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Wholesale Pricing and Evolutionarily Stable Strategy in Duopoly Supply Chains with Social Responsibility

Caichun Chai,[a, b] Tiaojun Xiao[b]

[a]Institute of Game Behavior and Operations Management, School of Management Science and Engineering, Nanjing University of Finance and Economics, Nanjing 210023, China
[b]School of Management and Engineering, Nanjing University, Nanjing 210093, China
caichunchai@163.com, xiaotj@nju.edu.cn (✉)

Abstract. This paper analyzes manufacturers' wholesale price decisions and the evolutionarily stable strategies of the retailers' marketing behavior in duopoly supply chains, where each chain consists of one manufacturer and many retailers. Each retailer chooses one of two marketing strategies: social responsibility or non-social responsibility (i.e., a firm only cares about the benefits of its shareholders). We identify the conditions under which a strategy profile is evolutionarily stable. Furthermore, we investigate the manufacturers' wholesale prices and find the following: (i) the retailer's social responsibility decreases the unit wholesale price; (ii) when the degree of the retailer's social responsibility is medium, the social responsibility of the retailer in a supply chain increases the profit of the retailer's own manufacturer and decreases the profit of the rival's manufacturer; otherwise, it decreases the profits of the two manufacturers; and (iii) when each retailer exhibits its social responsibility moderately, a triple-win situation can be achieved.

Keywords: Evolutionarily stable strategy, replicator dynamics, social responsibility, supply chain management

1. Introduction

Classical economics assumes that the duty of companies is to make as much money as possible. However, companies are parts of society, and their marketing strategies have unavoidable social consequences, implying that companies have a social role besides their commercial one (Magill et al. 2015). Hence, in addition to care about the economic interests, firms should also care about social responsibility. Corporate social responsibility (CSR) refers to incorporating social responsibility into the business operations to positively impact the environment and stakeholders, such as consumers, employees, investors, communities, and so on. The view of CSR is especially prevalent in countries such as France, Germany, and Japan, but in the United States and the United Kingdom, the extent of CSR is low. According to a survey by Yoshimori (1995), 97% of managers in Japan and 84% in Germany approve CSR, whereas in the United Stated and the United Kingdom, 76% and 70% of managers refuse to incorporate CSR, respectively. Even in the same country, there are some industries that approve CSR, while some industries refuse it; for example, according to a sample of 80 firms in the United States, there are 48 firms that use CSR strategies and 32 firms that refuse to use CSR strategies (Omran et al. 2002).

Recently, more and more international firms consider their stakeholders in the firms' operations. Here, 93% of participant managers from different firms declare CSR as an important factor for the firms' decisions (Cheng et al. 2014). However, according to the statistical data of Fortune (2013), a considerable number of local firms in China lack the awareness of CSR because they believe that CSR will damage the benefits that the firms can produce. A fundamental question this paper addresses is

as follows: Why, and under what conditions, does a firm try to take up CSR?

An important aspect of this paper is the fact that manufacturers sell their products through many retailers. That is, each supply chain consists of one manufacturer and many retailers. Two retailers from different supply chains are randomly matched and compete with each other. A CSR firm exhibits its CSR concern and incorporates its consumers' surplus into its objective (i.e., the objective of a CSR firm is to maximize the combination of its profit and its consumer surplus), and a non-social responsibility (NSR) firm seeks to maximize the interest of its shareholders. Obviously, the competition between retailers is not static, but rather is constantly changing with the environment. However, most of related papers focus on the static equilibrium of competition between retailers. The second question in the current article is as follows: How do the firms' management strategies change when their equilibrium states are disturbed? A third question asked in our research is as follows: What are the implications for manufacturers and consumers when retailers use a CSR strategy or NSR strategy? These questions are particularly important because the relationship between CSR activities and profitability and the implications of research on CSR are still uncertain (Servaes and Tamayo 2013).

The relation between CSR activities and profitability is unclear partly because of methodological concerns (Margolis and Walsh 2003). Much of the quantitative literature analyzes the relationship using empirical methods or a non-cooperative game theory (Goering 2012, Allen et al. 2014, Panda 2014, Saeidi et al. 2015). However, we develop an evolutionary game model of two supply chains to analyze the evolutionary stability of the retailers' marketing strategies and discuss the effect of CSR on supply chains. We find that the degree of a firm's CSR is a crucial factor that affects the firm's strategy. If both firms care about their social responsibilities moderately, then a CSR strategy is evolutionarily stable; otherwise, at least one firm uses an NSR strategy. A retailer using a CSR strategy decreases the unit wholesale price, increases its own manufacturer's profit, and decreases the rival's profit when one of the CSR level is moderate; if a retailer exhibits its CSR moderately, then a triple-win situation can be achieved, that is, the CSR strategy benefits the retailer itself, its manufacturer, and consumers; if the CSR level of a retailer is high enough, then the concern hurts both the retailer and its manufacturer.

The remainder of the paper is organized as follows: Section 2 is the literature review and our contributions to the literature. The basic model will be established in Section 3. In Section 4, we analyze the evolutionarily stable strategy of marketing strategies. Section 5 analyzes the unit wholesale prices of manufacturers. The conclusions and future research directions are shown in Section 6.

2. Literature Review

The current paper is closely related to CSR, the dynamics of supply chain with CSR, and the effect of CSR on the supply chain from a quantitative perspective.

We are interested in modeling the strategic decision of a firm in its use of CSR or NSR by employing the evolutionary game theory. CSR is concerned with treating the stakeholders of the firm ethically or in a socially responsible manner (Dahlsrud 2008). Jensen and Meckling (1976) point out that a firm is a set of interrelated contracts among the various factors, such as input suppliers, the purchasers of the final outputs. According to Jensen and Meckling (1976), the firm's claimants go beyond shareholders and bondholders to include customers, suppliers, employees, communities, and so forth. Cornell and Shapiro (1987) consider that although the firm is a contrac-

tual coalition that includes investor and non-investor stakeholders, the stakeholders other than investors, and managers play a significant role in the corporate strategy. Cespa and Cestone (2007) use a simple model in which stakeholders (other than shareholders) could affect the likelihood of CEO replacement and where incumbent CEOs could make manager-specific commitments to adopt a stakeholder-friendly behavior. McWilliams et al. (2006) develop a regression model to estimate the effect of CSR on the corporate social performance. However, these works discuss whether a firm should care about CSR from an ethical or cultural perspective, and even some of these empirical studies are considered to be unreliable because of methodological concerns.

In recent years, considering CSR in supply chains has become more and more popular. Based on some researches, Maloni and Brown (2006) and Eriksson and Sevensson (2015) synthesize an initial and expansive framework for CSR issues in supply chains, including elements such as culture, community, environment, fair trade, health and safety, labor, and procurement. Andersen and Skjoett-Larsen (2009), Levy (2009), and Gallear et al. (2012) investigate CSR in a supply chain using the case research approach and find that CSR affects the supplier, consumer, brand-owner, performance, and so forth. Welford and Frost (2006) and Cruz (2013) analyze the benefits and obstacles when a firm cares about CSR and obtains the benefits of CSR, which include risk reduction, staff recruitment and retention, cost savings, and building good relationships with stakeholders. Obstacles include a lack of resources and skills, a lack of awareness of stakeholders' demands and inefficient production techniques. Tate et al. (2010) and Chiang et al. (2011) analyze the effect of CSR on the supply chain from the perspectives of consumer orientation, external environment, community focus, and so forth. These existing studies discuss the effect of CSR on a single supply chain and do not consider the competition between supply chains. They mainly focus on whether CSR can reduce the cost or risk of firms and benefit consumer or environment.

Few papers study the effect of CSR on supply chains by establishing relevant models. Cruz (2008) and Cruz (2009) investigate the dynamics of a supply chain network using the multi-criteria decision-making behavior of the various decision makers, obtaining some qualitative properties of the dynamic trajectories that have some suitable assumptions. Panda (2014) and Goering (2012) consider the coordination of a supply chain with CSR; they think that a CSR firm cares about its own profit and consumer surplus and that the CSR concern can help coordinate the supply chain under certain conditions. However, Cruz (2008) and Cruz (2009) focus on the effect of CSR on the transaction cost, price, and level of social responsibility activities. Goering (2012) and Panda (2014) just study the role of CSR on the coordination of a supply chain; they discuss the equilibrium in the one-shot game and don't analyze the dynamics of the supply chain over time.

