Theory-Building in Organization Science with Agent-Based Computational Models: Past, Present, and Future

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Oxford Handbook of Agent-Based Computational Management Science

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Abstract: This paper traces the lineage of organizational theory back to *methodological individualism* as a mode of explanation in social sciences. In this framework, an organization is viewed as a multi-agent system, where an observed phenomenon at the aggregate organizational level is explained as the result of the behavior of and the interactions among the constituent individuals within the organization. In this context, a formal theory as an explanation through deductive logic can be expressed in two distinct ways, one through the use of a mathematical model and analysis and another through the use of a computational model and simulation. This paper offers a comparative review of these two approaches to theory development in organizational science. It first provides a brief review of the mathematical modelling literature, often referred to as organizational economics. This is followed by a review of the progress made in agent-based models of organizations. This sequence of reviews allows us to highlight the complementary roles that agent-based modeling approach and the formal mathematical modeling approach play with one another. We identify the lacunae in the organizational theory literature that could be filled with the agent-based modeling approach, thus charting a path forward.

It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.

Often quoted as 'everything should be made as simple as possible, but not simpler.'

- Albert Einstein, 'On the Method of Theoretical Physics', The Herbert Spencer Lecture delivered at Oxford, 10 June 1933.

1. Introduction

Theorizing about social/organizational systems has a long tradition of "methodological individualism" in social sciences (Weber, 1922; Coleman, 1990). It is a conceptual framework that views social or organizational phenomena as a logical consequence of interactions among individual motivations and behavior. This approach has been utilized most extensively in the field of economics in its construction of the theory of perfect competition as a way of explaining the market organization of economic activities among a population of consumers and producers. [Schumpeter, 1909]

In this paper, I claim that agent-based modeling (ABM) lies squarely within this tradition. Furthermore, I view ABM as a significant positive technological change in the development of theory-building in social and organizational sciences. To examine the contributions it has made to the development of organizational theory in an objective manner, I provide a historical overview of two distinct lines of research which, while sharing the common conceptual framework of methodological individualism, followed two divergent paths of development in terms of their modes of expression, behavioral assumptions, and the analytical apparatus chosen by the scholars in the respective camps. This retrospective analysis shows that there was a significant degree of path dependence in the development of the two lines of research, and suggests that it is now time to assess their respective achievements with an eye toward integrating the insights from both perspectives for the ultimate purpose of constructing a general unifying theory of organizations using ABM.

Organizational theories are built to provide logical explanations for the formation and behavior of organizations at the aggregate level with motivations and behaviors at the individual level. Broadly, these organizations could include "informal" organizations that are formed and sustained via social networks between individuals and the norms that implicitly govern individuals' behavior. In this chapter, however, I focus on "formal" organizations which are characterized by well-defined objectives and clearly specified intra-organizational authority structure within which a set of rules and regulations are enforced. A key feature of formal organizations is that they are designed to outlive their participants. As such, the organizational

structure is defined based on the rights, privileges, and authorities associated with the positions independently of the individuals occupying them.

It should be noted that I make no attempt here to provide an exhaustive survey of the ABM literature as it relates to organization theory. Instead, my aim is to review a selection of papers in formal organizational economics and in ABM-based computational organizational theory that share the common structural framework of methodological individualism. This brings into clear focus those under-developed areas of research that could benefit from the complementary work between the two approaches. For more comprehensive surveys of the ABM literature, the readers are encouraged to consult a number of excellent surveys that have been made available in recent years (Fioretti, 2012; Grabner and Kapeller, 2015; Miller, 2015; Secchi, 2015; Smaldino et al., 2015; Wall, 2016; Grabner, 2016; Gomez-Cruz et al., 2017; Lorscheid et al., 2019).

2. On Theory-Building in General

In the deductive-nomological tradition of scientific explanations, a theory consists of two main "constituents": the *explanandum*, which is "the sentence describing the phenomenon to be explained," and the *explanans*, which is "the class of those sentences which are adduced to account for the phenomenon." (Hempel and Oppenheim, 1948) The soundness of a proposed theory rests on the condition that the explanandum must be logically deducible from the information contained in the explanans.

In this context, a *formal* theory entails a set of definitions and assumptions (typically expressed in mathematical forms) that leads to a conclusion through a chain of deductive logic. The process of building a formal theory, hence, starts with the identification of a phenomenon (or a pattern) to be explained, obtained from the set of empirical observations that are collected either intentionally or accidentally. The theorist then provides a chosen set of assumptions that, through the process of deductive reasoning, leads to the conclusion which approximates the initially identified phenomenon. The success or failure of the theory (as an explanation and/or as an instrument for generating predictions) is determined by how closely the conclusion reached at the end of the deductive process approximates the observed phenomenon.

