

## Formal Approaches to Management Theory

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A perusal of the pages of the *Academy of Management Review* (AMR) over the past decade might lead one to conclude that formal methods have no place in the development of management theory. From 1998 to 2007, for example, we could only find one article in this journal that actually used a formal approach – either analytic methods, a simulation or formal logic – to build its propositions. One therefore might naturally wonder why formal approaches have not been more prevalent in management research.

One possibility is that formal methods have little to contribute to management theory. That explanation seems unlikely to us (and not just because the articles in this issue serve as examples that strongly contradict it). Consider the disciplines on which management theory most commonly draws: economics and sociology. Nearly every theoretical article over the last decade that appeared in the *American Economic Review* used formal methods (almost exclusively analytic models). Even in sociology, the last ten years of the *American Journal of Sociology* (AJS) featured at least ten articles that built theory using formal approaches (divided fairly evenly across the methods featured in this special topic forum). Given that AJS publishes far fewer articles per year than AMR and that more than half of those articles are empirical, the ratio of ten to one would actually appear to understate the extent to which sociology relative to management favors the use of formal methods. Seeing as closely related social sciences have gained greatly from formal approaches, one might expect that management theory could benefit similarly.

A second possibility is that management scholars have not invested in acquiring the skills required to use formal methods. That explanation too appears to fall short, especially when one considers the response to the call for this special topic forum. We received a total of 75 submissions, a wealth of riches. Almost every one of these submissions moreover came from someone sitting in a business school and more than 90% of the authors of these manuscripts hold doctoral degrees from business schools (rather than, say, from economics departments). We also benefited from the advice of an extremely high quality pool of reviewers, many of whom had never before been involved with AMR. This overwhelming response surprised even us, the Special Topic Forum guest editors. But it nonetheless reveals that a large segment of management scholars have the training to pursue formal approaches to building theory, and thus a scarcity of skills cannot account for the infrequent usage of these tools in management research.

Though it falls beyond the scope of this introductory essay to determine precisely the reasons for the paucity of formal theory building in management research, we speculate that at least two factors come into play. First, we suspect that readers, reviewers and editors may not fully appreciate the relative advantages of formal versus informal approaches. They may therefore feel that the investment involved in reading and understanding these formal approaches is too dear. Second, those that do use formal methods may not consider AMR as a potential outlet simply because it has published so few articles using these methods in the past. At least partly in support of this second point, we would note that *Management Science* and *Organization Science* regularly publish papers that use analytic methods, simulations and formal logic to build management theory.

With this special topic forum, we hope to stimulate both the demand for and the supply of management research using formal approaches. By describing their advantages and by demonstrating them through example, we hope that readers and reviewers will become more attuned to the value of research that adopts a formal approach to theory building. And, by demonstrating that AMR has an interest in

publishing these papers, we hope to encourage management researchers to use them more often.

### **The benefits of building theory formally**

Formal approaches to theory building come in three main flavors, defined primarily by the methods used for articulating assumptions and then moving from those assumptions to propositions. In mathematical models, the researcher begins by outlining a set of mathematical conditions that describe the phenomenon of interest and then uses mathematical proofs to demonstrate propositions that follow from them. In simulations (also known as computational models), one similarly writes a set of conditions that represent the assumptions of the model, but instead of validating their implications via analytical proofs, one generates outcomes computationally across ranges of values for the parameters that determine those outcomes. Formal logic, meanwhile, translates natural language assumptions into statements in symbolic logic and then uses its own methods for proving the propositions implied by those statements. Although these approaches vary somewhat in their strengths and weaknesses for addressing particular theoretical questions, they nonetheless share at least three strengths relative to verbal theorizing (the natural language approach most commonly pursued in management research): (1) Precision and transparency; (2) Logical consistency; and (3) An ability to identify unanticipated implications.

*Precision and transparency:* Debates over the meaning of certain terms in the management literature have become notorious. What constitutes a “resource” in the resource-based view? What is a “dynamic capability”? What does it mean to “learn”, or to be “boundedly rational”? Although these disputes occasionally converge toward one accepted definition, they can just as easily continue without any apparent resolution despite decades of debate. Management, moreover, is not alone in this situation; all of the social sciences have had vigorous (and frequently unresolved) arguments over the meanings of key concepts.