In the current study, we analyze the effect of CSR on supply chains from a novel perspective by focusing on the firms' decisions to be CSR or NSR oriented. Our paper contributes to the literature in several ways. First, our paper studies the effect of CSR on the dynamics of two competitive supply chains with CSR rather than a supply chain. Second, our approach enables the analysis of the evolutionary stability of a strategy profile when the equilibrium state in the one-shot game is disturbed. Third, we develop an evolutionary game model to discuss the CSR activities and firms' values quantitatively, thus avoiding the argument on methodological concerns in empirical models. Finally, we study the unit wholesale prices of manufacturers from an evolutionary perspec-

tive and examine the impacts of the manufacturer's CSR when its retailers take a consumer-focused approach. We try to explain the reason why some manufacturers don't care about consumer surplus. This topic is seldom studied in the current literature.

3. The Basic Model

We consider that an economic system consists of two supply chains with homogeneous goods, and every channel consists of one manufacturer and many retailers that sell products in many completely distinct markets (Boyaci and Gallego 2002, Xiao and Yu 2006). These markets are completely distinct from each other because there are different physical locations. Our model is a two-population evolutionary game model in which all the retailers of a manufacturer belong to a population. Besides the equilibrium of retailers in the competition, we further discuss the dynamics of populations using the evolutionary game theory. A key concept in the evolutionary game theory is *evolutionarily stable strategy* (ESS), where a strategy is robust to evolutionary selection pressures. Suppose that individuals are randomly drawn from the two populations to play a two-person game and that each population just has a retailer in a given market. The roles of the large retailer population in the game are as follows: First, doing this ensures that the fraction of the retailers using a strategy is nearly continuous such that the evolutionary stability of a strategy profile can be well analyzed. Second, the population needs to be large enough so that the effects current individual actions may have on others' future actions can be neglected (Weibull 1995). So we assume that each manufacturer sells products through many retailers in a supply chain. The retailer from one channel competes with a retailer from another channel in a market, where the match between the retailers from different channels is random (i.e., a retailer does not know who the rival is before matching). The two different channels are denoted by $i = 1, 2$. We regard a retailer in channel i as an individual in population i, which consists of all the retailers in channel i. Each retailer has two pure marketing strategies: social responsibility (stakeholder-oriented) (S) and non-social responsibility (shareholder-oriented) (N). In the one-shot game, two retailers simultaneously determine the optimal quantities according to their marketing strategies.

Because each retailer faces two strategic choices (S or N), there are four possible strategy profiles in the model: (i) both retailers use strategy N (NN); (ii) both retailers use strategy S (SS); (iii) retailer 1 chooses strategy N, and retailer 2 chooses strategy S (NS); similarly, we have notation SN. We denote each strategy profile by a superscript, for example, superscript SS denotes case (ii).

Let the unit wholesale price of manufacturer i be w_i, $i = 1, 2$. For studying the effect of CSR activities on demand, we consider the inverse demand function of the market, as follows:

$$p = a - q_1 - q_2. \tag{1}$$

Here, p is the retail price of the products, and the parameter a denotes the price cap, $a > \max\{w_1, w_2\}$. q_i is the quantity of a retailer in channel i.

The manager of Ford Motor company, William Clay Ford Jr, said "We want to find ingenious new ways to delight consumers, provide superior returns to shareholders and make the world a better place for us all" (Meredith 1999, Lee 2008). According to William Clay Ford Jr, consumers affect the returns to a firm's owners, and the shareholders of the firm receive higher returns only when the firm cares about the consumers it serves. Being concerned about consumers is the most basic manifestation of CSR activity, for example, the recent events of Shiseido's sunscreen recall or Dutch egg off the shelf. The consumer

Table 1 Equilibrium Outcome under the Given Strategy for the One-Shot Game

strage	SS	NN	SN	NS
Quantity (q_1, q_2)	$q_1^{SS}=\frac{a-2w_1+w_2-\beta(a-w_1)}{3-\alpha(2-\beta)-2\beta}$, $q_2^{SS}=\frac{a+w_1-2w_2-\alpha(a-w_2)}{3-\alpha(2-\beta)-2\beta}$	$q_1^{NN}=\frac{1}{3}(a-2w_1+w_2)$, $q_2^{NN}=\frac{1}{3}(a+w_1-2w_2)$	$q_1^{SN}=\frac{a-2w_1+w_2}{3-2\alpha}$, $q_2^{SN}=\frac{a+w_1-2w_2-\alpha(a-w_2)}{3-2\alpha}$	$q_1^{NS}=\frac{a-2w_1+w_2-\beta(a-w_1)}{3-2\beta}$, $q_2^{NS}=\frac{a+w_1-2w_2}{3-2\beta}$
Price (p)	$\frac{a+w_1+w_2+a\alpha\beta-(a+w_1)\beta-(a+w_2)\alpha}{3+\alpha\beta-2(\alpha+\beta)}$	$\frac{a+w_1+w_2}{3}$	$\frac{a+w_1+w_2-(a+w_2)\alpha}{3-2\alpha}$	$\frac{a+w_1+w_2-(a+w_1)\beta}{3-2\beta}$
Profit (π_1, π_2)	$(1-\alpha)(q_1^{SS})^2, (1-\beta)(q_2^{SS})^2$	$(q_1^{NN})^2, (q_2^{NN})^2$	$(1-\alpha)(q_1^{SN})^2, (q_2^{SN})^2$	$(q_1^{NS})^2, (1-\beta)(q_2^{NS})^2$

is an important part of the stakeholder theory, and consumer surplus is of great significance for the embodiment of social welfare. Chai et al. (2018) consider a single population evolutionary game model and find that firms want to take up CSR (consumer surplus). According to Panda (2014) and Goering (2012), we use the consumer surplus to denote the benefit consumers receive. Consumer surplus is the difference between the maximum price that consumers are willing to pay for a product and the market price that they actually pay for the product. A retailer only cares about the consumers it serves. Following Panda (2014), Goering (2012), and Mankiw (2014), the amount of consumer surplus of retailer i is as follows:

$$\int_{p_{min}}^{p_{max}} q_i \mathrm{d}p = \int_{a-q_i-q_j}^{a-q_j} (a-q_j-p)\mathrm{d}p = \frac{1}{2}q_i^2. \quad (2)$$

An NSR firm seeks the maximization of its shareholders' interests, whereas a CSR firm cares about not only the interests of its shareholders, but also the welfare of its stakeholders (consumers). Hence, under strategy N, the marketing objective of retailer i is as follows:

$$\max_{q_i}(p-w_i)q_i = \max_{q_i}(a-q_1-q_2-w_i)q_i, i=1,2. \quad (3)$$

Under strategy S, the marketing objective of retailer 1 is

$$\begin{aligned}&\max_{q_1}[(p-w_1)q_1+\frac{\alpha}{2}q_1^2]\\ &=\max_{q_1}[(a-q_1-q_2-w_1)q_1+\frac{\alpha}{2}q_1^2].\end{aligned} \quad (4)$$

The marketing objective of retailer 2 is

$$\begin{aligned}&\max_{q_2}[(p-w_2)q_2+\frac{\beta}{2}q_2^2]\\ &=\max_{q_2}[(a-q_1-q_2-w_2)q_2+\frac{\beta}{2}q_2^2].\end{aligned} \quad (5)$$

where parameters $\alpha, \beta \in [0,1]$ represent the fraction or percentage of the total firm i's consumer surplus, that is, the degree of retailer i for caring about the consumers it serves. Note that $\alpha = 1$ ($\beta = 1$) means retailer 1 (2) is fully focused on its consumers; if retailer 1 (2) does not care about CSR, then $\alpha = 0$ ($\beta = 0$).

4. Equilibrium State and Evolutionary Analysis

In this section, as a benchmark, we first analyze the effect of consumer concern on the retail price, ordering quantity, profits of retailers, and equilibria of the one-shot game. Second, we study the evolutionarily stable strategy of retailers when the equilibrium state in the one-shot game is disturbed.

Table 1 summarizes the equilibrium outcome in the one-shot game, each player's profit, quantity, and unit retail price given the marketing strategy profile.