The chain of deductive reasoning, central to the theory-building exercise, may be described using different modes of expression, including the computational modeling approach. An account of computational models as a useful theory-building tool in social and organizational science is offered in Cohen and Cyert (1961):

> "A theory consists of three elements -- definitions, assumptions, and conclusions. ... The conclusion is a logical implication of the assumptions. The language in which the conclusion is derived from the assumptions is a matter of the theoretician's choice. In general, there are three languages that have been commonly used by economists for drawing a conclusion from a set of assumptions -- ordinary prose, pictorial geometry, and formal mathematics. ... A computer model is a model in

> which the implications of the assumptions, that is, the conclusions, are derived by allowing an electronic digital computer to simulate the processes embodied in the assumptions. Computer programs can thus be considered to be a fourth language in which the assumptions of a theory can be expressed and its conclusions derived. Actually, computer models might be viewed as special cases of mathematical models." [Cohen and Cyert (1961), pp. 113-116]

The choice of the methodology depends on the cost/benefit tradeoffs as perceived by the theorist. Theorizing in economics has traditionally focused on formal mathematical models as the preferred method. The main benefits of the mathematical modelling include the precision with which the assumptions and conclusions can be stated and the technical rigor with which the chain of deductive reasoning can be checked for logical consistency. The cost side of the equation, on the other hand, comes from the limitation in the theorist's ability to accurately track the chain of reasoning when many assumptions and definitions are required to characterize the observed phenomenon. The aspect of model building which qualifies it as "art" then rests on the delicate balance the theorist achieves between minimizing the analytical burden by reducing the number of required assumptions and generating a conclusion which is informative enough for appropriate comparison with the empirical observations (which comes from having greater details in terms of definitions and assumptions). The delicate nature of such balancing act is succinctly captured in the oft-quoted dictum of Einstein that "everything should be made as simple as possible, but not simpler."

The tradeoff defining the optimal structure of the theory as defined above depends critically on the computational capacity of the theorist carrying out the analysis. The most devastating criticism against the formal mathematical modeling approach is the insufficient or unrealistic specification of assumptions, often resulting from the theorist's need to keep the analysis tractable, which leads to overly general or unreliable conclusions. The best-known example of a formal mathematical model in social science is the neoclassical economic theory of competitive markets. The determination of the equilibrium price and quantity through the interaction of consumer demand and producer supply rigorously and elegantly captures the complex organization of the market systems. This analytical rigor, however, is obtained at the cost of using the set of over-simplified assumptions – e.g., perfect rationality of the individual decision makers – and restricting the focus of analysis strictly on the behavior of the system in the state of "equilibrium." This is akin to a physicist carrying out a highly controlled experiment in a laboratory setting such as an environment in perfect vacuum. It is often a leap of faith to believe that any law identified in such a controlled environment can then be used to further understand the real-life environment which is far from the conditions specified in the lab setting.

The computational modeling approach offers a way to relax (to a degree) the restrictiveness with which the assumptions must be specified to achieve an acceptable level of tractability in the resulting analysis. The ability to trace the chain of reasoning is no longer limited by that of the human modeler but is now determined by the computational capacity of the computer that carries out the analytical process through the execution of the computer program coded to follow the chain of deductive reasoning that forms the underlying theory. This enables the modeler to

introduce a wider set of definitions and assumptions that are more in line with the environment surrounding the observed phenomenon, hence increasing the believability of the theoretical conclusion thus derived. The agent-based modeling offers these possibilities while remaining in the same conceptual framework as other general social science programs (of which neoclassical economic theory is a member) that view the social system as an aggregation of individual decision makers, whose actions interact with one another to generate the observed macro-level patterns.

3. Methodological Individualism and Theory-Building in Organizational Science

The neoclassical microeconomic theory is built on the model of a market system under perfect competition. This model starts with a population consisting of two groups of individuals – consumers and producers (firms) of a well-defined set of goods and services. Individual consumers maximize their utility through consumption of those goods and services purchased at the going market prices, subject to their budget constraints. Individual producers maximize their profits obtained from selling at the going market prices the outputs they produced using available inputs and the best available production technology. Hence, all individuals in the market system are making their respective (consumption or production) decisions to solve a constrained optimization problem – i.e., the resulting choices are made "rationally." Furthermore, these choices are coordinated in the market such that the aggregate amount of the goods and services desired by consumers are exactly met by the aggregate outputs supplied by the producers at a unique equilibrium price – i.e., the market clearing price.

The formal (mathematical) theory of the markets under perfect competition describes the functioning of the above system in an elegant application of deductive logic to a set of simplifying assumptions. However, two objections have been raised over time against this analytical model: 1) the rational choice assumption applied to all individuals in the system may be too strong and does not correspond to the actual decision making process in practice; 2) the representation of the producer (firm) in the market as a single decision-making unit leaves the production and the management process within the firm a "black box." These two objections led to the development of two distinct lines of research in economics and management: 1) the field of organizational economics, which addresses the issues of internal organization of activities within the firm in a framework that is consistent with the traditional rational choice approach in economic theory of markets; and 2) the field of organizational theory and behavior as articulated by those scholars representing what is called the "Carnegie School," which deviates from the traditional economic approach by taking seriously the decision-making under "bounded rationality" and focusing on the *process* of organizational decision-making rather than the equilibrium outcome of such activities. It is notable that these two lines of work developed in parallel with very little overlap in terms of their subjects of inquiry or the mode of analysis.

The treatment of organization in the neoclassical theory of markets is limited to the concept of a "firm" which carries out the production. The firm is treated as a black box characterized solely by a production process (technology) that takes in a set of inputs and then puts out corresponding output. This process is captured by a mathematical function specified as the "production

function." The internal organization of activities within the firm was only *implied* by the concept of "economies of scale" in its production technology, which presumably results from the division of labor and specialization of the inputs as suggested by Smith (1776).

