We construct and analyze an acknowledgment network generated from academic publications and working papers produced at Cowles in the period between 1944 when *TGEB* was published and 1955 when the Cowles Commission was moved to New Haven. We analyze this network using blockmodeling techniques to reconstruct the informal role structure at Cowles. Our results indicate that the different roles that actors occupied help explain the early engagement with *TGEB* and the adoption of rational choice theories at Cowles. These results confirm that there is more to establishing a scientific idea than ensuring that it holds up to empirical scrutiny. Our findings highlight the importance of the social structure of an organization and its leaders in fostering early engagement with (and the adoption of) novel scientific ideas. Although existing historical accounts of the early adoption of expected utility theory have discussed Marschak's importance in this process (e.g., Moscati 2019), it is nontrivial to systematically and quantitatively show that this was indeed the case and how exactly he influenced adoption.

[2] See Moscati (2019, 2016) for a detailed history of the scientific debate and how it shaped the process of adopting the expected utility principle in economics.

The reception of the *Theory of Games and Economic Behavior* at Cowles

The following considerations treat the diffusion of game theory as the diffusion of an innovative scientific theory that proceeds in a threefold process (Herfeld & Doehne, 2019). First, after a scientific innovation is introduced, an initial phase of elaboration explores whether and how the idea can be applied in different academic fields. If considered useful for a particular field, it must secondly be translated into the theoretical language of that field before it can thirdly be adopted and applied to field-specific questions. This suggests a role typology of four different types of scientific contributions that undertake these steps: (1) the innovator contribution itself, (2) elaborators, (3) translators, and (4) specialist contributions. Starting from this role typology, the question arises when and why scientists will elaborate an innovative theory in the first place. The strategy of elaborating on someone else's innovative idea is *prima facie* not obvious for a scholar. It is risky because there is uncertainty about whether others will pick up on ane elaborated idea at all. Elaboration may establish an entry point for the scientific innovation to spread into a specific field, but it may also result in a dead end.

In the case of *TGEB*, persuading economists to elaborate on von Neumann and Morgenstern's contributions was not trivial, despite the book being received with enthusiasm (Dimand & Dimand, 1995, p. 158). Most of the reviews published until 1950 appeared in economics journals, and most of these reviews acknowledged *TGEB* as a groundbreaking achievement. Yet, the reviewers emphasized the technical achievements of the book more than its game-theoretic results, which received less than expected attention by comparison. Reviews by Kaysen (1946), Marschak (1946), and Stone (1948) praised the work for its novel mathematical apparatus for analyzing strategic interaction and for the generality and wide range of applicability of the concepts developed therein. Furthermore, economists saw the potential of the mathematical tools it contained to axiomatically ground, rather than merely postulate, their theory of human decision-making as part of their theory of markets (e.g., Copeland, 1945; Hurwicz, 1945). These contributions generated excitement about introducing new mathematical and logical tools to economics. Most reviewers agreed that *TGEB* had bestowed a wealth of novel analytical tools upon the economics profession.

At the same time, it was precisely this novelty that hindered the rapid adoption of these newly developed mathematical tools. Although von Neumann and Morgenstern introduced these techniques from the ground up, *TGEB* was mathematically challenging for economists while its practical value was not immediately apparent. Before 1944, traditional calculus had been predominantly used in economics, and most economists were not familiar with mathematical logic, topology, axiomatic set theory, the theory of relations, and fixed-point techniques. Such techniques were not part of economists' formal education, which presented a substantial barrier for them to actively engage with *TGEB* (Dimand & Dimand, 1995). Consequently, the adoption of game theory and the tools contained in *TGEB* proceeded rather slowly and only really picked up pace in the 1970s (Dimand, 2000; Weintraub, 2002).

At Cowles, the adoption process both resembled and differed from that in the economics profession at large. In their prominently published reviews, Cowles affiliates Herbert Simon, Leonid Hurwicz, Jacob Marschak, and Abraham Wald praised the book as a groundbreaking achievement in the foundations and development of economic theory (e.g., Hurwicz, 1945; Marschak, 1946). Together with Kenneth Arrow, Leonard Savage, William H. Riker, Ward Edwards, Gerard Debreu, Harry Markowitz, and others, they formed a group of scholars who engaged seriously with *TGEB*.[3] However, despite recognizing the novelty of game theory, they did not initially engage with it extensively. It was only when Martin Shubik entered the commission in the 1960s that Cowles scholars made significant contributions to game theory (Dimand & Dimand, 1995, 550 ff., Giocoli, 2003). What they adopted under Marschak's directorship was the axiomatized principle of expected utility, not game theory (Dimand & Dimand, 1995, p. 551, Herfeld, 2018).

This early focus on the expected utility principle is surprising, given that all but the first chapter of *TGEB* are concerned with game theory. Furthermore, von Neumann and Morgenstern themselves considered game theory, not expected utility theory, as their main contribution. The axiomatization of expected utility had only been a by-product of the minimax criterion in the first edition of the book (Giocoli, 2006); von Neumann and Morgenstern had not even introduced the proof of utility until the second edition of *TGEB* was published in 1947 with an appendix containing it (see Dimand & Dimand, 1995, p. 551, Giocoli, 2003, 2006). Therefore, as Dimand and Dimand (1995, p. 550) put it: "At Cowles, if anywhere, game theory could be expected to be taken up by economists."

At least three factors are relevant to better understanding the early engagement with *TGEB* at Cowles and the initial prioritization of the axiomatized expected utility principle over game theory. First, *TGEB* generally caught the attention of Cowles scholars because Cowles as a research institution attracted the most mathematically inclined economists of the day. While researchers at the commission were somewhat isolated from the rest of the profession, this quickly changed under Marschak's directorship when its research focus shifted and Cowles established itself as a key research institution in the American economics profession. Prior to Marschak's directorship, the commission's main research focus had been on macro-econometric modeling. At the time, decision theory, modeling individual choice, and axiomatization were not major themes of its research agenda. Yet, its staff already consisted of a group of highly skilled mathematical statisticians, econometricians, and mathematical economists. Although this new theory of games was technically challenging, promising Cowles scholars such as Arrow, Debreu, Koopmans, and Hurwicz were thus not put off by mathematical work (Dimand & Dimand, 1995, p. 550). They were educated in mathematics, physics, or mathematical statistics and equipped with the proper tools to engage with TGEB.[4]

Second, the commission constituted a specific research context that was conducive to exploring new ideas. It was what historians have characterized as a hybrid institution; a research environment somewhere between a university and a social science laboratory (Düppe & Weintraub, 2014). It fostered the development of innovative ideas partly because of its institutional agenda and organizational structure. Scholars were working outside the usual administrative bounds of academia (Thomas, 2015) in a way that was nonhierarchical, collaborative, and firmly focused on shared methodological commitments. Close interaction within this small group was enabled by direct communication channels, continuous exposure to each other's research, and a strong and constructive feedback

[3] For *TGEB*, we identified 29 "elaborator" contributions (co-)authored by 22 individuals (Herfeld & Doehne, 2019). Their authors include Savage, Simon, Markowitz, Arrow, Edwards, Nash, Debreu, Fishburn, Ellsberg, Raiffa, Allais, and Shapley, among others.

[4] Examples of research that engaged with *TGEB* in the late 1940s and early 1950s include Arrow et al., (1950, pp. 250–272) on optimal inventory policy, Hurwicz (1951) on decision rules for choice under risk and uncertainty, Abraham Wald (1950) and Leonard Savage (1954) on statistical decision-making and decision functions, and Rubin (1949) and Chernoff (1954) on rational selection of decision functions. Some scholars were working on axiomatics more generally, such as the mathematician Israel N. Herstein, who collaborated with the Princeton mathematician John Milnor (1953).

culture (Christ, 1994, p. 31, Erickson, 2010, Moscati, 2019). Scholars had the freedom to engage with new ideas without being constrained by the disciplinary conventions and bureaucratic procedures common in university settings. They regularly interacted and collaborated closely, sometimes even via co-authorship or within the same project (Herfeld, 2018). Mimeographed discussion papers were circulated and discussed in work-in-progress seminars and informal research staff meetings (Moscati, 2019, p. 169). Talks and seminars were attended by the whole staff. Such a research environment certainly contributed to the speedy circulation of and constructive engagement with new ideas.

