Towards Simulation Models of the Dynamics of Business Relations and Networks

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Abstract

Purpose of the paper and literature addressed: The dynamics and evolution of business relations and networks has received limited attention in IMP related research and the business literature generally. We take the first steps to developing a comprehensive simulation model that addresses these issues.

Research method: We identify the main mechanisms and business processes such models will need to include and review simulation and modelling literature that has attempted to represent such mechanisms and processes.

Research findings: The models reviewed provide the basis for developing agent based models of business networks and identifies where additional modelling efforts are required.

Main contribution: Developing the bases for a new generation of agent based models of dynamics and evolution of business relations and networks

INTRODUCTION

Researchers associated with the IMP Group and others have undertaken extensive research and theorising regarding the nature and determinants of business relations and networks (reviewed in Wilkinson 2001). A subject that has received limited attention is that of the dynamics of relations and networks, how they emerge and develop over time and the mechanisms and processes involved. Basic IMP thinking is dynamic in that it focuses attention on the interactions taking place in relations and how these shape the development of relationship atmosphere and structure but research on relationship change over time is limited mainly to:

a) Stage models in which a pre-given sequence of stages is assumed to occur with each providing the preconditions for the next, analysis of the processes involved in relation and network development (Ford 1980, Dwyer et al 1987),
b) Case studies and descriptive characterisations of relationship histories that highlight some of the processes going on (e.g. Kinch 1993, Narayandas and Kastri 2007)
c) General theories and Schematic models suggesting some of mechanisms and feedback effects that undery the dynamics of aspects of relations, such as trust and power (e.g. Wilkinson 1990, Huang and Wilkinson 2006).
d) Speculative accounts of the patterns of evolution (e.g. Johanson and Hakansson 1991)
e) Analysis of some of the mechanisms and processes involved in the dynamics and evolution of business relations and networks (e.g. Halinen and Törnroos 1998, Wilkinson and Young 2004)

Some simulation models have been developed that capture certain aspects of business network dynamics, such as the interaction between exchanges in connected relations using Boolean rules to represent the way exchanges are connected (e.g. Easton and Wilkinson 1997, Easton et al 1999, Easton et al 2007, Wilkinson and Wiley 2001) and to represent aspects of the evolution of a particular industry (e.g. Følgesvold and Prenkert 2009)

The purpose of this paper is to propose a way of researching the dynamics, evolution, and performance of business relations and networks using simulation methods. There has been a revolution in the development of simulation models of social and economic systems in recent times, built on the increasing power, speed, capacity and accessibility of computers and developments in object-oriented programming languages that lend themselves to the task of representing and modelling complex systems, including business relations and networks. These new types of models of complex systems are known as agent-based models because they build a model from the bottom up, starting with the characteristics of individual agents (actors in a system) and how they interact and respond to each other (for reviews, see Tesfatsion and Judd 2006). We are starting to see increased attention being paid to this type of modelling in marketing and business, e.g. Følgesvold and Prenkert 2009, Goldenberg et al 2001a and b, Winzar 2007).

We believe that the key features of business relations and networks can be represented in agent-based models and that such models can be used to explore the complex interactions between the many different mechanisms and processes involved and how they affect the way relations and networks develop and perform. The models would also provide a new type of management tool, along the lines of flight simulators, for use in developing and testing firms' strategies for participating in relations and networks. An example of this is the MIT Beer game developed to simulate the interaction between different types of firms in a distribution channel (e.g. Holweg and Bicheno 2002). The game is used to give managers the experience of playing a role in a simple physical distribution system in which they have limited knowledge and control of what goes on. It shows how complex dynamics arise, even though each firm is apparently acting rationally, due the delays, feedback effects and interactions among firms. No one type of firm can by itself control the outcomes by changing its strategy. More complex and realistic computer simulation models that now seem possible to build would open up valuable new ways for teaching, research and strategy and policy development.

In this paper we review a selection of agent-based models and other types of simulation models that have been developed to model the dynamics of various types of networks, including social, biological and mathematical networks, and examine their potential relevance for modelling key components of an agent based model of the dynamic and evolution of business relations and networks. To begin with we identify some of the main mechanisms and processes a comprehensive model of business relations and networks would have to represent, albeit in a simplified or stylised way. We then review the simulation for examples of attempts to model some of these key mechanisms and processes.