In large part, these debates over terms and the applicability of theories reflect the imprecision of natural languages, such as English. Natural languages have evolved over time and continue to change. For a variety of reasons, many, if not most, words in natural languages therefore have multiple meanings. The listener or reader attempts to infer which one of these meanings the communicator intended by considering the context in which they find it. But this process leaves ample room for ambiguity and subjective interpretation. One listener or reader might decide that a phrase means something very different from what another one does.

Although one can attempt to communicate ideas clearly through natural languages, the very flexibility and instability of these languages makes doing so an uphill battle. By contrast, mathematics and formal logic have been designed with precision in mind. Because of this precision, translating a natural language idea into a formal, symbolic representation can be challenging. Whereas one can state an assumption or a proposition in natural language without even fully understanding oneself the meaning of the statement, formal languages require that the communicator understands the concept deeply. In fact, we would assert that much of the value of using formal methods stems from the fact that it forces the researchers using them to think thoroughly through the concepts that they invoke. Once the theory has been translated into a formal language, everyone who sees it knows exactly what it means. Though the informal interpretation of the terms of the formal theory might vary from reader to reader, the formal characterization ensures that all of these interpretations have a common core.

That precision has at least two advantages in management research. First, it facilitates the accretion of knowledge. If different researchers use the same term to refer to several different concepts when they develop theoretical propositions, then it becomes exceedingly difficult to understand whether and how their arguments interact. Sometimes, researchers duplicate effort by forwarding fundamentally equivalent ideas under new names. At other times, progress comes to a halt when researchers appear to arrive at contradictory conclusions (perhaps because they use the same natural language terms but imbue them with different meanings).

Second, empirical researchers can more easily and accurately test theoretical propositions when little ambiguity surrounds the meaning of – and hence the appropriate measurement of – the central concepts. Progress in empirical research comes primarily from the ability to falsify theories. But without precise propositions, one often cannot say whether an empirical test refutes a theory or whether it simply failed to operationalize it adequately.

*Logical consistency:* No one intentionally forwards a logically inconsistent argument, but it is nonetheless surprisingly easy to do. For example, one might not recognize an implicit assumption and therefore fail to identify some critical condition necessary for the theory to hold. Or, one might miss the fact that two (or more) assumptions act in opposite directions. Or, less crucially, one might simply impose an unnecessary, possibly redundant, assumption. As theories become increasingly involved and incorporate more and more factors, the opportunities for errors of omission and commission inevitably increase.

But even if the assumptions have been correctly specified and stated, people still regularly come to the wrong conclusions about the implications of those assumptions. The problem is that when relying on verbal theorizing, people rarely think logically through each stage of the chain of an argument; rather, they rely on their intuitions to identify the implications. Our intuitions, however, often prove wrong. Consider the Monty Hall problem (Selvin, 1975). A contestant on a game show can choose from curtains A, B and C. Two of these curtains have goats behind them and one has a car; if he picks the one with the car, he wins it. Let's assume that he initially chooses curtain A. The host then opens curtain B, which has a goat behind it, and asks the contestant whether he would like to choose a different curtain. Should he switch? Most people believe that each of the remaining two curtains has a 50% chance of having the car and, therefore, that the contestant should be indifferent between staying with his original choice and shifting to curtain C (Granberg and Brown, 1999). But mathematics demonstrates clearly that the contestant should switch. In fact, his original choice, curtain A, has only a one-third chance of having the car behind it, while curtain C has a two-thirds probability of

being the winning curtain (because the host intentionally chooses a curtain that does not have the car behind it, thereby revealing information about the other option). One could therefore easily imagine that someone developing a natural language theory of the Monty Hall problem might posit an intuitively appealing but incorrect proposition. More generally, researchers that rely entirely on verbal theorizing have little to prevent them from arriving at errant conclusions.

All formal approaches share the advantage of having tools available for ensuring logical consistency. Analytic models and formal logic use proofs. Simulations meanwhile calculate the implications of a variety of scenarios numerically. In any of these approaches, researchers must explicate all of the necessary assumptions because, without them, one could not derive the results. Redundant and superfluous assumptions moreover become relatively obvious when writing proofs (though those using simulations cannot spot them so easily). Proofs and computational methods, moreover, ensure that the results do follow from the assumptions. In the Monty Hall example, one could have used any of these approaches to arrive at the correct answer. The researcher might make an error in the application of these methods, but, because the rules are clearly defined, readers and reviewers alike can easily audit the assumptions and the chains of logic leading to the propositions.