From Table 1, we see that q_1^{SN} increases with α, which means the market demand of a retailer is positively related to the degree of its consumer concern. Hence, there is a positive relationship between CSR activities and consumer demand. As long as the retailer uses strategy S, then the retailer will order more products and sell them to consumers using a lower price than the retailers using strategy N. Hence, having a CSR strategy can increase the

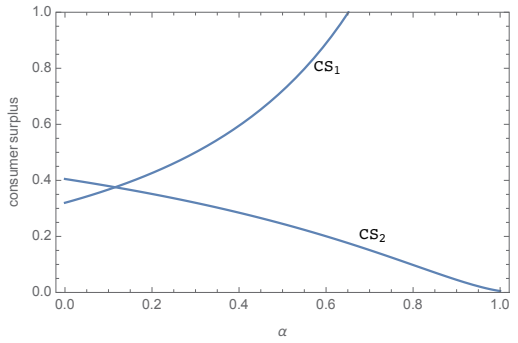

Figure 1 The Consumer Surplus Versus the Degree of the Retailer's Consumer Concern α

consumer surplus of the retailer using strategy S. The result is shown in Figure 1. However, does strategy S benefit the retailers themselves? What are the conditions for retailers to adopt strategy S ?

We use

$$\pi_1^{SS} = \frac{(1-\alpha)[a-2w_1+w_2-\beta(a-w_1)]^2}{[3-\alpha(2-\beta)-2\beta]^2} = (1-\alpha)(q_1^{SS})^2$$

to denote the material payoff of retailer 1 when both retailers 1 and 2 choose strategy S.

$$\pi_2^{SS} = \frac{(1-\beta)[a-2w_2+w_1-\alpha(a-w_2)]^2}{[3-\alpha(2-\beta)-2\beta]^2} = (1-\beta)(q_2^{SS})^2$$

denotes the material payoff of retailer 2 when both retailers use strategy S. Similarly, we obtain $\pi_1^{SN}, \pi_2^{SN}, \pi_1^{NS}, \pi_2^{NS}, \pi_1^{NN}, \pi_2^{NN}$.

At each instant, every retailer is using one of the two strategies: strategy N or strategy S. Let the fraction of retailers choosing strategy N in supply chain 1 be x at this moment and that in supply chain 2 be y. This means that in channel 1, the fraction of retailers adopting a non-social responsibility strategy and the one adopting social responsibility strategy are x and $1-x$, respectively; and those in channel 2 are y and $1-y$, respectively. For example, if the number of retailers in channel 1 is A, then there are xA retailers who adopt strategy N, and $(1-x)A$ retailers who use strategy S.

Proposition 1 *(1) When* $\alpha \geq 3/4, 3-2\beta-\alpha(2-\beta)^2 \geq 0, \beta \geq 3/4$ *and* $3-2\alpha-\beta(2-\alpha)^2 \geq 0$, *there are three Nash equilibria: two pure strategy equilibria* (N,N), (S,S), *a mixed strategy equilibrium* $(x^*, y^*) \in (0,1)\times(0,1)$ *(detail expression refers to the proof of Proposition 1);*
(2) When $3-2\beta-\alpha(2-\beta)^2 \geq 0, \alpha \leq 3/4, \beta \leq 3/4$ *and* $3-2\alpha-\beta(2-\alpha)^2 \geq 0$, *strategy* (S,S) *is a Nash equilibrium;*
(3) When $3-2\beta-\alpha(2-\beta)^2 \geq 0, \alpha \leq 3/4, \beta \geq 3/4$ *and* $3-2\alpha-\beta(2-\alpha)^2 \leq 0$, *there is a unique pure strategy equilibrium* (S,N);
(4) When $3-2\beta-\alpha(2-\beta)^2 \leq 0, \alpha \geq 3/4, \beta \leq 3/4$ *and* $3-2\alpha-\beta(2-\alpha)^2 \geq 0$, *there is a unique strategy equilibrium* (N,S).

All proofs of these propositions are given in Appendix. Based on Case (2) in Proposition 1, we find that retailers moderately concerned about consumers use strategy S. When both retailers care about their consumers moderately, strategy S is the dominant strategy for both retailers. Combining the result and Figure 1, if retailers exhibit a moderate level of concern for consumers, then using strategy S can induce a win-win result, that is, strategy S benefits retailers themselves and their consumers. When both retailers' consumer concerns are high enough ($\alpha \geq 3/4, 3-2\beta-\alpha(2-\beta)^2 \geq 0, \beta \geq 3/4$ and $3-2\alpha-\beta(2-\alpha)^2 \geq 0$), strategy profile (S,S) is Pareto dominated by strategy profile (N,N) when the two wholesale prices are close to each other. Proposition 1 shows that the marketing strategy depends on both retailers' consumer concerns. There is a positive relationship between retailers' profits, consumer surplus, and CSR activities under both retailers care about their consumers at almost the same level. The relationship is negative if the degrees of both retailers' consumer concern are distinct. Figure 2 shows the effect of the degree of retailers' consumer concern on the profits of retailers.

From Figure 2, when only one retailer uses strategy S, using a CSR strategy decreases the rival's profit and increases the retailer's own

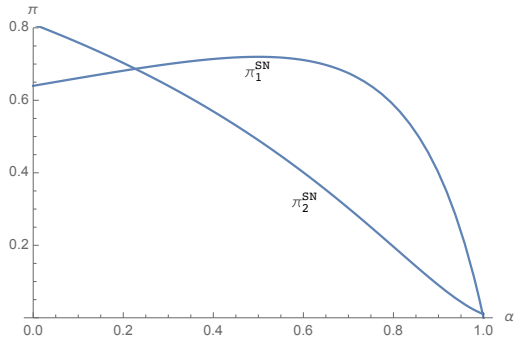

Figure 2 Profits of Both Retailers Versus Retailer 1's Consumer Concern α

profit when the degree of its consumer concern is less than one half, but it decreases both profits when the degree is larger than one half (in fact, there exists a stable CSR parameter). But the consumer concern hurts itself even more when the concern is high enough. For example, let $a = 4, w_1 = 1.2, w_2 = 1.2, \beta = 0, \alpha = 0.8$ and $\alpha = 0.9$; the reduced profit of retailer 1 is about 0.26, the reduced profit of retailer 2 is 0.11. From Proposition 1 and Figure 2, even if the rival is selfish, the retailer should exhibit its CSR moderately to gain competitiveness. Further, combining with Figure 1, we find that it leads to a win-win result (benefits the retailer and its consumers).

Which one should be played when there are multiple Nash equilibria, that is, what is the true "solution" of a game? Moreover, an equilibrium state will almost always be disturbed, if the equilibrium state of retailers in the supply chains is disturbed, whether the supply chains return to the equilibrium state or not. For example, a manufacturer sells its final products through some supermarkets, and the interaction is a long-term and repeated process in which the short-term equilibrium is usually disturbed. So when the game is not a one-shot game, which strategy is played in the repeated game? Is the Pareto dominant strategy selected in a long-term situation? How do retailers involved in the actual game setting find the Nash equilibrium if they don't have knowledge of the game theory?

We answer the above questions by employing the evolutionary game theory. In an evolutionary game, the strategies with higher material payoffs are more likely to be followed. Our model is a polymorphic model where each retailer chooses a strategy from two pure strategies. We assume that the population's behavior evolves following the replicator dynamic system (or Malthusian dynamic system), which is a general dynamic system in the evolutionary game theory (Taylor and Jonker 1987, Friedman 1991, Roca et al. 2009). In a replicator dynamic system, the proportional rate of growth of the individuals using a strategy in the population is given by the extent to which the strategy does better than the population average. Thus, the growth of the proportional rate that retailers use strategy N in supply chain 1 $\dot{x}/x$ equals the difference between strategy N's fitness $\vec{e}_1\mathbf{M}(y, 1-y)^T$ and the average fitness $(x, 1-x)\mathbf{M}(y, 1-y)^T$ of the population, where $\dot{x} = \mathrm{d}x/\mathrm{d}t$, $\mathbf{M}$ is the payoff matrix of population 1, and $\vec{e}_1 = (1, 0)$ denotes that all firms choose strategy N. To find the dynamics of the supply chains over time, we discuss whether the system can return to the equilibrium state under replicator dynamics and which equilibrium should be selected. The replicator dynamics for population 1 is as follows:

$$\dot{x} = x(1-x)[y\pi_1^{NN} + (1-y)\pi_1^{NS} - y\pi_1^{SN} - (1-y)\pi_1^{SS}]. \tag{6}$$

The replicator dynamics for population 2 is the following:

$$\dot{y} = y(1-y)[x\pi_2^{NN} + (1-x)\pi_2^{SN} - x\pi_2^{NS} - (1-x)\pi_2^{SS}]. \tag{7}$$

Systems (6) and (7) are the continuous frequency dynamic systems for the two populations consisting of the retailers in supply chains 1 and 2, respectively.