Coase (1937) was the first attempt to add realism into the concept of firm in theory. It lay undiscussed for decades until 1960s. The line of research that has developed since along the direction suggested by Coase may be categorized as "Theory of the Firm" which tries to define the boundaries of the firm by identifying the line that divides those actions taking place inside the firm and those that take place outside through market transactions.

Another line of research in Organization Theory has developed that looks into the internal organization of the firm. This line was initiated by Cyert and March (1963), which had as its precursor Simon (1947) and March and Simon (1958). This line emphasized the importance of actual decision making in a firm, introducing the concept of "bounded rationality." Organizational structure and intra-firm communication and information transmission were other topics of interest. Furthermore, Cyert and March (1963) recognized the importance of digital computers and foresaw its growth in social science research as an important theory-building tool.

In this paper, we will first examine the development of formal mathematically formulated organization theories along these two distinct lines. We will then examine the line of work that utilizes ABM for building organization theories, while maintaining methodological individualism as its conceptual framework. This will allow us to identify exactly where ABM has been used effectively as a tool complementing formal approaches, and also where there has been a significant lack; hence, providing a roadmap for the path ahead.

4. A Historical Overview of Formal Theory-Building in Organizational Economics

The literature on organizational economics can be divided into two groups, depending on the resolution of the analytical lens afforded by the methodological individualism: 1) a macro perspective taking each firm (organization) as an individual decision unit and focusing on the emergence and existence of such firms in the population of agents within a multi-agent system (such as a specific market or the aggregate economy) – we shall call this the "Theory of the Firm"; 2) a micro perspective taking a firm (organization) as given and looking into the internal organization of the activities among individual members within the firm – call it the "Theory of Internal Organization". The macro perspective hence entails a wider angle viewpoint at a lower degree of resolution, whereas the micro perspective requires a narrow angle viewpoint at a higher degree of resolution. In this section, we briefly review the theory-building efforts by theorists in the field of economics in these two categories. This will provide us with a relevant conceptual framework for organization theory within which to position ABM research, helping us identify the issues of significant importance.

4.1. Theory of the Firm: Scale and Scope of the Firm

Coase (1937) first posed the question of why certain economic activities are organized within formal hierarchical structures using explicit planning and coordination as opposed to being carried out through the price mechanism in the marketplace. According to Coase, there are costs to carrying out transactions, and these costs depend on the nature of transactions and how they are organized. Staying in line with the ideas of economic rationality and the principle of efficiency, Coase claimed that there is a tendency for the firm to choose to carry out a given transaction internally if it is more cost-efficient to do so than to use the market to carry out the same transaction. While the Coasian theory of the firm is simple, intuitive, yet profound, the original work did not elaborate on the nature of transactions and how they affect the costs. As the result, these ideas were not picked up for further research until 1960s.

It was Williamson (1967, 1979, 1985) who elaborated on Coase's theory of the firm by looking into the nature of the cost associated with different types of transactions. In particular, he defined "relationship-specific" investment (i.e., asset specificity) as a crucial element in defining the cost of transaction. The transaction cost arising from asset specificity through opportunistic behavior on the part of the participating parties and the unavoidable incompleteness in the long-term contracting were shown to be central to the firm's decision to either "make or buy" the product, which led to the issue of vertical integration (i.e., vertical boundary of the firm). Ultimately, this research produced the intuitive outcome that the structure of a firm depends on its market strategy (defining the set of product to produce), the available technology (defining the set of inputs needed for production), and the cost of contracting for those inputs. Williamson's work was further developed into the property rights literature, where the allocation of asset ownership and the residual control became central to the cost of long-term contracting (Grossman and Hart, 1986; Hart and Moore, 1990; Hart, 1995).

Alchian and Demsetz (1972) offered another perspective on the theory of the firm by identifying the joint team production among multiple workers as the critical characteristic of a firm. Within this framework, they emphasized the potential for the free rider problems that are likely to lead to an insufficient supply of productive inputs like effort. To induce the necessary amount of effort from the workers, firms should then hire a manager (principal) to monitor the behavior of workers (agents). The monitor should be given title to the net earnings of the firm so that he has the proper incentives to work. Such an arrangement can induce efficient supply of efforts. At the same time, it will change the partnership or the team into a capitalistic firm with the monitor acting effectively as the owner. Further refinements along this line came in the form of providing specific conditions under which the separation of ownership and labor can occur so that the principal's job is not to monitor but rather to administer incentive schemes for credible policing of individual incentives. This line of research then focused on designing optimal incentive contracts in the principal-agent framework (Holmström and Milgrom, 1991, 1994; Holmström and Tirole, 1991; Holmström, 1999).

4.2. Theory of Internal Organization: Organization of Activities within the Firm

Internal organization of a firm refers to the construct of an organization with regards to how tasks are assigned, communication flows, hierarchy levels are maintained, and other operations are managed to help an organization achieve its goals.

It is reasonable to say that the overall blue print and the clear statement of the agenda for this research were provided by three scholars, Simon, March, and Cyert, who represent what is known as the Carnegie school of organization theory. Carnegie school is characterized by the research presented in three books: Simon (1947), March and Simon (1958), and Cyert and March (1963). March and Simon (1958), in particular, departs from the traditional organization theory (scientific management theory and the efficiency-based theory of administrative organization) dominant up to that point, and present four major factors that clearly map out the directions of their program: 1) introduce motivation and incentives into decision making in organizations; 2) recognize the potential for organizational conflicts (individual or group conflicts within an organization; 3) recognize the cognitive limits on rationality; and 4) address how the cognitive limits on rationality affect the processes of organizational change and program development.