KEY COMPONENTS OF A MODEL OF THE DYNAMICS AND EVOLUTION OF BUSINESS RELATIONS AND NETWORKS

The type of model we seek to develop is not variables based like many of the comparative static models we see in the literature, with all their boxes and unidirectional arrows. Variables are abstract dimensions of the structure and behaviour of a system but firms and managers do not deal with variables, they act and react to others and to the events that happen. While we may be able to capture some of this in terms of the attributes of the actors and actions involved and be able to compute correlations among attributes based on cross sectional surveys this tells us little about the actual processes going on over time in a relation or network and how and why one thing leads to another. Variance based linear models based on cross sectional research also make assumptions about the nature of the entities involved, the meaning of causation and the role of time, which limit what we can see and learn (Buttriss and Wilkinson 2006, Van de Ven and Poole 2005).

What we require are process models, which capture the way actions and interactions take place over time and the effects these have on those involved, including what they learn, how they perceive others, how they make decisions and how they adapt. This involves representing in a model the key causal mechanisms underlying what goes on. The term mechanism is often loosely used and can be confusing. It has to do with how something has an effect; the actual physical, mechanical, psychological, economic, sociological etc. processes that are involved in one thing leading to another. We all live and work with mechanisms and processes not variables. A simple definition of mechanisms is from Campbell (2005) "Mechanisms are the processes that account for causal relationships among variables." A fuller definition is from Hedtrom (2005):

> "Mechanisms consist of entities with their properties and the activities that these entities engage in, either by themselves or in concert with other entities...a constellation of entities and activities that are organized such that they regularly bring about a particular type of outcome."

Mechanisms are often left implicit in our causal explanations of events, especially if we are focusing on the behaviour of variables rather than actors. Thus we may say that a manager's trust in another firm depends on how reliable or benevolent a firm has acted in the past. This implies that if the other firm's behaviour in terms of reliability and benevolence changes it could affect the amount of trust the manager has in it. But unspecified are the processes involved, what kinds of changes in behaviour are perceived by the manager as evidence of better behaviour, how is this communicated to the manager? How accurate are perceptions likely to be due to thresholds of awareness and attention, bounded rationality and selective perception processes? How do changes in perception cause changes in trust, is it a simple addition as suggested in some models of behaviour, or a more complex psychological sensemaking process? What happens as a result of changes in amount of trust and how and why? Mechanisms are everywhere because that is the way things work but identifying them is not something we are trained to do. In the physical sciences and engineering they are much more concerned with mechanisms as they try to understand how things work and use this knowledge to make other things. Instead of analysis the focus is on synthesis.

A computer simulation of the kind we are discussing is basically about representing mechanisms. These are captured in the computer programs driving the behaviour and responses of each actor in the system. Actors in business relations and networks are people in their roles as managers and workers, collective actors like firms and other organisations and inanimate or passive actors, such a physical products, resources, machinery and geography. People are biochemical, physical systems as well as psychological and social actors. The types of mechanisms involved in business networks includes psychological, social, economic and material processes. We cannot capture all of them in detail in a computer model and nor would we want to as the model would then be as complicated as the business networks we want to study. Instead, we have to simplify, capture the essence of the main mechanisms involved and gradually assemble them into a more comprehensive model in a modular kind of way. We start with simple models of different mechanisms, study how they work, then combine them into larger more complete models and study how they interact with each other and if there is any emergent behaviour. We continue like this calibrating and testing our models as much as we can against real world systems and processes until we have a model that can be used by researchers, teachers, managers and policy makers in meaningful ways to address particular kinds of problems and issues. Models of this kind have been and are being developed in other contexts and we can learn from them as well as from more basic work on particular types of mechanisms. But before we do this we need an idea about what kinds of mechanisms should be modelled.

Based on previous research and theory on the nature of business relations and networks we have identified five general types of mechanisms to focus on, which we believe are central, and which comprise various sub-mechanisms. The mechanisms are distinguished in terms of the type of phenomena they seek to explain but the same kind of underlying mechanism may be relevant to more than one type of phenomena, such as various psychological mechanisms.

