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Competition and evolution in multi-product supply chains: An agent-based retailer model

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ABSTRACT

Facing such issues as demand uncertainty and in- and cross-channel competition, managers of today's retail chains are keen to find optimal strategies that help their firms to adapt to the increasingly competitive business environment. To help retail managers to address their challenges, we propose in this paper an agent-based retail model (ARM), grounded in complex adaptive systems, which comprises three types of agents, namely suppliers, retailers, and consumers. We derive the agents' optimal behaviours in response to competition by evaluating the evolutionary behaviour of the ARM using optimisation methods and genetic algorithm. We find that consumers' ability to collect pricing information has a significant effect on the degree of competition in retail chains. In addition, we find that the everyday low price (EDLP) strategy emerges from the evolutionary behaviour of the ARM as the dominant pricing strategy in multi-product retail chains.

1. Introduction

A supply chain is composed of a large number of autonomous entities, e.g., suppliers, manufacturers, distributors, retailers etc., which work together in a dynamic business environment. Generally, firms in a supply chain collaborate with their upstream and downstream partners, and need to react to their rival firms' competition as well. Both competition and collaboration are the driving forces of supply chain evolution.

Retailers, which are at the end of supply chains, sell goods or commodities directly to consumers. In today's competitive and fast-changing retail markets, there are issues that retailer managers need to adequately address for their firms' survival and prosperity. The issues include: (1) demand uncertainty. Consumers having different preferences seek to minimise their cost of obtaining goods and maximise their utility from these goods (Bell et al., 1998). Therefore, variability in consumer behaviour makes it difficult for retailer managers to accurately forecast consumer demand. (2) In- and cross-channel competition. Many products are transferred and distributed to a great number of retailers, e.g., fast-moving consumer goods (FMCG) like soft drinks can be bought from different retailers, such as supermarkets, convenience stores, mom-and-pop shops, and even street hawkers. The wide variety of alternatives for distributing similar products leads to fiercer competition among retailers, making pricing a key marketing element in peer competition. (3) Optimal pricing of multiple products. In a store, there are many homogeneous or heterogeneous products that are substitutable for consumers because their preferences for each product vary. Consequently, multi-product pricing is getting much more complex along with the rapid development of new products. (4) Inventory policy. The introduction of products with shorter life cycles, together with decreasing brand loyalty of consumers, has presented great challenges of inventory management to retailers. From the retailer's standpoint, these issues make the supply chain a highly dynamic and competitive environment with ever growing complexity.

Over the past years, researchers have made a lot of attempts to model and optimise the retailer's decisions. Previous research on the above issues has been predominantly based on the methods of Operation Research (OR). Under given assumptions, OR-based modelling of the retailer's operations has focused on finding optimal solutions for such issues as pricing strategy, inventory management, and competition effects (Kwon et al., 2007). However, analytical methods are impractical in today's retailing context, which is extremely complex (as the problems concerned are often non-linear and non-convex with mixed integer and continuous variables), because the mathematical model requires excessive computing time when realistic cases are considered (Mele et al., 2006; Thierry et al., 2008). Therefore, simulation-based

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modelling methods, such as agent-based modelling (ABM), have been introduced to deal with complex issues by dynamic modelling of the behaviours of firms in supply chains. Drawing on OR and game theory, integrating supply chain management with ABM captures many of the challenges met by changing supply chain practices (Chaib-draa and Müller, 2006). Moreover, some researchers propose treating a supply chain as a complex adaptive system (CAS) in order to understand how the supply chain adapts to and co-evolves with the dynamic environment in which it exists (Li et al., 2010; Surana et al., 2005).

In this paper we propose an agent-based retailer model (ARM) from the CAS perspective, in which there are two products and three types of agents, namely suppliers, retailers, and consumers. We solve the ARM using a genetic algorithm (GA) to address the following research questions: (1) what is the optimal pricing strategy for the retailers in such a competitive market environment? (2) What is the optimal inventory control policy for retailers in the presence of price-sensitive consumers? (3) If the two products differ in their wholesale prices and consumers' preferences, what are the differences in pricing and inventory control for them? (4) Some retailers may be eliminated in an increasingly competitive environment over time, which can be considered as "evolution". What kinds of retailers can survive in the evolution? (5) From the consumer's standpoint, how does his utility change with the evolution? We make a contribution by resolving the above challenging research and practical issues.

The remainder of the paper is organised as follows: In Section 2 we give a concise review of the related studies in the literature. In Section 3 we present the ARM, including the assumptions and technical details, in detail. In Section 4 we design a series of experiments to observe the evolution of the ARM under different scenarios. In Section 5 we present the data analysis and discuss the results. In Section 6 we conclude the paper and discuss the research and managerial implications of the study. We also acknowledge the research limitations and make suggestions for future research.