Third, prioritizing the principle of expected utility at Cowles can be partly explained by the specific role that Jacob Marschak played in the years immediately after *TGEB's* publication. We label this role an "academic opinion leader" and propose that the presence of academic opinion leaders can significantly shape the adoption of new scientific ideas. We borrow the term "opinion leader" from the diffusion of innovation literature, where it characterizes persons providing information and advice about the innovation to other members of the community; opinion leadership signals "the degree to which an individual is able to influence other individuals' attitudes or overt behavior informally in a desired way with relative frequency" (Rogers, 2003, p. 27). This role is not a function of a person's formal position but has been earned and maintained by the individual's competence, social accessibility, and conformity to the community's norms. Academic opinion leaders have a unique and influential position in their community's communication structure in that they are at the center of interpersonal communication networks. As such, they "express the [social] system's [informal] structure" (Rogers, 2003, p. 27). In a scientific community, an academic opinion leader is a technically sophisticated scientist from whom others seek orientation, advice, feedback on their research, and discipline-specific information and who can thus shape these others' individuals' interests, careers, and research processes informally yet in a way that aligns with the agenda of a research institution. Academic opinion leadership goes beyond the narrow function of a scientist to develop or elaborate on theories.

These three factors also shaped the informal social structure of the Cowles Commission. Because knowledge is produced and elaborated upon within such a social structure, these factors contributed in different ways to the early engagement with *TGEB* at Cowles. In the following, we attempt to systematically reconstruct this informal social structure to elicit patterns in Cowles scholars' adoption behavior.

Method and dataset

To infer how the social structure at Cowles channeled engagement with *TGEB* and the adoption of one particular aspect of it, expected utility theory, we examined the publication output of Cowles scholars for evidence. We conducted a systematic analysis of the acknowledgments sections of all research and discussion papers that were published between 1944 and 1970 in either the *Cowles Foundation Discussion Paper Series* (*CDP*) or reprinted in the *Cowles Foundation Paper Series* (*CFP*). Both series contain papers that were written by research staff and visiting faculty during their affiliation with Cowles. In this period, a total of 1059 papers were published in these series (373 *CFP* and 686 *CDP*). We manually examined all papers for whether they reference *TGEB*, either by citing the text or by explicitly referencing von Neumann and Morgenstern's key contributions in the

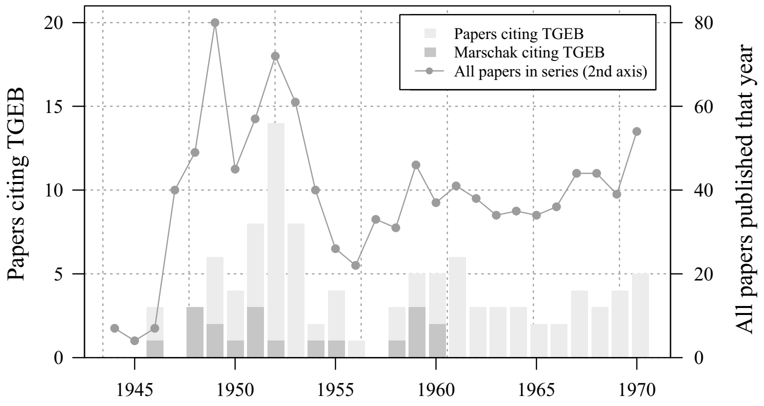

Fig. 1 Number of papers published each year, number of papers that cite *TGEB*, and number of papers by Marschak that cite *TGEB*

bibliography.[5] Because we study the early adoption period of *TGEB*, we did not consider references that only cited follow-up publications related to game theory or expected utility theory but did not reference *TGEB* directly. In this sense, our approach is conservative, as it narrows the analysis to von Neumann and Morgenstern's initial contribution.

We found that 101 of the 1059 papers published in our corpus between 1944 and 1970 referenced *TGEB*. Furthermore, engagement with *TGEB* at Cowles had an early high point in the early 1950s: 8 of 57 papers published in 1951, 14 of 74 papers published in 1952, and 8 of 61 papers published in 1953 referenced *TGEB*. The barplots presented in Figure 1 show the number of publications that referenced TGEB each year (with the number of papers written by Marschak highlighted by dark shading), as well as the total number of publications published each year (on the secondary axis).

Although Fig. 1 shows that Marschak authored more than half of the papers that referenced *TGEB* before 1950, we also see that the number of publications does not allow a clear-cut assessment of the importance of any one individual. As early as 1952, Marschak only authored one of 14 papers engaging with *TGEB*. Consequently, early engagement with *TGEB* was a collective enterprise with diverse individuals soliciting and receiving feedback on the texts and ideas they developed on the topic. We also see that after the initial wave of review articles following *TGEB's* publication and a year of no citations of *TGEB*, citations surged after 1947. This suggests that it was the axiomatized principle of expected utility contained only in the 1947 edition of *TGEB* that Cowles scholars referred to rather than game theory. A network analysis of acknowledgments made in the papers allows us to trace this process more clearly.

We reconstruct the social structure at Cowles by analyzing the acknowledgment sections of papers published in both series during the early engagement with *TGEB*. We focused the analysis on the Chicago period before the commission's move to New Haven, when James Tobin was appointed director (Hildreth [1986], 2012). During its Chicago years, the adoption of *TGEB* was still uncertain then, and its future path was not yet evident. We assume that most of the papers whose acknowledgments we analyze were discussed in small groups

[5] In line with citation norms for mathematical papers at the time, some papers did not explicitly cite *TGEB* but referred instead to its key concepts by name, such as the "von Neumann Morgenstern Utility Function," "vNM-utilities," etc. We took such direct references as sufficient indication of engagement with *TGEB*.

[2] The co-operation of Mr. Andrews was made possible by a grant of the Social Science Research Committee, the University of Chicago. Dickson H. Leavens, Cowles Commission, supplied painstaking editorial help, in addition to laying out computations and drawing diagrams. T. Koopmans, Cowles Commission, read and criticized large parts of the manuscript. Thanks are due to Abraham Wald, Columbia University, for unfailing interest and aid in questions of statistical method. Herman Rubin, Cowles Commission, provided several important proofs. Leonid Hurwicz, Cowles Commission, gave valuable suggestions.

Fig. 2 Example of an acknowledgment, taken from CFP No. 0005, "Random Simultaneous Equations and the Theory of Production", by Jacob Marschak and William H. Andrews, Jr. and published in *Econometrica* in 1944

and one-to-one interactions, work-in-progress seminars, conferences, and workshops held at Cowles. We expect this to be reflected in the acknowledgment sections of these papers, and indeed 162 of the 488 papers examined identify named individuals. Written by 53 (co) authors, these papers acknowledge 167 individuals in total.

Acknowledgments signal engagement with a paper by those acknowledged. They reveal informal relations that scholars maintain with their peers, based on topical overlap and research content. As research in the library and information science literature shows, we do not and cannot assume that acknowledgments *always* record all formal and informal interactions related to the paper in question (Cronin, 1995). However, they are certainly a good proxy by signaling sources of inspiration and input given in discussions, workshops, and other discursive settings. They indicate feedback received on a manuscript at any stage in the research process and on any level of analysis, be that on the theory or methods used, the data collected, the data collection procedure, or the analysis and interpretation of results. Yet, they differ from citations because they are not reducible to scientific content. Instead, they contain tacit information about the type of relations between scholars. They can signal an informal hierarchy between advice-givers and advice-receivers; the advice can be on research content but may go beyond that. They signal appreciation of patrons, sources of funding, and other kinds of institutional dependency relations. It is in this sense that analyzing acknowledgments capture an essential part of the social structure at Cowles.[6]

Figure 2 presents a representative acknowledgment, taken from an article that was co-authored by Jacob Marschak and William H. Andrews, Jr. and issued as Cowles Foundation Paper No. 5 in the *CFP* series. It illustrates ways in which acknowledgments express social relations between the authors and acknowledged parties.

The acknowledgment includes information on funding, recognizes the editorial contribution of one Dickson H. Leavens, and acknowledges scholars for criticism, substantive feedback on content and method, and contributions to proofs. It indicates that the parties it acknowledges influenced the final content of the paper. This pattern is representative of the acknowledgments that form the empirical basis of our analysis. In total, we identified four types of acknowledged parties: named individuals, institutions, anonymous reviewers, and unspecified workshop and seminar participants. For our analysis, we consider all acknowledgments of named individuals, irrespective of the nature of their contribution, their occupation, or their official affiliation status with Cowles. As will be shown, the network algorithms used to process the data, notably the blockmodeling analysis, reliably discerns specific individuals by their roles at Cowles. For example, we see that the blockmodel

[6] Note that acknowledgments norms and practices differ widely across disciplines (see e.g., Cronin et al., 1992, 1993), which is—however—a more general challenge to scientomentric analyses, such as citation-, co-citation-analyses, etc.

algorithm systematically clusters individuals who were acknowledged for editorial assistance but who did not themselves author papers into a different (more peripheral) group from those who authored papers that engaged with *TGEB*.