Cyert and March (1963) go on to state:

> "We believe that, in order to understand contemporary economic decision making, we need to supplement the study of market factors with an examination of the internal operation of the firm – to study the effects of organizational structure and conventional practice on the development of goals, the formation of expectations and the execution of choices." [Cyert and March (1963), p. 1]

Cyert and March's call for arms developed into two distinct branches, the first taking the assumption of bounded rationality and utilizing the computational method to address the internal organizational issues, and the second remaining in the neoclassical assumption of perfect rationality. Because the first group of papers using bounded rationality increasingly came to rely on computational methodology, we will review these in the next section where we will be talking about the computational methodology as applied to theory building. In contrast, the second group of work remained very much in the orthodox camp of profit and utility maximization as the driving engine of choice. The formal theories built in this framework will be reviewed in this section.

Rational choice in economic theory entails choosing the optimal course of action out of all feasible options. The choice, in this context, depends on the information the decision maker has about the decision environment as it defines the set of feasible options, as well as on the incentives he faces based on his underlying preferences. In this sense, rational decision making by an individual rests on two factors, knowledge and incentives.

In an organization facing a complex environment, no one individual has the comprehensive set of knowledge required for different kinds of decisions at all times. Instead, the set of knowledge available in an organization tends to be dispersed among multiple individuals. Since the quality of the decision depends on the decision maker's access to the relevant knowledge, the crucial

issue for the organization is how to structure its internal authority relationship to achieve "collocation" of knowledge and decision authority. Two possible options exist in this framework: 1) move the knowledge to the person with the decision authority – information transmission; and 2) move the decision authority to the person with the knowledge – delegation of authority.

The ultimate choice between the above options depends on the cost of transmitting information (which is determined by the available information/communication technology) and agency cost – i.e., the degree to which incentives of different individuals become mis-aligned as decision authority is delegated. Considering these two countervailing forces together, the optimal location of decision authority is found as that which minimizes the total organization costs consisting of the information cost and the agency cost. One of the arguments in favor of the market coordination, forcefully made by Hayek (1945), is that the cost of information transmission is prohibitively high in a market system and, hence, the extent of knowledge transfer is limited. Hayek (1945) argued in favor of the decentralized market coordination for its superior capacity to respond to a changing environment by co-locating decision-making authority with the knowledge required for those decisions:

> "If we agree that the economic problem of society is mainly one of rapid adaptation to changes in the particular circumstances of time and place, decisions must be left to the people who are familiar with these circumstances, who know directly of the relevant changes and of the resources immediately available to meet them. We cannot expect that this problem will be solved by first communicating all this knowledge to a central board which, after integrating all knowledge, issues its orders. We must solve it by some form of decentralization." [Hayek (1945), p. 524]

This view was further examined and elaborated upon by Jensen and Meckling (1992). Recognizing that decentralization of decision rights in a system of self-interested individuals may bring with it the well-known agency problem (Jensen and Meckling, 1976), they identified the alienability of decision rights as the market's solution to such control problems.[1] However, the firms in the market economy represent sub-groups of population, in which the decision making authorities are transferred internally without the corresponding alienability (which belongs only to the owner of the firm).[2] As the alienability is what allows a system to overcome the control problem, the firms must then use an alternative set of mechanisms which can efficiently solve the problem while facing the same informational constraint that a market economy faces. Jensen and Meckling offers the allocation of decision rights as one such mechanism that can be considered

[1] Alienability of decision rights facilitates their exchange in the market. The corresponding right to capture the proceeds from the exchange then ensures that 1) the decision rights will go to the ones with better information as they tend to value them more and 2) the market exchange will provide an automatic reward an punishment mechanism for those who possess the decision rights.

[2] A natural question that arises in this context is why and how these firms are initially formed and sustained in the long run. Jensen and Meckling's theory is not capable of answering this question directly, as they take the organizational boundary as fixed. They do, however, acknowledge the significance of this question and point to the the theory of transaction costs in Coase (1937) and Williamson (1975) for support.

jointly with the agency cost originating from the misalignment of preferences between the different levels of the organization.

As discussed above, the traditional literature on organizational knowledge typically assumed the overall set of knowledge as fixed, ignoring the process of acquiring the knowledge itself. Garicano (2000) offers a model of communication and knowledge acquisition in production. His model starts with a set of problems distributed on the basis of the degree of commonness. Workers in the organization can learn to solve these problems at a cost, which is defined as the cost of knowledge acquisition. The workers then choose to learn those problems that are common enough to justify the learning cost, while remaining ignorant of the rest of the problems. The workers are also allowed to communicate knowledge sets they uniquely possess as required. The problem for the organization is then to match problems to the workers with the knowledge to solve them, while the workers may ask other workers for the solution. In this framework, Garicano finds that specialization occurs inside the hierarchy such that one class of workers specializes in production while all other classes specialize in problem solving to support the workers. Furthermore, an organization having multiple layers has a pyramidal structure with the workers in the first layer specializing in production and the rest specializing in solving problems. His model is also capable of examining the impact of technological change (which affect the costs of communication and knowledge acquisition) on the organizational design in terms of span of control, sizes of production workers vs. knowledge workers, and the depth of the hierarchy.