The populations are said to be at an ESS if they cannot be invaded by a small (relative to the number of the initial population)

subpopulation of individuals using a different individual strategy (Weibull 1995). To study the dynamic characteristics of behavior, a dynamic system such as replicator dynamics is often incorporated. An equilibrium of the replicator dynamic systems (6) and (7) is a point $(x, y) \in [0,1] \times [0,1]$ such that $\dot{x} = \dot{y} = 0$.

Based on the right-hand side of systems (6) and (7), points (0, 0), (0, 1), (1, 0), and (1, 1) and the equilibria in Proposition 1 are the equilibrium points of the replicator dynamic system. Obviously, the strategy of a retailer is not unique; retailers should choose their strategies based on the stability of the equilibrium outcome. So how does the system change in the long-term evolution? According to the above analysis, we assume that the evolutionary process satisfies replicator dynamics. For getting a stable strategy in the long-term, we discuss the stability of equilibria under replicator dynamics.

According to Taylor and Jonker (1987) and Cressman (1992), a locally asymptotically stable equilibrium of a bi-matrix game with two players and two strategies is an ESS. Therefore, based on the stability theory of differential equations, the evolutionary stability of equilibria is determined by the eigenvalues of the corresponding Jacobian matrix.

Proposition 2 *The stability of equilibria for replicator dynamics is as follows:*
(i) As $-3 + \alpha(2-\beta)^2 + 2\beta < 0$ *and* $-3 + \beta(2-\alpha)^2 + 2\alpha < 0$, *the point (0, 0) is an ESS;*
(ii) As $-3 + \alpha(2-\beta)^2 + 2\beta > 0, \beta < 3/4$, *the point (1, 0) is an ESS;*
(iii) As $-3 + \beta(2-\alpha)^2 + 2\alpha > 0, \alpha < 3/4$, *the point (0, 1) is an ESS;*
(iv) As $\beta > 3/4$ *and* $\alpha > 3/4$, *the point (1, 1) is an ESS.*

From Proposition 2, all retailers in supply chain 1 will choose strategy N, and all retailers in supply chain 2 will choose strategy S when $-3 + \alpha(2-\beta)^2 + 2\beta > 0$ and $\beta < 3/4$; on the other hand, when $-3 + \beta(2-\alpha)^2 + 2\alpha > 0$ and $\alpha < 3/4$, all retailers in supply chain 1 will use strategy S, and all retailers in supply chain 2 will use strategy N. Hence, if the degree of consumer concern is over three-fourths and the degree of concern in another supply chain is less than three-fourths, then the retailers in the first supply chain should use strategy N, and the retailers in the second supply chain should adopt strategy S. When the degree of the retailers' CSR implementation is in a similar range, retailers should use a symmetry strategy; accordingly, if the difference between two CSR concerns is large, retailers should choose an asymmetry strategy, depending on their degrees of consumer concern. The results imply the following two insights: First, when the types of retailers and their rivals are similar, then competitive retailers should use a similar strategy in the long term. Second, when there are large differences between the types of retailers and their rivals, retailers should choose different strategies. Figure 2 implies that when the retailer cares about its consumers to a high enough level, the concern will hurt its own profit, and the CSR strategy is not evolutionarily stable. But when the degrees of both retailers' consumer concerns are moderate, the CSR strategy is evolutionarily stable. Thus, retailers who care about their consumers moderately should use strategy S in the long term, and the retailers with high or low consumer concern should choose their marketing strategy depending on the rival's consumer concern.

x, y, or the fraction of retailers using strategy N, can also be interpreted as the market share of the NSR retailer in populations 1 and 2, respectively. In the above analysis, we study the evolution of two supply chain strategies that affect the average profits and market shares of retailers from the two supply chains. The market shares of the retailers' optimal average profits are given by Proposition 2. By using a numerical simulation, we know roughly the equilibrium at which a point will evolve.

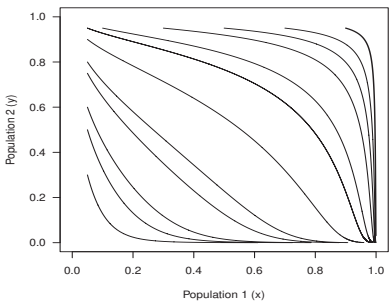

Figure 3 The Phase Portrait of the Supply Chains with $\alpha > \beta$

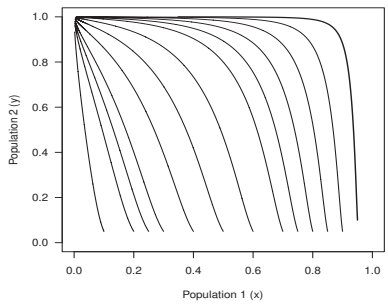

Figure 4 The Phase Portrait of the Supply Chains with $\alpha < \beta$

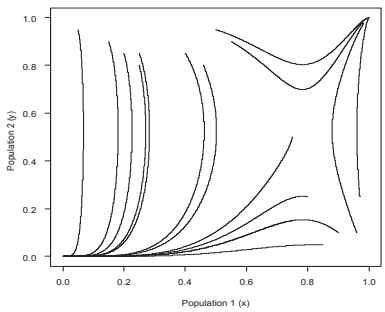

Figure 5 The Dynamics of the Supply Chain when $\alpha = 0.8$ and $\beta = 0.8$

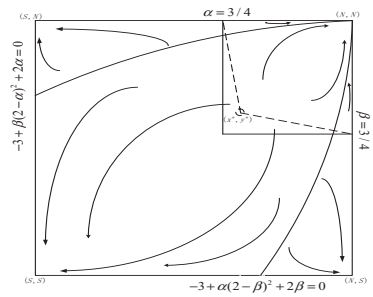

Figure 6 Evolutionary Path for the Supply Chains

Let $a = 4, w_1 = 1.2, w_2 = 1$, and the initial state (0.3, 0.2); we draw Figures 3 and 4 for the supply chain dynamics over time. For different values of the parameters, the evolutionary paths often are different. However, the basic characteristics of the effect of the parameters on the evolutionary paths are similar. In Figure 3, the values of retailers' concern parameters are $\alpha = 0.85$ and $\beta = 0.3$; in Figure 4, the values are $\alpha = 0.3$ and $\beta = 0.85$.

Basing on our analysis, exhibiting CSR moderately is good for retailers. Furthermore, according to Proposition 2, we get the following corollary:

Corollary 1 *If* $3 - \alpha(2-\beta)^2 - 2\beta > 0, 3 - \beta(2-\alpha)^2 - 2\alpha > 0, \alpha > 3/4$ *and* $\beta > 3/4$, *both (0, 0) and (1, 1) are ESS.*

From Corollary 1, we know that under some conditions, all retailers in both supply chains will choose a symmetrical strategy, they all use CSR or NSR strategy. The dynamics of the game under these conditions are shown in Figure 5.

Corollary 1 and Figure 5 show that when retailers are similar and each retailer cares about its consumers to a high enough level, they should use a similar strategy to get their competitive advantages. Which equilibrium ((S, S) or (N, N)) is selected depends on the current state of two supply chains. When the current state is located at the top right of the interior steady state (the interior equilibrium), (N, N) is selected; when the current state is located at the lower left of the interior steady state, (S, S) is selected. Hence, if most retailers with high enough levels of CSR adopt CSR strategy in the current state, these retailers can't get a higher average profit than others in the long-term competition. The evolutionary dynamics for the supply chains are shown in Figure 6.