2. Literature review

This paper is closely related to three streams of research, namely ABM, supply chain evolution, and retailer competition effects.

ABM, which is a new analytical method for computational social science, combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming (Briscoe, 2010). The term "agent" denotes an individual or organisation that has the following characteristics: autonomy, social ability, reactivity, and proactiveness (Wooldridge and Jennings, 1995). Therefore, a firm in a supply chain, which carries out tasks by itself and interacts with other companies, is fit to be modelled as an agent using computer programs to simulate its behaviour and gain insight into supply chain management. Recently, the multi-agent system (MAS) approach, a sub-domain of ABM that comes from the discipline of distributed artificial intelligence (DAI), has been widely adopted as an intelligent IT support tool to study various SCM issues such as decision making of supply chain partners (García-Flores and Wang, 2002; Li, 2007), supply chain coordination (Kanda and Deshmukh, 2008), planning and scheduling optimisation problems in manufacturing processes (Caridi and Sianesi, 2000; Monostori et al., 2006), resource allocation (Brandolese et al., 2000) etc. In fact, only a few studies have been conducted on the retail market using MAS. For example, Chang and Harrington (2000) examined the relationship between the degree of discretion given to store managers and the rate of innovation at the store level. In their study, they modelled distributed organisations as multi-agents, each of which is capable of generating new ideas. Yu et al. (2004) proposed an agent-based retail electricity market consisting of four kinds of participant agents and used coloured Petri net technology to represent communication and cooperation of the agents in the market. By simulating their trading procedures in modern power systems, they obtained results that the proposed retail electricity market could increase efficiency, reduce operational cost, and give consumers more alternatives. Heppenstall et al. (2007) designed a multi-agent model to simulate the petrol retail market, and employed a geographical information system (GIS) and GA to explore the parameterisation and verification of the model. Despite increasing studies on MAS-based SCM, there have been few agent-based models proposed to investigate the effects of competition among retailers in a bottom-up way.

Supply chain evolution treats a supply chain as a continuing evolving dynamic process driven by a number of factors. Common methods to study supply chain evolution include case study, evolutionary game theory, and ABM from a CAS perspective. Examples of works employing the first two methods include the following. Fearne (1998) suggests that establishing trust in supply chain partnerships is important by describing the evolution of supply chain partnerships in the British beef industry using a case study. Fujita and Thisse (2006) find that the development of new information and communication technologies is one of the major forces that should be accounted for in order to better understand globalisation and the evolution of the supply chain. Zhu and Dou (2007) propose an evolutionary game model between governments and core enterprises in greening supply chains, and find three evolutionary stable strategies in three cases. Jalali Naini et al. (2011) employ evolutionary game theory and the balanced scorecard (BSC) for environmental supply chain management (ESCM). To understand the complexity of supply chains, CAS theory, proposed by Holland (1996), has been applied to model the dynamic and evolutionary behaviours of SCM systems. Choi et al. (2001) argue that supply chains should be recognised as a CAS for managing supply networks. Li et al. (2010) provide a complex adaptive supply network (CASN) based on CAS and fitness landscape theory to investigate the evolutionary complexity issues such as emergence, quasi-equilibrium, chaos, and lock-in of CASNs. These works, especially CASN studies, have enriched our understanding of the evolution of supply chains. However, previous research has largely neglected consumers' evolutionary behaviours and often assumes that the consumers exist in a static environment. On the contrary, consumers in fact have the power through their fast-changing behaviours to change the evolution direction of the retailer's network in today's dynamic business environment.

As regards research on the competition effects of retailers, there exists a large body of works. For the sake of conciseness, we do not provide a comprehensive review of the literature in this area. For excellent surveys on this topic, we refer the reader to Kopalle et al. (2009) and Bijvank and Vis (2011). Besides, as increasing numbers of firms enter the retail market in which consumers with heterogeneous tastes exist, product differentiation and price competition should be considered. Therefore, we refer the reader to Soon (2011) for a detailed survey of the existing literature on multi-product pricing models. The vast majority of these studies are OR-based or empirical in nature, which focus on the design and optimisation of the retailer's pricing strategy and inventory control policy based on the assumption that the retail chain is an integrated, static organisation. Although specific optimal solutions can be obtained from analytical models via mathematical analysis, these models are often limited in their ability to map the dynamics of the retail chain that is non-linear and complex (Pathak et al., 2007).