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How altruism works: An evolutionary model of supply networks

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ABSTRACT

Recently, supply networks have attracted increasing attention from the scientific community. However, it lacks serious consideration of social preference in Supply Chain Management. In this paper, we develop an evolutionary decision-making model to characterize the effects of suppliers' altruism in supply networks, and find that the performances of both suppliers and supply chains are improved by introducing the role of altruism. Furthermore, an interesting and reasonable phenomenon is discovered that the suppliers' and whole network's profits do not change monotonously with suppliers' altruistic preference, η, but reach the best at $\eta = 0.6$ and $\eta = 0.4$, respectively. This work may shed some light on the in-depth understanding of the effects of altruism for both research and commercial applications.

1. Introduction

In the last decade, Supply Chain Management (SCM) has made significant strides in both theoretical and practical fronts [1–6]. However, how to manage relationship with suppliers (or retailers, dealers) still remains a huge challenge, since firms have to face the coexistence problem of cooperation and competition with other firms in an interdependent environment. As pointed out by Simchi-Levi et al. [1], supply chain analysis inspires new research ventures that blend operations research, game theory, and microeconomics. However, although quantitative supply chain analysis provides insight into understanding competition and cooperation among firms, there are limitations to understand the nonlinear dynamics and social impacts on free market structures [7]. SCM is the management of a network of interconnected businesses, which suggests that the complexity and adaptivity should not be ignored in a network background [8–11]. In addition, the mainstream research supposes that agents in supply chains intend to make self-maximizing decisions. These operational decisions are on the basis of agents' optimal prediction of the future. However, these so-called "optimal" behaviors could not be easily predictable, sometimes even unbelievable when a large number of agents interact in a complex supply network. Actually, it will be crucial to examine the evolution of supply networks over an extended time horizon [7], e.g., Barabási et al. proposed an evolutionary model of social network's time evolution [12]. Different from the rational focus on the future benefits, they behave dependently on their past behaviors. Furthermore, there are sufficient evidences indicating that firms care about their partners' profits in the chain as well as their own, in order to keep or improve the competitiveness of the total supply chain [13]. For example, Steiner contends that business decision-making today is a mixture of altruism,

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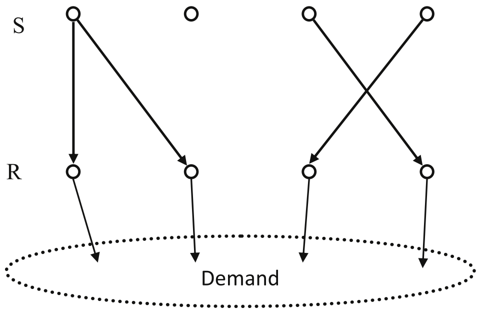

Fig. 1. A simplified supply network, where S and R represent suppliers and retailers, respectively, and arrows represent the direction of physical flows.

self-interest, and good citizenship [14]. At the same time, many behavioral economic researchers have developed various forms of interdependent social preferences to justify experimental observations [15–18]. The main concepts of existing interpretations are based on fairness, or altruism. That is to say, people consider fairness based on relative payoffs, or how monetary payoffs are distributed among them [19–22]. Though Tooby and Cosmides [23] have argued that people may help friends who are unlikely to pay back, DeScioli and Robert empirically demonstrated that the altruism did contribute to the formation of alliance [24]. Moreover, it is also demonstrated that the existence, incentives, and effects of altruism are wildly existing in human behaviors from the perspectives of both social science and biology [25–29].

In this paper, we investigated the effects of altruism on an evolving supply network: how suppliers' altruistic decision-making mechanism affects the suppliers' performance from the perspective of evolutionary dynamics [30]. In addition, we proposed a model to evaluate how altruism benefits supply networks, in which an evolutionary pricing mechanism is proposed under the assumption that firms are altruistic when they make decisions. The results show that suppliers have incentives to be altruistic, because the altruistic decision-making mechanism makes them better.

The rest of this paper is organized as following. In Section 2, we describe some settings of our model in Section 2 and the mechanism in Section 3. After this, we present the model results and analysis in Section 4, and conclude in Section 5.

2. The settings of model

In this section, we study a supply network in which n retailers order one type of product from m suppliers and sell it to consumers who decide the market demand. In this supply chain from suppliers to the final consumers, the retailers actually play the role of matchmaker with whom the market becomes more efficient [31]. Normally, a retailer can order products from more than one supplier. However, for simplicity, we assume that one retailer is supplied only by one supplier in this paper,[1] and the quantity that he orders at time t is denoted by $b_i(t)$, $i = 1, 2, \ldots, n$. For a single supplier, he can supply for all the retailers in the market. Fig. 1 shows an example of a simplified supply network.

In the following, we shall first describe the entities in the supply network. Second, the underlying mechanisms of pricing, demand satisfaction and supplier selection are introduced. We finally give decision sequences and present a process for simulations.

2.1. Suppliers

In the initial status, each retailer randomly chooses one supplier. At time step t, the suppliers respectively propose a wholesale price combination $W(t) = [w_1(t), w_2(t), \ldots, w_m(t)]$ at time step t. Denote the profit of retailer R_i at time step t by $\pi_i^r(t)$, and that of supplier S_j by $\pi_j^s(t)$, respectively. Let $A(t) = [a_{ij}(t)]$ be an adjacent matrix at time step t, in which $a_{ij}(t) = 1$ if retailer R_i orders from supplier S_j, otherwise $a_{ij}(t) = 0$. Then, $\pi_j^c(t) = \pi_j^s(t) + \sum_{i=1}^{N} \pi_i^r(t)a_{ij}(t)$ indicates a total profit of the supply chain supplied by supplier S_j, which potentially is a tree with S_j as its root. Provided supplier S_j's sold quantity $Q_j(t)$, then his profit is

$$\pi_j^s(t) = w_j(t)Q_j(t) - c_j^p Q_j(t), \quad j = 1, \ldots, m, \tag{1}$$

where c_j^p is unit producing cost of S_j, randomly determined in the following simulations.

2.2. Retailers

Let $p_i(t)$ be a retailing price set by retailer $R_i (i = 1, \ldots, n)$, and $P = [p_1, \ldots, p_n]$. As mentioned above, retailer R_i faces a newsvendor problem [32,33] with a stochastic demand $D_i = D_i(P)\xi_i$, where ξ_i is a random variable $i = 1, \ldots, n$. Without loss

[1] It does not mean the absence of competition among suppliers. Potentially, suppliers compete with each other, since retailers maybe cut their order quantities when they face a high wholesale price.