Analysis and findings

One way of interpreting acknowledgments is as signals of appreciation for scholars who are influential in a community. We distinguish between two kinds of influence: scientific and institutional. An acknowledged person is scientifically influential if they are a pioneering, productive, successful, and thereby inspiring researcher with expertise on a specific topic; and a person is institutionally influential if they occupy an important administrative position in the community or at a relevant research institution. Scientific and institutional influence can interact in important ways. For instance, an institutionally influential individual can also be scientifically influential and shape a research agenda at an institution by influencing the research of their peers. Acknowledgment relations indicate both kinds of influence, often at the same time.[7]

We use social network analysis to measure this double influence. From acknowledgments expressed in the 488 papers published from 1944 to 1955, we constructed an acknowledgments network that connects the authors of papers with the individuals they acknowledged. In formal notation, this network consists of a set of individuals, represented as vertices, V, and the acknowledgment relations between them, represented as edges, yielding a graph G (V, E). The vertex set consists of the 53 individuals who (co)authored one or more of the 162 papers that included acknowledgments and of 167 individuals who are acknowledged by these authors. As 33 individuals were both authors and acknowledged, the network contains 187 nodes in total. Thus, an acknowledgment relation is established each time an author acknowledges another person in one of their papers.

Coauthored papers that acknowledge more than one person establish acknowledgment relations between each author and every acknowledged individual, resulting in 528 acknowledgment relations in total.[8] Tie weights capture repeated acknowledgments. A tie of weight $e_{ij}=k$ is established by author i acknowledging individual j in one or more papers, with k being the number of papers authored by i in which j is acknowledged. For example, between 1944 and 1955, Jacob Marschak (co-)authored four papers that acknowledge Arrow, resulting in a tie of strength $k=4$ leading from Marschak to Arrow. Thus, the network is weighted and directed.

It is important to note that some information is still lost in this process of specifying edge weights. For example, consider a potential biasing effect of multi-authored papers on the resultant network. The decision not to fractionalize edge strengths by the number of coauthors creates the potential issue that observed network characteristics could be driven by outlier cases. Compare, for example, the case of a single author who has 10

[7] This is not to say that acknowledgments cannot additionally signal other relations, such as friendship or close collegial relations. However, we consider such cases to be the exception rather than the rule.

[8] Two CDP papers list unconventional authorships. The scanned print of CDP Ec2049 identifies as author "Martin Beckman (with the assistance of C. B. McGuire)"; CDP Ec2122 lists "Martin Beckman with the assistance of F. Bokolski". We treated McGuire and Bokolski as Beckman's co-authors. We note that the results presented below, particularly the group assignments via the blockmodeling analysis, are robust to treating McGuire and Bobkoski as acknowledged individuals instead.

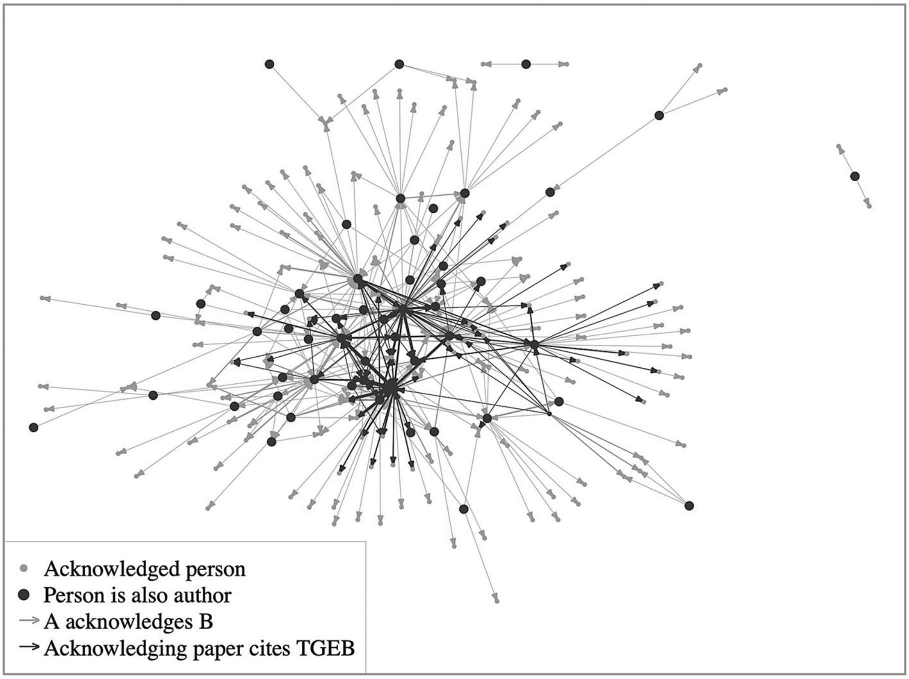

Fig. 3 The acknowledgment network representing persons and the acknowledgment relations expressed between them in research papers published at the Cowles Commission between 1944 and 1955

publications acknowledging one person each against the case of a single paper with three authors acknowledging 10 people. The 10 publications of the former create 10 ties, while the single paper of the latter creates $3 \times 10 = 30$ ties. For our purposes, this issue is mitigated by the fact that 86.5% of the papers in our sample were single-authored and only 1.4% had three or four coauthors. Moreover, an inspection of the data reveals that persons acknowledged in papers that acknowledge many persons are often peripheral to the acknowledgment network. For example, the most extreme outlier of our sample is *CFP 44*, entitled "Optimal Inventory Policy", presented by Arrow, Harris, and Marschak at the 1950 Logistics Conference of the RAND Corporation (Arrow et al., 1951). In it, the authors acknowledge Debreu, Simon, Newell, (Joyce) Friedman, Kruskal, and Tompkins, resulting in $3 \times 6 = 18$ acknowledgments. As Harris, Newell, Friedman, Kruskal, and Tompkins all remain peripheral to the series, 12 of the 18 acknowledgment relations that are established by *CFP 44* ultimately remain quite negligible for our analysis.

Figure 3 depicts the acknowledgments network. The width of ties identifies how often an author has acknowledged the recipient of the tie, and the dark shading of ties identifies whether at least one of the acknowledgments is expressed in a paper that references *TGEB*. Individuals who (co)authored one or more texts in either paper series are identified as large, darkly shaded nodes.

We can make some initial observations about this network. Because of how it has been constructed, there are no isolates, i.e., nodes that are not connected with another node. Moreover, as authors usually do not acknowledge themselves, there are no reflexive ties. The distribution of authorships and acknowledgments across individuals is highly skewed: 103 of 187 individuals were acknowledged only once at most, while seven were acknowledged more than 15 times. This indicates what we intuitively expect: not all individuals were equally involved in the intellectual discussions at Cowles. Indeed, the network includes acknowledgments of secretarial astaff, thesis advisors, mentors, and scholars outside of Cowles.

Descriptive statistics related to the individuals and their network positions offer first insights into Cowles' social structure. Table 1 lists the 30 individuals who (co-)authored two or more papers that included acknowledgments in either series, the total number of publications they (co-)authored with or without acknowledgments, how often they acknowledged others, and how often they were acknowledged by others.As a person's involvement in discussions at Cowles depends on when they joined Cowles and the duration of their tenure in the period under consideration, Table 1 reports on the duration of their tenure at Cowles as of 1955. Additionally, we report on each individual's eigenvector centrality. Eigenvector centrality is a recursive measure of how

Although eigenvector centrality is not without defects, as a measure it provides a first indication of what it means for a node to occupy a central position in a network. Table 1 shows Marschak and Koopmans to be the most central scholars in the acknowledgements network, followed by Hurwicz, Herstein, and Arrow.

As only around 10% of all papers published between 1944 and 1955 in both series engaged with *TGEB*, we suggest that not all the 187 acknowledged individuals in our sample were equally relevant for the early adoption of *TGEB*. We therefore examined which of the acknowledgments were made in papers that referenced *TGEB*. In Fig. 3, the acknowledgment relations expressed in contributions that engaged with *TGEB* are identified by darkened shading. While only around 10% of all papers in our sample referenced *TGEB*, 32 of the 162 papers, or almost 20%, of papers that include acknowledgments did so. We take this to indicate a disproportionately interactive engagement with *TGEB* at Cowles in the years following its publication.