Dessein (2002) provides a rational choice model of a hierarchy in which a principal may delegate the authority instead of requiring the agents to communicate the local information. The cost of communication here is not the direct technological cost of information transmission (as assumed in the traditional literature), but rather an *implicit* cost arising from the noise contained in the strategically transmitted information. [Crawford and Sobel (1982)] Such noisy information is a likely outcome in equilibrium if the objectives of the agents are not aligned and the inter-agent communication is "strategically" motivated. The main finding is that a principal prefers to delegate control to a better informed agent rather than communicate with this agent if the incentive conflict is not too large relative to the principal's uncertainty about the environment. This work is significant in that it goes beyond the known tradeoff between the costs of information and agency and addresses the impact of strategic communication on the optimal organizational structure.

Alonzo, Dessein, and Matouschek (2008) extends the analysis of Dessein (2002) by exploring the advantages of centralization vs. decentralization when managers are privately informed about their local markets and communicate strategically both vertically (toward the principal) and horizontally (among themselves). In their model, vertical communication tends to be always more informative than horizontal communication, as the objectives between the center and the local managers are better aligned than those between the managers of different local units. Considering the tradeoff between coordination and adaptation in this setup, they find that decentralization allowing for horizontal communication can still dominate centralization with vertical communication, when there exists increased need for coordination. The underlying argument is that the divisional managers tend to be aware of their mutual interdependence and,

consequently, their communication and coordination can be more effective under decentralization, compared to the case of centralization when the managers anticipate the forced coordination from the headquarters.

The above models have brought forth the significance of incentives and strategic information transmission in the context of internal organization of activities. Further refinement and elaboration of Garicano's (2000) model have been made in Garicano and Wu (2012) and Bloom, Garicano, Sadun, and Van Reenen (2014). Dessein's (2002) model has been extended in Dessein, Lo, and Minami (2021) to look at the impact of environmental volatility on the firm's organizational structure.

5. Agent-Based Modeling (ABM) Approach for Theory-Building

The underlying conceptual foundation for the formal organization theory as laid out in organizational economics is the rational choice at the individual level and the structural outcome as an equilibrium in a multi-agent organization. In contrast, the underlying motivating factor for the computation-based organizational theory has been the "evolutionary" perspective with the process of "adaptation" at the individual or organizational level as the central driving mechanism.

Cyert and March (1963) laid down the conceptual foundation and provided a detailed agenda for this line of research in organization theory based on the process-centric view of organizational decision making: "We believe that, in order to understand contemporary economic decision making, we need to supplement the study of market factors with an examination of the internal operation of the firm – to study the effects of organizational structure and conventional practice on the development of goals, the formation of expectations, and the execution of choices." [Cyert and March (1963), p. 1] As one of their main research strategies in this regard, they proposed to:

> "*Develop process-oriented models of the firm*…. The emphasis on studying actual decision process implies a description of the firm's decision in terms of specific series of steps used to reach that decision. The process is specified by drawing a flow diagram and executing a computer program that simulates the progress in some detail. We … study the actual making of decisions and reproduce the behavior as fully as possible within the confines of theoretical manageability." [Cyert and March (1963), p. 2]

The early works in this line of research utilized computational modeling and analysis, but the methodological individualism was only carried out to the level of organization as the decision unit. The internal organization of activities, while much discussed at the intuitive level, was only 'implicitly' reflected in those models by way of differing degrees of bounded rationality in organizational decision making. Hence, the relationship between the internal organizational structure and the efficacy of organizational decisions was assumed rather than endogenously generated as part of the model.

More recent works in this line of research have pursued enhancing the analytical resolution to the level of individuals within the organization, pushing the methodological individualism beyond the organizational level and exploring the relationship between the hierarchical structure of the organization and its performance under various environmental conditions. Agent-based modeling represents the most recent methodological innovation in this line of work. In this section, I review the recent developments in this body of work that utilize ABM for the purpose of understanding organizational behavior.

5.1. Early Works

Cohen, March, and Olsen (1972) follows the agenda proposed by Cyert and March (1963) and explores bounded rationality in organizations by building a "behavioral theory of organized anarchy." The model entails a decision-making process characterized by goal ambiguity, unclear technology, and varying participants. The simulation model is specified in terms of four streams of : 1) choices, 2) problems, 3) flow of solutions, and 4) energy from participants. The decision structure is then captured by the mapping of choices onto decision makers and the mapping of problems onto choices, while the organizational structure is captured by the distribution of energy among decision makers – i.e., the amount of time spent on problems by decision makers at different hierarchical levels. The simulation model is applied to a case of decision-making in universities. The model is more suited for educational institutions with a more flexible structure but is less likely to be relevant for business organizations with relatively clear goal and well-defined decision structure and organizational structure. Nevertheless, the paper is significant for two reasons. First, it takes the first step toward computationally modeling the organizational decision-making process. Second, it demonstrates that the kind of "garbage can decision process" addressed in this paper can persist in formal organizations because of the selective advantage it may confer through diversity in an unstable and unpredictable environment. This latter property will become an important part of modelling the adaptive search process in the development of organization theory.