*Unanticipated implications:* The availability of these tools has another added benefit: one can use them to derive unanticipated implications of the assumptions. Most exercises in verbal theorizing involve recognizing a relationship between two factors, say resources and profitability, and then trying to determine a set of assumptions that would lead to such a relationship. In essence, one moves backwards from propositions to assumptions. A clear disadvantage of this approach is that one cannot find the unexpected (though it may later rear its head in empirical research testing these propositions). By contrast, formal approaches can help the researcher to identify even the most surprising and counterintuitive implications that might follow from a set of assumptions.

Consumers of research using formal approaches often cannot fully appreciate this ability to identify unanticipated implications for two reasons. In some cases, when these implications clearly run counter to reality, they may force the theorist to revisit the initial premises of the model and therefore they may appear only as an intermediate (and unpublished) stage of the research. In other cases, by the time they appear in print, not only have these implications been derived, but also the intuition underlying them has been explicated and therefore the results – though originally surprising – may even seem somewhat obvious (though only in retrospect).

But the value of this ability to explicate more completely the implications of a set of assumptions can be seen in the breadth of propositions derived from relatively simple models. Readers new to formal approaches are often surprised by the complexity of the behaviors that emerge from relatively few assumptions.

Simulations of the behavior of flocks of birds, herds of animals and schools of fish, for example, have demonstrated that a very small number of rules (as few as three) can generate realistic simulations of groups of animals in motion (Reynolds, 1987). In management research, Postrel (this issue) also illustrates the wide range of implications that one can derive from a small set of assumptions.

Beyond simply generating additional interesting propositions, this ability to identify unintended implications also accelerates progress in understanding a phenomenon. Additional propositions offer empirical researchers more targets, more opportunities to falsify the theory. If the propositions follow from the assumptions and empirical analysis falsifies one or more of these propositions, then it suggests that one or more of the assumptions must not hold as well. Researchers must then revisit their theories.

### **Analytical models, simulations and formal logic**

Despite these advantages, each approach to formal theory building is not without its limitations. The use of mathematical methods, for example, sometimes requires unappealing assumptions. Simulations have the disadvantage of only being able to

prove the existence of a relationship between a set of inputs and an outcome; they cannot determine the necessity of a set of conditions. Formal logic, meanwhile, does not as readily accommodate functional forms of relationships and therefore cannot always adjudicate between the expected effects of countervailing forces.

Each of these limitations nevertheless applies only to a particular formal approach. These tradeoffs therefore might constitute a reason for choosing one formal method over another, but none of them suggests that one would want to eschew formal methods altogether. Although it is beyond the scope of this introduction to review each approach in detail, let us expand a little on the relative strengths of each.<sup>1</sup>

*Analytic models:* Some see analytic models as the “gold standard” of formal approaches. The translation of assumptions and definitions into mathematical statements and then the use of proofs to validate propositions mean that these methods impose a strict discipline on clarity and logical consistency. The use of mathematics, moreover, allows one to model the interactions of many, many “moving parts” – pieces of the model that influence its behavior – with the confidence that one’s conclusions do indeed follow from one’s premises.

Both the greatest strength and the greatest limitation of analytic methods stem from the need to produce a model with analytically tractable solutions. On the positive side, mathematical methods encourage the theorist to distill a situation to its essence. Consider, for example, the Prisoner’s Dilemma. This scenario elegantly captures the problem of shirking in team cooperation. It does not describe all of the complexity of a real-life encounter, but it does capture the problem’s essential features. By abstracting away from the details of a particular case, it provides deep insight into an entire class of situations. Indeed, the art of analytic analysis appears in the ability to identify, to abstract and to match to a mathematical approach the

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<sup>1</sup> For those who wish to delve more deeply into one or more of these approaches, we would recommend Harrison et al (2007) for simulation and Hannan, Pólos and Carroll (2007) for formal logic. Mathematics includes such a vast array of approaches and tools that we cannot recommend any single survey.

essential elements of the situation being modeled. But sometimes the depiction of a situation does not fit well with any analytical framework. Attempts to force it into one may therefore result in a theory with little face validity.

*Simulation:* In situations that elude mathematical methods, simulation may provide an attractive alternative. Before moving forward, we should note that although simulation research sometimes refers to particular sets of inputs as “experiments” and the results of these experiments as “data”, simulation is almost always an exercise in theory building; it is not empirical research.

Simulations run the gamut from the simple to the complex. The primary advantage of these computational models relative to analytic methods is that they allow much greater flexibility in certain sorts of assumptions made by the theorist. For example, simulations can accommodate any functional form that one might imagine linking two (or more) variables. But simulations also face their own constraints. The investigation of some classes of problems – such as games with an infinite number of periods – remain computationally intractable even with access to colossal computer power. Whether mathematical methods or simulation offers the preferable approach, therefore, depends on the problem.