Table 2 The Unit Wholesale Prices and Profits of Manufacturers with Different Retailers

	Wholesale price (w_1, w_2)	Profit (π_{m1}, π_{m2})
$-3+\alpha(2-\beta)^2+2\beta<0$, $-3+\beta(2-\alpha)^2+2\alpha<0$, (SS)	$\frac{(2-\alpha)[c_2+2c_1(2-\beta)]+a[5-4\beta-\alpha(3-2\beta)]}{15-4\alpha(2-\beta)-8\beta}$, $\frac{a[5-2\alpha(2-\beta)-3\beta]+[c_1+2c_2(2-\alpha)](2-\beta)}{15-4\alpha(2-\beta)-8\beta}$	$\frac{(2-\beta)g^2(c_1,c_2,\alpha,\beta)}{[15-4\alpha(2-\beta)-8\beta]^2[3-\alpha(2-\beta)-2\beta]}$, $\frac{(2-\alpha)g^2(c_2,c_1,\beta,\alpha)}{[15-4\alpha(2-\beta)-8\beta]^2[3-\alpha(2-\beta)-2\beta]}$
$-3+\beta(2-\alpha)^2+2\alpha>0$, $\alpha<3/4$ (SN)	$\frac{(4c_1+c_2)(2-\alpha)+a(5-3\alpha)}{15-8\alpha}$, $\frac{5a+2c_1+8c_2-4a\alpha-4c_2\alpha}{15-8\alpha}$	$\frac{2[c_1(7-4\alpha)-c_2(2-\alpha)-a(5-3\alpha)]^2}{(15-8\alpha)^2(3-2\alpha)}$, $\frac{(2-\alpha)[2c_1+a(5-4\alpha)-c_2(7-4\alpha)]^2}{(15-8\alpha)^2(3-2\alpha)}$
$-3+\alpha(2-\beta)^2+2\beta>0$, $\beta<3/4$ (NS)	$\frac{5a+8c_1+2c_2-4a\beta-4c_1\beta}{15-8\beta}$, $\frac{(c_1+4c_2)(2-\beta)+a(5-3\beta)}{15-8\beta}$	$\frac{(2-\beta)[2c_2+a(5-4\beta)-c_1(7-4\beta)]^2}{(15-8\beta)^2(3-2\beta)}$, $\frac{2[c_2(7-4\beta)-c_1(2-\beta)-a(5-3\beta)]^2}{(15-8\beta)^2(3-2\beta)}$
$\alpha>3/4, \beta>3/4$, (NN)	$\frac{1}{15}(5a+8c_1+2c_2)$, $\frac{1}{15}(5a+2c_1+8c_2)$	$\frac{2}{675}(5a-7c_1+2c_2)^2$, $\frac{2}{675}(5a+2c_1-7c_2)^2$

Here $g(c_1,c_2,\alpha,\beta)=c_1[7-2\alpha(2-\beta)-4\beta]+a[\alpha(3-2\beta)+4\beta-5]-c_2(2-\alpha)$.

5. The Unit Wholesale Price Decisions

We have discussed the effect of retailers' CSR on consumer surplus, market price, and retailers' profits in the short term and long term and have obtained the evolutionarily stable strategies of retailers. In this section, we study the unit wholesale price decisions of manufacturers after predicting the decisions of the retailers.

5.1 The Wholesale Price Decisions for Manufacturers without CSR Concern

Though retailers exhibit their CSR through consumer concern, some manufacturers do not have similar behaviors; for example, in the retail platform arena, companies such as Best-Buy, Amazon, and Jingdong have a lot of promotions or cause-related marketing. However, we have not found similar activities in the direct stores of some manufacturers. Hence, we first discuss the unit wholesale price decisions of manufacturers that do not have to worry about consumers. The optimization problem of manufacturer i is $\max_{w_i}(w_i-c_i)q_i$, where c_i is the unit production cost of manufacturer i. According to the analysis in Section 4, retailer i has four kinds of ordering strategies: $q_i^{SS}, q_i^{SN}, q_i^{NS}, q_i^{NN}$.

Based on Proposition 2, the dynamics of retailers from two supply chains are shown in Figure 6. So manufacturers can make the wholesale price decisions according to the retailers' marketing strategies. When both retailers have high levels of CSR implementation, that is, $-3+\alpha(2-\beta)^2+2\beta<0, -3+\beta(2-\alpha)^2+2\alpha<0, \alpha>3/4$ and $\beta>3/4$, both (S,S) and (N,N) are evolutionarily stable. The selection of retailers depends on the current state of two supply chains. However, if manufacturers know the current state of retailers in two supply chains, it can show the selection of retailers. Obviously, the manufacturer$i$ is seeking a wholesale price w_i to maximize $u_{mi}=(w_i-c_i)q_i^{SS}$ for the retailers' strategy profile (S,S). It is easy to verify that both u_{m1}, u_{m2} are concave if $-3+\alpha(2-\beta)^2+2\beta<0$ (refer to the proof of Table 2). By directly calculating, we get the wholesale price under strategy profile (S,S). The equilibrium outcome is shown in Table 2. Furthermore, we get Proposition 3.

Proposition 3 *Manufacturers offer a lower unit wholesale price to the retailer adopting strategy S*

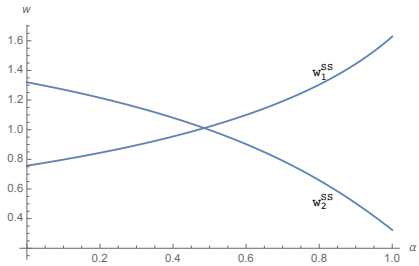

Figure 7 The Unit Wholesale Price Versus CSR Parameter α with $\beta = 0.4$

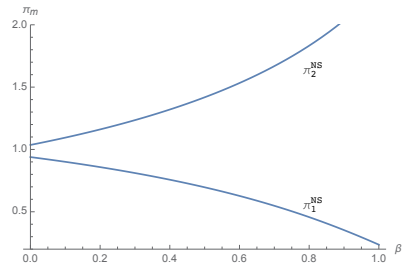

Figure 8 The Manufacturers' Profits Versus a CSR Parameter β

than to the retailers adopting strategy N.

Proposition 3 implies that manufacturers charge the retailers using a CSR strategy a lower wholesale price than the retailers adopting an NSR strategy to support the responsible behavior toward society. Furthermore, we discuss the effect of retailers' degree of caring about their consumers on the unit wholesale price and the profits of the manufacturers.

Proposition 4 *(1) Retailers' CSR concerns decrease the unit wholesale price;*
(2) When the difference of unit production cost of two manufacturers is small, especially $|c_1 - c_2| < min\{(55 - 60\beta + 16\beta^2)(2a - 4c_2 - c_1)/2, 3(a - c_2)(20 - 25\beta + 8\beta^2)/(33 - 33\beta + 8\beta^2), (55 - 60\alpha + 16\alpha^2)(2a - 4c_1 + c_2)/2, 3(a - c_1)(20 - 25\alpha + 8\alpha^2)/(33 - 33\alpha + 8\alpha^2)\}$*, then retailers' CSR concerns increase the profit of their own manufacturer and decrease the one of their rival's manufacturer when only one retailer uses strategy S.*

From Proposition 4, we know that if one retailer uses strategy S and its rival uses strategy N, then the retailer's CSR concern increases its own manufacturer's profit and decreases the rival manufacturer's profit. Therefore, for a retailer, using a CSR strategy is good for itself, its manufacturer, and the total supply chain. The results are reported in Figures 7 and 8, where the default values of the parameters are: $a = 4, c_1 = 0.4, c_2 = 0.3$.

Because both retailers from the two supply chains care about CSR, the expressions are too complex to have too many parameters, so we give the results using the numerical simulation (Figure 9). $\beta = 0.5, 0.93$ corresponds to the solid and dashed lines, respectively. The default values of the other parameters in Figure 9 are the same as those in Figures 7 and 8.

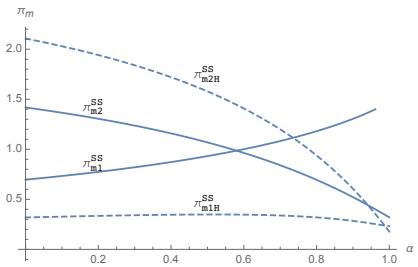

Figure 9 Profits of Manufacturers Versus α

From Figure 9, the profit of manufacturer 2 always decreases with α no matter how much β changes. For manufacturer 1, when the value of parameter β is moderate, the profit always increases with α; however, when the value of β is high enough, the profit increases and then decreases with α. Thus, we have the following:
(i) Retailers' CSR concerns increase the profit of their manufacturer and decrease the profit of their rival's manufacturer if one of CSR concerns is moderate; this is shown in Figure 9 with solid lines;
(ii) Retailer's CSR concern decreases the profits of both manufacturers if both CSR concerns are high (higher than 3/4) but not close to 1; this is shown in Figure 9 with a dashed line.