The shaded ties in Fig. 3 identify a dense core of highly interconnected individuals at the center of the network. This core reflects the intense discussion and feedback culture at Cowles. The papers that engage with *TGEB* were (co-)authored by 15 individuals and acknowledge 63 individuals in total. However, there are subtle differences in who acknowledged whom, both in general and with regard to work that engaged with *TGEB*. These differences might tell us something about which individuals were crucial in fostering adoption. We identify the differences in the distinct roles that scholars occupied at Cowles and the degree of influence on the adoption that scholars exercised through their roles.

To uncover these role differences, we applied a blockmodeling algorithm. Blockmodeling is a technique that groups individuals by structural similarities in the relations they maintain with members of the various groups (Doreian et al., 2005; Lorrain & White, 1971; White et al., 1976). How this works is best understood by considering the sociomatrix of the network. A sociomatrix is a square matrix that represents each individual in a network by a row and corresponding column so that self-directing ties fall onto the diagonal. Elements of this square matrix indicate whether or not any two nodes i and j are connected, with the strength of that connection identified by the value in row i and column j of the sociomatrix.

The blockmodeling algorithm belongs to a family of hard clustering algorithms that assign each individual to a single group. This has the effect of stressing separation between communities because no individual can belong to more than one community at the same time. This approach has the advantage that groups can be assigned labels based on the blockmodel structure, allowing for a clear role system to emerge (Boorman & White,

Table 1 Individuals who (co-)authored two or more papers (with acknowledgments) in either series

ID	Name	Tenure at Cowles (as of 1955)	(Co-)authorships			Acknowledgments				Network centrality (Eigen-vector)
				Engagement with *TGEB*		Incoming		Outgoing		
			All	#	First	Persons	#	Persons	#	
1	Marschak, Jacob	13	53	13	1946	20	36	34	61	1.00
2	Koopmans, Tjalling	13	60	4	1949	18	36	15	22	0.96
3	Herstein, Israel	2	12	3	1952	8	17	3	6	0.72
4	Hurwicz, Leonid	14	30	3	1946	11	22	20	29	0.69
5	Debreu, Gérard	6	29	7	1951	9	16	26	68	0.62
6	Radner, Roy	5	17	1	1951	5	11	6	11	0.60
7	Arrow, Kenneth J.	13	30	10	1949	11	18	25	37	0.57
8	Hildreth, Clifford G.	7	15	3	1951	11	16	16	23	0.55
9	Chernoff, Herman	7	16	1	1954	1	4	6	7	0.31
10	Beckmann, Martin J.	5	30	2	1952	10	11	20	35	0.27
11	Simon, Herbert A.	13	19	4	1950	4	6	17	22	0.26
12	Reiter, Stanley	2	7	0	N	2	4	2	4	0.26
13	McGuire, Charles B.	3	3	0	N	4	7	5	6	0.18
14	Christ, Carl F.	7	10	0	N	5	8	10	11	0.17
15	Milnor, John W.	0	2	2	1952	1	2	1	2	0.10
16	Gurland, John	5	7	0	N	2	2	6	7	0.09
17	Markowitz, Harry M.	6	11	3	1950	4	4	7	8	0.09
18	Brunner, Karl	2	2	0	N	1	1	10	11	0.08
19	Klein, Lawrence R.	13	11	0	N	3	3	8	10	0.05
20	Winsten, Christopher	2	6	0	N	1	1	6	8	0.05
21	Houthakker, Hendrik	3	11	0	N	3	4	9	11	0.05
22	Muth, Richard F.	2	4	0	N	2	2	2	2	0.02
23	Patinkin, Don	7	7	0	n	2	2	13	15	0.01

Table 1 (continued)

ID	Name	Tenure at Cowles (as of 1955)	(Co-)authorships			Acknowledgments				Network centrality (Eigen-vector)
				Engagement with *TGEB*		Incoming		Outgoing		
			All	#	First	Persons	#	Persons	#	
24	Haavelmo, Trygve	13	12	0	N	3	4	8	9	0.01
25	May, Kenneth	5	2	0	N	0	0	2	2	0.00
26	Girshick, M.A.	5	3	0	N	0	0	3	3	0.00
27	Reiersol, Olav	1	7	0	N	0	0	3	3	0.00
28	Harberger, Arnold C.	6	6	0	N	0	0	8	12	0.00
29	Chipman, John S.	1	2	0	N	0	0	8	11	0.00
30	Goodman, Leo A.	0	2	0	N	0	0	3	3	0.00

Columns 4 to 6 give the total number of (co-)authored papers, the number of (co-)authored papers that engage with *TGEB*, and the first year of a person's engaging with *TGEB*. *Tenure* refers to the duration of each person's affiliation as of 1955. Incoming and outgoing acknowledgment relations are reported as the number of connected persons and the number of acknowledgments received/made (#). For example, Koopmans was acknowledged 36 times by 18 individuals.

Table 2 Groups of structurally similar individuals in the acknowledgments network

Group	Individuals					Papers		
	Persons	Affiliated (%)	Tenure	Authors	Adopters	All	Citing *TGEB*	Share (%)
G1	4	100	10.50	4	4	44	15	34
G2	21	52	3.48	10	9	59	20	34
G3	25	44	1.52	8	1	34	1	3
G4	137	32	1.35	30	0	47	0	0

Tenure refers to the average length of affiliation in 1955. *Adopters* refers to (co-)authorship on one or more of the 102 papers that reference *TGEB* between 1944 and 1955 (including papers without an acknowledgment section).

1976). Individuals are assigned social roles by the relations they maintain within their own and with other groups. Sorting the sociomatrix by group assignments reveals separable blocks of relations that define how the groups relate to one another.

At an aggregated level, this reveals patterns in relations connecting groups of structurally similar individuals. If, for example, members of group A acknowledge members of group B but not vice versa, then the block of relations going from members of A to members of B will mostly contain nonzero values, whereas the block of relations going from members of B to A will consist mostly of zero values. Such asymmetries suggest that members of group A stand in a systematic relation to members of group B. These relations between groups can be interpreted as a higher-order role system to which individuals are assigned by their group membership.

To identify groups of structurally similar actors from acknowledgment relations, we assume that sending an acknowledgment is not the same as receiving an acknowledgment. Moreover, not all acknowledgments are equally important. We therefore compared each individual with every other individual in the network on three dimensions: whom they acknowledged, whom they were acknowledged by, and how important their acknowledgers were as measured by the number of acknowledgments their acknowledgers had received. To measure the extent to which any two of the 187 individuals in the network are (dis-)similar to one another in terms of network position, we calculated the pairwise covariances[9] on all three dimensions. This amounts to applying a similarity metric to the stacked sociomatrices. Because no two individuals are structurally equivalent on this measure, we group individuals into a predefined number of structurally similar network positions. Specifically, we partitioned the 187×187 sociomatrix into four groups of structurally similar individuals using Ward's minimum variance method, which minimizes the within-group variance in dissimilarities (Ward, 1963).

Figure 4 shows parts of the sociomatrix with individuals sorted into groups by their structural similarity. To preserve space, we included in this representation only the 30 individuals who (co-)authored two or more papers with acknowledgments. A full list of group assignments for all 186 individuals in the acknowledgment network is given in the Appendix. Each group contains individuals who acknowledge (in rows) and are acknowledged

[9] Different similarity measures can be used to quantify similarities in vector space (e.g., cosine similarity, or Euclidean distance). Each yield marginally different outcomes. Consequently, the choice of similarity metric must be evaluated against expert knowledge of the setting. As we elaborate in the following, the covariance similarity metric yields a grouping that is highly consistent with historical accounts.