1. Mechanisms related to specialisation and division of labour

Firms in business networks are heterogenous, comprising competing and complementary firms, including buyers and sellers, intermediaries, producers, suppliers, service suppliers etc. Firms specialise in particular assortments of activities that match their capabilities, skills resources and capacity and offer value to other firms. Firms also source inputs from and/or rely on services performed by other firms with different resource endowments specialising in different assortments of activities because of the value they provide compared to alternatives, including insourcing. The processes of insourcing and outsourcing involve decision-making and evaluation processes, whereby firms compare the perceived costs and benefits of alternative potential suppliers in their consideration set. The costs and benefits change over time as firms become aware of better alternatives and firms' scale and scope changes as a result of their performance over time and changes in market conditions (Dixon and Wilkinson 1986). This alters the patterns of specialisation in the network and who interacts with whom. Scale and scope effects enable firms to reduce their costs of performing particular activities altering their attractiveness to other firms as suppliers and customers. Changes in the scale, scope and frequency of transactions as markets expand or shrink and the relationships between firms develop (see 3. below). These impact on transaction costs and the benefits and costs of dealing with other firms affecting the kinds of specialisation that are viable (Dixon and Wilkinson 1986). Technology is also important, a type of environmental condition, as this affects how quickly costs fall in relation to changes in scale and scope and how activities are interconnected, such as whether they are complementary or competing (see 5. below). Opportunities for various types of intermediaries to emerge arise, that specialise in particular activities on behalf of other firms e.g. wholesalers, component suppliers, transport agencies, system suppliers. Everyone is familiar with the diagram in marketing text books which illustrate that intermediaries result in efficiencies due to reduced transactions and bulkier transactions but the processes by which this happens is not well understood (Wilkinson 1990).

2. Business Mating Mechanisms: The formation of relations and networks

The mechanisms here have to do with how firms encounter each other and how they choose and refuse and get chosen as potential relationship partners. This could vary from random processes to ones that are influenced by past interactions, predispositions and communication networks. How firms switch partners is also relevant which depends on the processes taking place in the focal relation (see 2 below) and how they learn about and evaluate alternatives.

3. Business Dancing Mechanisms: Interacting in Relations

Once a relation is initiated other types of mechanisms come into play in terms of the processes of interaction, including exchange mechanisms and social interactions through which people and firms learn about each other, adapt to each other and gain and lose resources and benefits. Firms may use various types of strategies in deciding how to interact and adapt them over time based on the experience and outcomes occurring. This means we need to model learning and adapting processes as well as communication and exchange processes. Relationship termination and decline processes must also be possible as well as development. This will partly depend on what is happening in other connected relations and the more general environment.

4. Mechanisms Connecting Relations

IMP researchers have led the way in studying connected relations and we have some idea of the different types of impacts and functions of connected relations (e.g. Anderson et al 1994, Blankenburg-Holm et al 1996, Wiley et al 2009). But these are the results of various kinds of underlying mechanisms, including the way exchange in one relation depends on exchange taking place or not in another relation at the same time or in advance of the focal exchange (Easton and Wilkinson 1997, Easton et al 1999, Easton et al 2007), as well as communication, innovation and learning processes and technological processes.

5. Environmental Mechanisms and their Impact

Any business network operates in a context that includes other industries and networks, markets and the general macro environment. It is not the purpose of the models we propose to model the environment as such, as this would make our task impossible. But we can include aspects of the environment and how it changes over time into our model, including the speed and variability of change and any feedback effects that may arise from actions taking place in a focal network. For example in a comprehensive agent based model of the development, evolution and demise of the Anazasi Indian tribe in America, the modellers were able to include the known history of weather patterns and the physical geography of the environment into their model (Axtell et al 2002). In a similar way a generic model of business relations and networks can be adapted and recalibrated to fit better with particular business contexts and environments to examine how it performs and why.

We will not be able to adequately represent all of these mechanism in one model, as it would probably be too complex to make sense of. However, some representation of each of the four types of mechanisms has to be part of any complete model of business relations and networks. In the following we review previous research that has been undertaken to model each of these types of mechanisms and sub mechanisms in various types of systems as a basis for developing our own model.