In fact, if the CSR concern of a retailer is moderate, a lower wholesale price can increase the profit of the manufacturer and decrease the profit of the rival's manufacturer. As a result, this increases the competition between the

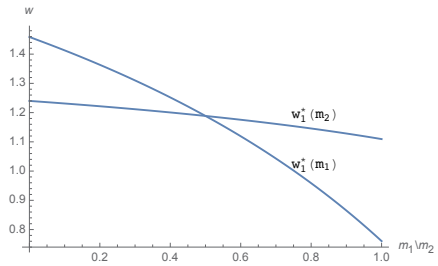

Figure 10 The Unit Wholesale Price Versus the Manufacturers' Consumer Concerns

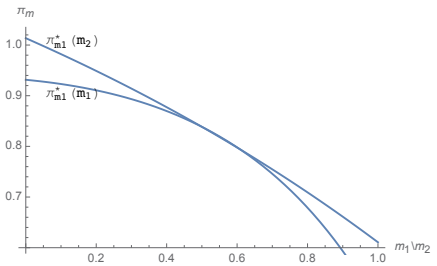

Figure 11 Profits of Manufacturers Versus Their Consumer Concerns

supply chains. However, if the retailer's CSR concern is high, the CSR concern of the retailer will decrease the profit of its own manufacturer and the profit of its rival's manufacturer because the CSR concern sacrifices the interests of the firm who cares about CSR. However, from Figure 9, we know that the retailer's CSR concern decreases the profit of the rival manufacturer even more. Combined with these results and the results in the one-shot game between retailers, we find that if the retailer exhibits its CSR practices moderately, then a triple-win outcome can be achieved, that is, the moderate CSR concern benefits the retailer itself, its manufacturer, and consumers.

5.2 The Wholesale Price Decisions for Manufacturers Adopting a CSR Strategy

To further explain why some manufacturers do not care about CSR, we can discuss the effects of manufacturers' CSR practices on the equilibrium wholesale prices and profits. Similarly, we consider the consumer concern is the exhibiting of manufacturers' CSR practices. The optimization problem of manufacturer i with consumer concern is $\max_{w_i}(w_i - c_i)q_i + m_i q_i^2/2$, where $0 \le m_i \le 1$ denotes the degree manufacturer i cares about its consumers. Here, we find that the manufacturers' consumer concern decreases both the manufacturers' equilibrium wholesale prices and profits. The results are shown in Figures 10 and 11, where the values of the parameters are as follows: $a = 4, c_1 = 0.4, c_2 = 0.3, \alpha = 0.2, \beta = 0.1, m_1 = 0.5$, or $m_2 = 0.5$.

Here, $w_1^*, w_2^*, \pi_{m1}^*, \pi_{m2}^*$ denote the wholesale prices and profits of manufacturers 1 and 2 when both retailers use a CSR strategy. In fact, when the retailer does not care about a consumer surplus, the above results are still true (i.e., when $\alpha = 0$ or $\beta = 0$, we also see that the manufacturers' consumer concerns hurt both manufacturers). From Figures 10 and 11, we find that the manufacturer's consumer concern hurts both manufacturers' profits, and the concern hurts itself even more when its consumer concern is relatively high. Thus, in the real world, many manufacturers don't care about their consumer surplus as retailers do.

6. Conclusions and Future Research

Dr. Elaine Sternberg stated that, "The defining purpose of business is to maximize owner value over the long-term by selling goods and services" (Cadbury 2006), which refers to value rather than money and to the long-term objective of a firm. What we do in this paper revolves around what Dr. Elaine Sternberg pointed out.

In this paper, we have considered the strategic decisions of firms in different supply chains. Each supply chain consists of one manufacturer and many retailers. Retailers make decisions about being CSR oriented or NSR oriented. The NSR firm is seeking to maximize the profits of its shareholders, and the purpose of a CSR firm is to maximize the value of its owners. We have obtained the sufficient conditions to show that a CSR strategy is evolution-

arily stable and the sufficient conditions that show an NSR strategy is evolutionarily stable. Correspondingly, the conditions for the relationship between CSR activities and the firm's value that show if this relationship is positive or negative are obtained according to the stability of the CSR or NSR strategy. When the levels of two competitive retailers' consumer concern are high enough, the ESS is also related to the current state of the market.

Furthermore, we have examined the effects of retailer's consumer concern on the unit wholesale price strategies of manufacturers. We have found that manufacturers should charge CSR retailers a lower unit wholesale price. When a CSR concern is moderate or only one retailer uses a CSR approach, this increases the profit of the retailer's own manufacturer and decreases the profit of the rival's manufacturer; otherwise, the CSR concern decreases the profits of both the manufacturers. However, the manufacturer's consumer concern decreases both manufacturers' unit wholesale prices and profits, and the manufacturer's concern hurts itself even more when its consumer concern is relatively high. A triple-win situation, that is, the CSR approach benefits the retailer itself, its manufacturer, and consumers, can be achieved when retailers take a moderate approach toward their CSR practices.

In this paper, we have assumed that the match type between retailers is uniform and random. Nevertheless, there also exist many nonrandom matches in the real world. A further research avenue is to extend our results by considering equilibrium with nonrandom matching, such as assortative matching. Second, from our results, the CSR strategy of a firm affects consumer demand indirectly. It would be interesting to study the direct effect of CSR on market demand. In addition, a firm is a part of society, so besides its commercial role, the firm has a social role, and its success or failure may have an important impact on its stakeholders, not only on consumers. So we are also interested in considering the benefits of other stakeholders, such as employees and the environment.

Appendix A Proofs

Proof of Proposition 1. From Table 2, we get the payoff advantage for retailer1 $\Delta w_1 = y\pi_1^{NN} + (1-y)\pi_1^{NS} - y\pi_1^{SN} - (1-y)\pi_1^{SS}$. Similarly, the payoff advantage for retailer 2 is as follows: $\Delta w_2 = x\pi_2^{NN} + (1-x)\pi_2^{SN} - x\pi_2^{NS} - (1-x)\pi_2^{SS}$.

From $y\pi_1^{NN} + (1-y)\pi_1^{NS} - y\pi_1^{SN} - (1-y)\pi_1^{SS} = 0$ and $x\pi_2^{NN} + (1-x)\pi_2^{SN} - x\pi_2^{NS} - (1-x)\pi_2^{SS} = 0$, we see

$$y^* = \frac{\pi_1^{SS} - \pi_1^{NS}}{\pi_1^{SS} + \pi_1^{NN} - \pi_1^{NS} - \pi_1^{SN}} = \frac{[3-2\beta-\alpha(2-\beta)^2]A_1}{[3-2\beta-\alpha(2-\beta)^2]A_1 + (4\alpha-3)A_2},$$

and

$$x^* = \frac{\pi_2^{SS} - \pi_2^{SN}}{\pi_2^{SS} + \pi_2^{NN} - \pi_2^{NS} - \pi_2^{SN}} = \frac{[3-2\alpha-\beta(2-\alpha)^2]B_1}{[3-2\alpha-\beta(2-\alpha)^2]B_1 + (4\beta-3)B_2}.$$

Here,

$$A_1 = 9(3-2\alpha)^2[a - a\beta + w_2 - (\beta-2)w_1]^2 > 0,$$
$$A_2 = (a - 2w_1 + w_2)^2(3-2\beta)^2(3-2\beta-2\alpha+\alpha\beta)^2 > 0,$$
$$B_1 = 9[a - a\alpha + w_1 - (\alpha-2)w_2]^2(3-2\beta)^2 > 0,$$
$$B_2 = (a - 2w_2 + w_1)^2(3-2\alpha)^2[3-2\beta+\alpha(\beta-2)]^2 > 0.$$