	Group 1				Group 2								Group 3							Group 4											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	
Koopmans, T. (42–73) (1)		3		1		2							1	2	2	2															Group 1 (n=4)
Marschak, J. (42–73) (2)	2		2	1	4	2	3	5	1		4		1											1							
Hurwicz, L. (41–61) (3)	3	2			2	3	1									2					1										
Herstein, I. (52–54) (4)				B1			3					B2							B3											B4	
Arrow, K. (42–64) (5)	2	4					2		2																						Group 2 (n=21)
Hildreth, C. (48–61) (6)			4	2			1	1										1													
Debreu, G. (49–73) (7)	6	4	5	7	1	1		2	2	1		2						1	1												
Radner, R. (50–73) (8)		3		1									2																		
Simon, H. (42–61) (9)	2		2					2																							
Markowitz, H. (49–64) (10)		1				2								1																	
Chernoff, H. (47–54) (11)		1		1	2			1																							
Milnor, J. (12)				B5			2					B6							B7											B8	
Beckmann, M. (50–61) (13)	5	4		3	1					1					1		2						1								Group 3 (n=25)
Christ, C. (48–67) (14)	1	1	1		2																										
McGuire, C. (52–61) (15)	2			1						1			1																		
Reiter, S. (48–50) (16)	2		2																												
Houthakker, H. (52–67) (17)						1																									
Gurland, J. (49–54) (18)			2			1																									
Winsten, C. (52–54) (19)	1			B9								B10	1		3				B11											B12	
Haavelmo, T. (42–61) (20)		2	1																												Group 4 (n=137)
Klein, L. (42–61) (21)	2	2	1														1			1											
Patinkin, D. (42–49) (22)		1			1															2	1										
Muth, R. (52–54) (23)													1																		
Brunner, K. (49–51) (24)	1	1	1		1	1				1				2								1									
May, K. (42–47) (25)																															
Girshick, M. (42–47) (26)																															
Reiersol, O. (49–50) (27)	1																														
Harberger, A. (48–54) (28)	2				2	1								2																	
Chipman, J. (50–51) (29)							2						1																		
Goodman, L. (30)				B13		1						B14							B15											B16	

Fig. 4 Sociomatrix of the acknowledgment network, partitioned into four groups. Only the 30 individuals who (co-)authored two or more papers with acknowledgments are depicted (see Appendix for a full list of group assignments).The numbers in brackets next to persons' names denote the period that person was affiliated with the Cowles Commission. Numbers in brackets on the right-hand axis denote total group size, including persons who (co-)authored fewer than two papers in the dataset.

(in columns) in similar ways. The four groups identified as G1 to G4 are separated by bold lines that split the sociomatrix into 16 blocks of relations, B1 to B16. The basic idea of blockmodeling is that each block encapsulates the relations between members of the group that is mapped onto the rows and members of the group that is mapped onto the columns. Within-group relations are captured on the diagonal blocks and between-group relations are captured off the diagonal.

The blockmodeling algorithm groups individuals such that the variance in the number of within-group and between-group connections is maximized. The sociomatrix represents this as blocks either being very sparsely or very densely populated with ties, and the corresponding connections between groups are either strong or weak. Blockmodeling thus not only groups individuals according to their similarity in roles in the adoption of a new scientific idea; it also does so in a way that relates the groups to one another. Furthermore, it identifies individuals who bridged blocks. We can interpret this as a way in which the social structure creates opportunities for individual role-bearers, for instance, academic opinion leaders, to integrate mutual engagement across groups through discussion and feedback functions.

Block B1 on the upper left side of Fig. 4 represents the reciprocal acknowledgments among the four members of G1, which comprises Marschak, Koopmans, Hurwicz, and

Herstein. This block is dense, with most viable ties having nonzero values. For instance, Koopmans acknowledged Marschak in three papers, of which at least one engaged with *TGEB*, whereas Marschak acknowledged Koopmans in two papers, neither of which engaged with *TGEB*. In total, the members of this group acknowledged each other 14 times, with Marschak and Hurwicz giving five acknowledgments each and Koopmans acknowledging his fellow group members four times. Herstein is the only group member who did not acknowledge any of his three fellow group members. Instead, he thrice acknowledged the contribution of Debreu; a member of G2. In this, his acknowledgment behavior resembles Marschaks, who also acknowledged Debreu three times alongside numerous acknowledgments to other members of G2.

To the right of block 1 is block 2, which contains the acknowledgments expressed by members of G1 to members of G2. G2 has 21 members, among them prolific scholars who made seminal contributions to the development of game theory and expected utility theory, including Arrow, Chernoff, Debreu, Simon, Radner, Markowitz, and Milnor. Four of the eight authors of key "elaborator" publications identified by Herfeld and Doehne (2019) have been assigned to G2, which suggests that G2 is the group of early adopters that began to elaborate on *TGEB*. G2 members acknowledged members of G1 and members of their own group but generally did not acknowledge members of G3 or G4. The mutual acknowledgment activity in G2 occurs mostly among Arrow, Debreu, and Simon. This seems plausible in retrospect, as all three scholars would subsequently prove to be of the same caliber, had overlapping research interests, such as in decision-making under uncertainty and general equilibrium analysis, and would even co-author papers.

Table 2 summarizes the four groups that have been identified by the algorithm. Marschak, Koopmans, Hurwicz, and Herstein of G1 were long-term affiliates with Cowles. By 1955, they had on average been at Cowles for 10.50 years. They actively published in either series and by 1955, they had (co-)authored at least one paper that referenced *TGEB* and had thus adopted *TGEB*. Indeed, 15 of the 44 papers (co-)authored by members of G1 referenced *TGEB*.

We also see that G2 includes 21 individuals, of which 10 (co-)authored one or more papers in either series. In total, these 10 authors produced 59 papers, of which 20 referenced *TGEB*. In addition to the individuals listed in Fig. 4, G2 includes Savage and Rubin. Of the 10 individuals (co-)authoring one or more papers in these series, 9 engaged with and referenced *TGEB* at least once. By contrast, members of G3 and G4 only published one paper on *TGEB* in total. Fewer than half of their members even held an affiliation with Cowles; by 1955, the average tenure of affiliation lay at 1.52 (G3) and 1.35 years (G4). Only one in three individuals in G3 and one in five individuals in G4 (co-)authored one or more publications in these series until 1955. Consequently, Table 2 confirms what Fig. 4 suggests: Members of G1 and G2 were central to the early engagement with *TGEB*, whereas G3 and G4 were less so.

We next consider how the different groups relate to one another. Because individuals have been assigned to groups based on structural similarity, members of the same group occupy similar, well-defined positions in the social structure (Doreian et al., 2005; Lorrain & White, 1971). For example, Fig. 4 shows that although many members of G3 and G4 acknowledged Koopmans, Marschak, and Hurwicz, these acknowledgments were rarely reciprocated. Marschak primarily acknowledged members of G2 whereas Koopmans mainly acknowledged members of G3, including Beckmann, McGuire, Christ, and Reiter, who were all affiliated with Cowles during his directorship.

To reveal these asymmetries in acknowledgments between groups, we proceeded by calculating block density as the number of connections observed in each block divided by the

Table 3 Matrix of within-group and between-group relations based on tie density

	G1	G2	G3	G4
G1	1	1	1	1
G2	1	1	1	0
G3	1	0	0	0
G4	0	0	0	0

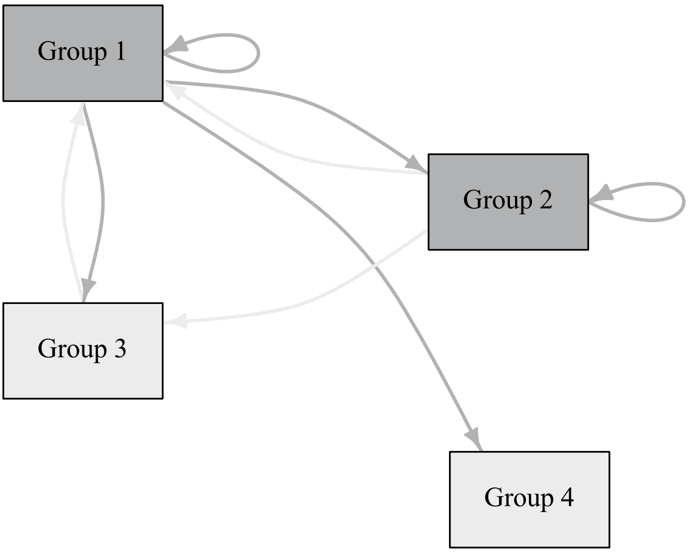

Fig. 5 Network representation of the hierarchical social structure at Cowles. Dark ties identify intergroup acknowledgment relations expressed in papers that reference *TGEB*. Dark groups identify groups that engaged intensely with TGEB

number of connections possible within blocks. We then binarized the 16 blocks at their median density so that half of the between-group connections are coded as zero and the other half are coded as one (Doreian et al., 2005). This yields the matrix given in Table 3.[10]

Table 3 reveals that the social structure is organized hierarchically with G1 and G2 at its core and G3 and G4 in a staggered periphery. This hierarchy suggests that the influence of individuals in the network diminishes from G1 to G4. The early engagement with *TGEB* occurred mainly among core Cowles affiliates and not at the periphery of the social structure. This indicates a difference in roles between members of distinct groups and therefore suggests a hierarchical social structure. The within-group and between-group relations in Table 3 can be expressed as the aggregated network shown in Fig. 5.