Relative to analytic models, simulations have at least two disadvantages. First, because the method itself imposes relatively less discipline on the theorist, these models can become so complex that their inner workings end up being opaque. One can still observe how outcomes vary with changes in the inputs, but the interactions become so convoluted as to prevent the researcher from being able to determine *why* these relationships exist. When the individual components of the simulation are well understood, however, even such highly detailed and complex simulations can be useful. For example, physicists often build incredibly complicated simulations to determine the expected behavior of large-scale systems. They understand the behavior of each component – for example, a molecule or an elementary particle – extremely well, and they also have detailed knowledge of how small numbers of

these components interact, but they must nonetheless rely on simulations to predict the behavior of hundreds, thousands, millions or even billions of these components.

Second, simulation does not constitute a proof. Simulations sample a finite – though potentially very large – number of cases from an infinite set of possibilities (at least when the model includes continuous parameters). One therefore can say that some specific set of assumptions leads to a particular outcome, but one does not know whether any of those assumptions are necessary, or whether some unanalyzed set of assumptions might also prove sufficient to yield the results. Sampling the parameter space as widely and with as fine a resolution as possible can help to allay these concerns, but it does not alleviate them.

In many cases, theorists can combine simulation methods with analytic techniques, capturing a little bit of the best of both approaches. One might, for example, build a simplified model that does not incorporate all of the interesting features of a phenomenon but that does fit within the restrictions of some mathematical framework. After characterizing that model, one might then exploit computational methods to relax some of the assumptions or to extend the features of the model. Such an approach nicely exploits the ability of analytic methods to identify both necessary and sufficient conditions, while still allowing the consideration of those cases that stymie analytical analysis (but that remain amenable to simulation).

*Formal logic:* In many ways, formal logic is similar to mathematical methods. Indeed, mathematics uses first-order logic. Since many of the applications of formal logic to management and organizations also rely on a first-order logic, such as Péli (this issue), these papers differ little in their relative strengths and limitations from mathematical methods.

The biggest difference between formal logic and both analytic and simulation methods arises when researchers select or define alternative logics (i.e. other than first-order logic). In management research, for example, Hannan, Pólos and Carroll (2007) have developed a non-monotonic logic, a formal language, for theory building (for an example of the application of this logic, see Kuilman, Vermuelen and

Li, this issue). This logic includes a number of modifiers and relationships that allow the researcher to represent more accurately the incompleteness of our empirical understanding of a phenomenon. For example, it allows quantifiers like “normally” and “presumably” that first-order logic cannot accommodate (and defines a consistent set of rules for dealing with these quantifiers). It therefore can provide a more realistic basis for developing and combining theory fragments that describe phenomena that still require a great deal of empirical exploration.

Although the ability to develop the language used to build theory might seem to reduce dramatically the discipline imposed by formalization on theorists, logicians have developed a strict set of rules that all formal languages should meet to ensure their precision and completeness. All formal logics therefore have all the rigor of mathematical methods, requiring precise assumptions and definitions and allowing one to prove propositions and to identify necessary and sufficient conditions.

Though formal methods provide powerful tools for developing theory, we would not claim that verbal theorizing – that is, the use of natural languages to build theory – has no place in management research. Whereas formal methods operate deductively, natural languages more readily accommodate induction and intuition. Hence, when an interesting phenomenon is first identified, conjectures, expressed in natural languages, can provide a useful starting point. These conjectures can help to guide empirical researchers in terms of what data they should collect and what questions they should attempt to answer. As the phenomenon becomes better understood, researchers can then revisit the theory with formal tools to develop a more precise, transparent and logically consistent description of it.

### **The papers in this issue**

As noted above, we had an embarrassment of riches from which to choose. We selected papers for this special topic forum not just for their high quality and the importance of their managerial implications, but also for their ability to highlight the variety and value of formal approaches.

Because of the breadth of papers in the special issue, one could choose to order them in multiple ways. We have chosen a rough grouping by subject, but the papers have many other points of contact.

The first three papers deal broadly with the issue of entrepreneurial entry, but each approaches it using a different formal method. Parker and Alvarez (this issue) model the decision problem of how a pair of entrepreneurs should allocate the rights to control a new venture. Although perfectly rational actors would give control to the higher ability member of the team, they interestingly demonstrate that, under conditions of subjective rationality, the team will allocate control rights to the more optimistic of the two.<sup>2</sup> This misallocation of control rights can lead startups to perform poorly. Given the well-known propensity of entrepreneurs to be over-optimistic, this result strikes us as particularly interesting.