According to Table 1, we have

$$\pi_1^{SS} - \pi_1^{NS} = \frac{\alpha[3-\alpha(\beta-2)^2-2\beta][a-a\beta-(2-\beta)w_1+w_2]^2}{(3-2\beta)^2[3-\alpha(2-\beta)-2\beta]^2},$$
$$\pi_1^{NN} - \pi_1^{NS} = \frac{\alpha(4\alpha-3)(a-2w_1+w_2)^2}{9(3-2\alpha)^2},$$
$$\pi_2^{NN} - \pi_2^{NS} = \frac{\beta(4\beta-3)(a-2w_2+w_1)^2}{9(3-2\beta)^2},$$
$$\pi_2^{SS} - \pi_2^{SN} = \frac{\beta[3-\beta(\alpha-2)^2-2\alpha][a-a\alpha+w_1-(2-\alpha)w_2]^2}{(3-2\alpha)^2[3-\alpha(2-\beta)-2\beta]^2}.$$

If $[3-2\beta-\alpha(\beta-2)^2](4\alpha-3) > 0$ and $[3-2\alpha-\beta(\alpha-2)^2](4\beta-3) > 0$, then we have $0 < x^* < 1$ and

$0 < y^* < 1$, (x^*, y^*) is an interior equilibrium. When $\alpha \geq 3/4, 3-2\beta-\alpha(2-\beta)^2 \geq 0$, there are $\pi_1^{NN} \geq \pi_1^{SN}$ and $\pi_1^{SS} \geq \pi_1^{NS}$; when $\beta \geq 3/4, 3-2\alpha-\beta(2-\alpha)^2 \geq 0$, there are $\pi_2^{NN} \geq \pi_2^{NS}$ and $\pi_2^{SS} \geq \pi_2^{SN}$. Hence, (N, N) and (S, S) are two pure strategy Nash equilibria. So Part (1) holds. Similarly, we can show other parts in Proposition 1.

Proof of Proposition 2. Hofbauer and Sigmund (1988) give the linearization method of using the Jacobian matrix to analyze the stability of replicator dynamics. Then, we linearize the systems (6)-(7) using the Jacobian method. The Jacobian matrix **J** of the replicator dynamics is as follows:

$$\begin{bmatrix} (1-2x)[y(\pi_1^{NN}+\pi_1^{SS}-\pi_1^{NS}-\pi_1^{SN})+\pi_1^{NS}-\pi_1^{SS}] & x(1-x)(\pi_1^{NN}+\pi_1^{SS}-\pi_1^{NS}-\pi_1^{SN}) \\ y(1-y)(\pi_2^{SS}+\pi_2^{NN}-\pi_2^{SN}-\pi_2^{NS}) & (1-2y)[x(\pi_2^{SS}+\pi_2^{NN}-\pi_2^{SN}-\pi_2^{NS})+\pi_2^{SN}-\pi_2^{SS}] \end{bmatrix}$$

Thus, the Jacobian matrix of replicator equations at the point (0, 0) is the following:

$$\begin{bmatrix} \lambda_1^* & 0 \\ 0 & \lambda_2^* \end{bmatrix}$$

Hence, the eigenvalues are as follows:

$$\lambda_1^* = -\frac{\alpha[3-\alpha(\beta-2)^2-2\alpha][a-a\beta+(\beta-2)w_1+w_2]^2}{[(3-2\beta)(3-2\alpha-2\beta+\alpha\beta)]^2},$$
$$\lambda_2^* = -\frac{\beta[3-\beta(\alpha-2)^2-2\beta][a-a\alpha+(\alpha-2)w_2+w_1]^2}{[(3-2\alpha)(3-2\alpha-2\beta+\alpha\beta)]^2}.$$

According to the stability theory of ordinary differential equation, as $\lambda_1^* < 0$ and $\lambda_2^* < 0$, the point (0, 0) is asymptotically stable. Hence, it is an ESS. According to the expression of λ_1^* and λ_2^*, $\lambda_1^* < 0$ and $\lambda_2^* < 0$ if and only if $3-\alpha(\beta-2)^2-2\alpha > 0$ and $3-\beta(\alpha-2)^2-2\beta > 0$, so part (i) in Proposition 2 is true. Similarly, we can prove the parts (ii, iii, iv) in Proposition 2.

Proof of Table 2. We only prove the second case in Table 2, that is, the strategy profile of retailers is (S, S). The optimization problems of manufacturers 1 and 2 are, respectively, the following:

$$\max_{w1} u_{m1} = (w_1 - c_1)\frac{a(1-\beta)-(2-\beta)w_1+w_2}{3-\alpha(2-\beta)-2\beta},$$
$$\max_{w2} u_{m2} = (w_2 - c_1)\frac{a(1-\alpha)+w_1-(2-\alpha)w_2}{3-\alpha(2-\beta)-2\beta}.$$

Note that $\partial^2 u_{m1}/\partial w_1^2 = -2(2-\beta)/[3-\alpha(2-\beta)-2\beta] < 0$, $\partial^2 u_{m2}/\partial w_2^2 = -2(2-\alpha)/[3-\alpha(2-\beta)-2\beta] < 0$ for $3-\alpha(2-\beta)^2-2\beta > 0$, i.e., u_{mi} is concave over w_i, $i = 1, 2$.

Solving the first-order conditions $\partial u_{m1}/\partial w_1 = 0$ and $\partial u_{m2}/\partial w_2 = 0$ for (w_1, w_2), we get the wholesale prices as follows:

$$w_1^{SS} = \frac{(2-\alpha)[c_2+2c_1(2-\beta)]+a[5-4\beta-\alpha(3-2\beta)]}{15-4\alpha(2-\beta)-8\beta},$$
$$w_2^{SS} = \frac{[c_1+2c_2(2-\alpha)](2-\beta)+a[5-2\alpha(2-\beta)-3\beta]}{15-4\alpha(2-\beta)-8\beta}.$$

Inserting the equilibria (w_1^{SS}, w_2^{SS}) into the profit function of manufacturer i, $\pi_i = (w_i - c_i)q_i$, we obtain the following:

$$\pi_{m1}^{SS} = \frac{(2-\beta)[c_1(7-4\alpha-4\beta+2\alpha\beta)-c_2(2-\alpha)-a(5-3\alpha-4\beta+2\alpha\beta)]^2}{[15-4\alpha(2-\beta)-8\beta]^2(3-2\alpha-2\beta+\alpha\beta)},$$
$$\pi_2^{SS} = \frac{(2-\alpha)[c_2(7-4\alpha-4\beta+2\alpha\beta)-c_1(2-\beta)-a(5-4\alpha-3\beta+2\alpha\beta)]^2}{[15-4\alpha(2-\beta)-8\beta]^2(3-2\alpha-2\beta+\alpha\beta)}.$$

Similarly, we obtain the wholesale prices and profits under the other strategy profiles.

Proof of Proposition 3. From Table 2, if both retailers adopt strategy S, the unit wholesale prices are as follows:

$$w_1^{SS} = \frac{(2-\alpha)[c_2+2c_1(2-\beta)]+a[5-4\beta-\alpha(3-2\beta)]}{15-4\alpha(2-\beta)-8\beta},$$
$$w_2^{SS} = \frac{[c_1+2c_2(2-\alpha)](2-\beta)+a[5-2\alpha(2-\beta)-3\beta]}{15-4\alpha(2-\beta)-8\beta}.$$

When both retailers adopt strategy N, the unit wholesale prices are as follows:

$$w_1^{NN} = \frac{1}{15}(5a+8c_1+2c_2),$$
$$w_2^{NN} = \frac{1}{15}(5a+2c_1+8c_2).$$

So

$$w_1^{SS} - w_1^{NN} = -\frac{2\beta(2-\alpha)(5a-c_1-4c_2)+\alpha(5a-c_2-4c_1)}{15[15-4\alpha(2-\beta)-8\beta]} < 0,$$
$$w_2^{SS} - w_2^{NN} = -\frac{2\alpha(2-\beta)(5a-4c_1-c_2)+\beta(5a-c_1-4c_2)}{15[15-4\alpha(2-\beta)-8\beta]} < 0.$$

Similarly, we get $w_1^{SN} - w_1^{NN} < 0$, $w_2^{SN} - w_2^{NN} < 0$. Then, Proposition 3 is true.