[10] This approach considers repeated acknowledgments between two individuals. As a robustness check, we applied the same procedure to the unweighted sociomatrix (i.e., multiple acknowledgments between individuals count only once). Then, G2 no longer acknowledges G3, but G4 acknowledges G1, offering even stronger evidence of a hierarchical social structure in which G1 is acknowledged by all groups, G2 is acknowledged by two groups, and G3 and G4 are only acknowledged by one group, G1.

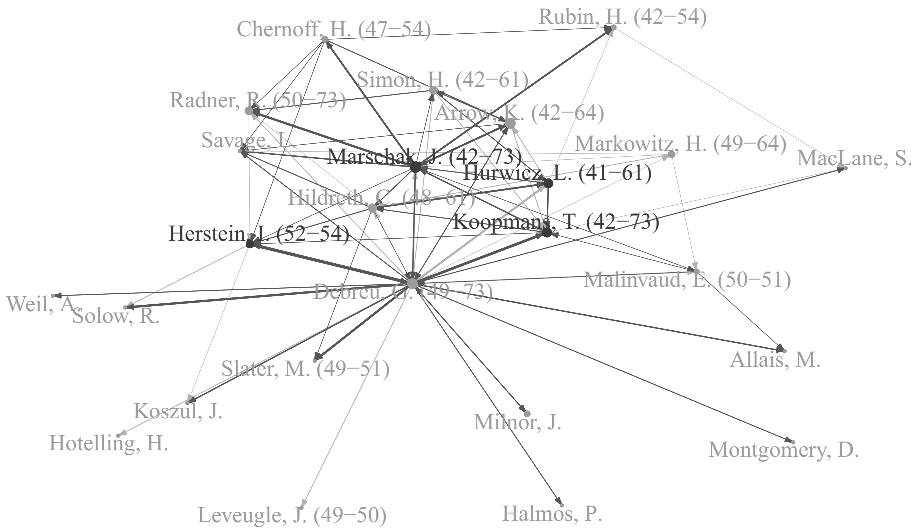

Fig. 6 Acknowledgments network among members of G1 and G2, 1944–1955. Members of G1 are identified by dark gray shading of the nodes. Dark ties represent acknowledgments in papers that cite *TGEB*

Figure 5 visualizes the connections among the four groups. Reflexive ties (or loops) identify groups whose members engaged intensely with each other. Dark coloring identifies groups that engaged with *TGEB* and connections between groups that are established in papers engaging with *TGEB*.

Closer examination of those connections—or the relations—within and between blocks constitutes the core of our analysis in that such an examination suggests how engagement with *TGEB* proceeded within this hierarchical social structure; they thereby capture this structure at Cowles. The loops show that members of G1 and G2 cultivated an intense within-group discussion and feedback environment, as has been established as characteristic of the Cowles Commission in historical accounts (e.g., Christ, 1994; Erickson et al., 2013). Yet, members of the same group engaged with each other about different issues. Members of G1 acknowledged each other, including in publications that engaged with *TGEB*. By contrast, engagement with *TGEB* was an essential basis for the mutual engagement of members of G2. The latter were also overall the most productive in their engagement with *TGEB*. They (co-)authored more than half of all papers that engaged with *TGEB* until 1955 in both series (cf. Table 2). Another difference between G1 and G2 members was that the latter did not promote *TGEB* across group boundaries. In contrast, G1 fostered early engagement with *TGEB* across all four groups. The arrows from G1 to G2, G3, and G4 all show that G1 disproportionately engaged with *TGEB*, suggesting that G1 actively disseminated rational choice theories and provided and solicited feedback from across the core-periphery spectrum.

G1 and G2 are closely connected. Their main connection regarding *TGEB* is between Marschak (G1) and Debreu (G2). In his papers citing *TGEB*, Marschak acknowledged most of the scholars in G2. Conversely, members such as Arrow, Chernoff, Debreu, and Radner of G2 acknowledge Marschak. Debreu also was crucial in enabling connections between groups. He acknowledged almost everyone in G2 in papers that engaged with *TGEB* (see Fig. 4). Interestingly, few individuals within G2 reciprocated. Rather, he had the backing of members of G1. Thus, G1 and G2 are strongly connected in their engagement with *TGEB*. Their close connection signals not only mutual exchange and extensive feedback on their members' papers but also that some authors exerted more influence than others.

Figure 6 presents the acknowledgments network among members of G1 and G2. We see that G2 also included notable scholars such as Robert Solow, Maurice Allais, and Leonard Jimmie Savage who were omitted from the sociomatrix depicted in Fig. 4 as they (co-)authored fewer than two papers that included acknowledgments in either series.

Having established that early engagement with *TGEB* originated at the core of the discussion network at Cowles, we can consider the particular role that individuals such as Marschak and Koopmans played in this process in more detail. We do so by considering interactions within and between G1 and G2. The main connection between members of G1 and G2 concerning *TGEB* is Marschak. However, while members of G1, notably Marschak, acknowledged members of G2 in papers on *TGEB*, the engagement of members of G2 with *TGEB* was largely an in-group affair.

By several measures, G1 is the most central group in our network. Matching the group members to Table 1, we see that the four members of G1 score the highest overall on network centrality. G1 contains the two most central individuals, the Cowles directors Koopmans and Marschak, alongside Herstein and Hurwicz. All four were extensively acknowledged overall and disproportionately acknowledged by members of G2 (Fig. 4), with Hurwicz, Herstein, and Koopmans each receiving 11 acknowledgments and Marschak receiving 13. This explains why all four were grouped as G1: The next-highest recipient of acknowledgments from G2 outside of G2 is Milton Friedman in G3, who received three acknowledgments from G2.[11]

Within G1, however, there are noticeable differences in acknowledgment patterns between Herstein and Hurwicz on the one hand and Marschak and Koopmans on the other. While all four were acknowledged by G2 members, Marschak and Koopmans were also disproportionately acknowledged by members of G3 and G4. Marschak received 18 acknowledgments in total and Koopmans 20, whereas Hurwicz and Herstein were acknowledged only 9 and 4 times respectively, with all of Herstein's acknowledgments coming from G3. So, although the algorithm grouped all four in G1, the two directors differ markedly from the other two in their overall position in the acknowledgments network. This suggests a basic difference between Koopmans and Marschak's roles as research directors and Hurwicz and Herstein's as research staff.

There are also important differences between Koopmans and Marschak. That Marschak and Koopmans mutually acknowledged each other indicates a topical overlap in their research interests and mutual engagement with each other's work. However, while Koopmans acknowledged Marschak's contribution in a paper that referenced *TGEB*, Marschak did not acknowledge Koopmans in any of his 13 papers engaging with *TGEB*. Furthermore, whereas Koopmans engaged most strongly with members of G3, Marschak engaged primarily with members of G2, who would prove instrumental in the early engagement with

[11] The algorithm's grouping of Marschak and Koopmans with Herstein and Hurwicz seems plausible as all four scholars made similar contributions to decision and game theory. From 1942 onwards, Hurwicz was their direct colleague for several years, first as research staff member and later as research consultant. Marschak and Hurwicz's reviews were both highly influential in exposing Cowles scholars to *TGEB*. Together with Milnor (G2 member), Herstein developed a simpler axiomatization of the von Neumann–Morgenstern expected utility principle (Herstein & Milnor, 1953) and thus made an important contribution to the subsequent dissemination of expected utility theory. In short, all four authors were doubtlessly scientifically central.

TGEB and especially with the development of the expected utility principle. This indicates a temporal dimension in their engagement with *TGEB* and a division of labor between the two, with Marschak playing the main role in promoting adopting rational choice theories from the beginning.

Overall, Marschak was by far the most prolific author and the most active acknowledger between 1944 and 1955. He (co-)authored 53 publications, of which 13 engaged with *TGEB*. Remarkably, 27 of his 61 acknowledgments were to members of G2 for engaging with his papers. Moreover, 22 of these 27 acknowledgments were made in papers that engaged with *TGEB*. The number of his acknowledgments to G2 exceeds the number of his acknowledgments to members of any other group. Marschak was also the scholar most extensively acknowledged overall by members of G2. Indeed, the number of acknowledgments of Marschak by G2 members is far higher than that of any individual in any of the four groups. This supports the hypothesis that Marschak in his central role exerted more influence on research undertaken at Cowles than any other scholar and that he channeled this research toward topics related to *TGEB*.

