6 Agent-Based Analysis of Dynamic Industrial Ecosystems: An Introduction

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INTRODUCTION

The agent-based approach, which is used in the chapters of this section, explicitly studies the emergent macro-level phenomena from interactions at the micro-level between autonomous agents. Individual attributes and strategies of the agents can influence the emergent patterns, the information derived by the agents, and the structure of the network of agents.

Agent-based analysis can be performed by conceptual (like in Chapter 9) as well as computational approaches (like Chapter 7 and 8). The computational approach is referred to as agent-based modeling.

Agent-based modeling within social science has its roots in the early 1970s. Initially developed during the 1940s, the technical methodology of computational models of multiple interacting agents arose when John von Neumann started to work on cellular automata (van Neumann 1966). A cellular automata is a set of cells where each cell can be in one of multiple predefined states, such as forest land or farm land. Changes in the state of a cell occur based on the prior states of the cell's own history and the history of neighboring cells. Cellular automata became more popular in light of a creative application by John Conway, named the Game of Life (Gardner 1970). *The Game of Life* illustrated how the following simple rules of local interaction could lead to the emergence of complex global patterns.

In contrast to cellular automata, agent-based models enable a researcher to examine the heterogeneity of agents beyond their specific location and history. A pioneering contribution is the work of economist Thomas Schelling (1971; 1978) who developed an early agent-based model by moving pennies and dimes on a chessboard according to certain simple rules. His model had a surprising result: although each agent tolerated neighbors who are different (being a penny or a dime) and thus only moved when they had many dissimilar neighbors, the population ended up in segregated groups. Political scientist Robert Axelrod made a major contribution with his repeated prisoner dilemmas (PD) tournaments (Axelrod 1984). Axelrod invited scholars from all over the world to submit strategies that would be programmed to play repeated prisoner dilemma games against other submitted strategies. The winner in two successive experiments (submitted by Anatol Rapoport) was the simple rule, Tit-for-Tat. Players in a two person repeated, prisoner dilemma who followed this strategy, would start with cooperation. In subsequent rounds, one player would then copy the action of the other during the previous round. Thus if both players continued to cooperate in any one round, both would continue to cooperate in the next round, until one defected (= not cooperated) leading to a defection by the other. After the tournament, using an agent-based simulation, Axelrod showed why Tit-for-Tat strategies can evolve starting from various distributions of initial strategy populations.

The founding contributions of agent-based models were thus theoretical and abstract. They showed how simple rules of interaction could explain certain macro-level phenomena such as spatial patterns and levels of cooperation. During the last 20 years, the number of publications of simulations of populations of interacting agents who play games and exchange information has grown substantially. In the last ten years, we see an increasing use of agent-based models in various application areas like economics (Tesfatsion and Judd 2006), geography (Parker, et al. 2003), sociology (Macy and Willer 2002), political science (Kollman, et al. 2003), anthropology (Lansing 2003) and cognitive science (Goldstone and Janssen 2005).

During the last five years, agent-based modeling has been applied within industrial ecology (e.g. Axtell, et al. 2001; Janssen and Jager 2002; Schwoon 2006; Kraines and Wallace 2006). Agent-based approaches are used within industrial ecology to address a number of fundamental themes that will be discussed in further detail: (1) collective action, (2) innovation processes, and (3) system analysis.

Collective action

Firms who like to exchange waste flows experience a social dilemma: are firms willing to make the investments now to become more dependent on the performance of other firms and have monetary benefits in the longer term? What if a firm invests their production structure to be able to use the waste flows of a neighboring firm, who may move, get bankrupt, or not produce the same waste flows in the future?

Within the study of industrial ecosystems, the industrial symbiosis in the Danish village, Kalundborg, has been an illuminating example of a successful industrial park (Ehrenfeld and Gertler 1997). Since the 1960s six industrial plants invested in useful exchange of waste streams (like water, heat, stream, fly ash, gypsum, etc), leading to significant savings of energy and natural resources in addition to monetary benefits. The success of Kalundborg has been attempted to be copied in other places, without much success. A potential reason is attributed to the unique situation of Kalundborg, a small village where the managers of most of the firms came from the local community who regularly met each other. From the study of collective action, it is known that repeated interaction contributes to the self governance of common resources and the provision of public goods (Dietz, et al. 2003). Imposing the exchange of waste flows between firms, while seeming logical on paper, may not function well in practice due to a lack of social capital to solve the social dilemmas. Agent-based analysis (Howard-Grenville and Paquin, this volume) and agent-based modeling might help to understand the conditions under which industrial ecosystems might emerge.

Innovation processes

Agent-based modeling is used to study innovation processes to address the conditions under which new innovations evolve and how new products and practices diffuse in a population of producers and consumers (Andrews, this volume; Janssen and Jager 2002; Schwoon 2006; Ma and Nakamori 2005). This use of agent-based modeling refers back to the field of evolutionary economics (e.g. Nelson and Winter 1982), where simulation models are used to simulate innovation, diffusion and learning of firms and organizations. Evolutionary economics traditionally focuses on innovations affecting the monetary performance of the firms involved who have various types of capital and labor inputs. Firms balance the need for innovation and imitating good innovations from competitors. Although investments in Research & Development might be costly, there are benefits of being ahead of the curve and shaping the technological landscape. Evolutionary processes are used to investigate which strategy types employed by firms are more effective in different types of markets. Applying this type of analysis to industrial ecosystems requires the explicit inclusion of material and energy flows (inputs and outputs).

System analysis

In a similar vein as the study of innovation processes, agent-based models can be used as a computational laboratory to test the implications of various policies and future scenarios, as done by Batten and Grozev (this volume). Agent-based models for policy analysis have been used for such exploration in economics (Tesfatsion and Judd 2006) and land use change (Parker, et al. 2003). The goal of such an analysis is to explore, not predict, possible future given scenarios of explicit assumptions of agent behavioral strategies, rules and regulations and external perturbations (such as price shocks).

Based on the state-of-the-art knowledge, simulation models of industrial ecosystems can be constructed, like the electricity market in Batten and Grosev, to understand the complex interactions and to investigate the consequences of possible policies. Such models can be used in participatory processes to enhance learning and explore future scenarios of complex social-ecological systems (Downing, et al. 2000).

CONCLUSION

Agent-based modeling and analysis is a fruitful way to include more social science in the study of industrial ecosystems (Janssen, et al. 2001). Industrial ecology has traditionally been dominated by an engineering focus, but more emphasis is given in recent years on the social science perspective. Since agent-based modeling is an increasingly used tool for the analysis of complex social systems, it is no surprise that applications are appearing on industrial ecosystems.

Agent-based models can especially provide new insights in collective action, innovation analysis and policy analysis for industrial ecosystems through the combination of the increasingly grounded social simulation models developed in other disciplines with detailed data collected on social processes of industrial ecosystems. The chapters in this section provide a stimulating contribution to reaching this ambition.

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