Proof of Proposition 4. From Table 2, we have the following:

$$\frac{\partial w_1^{SS}}{\partial \alpha} = \frac{c_2+2c_1(2-\beta)-a(5-2\beta)}{[15-4\alpha(2-\beta)-8\beta]^2} = -\frac{a-c_2+(a-c_1)(4-2\beta)}{[15-4\alpha(2-\beta)-8\beta]^2} < 0,$$
$$\frac{\partial w_1^{SS}}{\partial \beta} = \frac{2(2-\alpha)[c_1+2c_2(2-\alpha)-a(5-2\alpha)]}{[15-4\alpha(2-\beta)-8\beta]^2} = -\frac{2(2-\alpha)[a-c_1+(a-c_2)(4-2\alpha)]}{[15-4\alpha(2-\beta)-8\beta]^2} < 0.$$

So the retailers' CSR concerns decrease the unit wholesale price.

Similarly, when the difference between the unit production costs of two manufacturers is small, we have $\frac{\partial \pi_1^{NS}}{\partial \beta} = -[4(1-\beta)(a-c_1)+(a-3c_1+2c_2)][(55-60\beta+16\beta^2)(2a-4c_2+c_1)+2(c_1-c_2)]/[(3-2\beta)^2(15-8\beta)^3] < 0$, and $\frac{\partial \pi_2^{NS}}{\partial \beta} = [(5-3\beta)(a-c_2)+(2-\beta)(c_1-c_2)][3(a-c_2)(20-25\beta+8\beta^2)+(c_1-c_2)(33-33\beta+8\beta^2)]/[(3-2\beta)^2(15-8\beta)^3] > 0$.

So the second part of Proposition 4 holds. Thus, Proposition 4 is true.

Acknowledgments

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References

Allen F, Carletti E, Marquez R (2014). Stakeholder governance, competition and firm value. *CESifo Working pape* (No. 4652).

Andersen M, Skjoett-Larsen T (2009). Corporate social responsibility in global supply chains. *Supply Chain Management: An International Journal* 14(2):75-86.

Boyaci T, Gallego G (2002). Coordinating pricing and inventory replenishment policies for one wholesaler and one or more geographically dispersed retailers. *International Journal of Production Economics* 77(2):95-111.

Cadbury A (2006). Corporate social responsibility. *Twenty-First Century Society: Journal of the Academy of Social Sciences* 1(1):5-21.

Cespa G, Cestone G (2007). Corporate social responsibility and managerial entrenchment. *Journal of Economics and Management Strategy* 16(3):741-771.

Chai C, Xiao T, Francis E (2018). Is social responsibility for firms competing on quantity evolutionary stable? *Journal of Industrial and Management Optimization* 14(1):325-347.

Cheng B, Loannou L, Serafeim G (2014). Corporate social responsibility and access to finance. *Strategic Management* 35(1):1-23.

Chiang T, Che Z, Wang T (2011). A design for environment methodology for evaluation and improvement of derivative consumer electronic product development. *Journal of Systems Science and Systems Engineering* 20(3):260-274.

Cornell B, Shapiro C (1987). Corporate stakeholders and corporate finance. *Financial Management* 16(1):5-14.

Cressman R (1992). *The Stability Concept of Evolutionary Game Theory* (Springer-Verlag, Berlin, Heidelberg).

Cruz J (2008). Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making. *European Journal of Operational Research* 184(3):1005-1031.

Cruz J (2009). The impact of corporate social responsibility in supply chain management: Multicriteria decision-making approach. *Decision Support Systems* 48(1):224-236.

Cruz J (2013). Mitigating global supply chain risks through corporate social responsibility. *International Journal of Production Research* 51(13):3995-4010.

Dahlsrud A (2008). How corporate social responsibility is defined: An analysis of 37 definitions. *Corporate Social Responsibility and Environmental Management* 15:1-13.

Eriksson D, Sevensson G (2015). Elements affecting social responsibility in supply chains. *Supply Chain Management: An International Journal* 20(5):561-566.

Fortune (2013). Top 100 social responsibility firms in China (in Chinese). *Fortune* March.

Friedman D (1991). Evolutionary games in economics. *Econometrica* 59(3):637-666.

Gallear D, Ghobadian A, Chen W (2012). Corporate responsibility, supply chain partnership and perfor-

mance: An empirical examination. *International Journal of Production Economics* 140(1):83-91.

Goering GE (2012). Corporate social responsibility and marketing channel coordination. *Research in Economics* 66(2):142-148.

Hofbauer J, Sigmund K (1988). *Evolutionary Games and Population Dynamics* (Cambridge University Press, Cambridge).

Jensen M, Meckling W (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. *Journal of Financial Economics* 3(4):305-360.

Lee MDP (2008). A review of the theories of corporate social responsibility: Its evolutionary path and the road ahead. *International Journal of Management Reviews* 10(1):53-73.

Levy J (2009). A case for sustainable security systems engineering: Integrating national, human, energy and environmental security. *Journal of Systems Science and Systems Engineering* 18(4):385-402.

Magill M, Quinzii M, Rochet J (2015). A theory of the stakeholder corporation. *Econometrica* 83(5):1685-1725.

Maloni M, Brown M (2006). Corporate social responsibility in the supply chain: An application in the food industry. *Journal of Business Ethics* 68(1):35-52.

Mankiw N (2014). *Essentials of Economics (6ed)*,Higher Education Press.

Margolis J, Walsh J (2003). Misery loves companies: Rethinking social initiatives by business. *Administrative Science Quarterly* 48(2):268-305.

McWilliams A, Siegel D, Wright P (2006). Corporate social responsibility: Strategic implications. *Journal of Management Studies* 43(1):1-18.

Meredith R (1999). The newest ford generation takes the company spotlight. *New York Times* 14 May:C6.

Omran M, Atrill P, Pointon J (2002). Shareholders versus stakeholders: Corporate mission statements and investor returns. *Business Ethics: A European Review* 11(4):318-328.

Panda S (2014). Coordination of a socially responsible supply chain using revenue sharing contract. *Transportation Research Part E* 67:92–104.

Roca C, Cuesta J, Sánchez A (2009). Evolutionary game theory: Temporal and spatial effects beyond replicator dynamics. *Physics of Life Reviews* 6(4):208-249.

Saeidi S, Sofian S, Saeidi P, Saeidi S, Saaeidi S (2015). How does corporate social responsibility contribute to firm financial performance? the mediating role of competitive advantage, reputation, and customer satisfaction. *Journal of Business Research* 68(2):341-350.

Servaes H, Tamayo A (2013). The impact of corporate social responsibility on firm value: The role of customer awareness. *Management Science* 59(5):1045-1061.

Tate W, Ellram L, Kirchoff J (2010). Corporate social responsibility reports: A thematic analysis related to supply chain management. *Journal of Supply Chain Management* 46(1):19-44.

Taylor P, Jonker L (1987). Evolutionary stable strategies and game dynamics. *Mathematical Biosciences* 40(1-2):145-156.

Weibull JW (1995). *Evolutionary Games Theory* (The MIT Press, Cambridge, Massachusetts, London, England).

Welford R, Frost S (2006). Corporate social responsibility in asian supply chains. *Corporate Social Responsibility and Environmental Management* 13(3):166-176.

Xiao T, Yu G (2006). Supply chain disruption management and evolutionarily stable strategies of retailers in the quantity-setting duopoly situation with homogeneous goods. *European Journal of Operational Research* 173(2):648-668.

Yoshimori M (1995). Whose company is it? the concept of the corporation in Japan and the West. *Long Range Planning* 28(4):2-44.

Caichun Chai is a lecturer in School of Management Science and Engineering at Nanjing University of Finance and Economics, China. She received her Ph.D. in management science and engineering from Nanjing University in 2017, and M.S. in Mathematics from University of Science and Technology of China in 2007. As a visiting scholar, she has been for one year at University of California, Santa Cruz. Her research focuses on the supply chain management, evolution of corporate behavior, game theory, and dynamical systems.

Tiaojun Xiao is a Professor in School of Management and Engineering at Nanjing University. He received his Ph.D. in management science and engineering from Southeast University in 2001. Prof. Xiao was awarded the China National Funds for Distinguished Young Scientists in 2014. His current research interests include applied game theory, logistics and supply chain management, behavioral decision theory. He has authored or co-authored about 50 papers in several academic journals. He is an Editorial Board Member of Journal of Industrial and Management Optimization, etc.