The role of academic opinion leaders in science

Our analysis reveals at least two aspects about the early adoption of rational choice theories: First, it suggests that the adoption in part depended on the specific research environment at Cowles. We called this environment the "social structure" and characterized it by the various positions that scholars held in this structure. Only two roles are relevant for the adoption of *TGEB*: that of an academic opinion leader and that of an elaborator. As such, our analysis complements the role typology developed by Herfeld and Doehne (2019).[12] Second, our analysis suggests that some scholars could exert influence on the adoption of rational choice theories depending on their role. For instance, in the role of academic opinion leaders, Marschak and Koopmans were scientifically and institutionally central at Cowles and had a clear vision of its research agenda. And they were academic opinion leaders in that they pushed the research agenda at Cowles toward an engagement with *TGEB*. Thus, their role was structurally different from scientists primarily elaborating on *TGEB*.

Marschak fostered research on rational choice theories in his own way. With his technical papers, he substantially pushed toward conceptual progress of decision theory in the intellectual debates taking place in the profession at large. As Moscati (2016) shows, Marschak, alongside Friedman and Savage, played a key role in convincing no other than Paul Samuelson—a serious critic of EUT—to appreciate the usefulness of expected utility theory for economics. Marschak directed the topical emphasis on the expected utility principle (1) by circulating his own work, thereby ensuring continuous exposure of Cowles scholars to *TGEB*, (2) by organizing events and holding seminars on the topic of *TGEB*, and (3) by giving and receiving feedback on research undertaken at Cowles. Both his research papers and his book review of *TGEB* had been instrumental in beginning discussions about the toolbox it contained (Marschak, 1946). Alongside Hurwicz's review, Marschak's review was widely distributed and most likely discussed extensively by such scholars as Hurwicz,

[12] Note that in Herfeld and Doehne (2019), the roles identified refer to scientific contributions, not to individuals.

Koopmans, Arrow, and Simon (see also Hildreth, 1986, p. 98, Marschak, 1946, p. 97, fn. 2). In it, Marschak offered an accessible summary of *TGEB* and elaborated on its potential for economics by giving concrete examples of economic problems that would benefit from a game-theoretical analysis. Though not a mathematician himself, he certainly believed that *TGEB* should be an essential part of mathematical economics in the future.

Marschak presented *TGEB* not only as conforming to the standards of proper science (Cherrier, 2010, p. 449 ff., Herfeld, 2018) but also as a prime example of how tools from modern logic could assist progress in economics (Marschak, 1946, p. 114). He praised the "meticulous formalism," the separation between the axiomatic structure of the theory of behavior and empirical reality, the flexibility this detachment implied regarding the theory's applicability, and the rigor and precision that accompanied an improved scrutiny of logical foundations and a deductive analysis (Marschak, 1946). It was obvious to him that such a purely formal framework would enable its application to structurally similar problems in a variety of disciplines. For him, the next step was that economists modify this framework and translate the formal conclusions "into the language of the concrete field … economics in our case" (Marschak, 1946, p. 115). In concluding his review by noting that "[t]en more such books and the progress of economics is assured" (1946, p. 115), Marschak most likely envisioned that follow-up research on *TGEB* should be part of the commission's future research agenda.

More importantly, though, is that Marschak mainly promoted the axiomatized principle of expected utility, about which he was particularly excited (Arrow, 1991, p. 140). Already in the 1930s, he had engaged with Bernoulli's idea that agents only consider the average utilities when they evaluate risky options (Marschak, 1938). At Cowles, Marschak returned to the matter in several papers on the axiomatization of expected utility and the interpretation of expected utility theory (1948, 1949, 1950).[13] He frequently acknowledged Cowles researchers and regular visitors for feedback; names included Arrow, Chernoff, Debreu, Hurwicz, Simon, Rubin, Herstein, Savage, and Malinvaud (Moscati, 2019, p. 169). This prioritization of the expected utility principle is systematically confirmed by our analysis. By inviting feedback on his papers from such stellar scholars while providing the same for them, Marschak ensured continuous exposure to and active engagement with the problem of axiomatizing expected utility at Cowles. Fostering such exposure and engagement contributed in large part, we suggest, to the adoption not only of the ideas contained in *TGEB* but specifically of the expected utility principle at Cowles and shaped the research agenda in the years to come. It is this specific influence of Marschak, given his social role and particular research interests, which partly explains the early adoption of the expected utility principle and the delayed engagement with game theory at Cowles.

Marschak did not neglect the importance of game theory. In his role as director, Marschak also initiated discussions at a formal level. Von Neumann frequently visited Cowles, and in May 1945, Marschak invited him to give two lectures on game theory. From January to April 1949, a series of nine seminars on subjects related to *TGEB* was organized under Marschak's directorship, at which several scholars that would make some of the most important contributions to the development of game and decision theory gave talks.

As the titles of the talks listed in Table 4 suggest, discussions centered around theoretical aspects and concrete applications of decision- and game-theoretic concepts to problems

[13] See Moscati (2019, Part III) for a historical reconstruction. See Debreu's and Arrow's papers in Arrow et al. (1991) for an account of Marschak's contribution to the topics of utility theory and decision-making under uncertainty at Cowles.

Table 4 Talks in the Seminar series on *Theory of Games* in 1949. For a list of seminars, see https://cowles.yale.edu/commission-seminars [accessed on July 22, 2022]

Talks
January 9: L. J. Savage, "The Theory of Games: Zero-Sum Games."
January 20: K. J. Arrow, "The Theory of Games: Multi-Person Games."
February 17: K. J. Arrow, "The Theory of Games: Applications to Economics."
March 3: J. Marschak, "The Theory of Games: Measurable Utility."
March 10: M. A. Girshick, "The Theory of Games: Continuous Games."
March 31: L. J. Savage, "The Theory of Games: Application to Statistical Inference."
April 14: H. A. Simon, "The Theory of Games: Application to Politics and Administration."
May 12: H. Rubin, "Statistical Treatment of Nonlinear Econometric Models."
May 26: T. C. Koopmans, "Utility Analysis of Decisions Involving Future Periods."

in economics, politics, administration, and related disciplines. However, what apparently caught the attention of scholars in this seminar series was Marschak's discussion of von Neumann and Morgenstern's axiomatic version of cardinal utility in *TGEB's* second edition (Dimand & Dimand, 1995, p. 551). In the early 1950s, Koopmans—among others—began to revive von Neumann's contribution to game theory to address questions around resource allocation, in linear programming, and through his promotion of activity analysis (Düppe & Weintraub, 2014; Koopmans, 1949, 1951, Koopmans & Beckmann, 1957). Yet overall, game theory remained largely absent from the research agenda at Cowles until after 1955, when the commission moved to New Haven. It was two years later, in 1957, when Duncan Luce and Howard Raiffa published their seminal textbook *Games and Decisions* (1957) and thereby provided an accessible presentation of von Neumann and Morgenstern's ideas, that game theory became quickly adopted more broadly among social scientists before entering the mainstream in many fields.

Considering Marschak and Koopmans as academic opinion leaders helps to explain the adoption process of *TGEB* at Cowles. Marschak's intense engagement with the axiomatized principle of expected utility certainly attracted attention among Cowles scholars (see also Dimand & Dimand, 1995, p. 551). As an active director working on an axiomatization of expected utility, Marschak behaved and was perceived as such an opinion leader, which allowed him to exert credible influence on the research direction at Cowles.

Of course, there were other factors responsible for the emphasis on expected utility theory and the lacking interest in game theory at Cowles.[14] Before Nash (1950, 1953) formulated a solution concept that was less demanding than that of Morgenstern and von Neumann, non-cooperative game theory was constrained to two-person zero-sum games and thus conceptually limited (Giocoli, 2003). Furthermore, economists such as Hurwicz became skeptical about *TGEB's* potential for concrete applications and practical implications and thus about the relevance of game theory for economic problems (Hurwicz, 1953). This is not to say that these factors fully account for prioritizing the expected utility principle over game theory; we have not even attempted to convey the multifacetedness of the history of game theory. We suggest that a systematic analysis of Marschak's influence at Cowles indicates that his role as academic opinion leader enabled him to exert his influence

[14] See, e.g., Giocoli (2003), for an extensive analysis of this historical development.

and thereby fostered the adoption of *TGEB* and specifically helped the adoption of the axiomatized principle of expected utility at Cowles.