MODELLING BUSINESS NETWORK MECHANISMS

In the following we use representative examples of models in which one or more of the mechanisms of interest have been modelled. Some form part of more comprehensive models designed to represent actual systems and others are more abstract formulations, focusing on specific mechanisms. The models are divided into two broad types – those modelling the dynamics of the network itself and concern mechanisms more relevant to modelling business mating, connecting relations and environmental impacts. The second type is models of dynamics within a given network, which deals with business dancing mechanisms or the way interactions take place between and among actors and how they learn and adapt. These two types are not independent of each other, as the ongoing processes of interaction in and between relations is both shaped by and shapes relationship and network structures (Wilkinson 1990). A network is in a constant state of being and becoming.

1. MODELLING MECHANISMS RELATED TO SPECIALISATION AND DIVISION OF LABOUR

The effects of specialization in the presence of uncertainty and transaction costs is explored in the BankNet Simulator (Sapienza, 2000). Agents are supplied with random amounts of cash, which they seek to invest most profitably. They pass it on to agents that have performed better in selecting investment opportunities in earlier rounds. Additionally, in every given round, some agents receive an opportunity to invest in a value creating project. But the necessary investments are always greater than the amount of cash the agent currently has. It therefore needs to borrow from other agents, preferably those who have acquired a large capital stock through other agent's investments. Agents are able to gain from experience, which makes their investment choices more likely to succeed and thus they become more attractive for depositors. Furthermore, due to economies of scale and learning effects, the size of the available capital decreases an agent's marginal transaction costs, which makes bigger players even more attractive to potential investors.

After only a few hundred rounds the numbers of banks, i.e. agents that receive investments and requests to borrow money from them reduces drastically. A stationary state with a few specialized or intermediary banks emerges. The intermediaries are those with the lowest transaction cost and greatest experience, which generates the greatest absolute returns. In the early stages they are singled out through chance events and trial and error and, through being the first to gain economies of scale and experience, they increase their attractiveness.

This model captures the essential mechanisms underlying the emergence of intermediaries including random fluctuations, heterogeneity, positive feedback and lock-in effects, restricted choice, imperfect knowledge and learning effects, which can be adapted to show how intermediaries emerge in marketing and business networks. We have implemented this model in a more general way using Netlogo and plan to demonstrate it during the presentation.

Interactions between the formation of cooperative clusters and innovation are examined in another model develop by Gilbert et. al. (2001). Each agent pursues a specific “research strategy": focusing independently on its own area of expertise, imitate others’ successful behavior, or engaging in collective efforts. The latter agents combine their skills in clusters of partnerships, which can only be joined after a successful cooperation with one of its members. The simulation proves to be sensitive to initial conditions in an industry; such as the distribution of capital, the number of firms and their tendencies to develop and cooperate. While still at a very abstract level, it successfully reproduces stylized facts found in industries as diverse as communications and biotechnology.

2. Modelling Business Mating Mechanisms

Early on, simulation studies explored the development of games on network structures. Stanley et.al. (1995) ran iterated Prisoner’s Dilemmas (iPD) on networks, giving their agents the options to refuse interaction with neighbours who they expected to behave non-cooperatively. As a result, almost full cooperation emerges, and the resulting networks exhibit a high degree of structure. Tesfatsion (1997) further developed this model in what she calls her “evolutionary trade network game”. Using a more intricate matching mechanism than simple network connections, she examines the development of an iPD for two sided markets and one for one-sided intermediation. The simulation includes evolving strategies, memory, transaction costs and partner choice based on expectation. And it supports earlier findings that high levels of cooperation can be maintained in this more complex setting. It also shows how clusters of interacting players can emerge who interact with each other but not others. This includes the emerge of naïve cooperators who get taken advantage of by defectors until they are driven out of the market. Once defectors have to interact with more of their own kind their strategies and behaviour become more cooperative paying the way for naïve cooperators to once again emerge – cycle of changing patterns of interaction that she characterises as “Raquel and the Bobs.”