Nelson and Winter (1978, 1982) report on their decade-long research on an evolutionary theory of firms, in which they present models of firms having capabilities and decision rules that are modified over time to improve their chance of surviving in the marketplace. Because their focus was on the evolutionary process in the *market* involving adaptation and selection, they retained the "firm" as the unit of decision making in the model. They recognized the limitation in this approach and suggested further exploration of the evolutionary insight in the more realistic cases of firms being organizations that coordinate activities of multiple individuals within their structure:

> "Largely in the interests of establishing an understandable linkage between individual firm behavior and industry behavior, our formal models in this book suppress considerations of internal structure and organizational change. But, in principle, an evolutionary theory can treat organizational innovation just as it treats technical innovation. The problems of business strategy, like the issues

> explored by the behavioralists, clearly call for a rich and detailed modeling of individual organizations; the long-run challenge is to discover modeling techniques and analytical methods that will make a rich treatment of the individual firm compatible with tractability in the analysis of larger systems." [Nelson and Winter (1982), p. 38]

Despite this abstraction, their work is significant in that they bring to the fore the idea of organizational search as being driven by market-based selection mechanisms. This provides an ideal pathway to exploring the micro-to-macro nexus in organizational theory.

Levinthal and March (1981) builds a model of organizational learning through adaptive search for new technology. It extends the analysis of Nelson and Winter (1978) by addressing technological refinement and innovation. The model is limited to single-firm adaptation and does not consider the effects of competition, imitation, or other interactions among organizations. Its main contribution is introducing adaptation in the presence of environmental instability and ambiguity. This work is significant in that it has provided a direction for much of the work following in this line in the form of organizational search driven in part by the environmental condition.

Levinthal and March (1981) and the research reported in Nelson and Winter (1978, 1982) demonstrated the adaptive advantage coming from the exploration of new technological options in the form of inventions and innovations. Counteracting these advantages are the foregone benefits from continuing with the existing and proven technology given the organizational resources which are in limited supply. March (1991) pays due attention to this tradeoff between exploration and exploitation as two competing modes of adaptive search. The model is that of development and diffusion of organizational knowledge in which mutual learning takes place between individuals with diverse beliefs about reality and the "organizational code" which reflects the collective knowledge of the population. Over time, individuals adapt to the existing organizational code through socialization, while the organizational code adapts to the beliefs of those individuals that better align with reality. The main insight here is that neither one of the two strategies, exploration vs. exploitation, is universally optimal. The relative advantages of the benefits from the two strategies are dependent on the contexts of distributed costs and benefits and ecological interaction.

5.2. Organizational Learning as Adaptive Search

The early works as described above set the stage for the development of the computational theory-building in organization science. Two underlying concepts stand out as the determining factors for the subsequent path: 1) organizational decision-making significantly deviates from that modelled under the assumption of rational choice of optimizing individuals; 2) the behavior of organizations subject to bounded rationality can be described best as adaptive search and learning in an evolutionary framework. The next stage in this line of research directly took on these conceptual frameworks, but still maintained the extent of methodological individualism at

the organizational level and, hence, did not attempt to explicitly model the internal structure of the organization.

Levinthal (1997) describes organizational search as the process of the firm's adaptation in terms of its organizational form's fit to its operating environment. The set of all feasible organizational forms and the corresponding levels of organizational performance (fitness) are captured as a landscape over which the firm is seen to take a walk to look for a position that raises its level of performance over and above its current position. A critical element of the model is that it allows for the possibility of interdependence among a subset of organizational attributes which then causes the landscape to be rugged having multiple peaks. This model is a direct importation of Kauffman's (1993) NK-model of rugged landscape in evolutionary biology. While it allows one to ask a number of interesting population-level questions, it does not have the capacity to characterize the internal sources of diversity in organizational forms. As such, the set of questions raised in the paper parallels the ones already discussed in evolutionary biology, and the implications for organizational theory tend to be limited to analogy-based descriptions. Nevertheless, the paper is significant in that it puts the spotlight on the insight that the diversity in organizational forms at the population level result from what is known as "epistatic interaction" – i.e., interdependence among internal activities.

Levinthal (1997) assumed myopic search based on experiential learning, where the payoffs following an action is immediately and accurately realized. In reality, two complications can arise in this type of situation. First, the feedback in terms of the payoff may contain an element of uncertainty and, hence, be noisy. Second, the feedback may be delayed due to the action being only a part of a sequence of interdependent actions that lead to the final payoff. In both cases, taking an action requires certain degree of "cognitive" efforts from the decision maker to form a mental model of the search environment.

Gavetti and Levinthal (2000) is an attempt to address the first case. Their model considers a search mechanism that combine "forward-looking" cognitive behavior with the "backward-looking" experiential learning behavior of a decision maker. This is accomplished by representing the true state of nature using the NK model of rugged landscape and then endowing the decision maker with a lower-dimensional cognitive representation of their landscape. The cognitive part of the search then allows the decision maker to choose a region on the rugged landscape which then is supplemented with the experiential learning mode to identify the optimal position on the landscape, where the reinforcements are taken not on the basis of the actual payoffs but, instead, of the payoffs inferred from the chosen mental model. The combined learning mechanism, where cognitive representation guides the experiential learning, is seen to generate superior performance for the organization.

Denrell, Fang, and Levinthal (2004) also considers the simulated organizational search process under a model-based learning mechanism but in a way that addresses the second type of complication mentioned above. Their analysis sheds light on the importance of partial information in the form of routines, which may not be perfect in the short-term but may prove efficient in the long run by reducing the time spent in unproductive random search. Another

implication they derive from the computational output is that the turnover in organization can have serious consequences in organizational search, both positive and negative depending on the task structure faced by the organization.