Ganco and Aggrawal (this issue) meanwhile develop a simulation to develop a better understanding of the performance differentials between startups and diversifying entrants, and how those differentials depend on the environment. They build their simulation on a variant of the NK model that has been widely used in management research (e.g., Rivkin, 2000). Their model, extending the counter-intuitive idea that adaptation actually hurts organizations in turbulent environments, can both account for all of the existing empirical regularities that have been found and suggests several new propositions that researchers should explore.

Finally, Kuilman, Vermuelen and Li (this issue) consider how the nature of the environment at the time of founding influences the life chances of entrants. Empirical research has usually found that firms that enter during periods of intense competitive crowding suffer higher mortality rates. But some studies have also found the opposite pattern – lower mortality rates among those that enter during times of higher density. The articles reporting these findings appear to arrive at

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<sup>2</sup> Subjective rationality refers to the idea that actors must behave in a way that appears optimal given their beliefs and observations of the environment, but that may not be rational for the omniscient actor (Ryall, 2003).

contradictory conclusions, but Kuilman et al. demonstrate that one can incorporate them into a single theory by introducing the stage of the population's history as an addition factor. Whether density at the time of founding constitutes an advantage or a disadvantage depends on whether the population remains in the legitimating phase or whether it has achieved legitimacy and interactions have become primarily competitive. In essence, they introduce a scope condition.

We should note that the application of the non-monotonic logic in this paper is particularly instructive. Whereas the logic that Kuilman et al. use would have allowed them to resolve these conflicting findings simply by assuming that legitimacy takes precedence over competition (or vice versa), they avoid this easy solution. They avoid it because they have no good substantive reason to introduce a precedence ordering between competition and legitimacy. They therefore wisely avoid such an *ad hoc* assumption.

The next two papers investigate, again broadly, the problem of coordination and incentives. Postrel (this issue) introduces the novel idea of goal ambiguity into the well-understood effects of substitution versus complementarity in joint production. He shows that goal ambiguity can lead to a failure in the allocation of effort even when both actors have incentives only in terms of their joint output. Although this failure looks like a coordination problem, standard solutions to coordination failures – such as sequencing actors' decisions – may not solve this problem and may even exacerbate it. The managerial implications are clear: coordination and goal-clarification have synergistic effects on team performance.

Coff and Makadok (this issue) similarly explore an issue of clear managerial importance: How can a principal (an owner) ensure that agents (employees) do not freeride? In developing their theory, they point out that the manager actually has at least three levers under her control in achieving this outcome: authority, incentives and ownership. All of these vary from being more firm-like to being more market-like. Managers therefore have eight different forms of hybrid organization at their

disposal, and Coff and Makadok demonstrate that at least one of them should generate the optimal allocation of effort across the agents for any type of task.

Finally, we end with two pieces that provide new insight into macro-organizational behavior. Cowan and Jonard (this issue) develop a model of alliance formation in which successful partnership requires that two firms have moderately similar characteristics. They demonstrate that this single assumption can generate a surprisingly wide variety of network structures, including a tendency for repeated interaction and small-world structures. Their results therefore raise the possibility that the need for somewhat similar partners, rather than social factors, may explain a number of interorganizational structures. Since one could imagine the development of a parallel model at the level of the individual, their results may also provide insight into interpersonal networks.

Péli (this issue) meanwhile attempts to reconcile the idea that inertia and imprinting imply that population-level change should occur through the selection (failure) of organizations with the intuition that populations sometimes shift through the adaptation of their individual members. To resolve this apparent inconsistency, he suggests that environmental change may either be quantitative or qualitative in nature. The first, a quantitative change, might force firms to adjust their intensity of various activities, but the latter requires them to do entirely different things to survive. The former therefore allows adaptation, while selection reigns supreme in the latter regime. His approach to resolving this conundrum therefore recalls a similar solution that he posited to when broad versus narrow scope would benefit organizations (Péli, 1997).

We applaud the authors included in this Special Topic Forum for their creative and compelling contributions to management theory and for their able applications of formal methods. We also appreciate the efforts of all of those that took an interest in our call. We hope that the papers that appear here become but the beginning in a long line of interesting and insightful investigations that use formal approaches to develop management theory.

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