Pujol et. al. (2005) use mechanisms grounded in social exchange theory to examine the structure of a network emerging from local information, bounded rational optimization, and randomly arising conflicts. Agents play the support exchange game and have different levels of attractiveness and memory. Their behaviour leads to small-world and power-law network structures, i.e. the number of connections which would connect any given pair of agents is relatively low, and many agents have only a few connections while a few central players become hubs with many relationships. The resulting topological structure depends heavily upon the exchange game’s payoff structure and on the accuracy of information the agents receive about their neighbours' reliability. It demonstrates that market intelligence, regarding both customers and competitors can provide a competitive advantage and how incentive structures affect network development.

Another approach to explore a network structure resulting from simple, local rules is presented in Hamill (2009). The agents are distributed in a "social space" and have a "social reach" of varying length. Relationships can only be formed between agents that are sufficiently similar so they can reach each other. The motivation of this simulation is to provide a more realistic way to grow artificial networks than present models, such as random networks (Erdös and Renyi 1959) or network growth through preferential attachment Barabási and Albert (1999). Their results show that by controlling the mixture of reaches and system sizes, many statistical parameters of real networks can be reproduced.

This approach can be seen as a prototype of in-silico networks which grow on the basis of similarity. Beyond physical distance, this mechanism is compatible with many different concepts of distance, be it technical standards, corporate culture or simply awareness of an agent's existence.

3. Modelling Business Dancing Mechanisms

Zimmermann et. al. (2004) let agents interact in another iPD, but they give them the option to terminate a relationship if they are both defecting and are not satisfied with this outcome. A new partner can then be selected randomly or by choosing a "friend of a friend". These mechanisms lead to a hierarchical interaction network that sustains a highly cooperative stationary state. Connecting to friends of friends leads to the development of high clustering in the network. Interestingly enough Hanaki et. al. (2007) find that the latter mechanism does not favor cooperation in a setting where the termination of a relationship is based on myopic cost/benefit considerations.

In another simulation agents learn about the positive effects of loyal behavior on the costs of stock keeping and for demand fluctuations. Kierman and Vriend (2001) simulate the Marseilles Wholesale Fish Market, where the same actors meet every day. Sellers have to set the amount of fish they intend to sell on any given day and buyers choose at which sellers stall they want to queue and which price they would deem acceptable. Facing the queue, the sellers then have to decide in which order they will serve their customers and how much they want to charge. Sellers are only aware of "faces they have seen before", buyers do not remember exactly how good their previous choices turned out to be, but individual decision rules are constantly evaluated on basis of their outcome. So if a strategy turned out to be successful in the previous round, the buyer or seller is a little more likely to choose that particular strategy again.

The simulation reproduces stylized facts of price dispersion and high loyalty, which agree with empirical observations at the original Fish Market. In a coevolutionary process, buyers learn to become loyal as sellers learn to offer higher utility to loyal buyers. In turn the sellers learn to offer higher utility to loyal buyers as they happen to realize higher gross revenues due to reduced fluctuation in demand.

Forrester's beer game served as the basis to study the effects of trust on the performance of a five level supply chain network (Kim 2009). Five agents are located on each level of the game, and initially they are connected with every other player in the levels above and under them. Each of them is equipped with rules to forecast their demand, and manage their ordering and supplying decisions. The simulation explicitly includes a parameter called "trust" in these decision rules. Trust evolves throughout the simulation rounds, depending on the traded volume. The system reaches a stable state, strong and weak relationships persist and some agents are almost excluded from the production process, because they are considered to be not trustworthy enough. Again the simulation shows how trust can reduce uncertainty and leads to reduced transaction costs by reducing volatility and storage costs. In the same way as loyalty in the simulation of Marseille's Fish Market works, distinct cooperation structures evolve through another, social dimension in the interactions.

4. Modelling Mechanisms Connecting Relations

Many simulation studies examine the impact of network structure on cooperative behavior in game theoretic settings. Many network structures favor cooperation. Santos and Pacheco (2005) find an explanation for this surprising quality through the interconnection of hubs in many network topologies. Artificial, random networks do not necessarily connect such hubs with each other and as a consequence, cooperation is fostered much less strongly.