5.3. Organizational Structure

The models of organizational learning discussed above all assumed that the organization itself is the unit of decision making as if it takes its action based solely on the direction of the single decision maker at the top. This carries the methodological individualism to the level of the organization, abstracting away from the internal structure of the organization – a crucial aspect of organization theory as proposed by Cyert and March (1963). This section covers those models that explore the internal coordination of activities within the organization and how its overall performance is affected by the various ways in which the decision rights are allocated within the hierarchy. While the focus is on the internal structure of the organization, the main mode of organizational behavior in all of these papers is still the process of adaptive search and learning in a given environment as the organizations pursue improvements in its performance.

Chang and Harrington (2000) constructs a model of a multi-unit multi-level organization such as a retail chain characterized by a two-level hierarchy of the headquarters and multiple unit managers facing diverse local market environments. The organization engages in search over a landscape which is defined over the space of unit-level practices. The aggregate performance of the organization is the sum of the performances at the local unit level. The main question is whether the search for performance-improving search should take place in a decentralized manner where each local unit searches for improvements based on information from its local environment or in a centralized manner in which the center mandates the best practice across all units. As a variant of the usual rugged landscape models, they exogenously specify the local optima from outside and then examine the organizational performance over time as it searches over the landscape for the optima (unknown to them *ex ante*) under the two structural forms. The main result is that centralization outperforms decentralization when the local environments are sufficiently similar, while decentralization does better when the environments are very different. Furthermore, they find that centralization performs better over short horizons, while decentralization does better over long horizons. They also consider the structural performance in environments with turbulence and find that centralization outperforms decentralization when fluctuations are sufficiently large, while the reverse is true when fluctuations are sufficiently small. Hence, the main insight here is that the desirability of the organizational structure in terms of centralization vs. decentralization very much depends on the nature of the environment faced by the organization as well as the operating horizon over which the search takes place.

Rivkin and Siggelkow (2003) also asks the question of how organizational structure affects the firm's performance. Contrary to Chang and Harrington (2000) who construct the search landscape from the demand conditions in local markets, they follow the approach taken in Levinthal (1997) and construct their landscape with ruggedness by directly specifying the interdependence among activities carried out by the organization. Given the rugged landscape

thus built based on a fixed degree of interdependence, they then consider different organizational forms along the three main attributes: 1) vertical hierarchy with CEO and subordinate managers, where the CEO may be either active or passive (rubber-stamping); 2) subordinate managers with differing levels of capabilities with respect to the scope of search they can carry out; and 3) incentives with varying weights given between the departmental objective versus the organizational objective. As was the case in Chang and Harrington (2000), they find the performance of an organization to be dependent on the intricate ways in which these design attributes interact with one another. A main insight that they derive is the importance of firm's activity to balance search and stability on the realized level of performance. This intuition is reminiscent of March's (1991) work on the tradeoff between exploration and exploitation in organizational search as it is applied to the internal organization of activities.

The model and the analysis reported in Rivkin and Siggelkow (2003) are further extended and enriched in a series of related papers, including Siggelkow and Levinthal (2003), Siggelkow and Rivkin (2006), and Rivkin and Siggelkow (2007). Siggelkow and Levinthal (2003) considers a population of organizations faced with a new environment (rugged landscape), engaging in the adaptive search for the new optimum from a randomly chosen initial position under three distinct search strategies: 1) centralization, 2) decentralization, and 3) temporary decentralization with re-integration. They find the temporary decentralization to be optimal when there is a high degree of interdependence among a firm's activities. Siggelkow and Rivkin (2006) further refined the search strategies by introducing "search radius" to reflect the varying degree of boundedness in the managers' rationality as they search over the landscape. Rivkin and Sigglekow (2007) keeps the overall degree of interdependence among activities fixed, but considers different "patterns" of interaction as captured by the various types of influence matrices showing the linkages between the activities. They find that changing the exact pattern of interaction, even if the overall degree of interdependencies remains constant, can have a significant impact on the number of local optima. This implies that the performance of an organization can be influenced by the design of its production systems. [For further research on modularity in structural design and its effect on organizational search, see Baldwin and Clark (2000), Ethiraj and Levinthal (2004), and Fang, Lee, and Schilling (2010)]

6. Discussion and Conclusion

The review up to this point suggests that "path dependence" was a critical element in the divergent development of the two line of organizational research. Organizational economics brought the methodological individualism perspective into the study of organizations using the rationality-based economic models, which made it efficient to utilize the same class of analytical (mathematical) methods typically used in the traditional neoclassical economic theory. This body of work has identified a large number of significant factors in the organizational behavior, but its limitation is in the relative lack of discussion on the out-of-equilibrium process and the dynamic nature of organizational change in view of the constant Schumpeterian process of "creative destruction." [Schumpeter (1942)]

The computation-based organizational theory, on the other hand, developed on the basis of the view that human decision making is subject to bounded rationality, which invites explorations into organizational learning as the natural next step. As the perspective of methodological individualism was applied to the study of organization as a multi-agent system, these initial conceptual positions led to the eventual development of process-centric research agenda. The earlier review of the literature revealed that much of the work in this line of research are framed in the context of evolutionary process driven by adaptive search and selection based on the organization's fitness. While such process-centric approach provides a substantial advantage over the mathematical and economic models of organization for its capacity to address the issues of non-equilibrium dynamics, it suffers from the excessive reliance on arguments through analogies from evolutionary biology. In particular, many of these recent models discussed here view adaptive organizational learning in terms of search over rugged landscape, while engaging in much hand-waving when it comes to describing the underlying environmental factors that lead to such landscapes. This lack of coherent framework, within which the relevant characteristics of the search landscape can be linked to the specific causal factors, is a serious weakness in this line of research.