Limitations of the analysis

Our analysis has limitations. First, we recognize that acknowledgments alone yield only a partial reconstruction of the informal social structure of a research institution. Not all individuals were assigned a role that one would expect. For example, while acknowledged in four publications, Arthur Cowles III, founder and president of the commission until 1955, is assigned to the peripheral group G4. We take this to be quite simply because the three individuals he acknowledged in the one paper he co-authored in our sample, Manning, Danson, and Leavens, were no longer actively involved at Cowles. The fact that he was acknowledged twice indicates that he did not take as active a role in the day-to-day discussion culture as his contemporaries. That by itself is not surprising. However, the same holds for Samuelson, Schumpeter, Bronfenbrenner, Haavelmo, Buchanan, and other luminaries whose general influence on the economic discipline is not fully reflected by their assignment to G4.

We suggest two interpretations. One is that the algorithm's assignment of the individuals to this group reflects these individuals' remoteness from Cowles. Except for Arthur Cowles III, none of the aforementioned individuals were officially affiliated with the Cowles Commission. Another explanation relates to the period examined. For example, James Tobin, who succeeded Koopmans as director in 1956, did not join Cowles until 1954 and therefore does not feature prominently in the acknowledgments network. However, the fact that Tobin appears in the social structure at all is a strength of a data-driven approach. Our analysis identifies individuals who may not have featured as prominently in a systematic historical account. For example, his assignment to G1 identifies Israel Herstein's important role in these formative years of decision and game theory, even though his official affiliation with Cowles began only in 1952. As a professor of mathematics at the University of Chicago from 1950 onwards, Herstein came to Cowles just as the early engagement with *TGEB* hit its first peak.

Second, we did not examine shifts in the social structure within the twelve years analyzed. Although the data is time-stamped in the sense that we know when each publication was published, we did not explore changes in acknowledgments patterns over time. Because publication activity and engagement with *TGEB* varied substantially over time (cf. Figure 1), the data does not allow an annualized analysis. Moreover, variation in the length of time between the inception of an idea and its publication cautions against a too fine-grained temporal perspective.

Third, our focus on the commission's Chicago years excludes important contributors to the dissemination of *TGEB*, such as Martin Shubik, who joined Cowles as a research staff member in 1958, or of John Nash, who neither published in either series nor was ever acknowledged in either. We emphasize again that our focus is on showing the importance of academic opinion leaders in the early stages of the adoption process, before a theory has been engaged with and elaborated upon by a core set of scholars.

Finally, there are general limitations when applying quantitative methods to historical data (for a discussion, see Herfeld & Doehne, 2018). To reiterate our point: we do not see quantitative-empirical methods as replacing traditional historical approaches. Rather, they complement other historical approaches, such as concrete case studies and historical narrative (for a history of rational choice theories, see e.g., Dimand & Dimand, 1996; Erickson, 2015; Giocoli, 2003; Leonard, 2010; Weintraub, 1992), with systematic analysis.

Conclusion

We studied the early adoption of rational choice theories originating from von Neumann and Morgenstern's *Theory of Games and Economic Behavior*. We asked how the informal social structure at the Cowles Commission impacted the early adoption of rational choice theories and shaped the conditions for its subsequent diffusion. To reconstruct the social structure at Cowles, we applied network analysis -particularly blockmodeling - to acknowledgment data. We identified Jacob Marschak and Tjalling Koopmans as occupying the role of academic opinion leaders. Marschak in particular exerted his influence in the early adoption period not only as a scientist but also in his institutional role as its director. Our results suggest that there is more to establishing a novel and innovative scientific idea than simply formulating them in the hope that they will be adopted due to their innovativeness, their epistemic superiority, and their promise of scientific progress in surviving empirical scrutiny. They reveal the importance of formal and informal organizational structures and the relevance of institutional alongside scientific influence and leadership in explaining the adoption of scientific innovations. As such, our findings have important implications for understanding how innovative knowledge is broadcast among scientists and for planning and designing scientific institutions.

Appendix

Group	Group members (i.e., individuals acknowledged 1944–1955)
G1	Herstein, Israel N.; Hurwicz, Leonid; Koopmans, Tjalling C.; Marschak, Jacob
G2	Allais, Maurice; Arrow, Kenneth J.; Chernoff, Herman; Debreu, Gerard; Halmos, P.R.; Hildreth, Clifford G.; Hotelling, H.; Koszul, J.L.; Leveugle, Jules; MacLane, Saunders; Malinvaud, Edmond; Markowitz, Harry M.; Milnor, John Willard; Montgomery, Deane; Radner, Roy; Rubin, Herman; Savage, Leonard Jimmie; Simon, Herbert A.; Slater, Morton L.; Solow, Robert M.; Weil, A
G3	Beckmann, Martin J.; Boiteux, M.; Bush, Mr.; Christ, Carl F.; Fort, Donald; Friedman, Milton; Georgescu-Roegen, Nicholas; Gurland, John; Hood, William C.; Houthakker, Hendrik S.; Kruskal, Joseph; Lehmann, E.L.; Leontieff, Wassily W.; McGuire, Charles Bartlett; McQuillan, Mr. (United Airlines); Modigliani, Franco; Moore, Mr. (United Airlines); Newell, Alan; Reiter, Stanley; Syberg, Mr. (Scandinavian Airlines); Toernquist, Leo; Tompkins, C.B.; Wald, Abraham; Winsten, Christopher B.; Youngs, J.W.T

Group	Group members (i.e., individuals acknowledged 1944–1955)
G4	Adams, A.A.; Allen, Stephen G.; Anderson, Theodore W.; Andrews, William H.; Bavelas, A.; Blackwell, David H.; Bobkoski, Francis A.; Bohnert, Herbert; Bothwell, Frank; Bratton, Donald; Bronfenbrenner, Jean; Bronfenbrenner, Mrs.; Brown, Goerge W.; Brown, T.M.; Brownlee, O.H.; Brunner, Karl; Buchanan, James M.; Burks, Arthur; Burns, Arthur F.; Calvert, J.F.; Chenery, Hollis B.; Chipman, John S.; Coen, E.; Cohn, S.; Constable, E.W.; Cooper, Gershon; Cooper, W.W.; Court, L.M.; Cowles, Alfred; Cyert, Richard M.; Dalkey, Norman; Daly, Donald J.; Danson, Forrest; Dantzig, George B.; Divinsky, Nathan J.; Domar, Evsey D.; Dunaway, William L.; Easton, D.; Edwards, Ward; Evans, Griffith C.; Farrell, Michael J.; Faxen, Karl O.; Fei, John; Feigl, Herbert; Feller, William; Ferber, Marianne; Ferber, Robert; Foster, Bill; Fox, Kirk; Friedlander, D.; Friedman, Joyce; Frisch, Ragnar; Gelbaum, B.; Gelbaum, G.; Girshick, M.A.; Goodman, Leo A.; Graham, Frank; Grunberg, Emile; Gunn, G.T.; Haavelmo, Trygve; Hagen, B.E.; Hagen, Everett E.; Harberger, Arnold C.; Harris, Thedore; Henderson, A.H.; Herriott, John G.; Hills, E.; Hogg, Malcolm; Ichimura, S.; Johnson, D. Gale; Jones, William O.; Kalisch, G.; Kaplan, Abraham; Katona, George; Kendall, D.G.; Kiefer, J.; Klahr, Carl N.; Klein, Lawrence R.; Lazarsfeld, Paul; Leavens, Dickson H.; Lerner, A.P.; Lewies, H. Gregg; Love, Joy C.; Machlup, F.; Manning, Emma; May, Kenneth; McKenzie, Lionel W.; Metzler, Lloyd A.; Mickey, Ray; Morehouse, N.F.; Motzkin, Theodore S.; Muth, Richard F.; NA; Nelson, H.G.; Nelson, W.L.; Nerlove, Marc L.; Oort, Conrad; Orey, S.; Papandreou, A.G.; Patinkin, Don; Prais, Sigbert J.; Prest, Alan R.; Rasch, D.; Reiersol, Olav; Rogers, Walter S.; Rosenblatt, D.; Rosenbloom, Paul C.; Rubin, Hank; Samuelson, Paul A.; Schultz, Theodore W.; Schumpeter, Joseph A.; Schweitzer, Selma; Shores, Lois N.; Siegel, S.; Slater; Smithies, A.; Sratton, Donald; Stein, C.M.; Stone, Richard; Strotz, Robert H.; Suits, D.B.; Sutherland, J.G.; Sverdrup, Erling; Tekiner, Sami; Telser, Lester G.; Templeton, James G.C.; Thompson, Gerald; Thompson, Manley; Thurstone, L.L.; Tintner, Gerhard; Tobin, James; Tolley, George; Waterman, Daniel; Williams, M.S.; Wilson, Edwin B.; Wolfowitz, Jacob; Wolfson, Robert; Working, Holbrook

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