Wilhite (2006) analyses the effects of structure from a different perspective. Agents form a simple barter economy with two goods on fixed network structures. The agents will trade as long as they can improve their utility through further exchanges. His results show clearly, that strong inequalities in the distribution of wealth arise only based on an agent's position in a network, and the overall structure affects the performance of the overall system.

Generally, hubs are found to acquire more wealth, an effect which is strongly enhanced by the underlying structure. The central players in star-shaped networks and hierarchical tree structures can benefit strongly from their positions. Completely connected as well as power-law networks lead to very homogenous wealth distributions but require high costs for searches, relation maintenance and negotiation. Small-world networks provide a trade-off between the numbers of links, searches and rounds to market clearance and the homogeneity of the wealth distribution.

In the presence of limited resources or other sources of conflict, we may encounter the emergence of competing groups. Gavrilets et. al. (2008) assume that such groups are based on an underlying affinity network. Conflicts arise randomly between pairs, other agents can join in and support one side, based on their affinity towards the parties involved. The outcomes of these conflicts affect the agents' affinities over time, making the winning side more attractive. The simulations exhibit a sudden phase transition after which distinct alliances emerge, although their size varies strongly. Once this process has begun, there is no other reasonable strategy but to join one of these alliances.

5. MODELLING THE IMPACT OF THE ENVIRONMENT

Many external factors can affect the development of a network of interacting agents. The relation between the time scales of actions **on** the network and the speed of the rewiring process **of** the network was found to be one such key determinant. Pacheco et. al. (2006) show that essentially, a high rewiring speed can change the payoff structure of the PD and Snowdrift games so that they favor cooperation.

Lugo and Jiménez (2006) introduce taxes and subsidies to influence agents' behavior in early stages of a network based iPD game. Cooperation becomes relatively more attractive compared to defection. Smaller numbers of initial cooperators are needed to reach higher levels of cooperation, faster. Interestingly enough, they could switch off their tax-based transfer mechanism in stages and the system retained a high level of cooperation.

Lastly, economic exchange networks need not necessarily have the same structure as networks for information exchange. An initial step towards the exploration of interaction effects between more than one network structure is undertaken by Ladley and Bullock (2008). They look at all four possible combinations of scale-free and fully connected networks, one used to gather price information and the other used to find actual trade partners. Agents have the capability to adapt their trading and pricing strategies over several generations, relative to their fixed network position. It is found that the network's structure affects the learning of strategies and the profits of traders. Less densely connected networks lead to more heterogeneous payoffs. Well connected players have more choices and can make more profits, but the abundance of available (and possibly inaccurate) information may also lead to inferior results.

DISCUSSION AND CONCLUSIONS

The forgoing review of some exemplars of models dealing with different aspects of business relations and network processes and dynamics shows that the basis exists to develop more comprehensive dynamic, evolutionary models. Many more models exist that we can draw on but are beyond the scope of this papr to review. The models described also reveal the kinds of insight that can be derived from careful analysis and experimentation with even partial models.

We are proceeding to reproduce the essential features of relevant models of relations and networks using Netlogo as the platform in a business network context. Netlogo is freeware and is a more user friendly programming environment than other agent based systems that have been developed, such Swarm, Anylogic, Repast and Mason, which require expert programming skills. Also, the latest version it includes links or relations between actors as actors in their own right, as well as dimensions of the environment. Netlogo models can be scaled up at a later stage to run on more powerful platforms using high level languages.

The first level models of different mechanisms can be examined and tested and compared to real word mechanisms before moving on to combine them in more comprehensive simulations in a modular fashion. This will enable us to better understand interaction effects among mechanisms as well the effects of individual mechanisms. They can also be calibrated and tested against the stylised behaviour of real business networks. We will report on these developments at future IMP conferences.

Agent based simulations represent a new frontier and methodology for conducting research on the dynamics and evolution of complex systems such as business relations and networks. As Herbert Simon argues, “to ‘explain’ an empirical regularity is to discover a set of simple mechanisms that would produce the former in any system governed by the later” (Augier and March 2004, p5). Empirical research is limited to the analysis of business relations and networks that happen to exist. True understanding comes more from synthesis, the ability to grow and reproduce what happens to exist but also what could exist (Epstein 2006).

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