Recognizing the relative strengths and weaknesses of the two lines of research, an attempt is made in this section to chart the path forward by integrating the two perspectives in a way that can further enhance our understanding of the organizational behavior. The following short-term and long-term strategies are suggested for this purpose:

1) Model the strategy-structure nexus by connecting the internal organization of activities with the strategic interactions among competing organizations;
2) Endogenously grow a hierarchy by modeling the recursive process of delegation in view of the tradeoffs between communication cost and the agency cost;
3) Build a general unified model of organization that facilitates a sufficiently wide-angle view to generate insights into organizational ecology.

The idea that the structure of an organization depends on its competitive strategy in the market goes back to Chandler (1962). Although the importance of the relationship between strategy and structure has been accepted widely since then, there has been a relative lack of formal models built to address the issue in a systematic manner. The lack in the mathematical models is understandable as the integration of the strategy dimension and the structure dimension in a single model of organization substantially raises the degree of complexity, with the corresponding reduction in the analytical tractability. This, of course, makes the computational approach relatively attractive as an alternative method for model construction, even though the literature on ABM-based research has remained rather slim due to the formidable challenges caused by the complexities in the construction of an appropriate model. A preliminary step in this direction is taken in Chang and Harrington (2003).

Chang and Harrington (2003) explores the strategic choice of organizational structure in a setting where multi-unit/multi-level organizations engage in competition in local markets. Their model of organizational structure is taken directly from Chang and Harrington (2000) where an

organization can use either centralization or decentralization as a way of organizing search for improving its performance. While the original model was restricted to the search process of a single firm (with multiple local units) given the externally defined market demands, the extended version in Chang and Harrington (2003) introduces strategic interaction between multiple firms through the competition in local markets and links them to the internal structural choice of the firms. The demand for a firm's output in a local market evolves over time as consumers are also seen to engage in adaptive search for their preferred supplier. They identify an increasing returns mechanism working between the search processes of consumers and firms, which leads to a higher relative performance of the centralized organizational form when competition in the local markets become more intense.

The modeling of strategic competition in Chang and Harrington (2003) entailed substantial abstraction to minimize the number of relevant parameters to keep the computational load and the analytical tractability of simulation output at a manageable level. Nevertheless, the base model can be used as a starting point from which further extensions can be made. These extensions will involve enriching the inter-firm interactions in the product markets by incorporating insights from the theory of oligopoly and other related variants in the field of industrial organization. The firms' selection of organizational structure was also modelled in the framework of game-theoretic equilibrium. There are other options to capture this aspect of firms' decision making; most notably the use of bounded rationality and experiential learning.

The second proposal is motivated by the observation that all models, in both mathematical and computational lines, of organizational structure considered in this review assume externally fixed hierarchical structure. The firm's choice of organizational structure is, hence, restricted to the fixed levels assumed in the model. A useful line of research for ABM is to endogenously generate a hierarchy by allowing individuals to create additional layers by considering delegation of their decision rights to the next level of individuals by considering the information-incentive tradeoff specific to the level they belong to.

The generative algorithm underlying such a model would have to be recursive in structure, since each individual who is given the decision authority must also make a similar decision to further delegate the authority over the set of tasks he is assigned. The decision to delegate by each individual creates an additional layer in the organizational hierarchy. When the individuals at the bottom level of the hierarchy optimally choose not to delegate, the hierarchy stops growing. The main issue of interest in this setting would be the ultimate shape of the hierarchy thus generated, as represented by the depth of the hierarchy (number of levels), average span of control per manager, and the size of the organization as measured by the size of its membership.

It is widely accepted that the unique strength of ABM lies in its capacity to explain the emergence of a macro phenomenon by fully specifying the "generative" process that leads to the ultimate outcome. The last proposal to build a general unified model of organization is essentially a move to integrate the first two proposals by combining the model of internal organization with the model of external competition in a single model. This merging of the two perspectives will allow us to gain a wide angle view of organizations while maintaining the analytical resolution fixed at

a sufficiently high level to generate explanations for the population (of organizations) level phenomenon in terms of individual motivations and incentives within those organizations. Further extensions in this direction can consider formation of organizations – hence, their births – as well as their dissolution – their deaths – through the selective forces of market competition. This will allow us to grow not just an individual organization, but the entire population of organizations of varying forms, sizes, and other characteristics. Such extensions permit direct connection to the voluminous empirical literature in organizational ecology (Carroll and Hannan, 2000).

Shifting the scope of the analysis from a narrow angle perspective to a wide angle perspective while maintaining the methodological individualism down at the individual agent level, as proposed here, will surely pose formidable challenges in terms of the increased complexity in the model. Nevertheless, the application of agent-based modeling combined with the complementary insights from the two distinct lines of research reviewed here should provide the necessary support as we move forward.

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