IS SOCIAL RESPONSIBILITY FOR FIRMS COMPETING ON QUANTITY EVOLUTIONARY STABLE?

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Abstract. This paper studies the evolutionary stable strategies and preferences regarding corporate social responsibility of competing firms. Firms randomly compete with each other in pairs. Shareholder-oriented firms have no social responsibility concern, whereas a firm that is concerned with social responsibility is stakeholder-oriented. Each firm first picks one of two production strategies: shareholder-oriented or stakeholder-oriented, and then decides production quantity. We find that socially responsible firms have lower retail prices. The evolutionary stability of a strategy depends on product substitutability and the degree to which firms care about social responsibility. When product substitutability is relatively high, stakeholder-oriented strategy is the evolutionary stable strategy; if product substitutability is lower than a threshold, shareholder-oriented strategy is evolutionary stable; and with moderate product substitutability, both strategies are evolutionary stable.

Furthermore, we consider how the degree of social responsibility preference evolves according to the adaptive dynamics to continuously stable preference. We find that the non social responsibility concern behavior is not an evolutionary stable preference; there is a unique continuously stable degree of social responsibility preference. Furthermore, we find the evolutionary stability of shareholder-oriented and stakeholder-oriented depends on the initial distribution of firms' strategies under the continuously stable social responsibility preference.

1. Introduction. In recent years, corporate social responsibility (SR) has become an inevitable issue for managers. Firms’ SR strategies or discussions about these strategies are discussed in the popular and academic press. Government legislation require every publicly listed firm to disclose social responsibility reports. These pressures make SR an integral component of firms’ management strategy. SR is

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when firms go beyond profit-maximizing and incorporate some social welfare into their optimization problem. This could be considering and responding to the interests of its stakeholders, or adopting environmentally sustainable practices among others.

In this paper, a firm exhibits its SR by considering the benefit of stakeholders (consumers). That is, a SR concern firm should incorporate the welfare of its stakeholders, and not just that of those who have invested in the firm. According to the surveys of managers reported in Yoshimori [84], there were 97% managers considered that all stakeholders were important in Japan, there were 83% and 78% managers viewed the firm as being for all stakeholders in Germany and France. However, the main objective of a firm is to maximize the profits for those who hold the firms’ shares in the classical economics. A firm should develop incentive systems to induce agents, like managers of the firm, to act in the interest of the principals—the shareholders. In U.K. and U.S., there is a wide agreement that shareholders are the owners of the firm and managers have a duty to act in their interests. There were 76% managers considered the shareholders’ interests should be given priority in U.S., and the rate is 71% in U.K. [84].

The management strategy of a firm is affected by its environment (fundamental national or local institutions or legislations), it is also affected by its mission statement or preferences. For example, Coca-Cola states its commitment is to create interest for the owners, while Cadbury Schweppes states the task is to satisfy the interests of the shareholders, consumers, employees, etc. Omran et al. [60] investigate 80 firms from different industries in Europe, and according to the mission statements, get the amount of non-social responsibility concern firms is 32, those of SR concern firms is 48. In a KPMG [42] survey, there are 74% of the top 100 U.S. companies by revenue publish SR reports in 2008, up from 37% in 2005, 80% of the world’s 250 largest companies issue SR reports in 2008.

The debate on whether a firm should consider social responsibility has been articulating since corporate social responsibility began. Some people think pure shareholder-oriented firms are able to overcome constraints faced by lack of pledgeable income, reject the primacy of shareholders will result in poorer returns to shareholders. While some people think a non-social responsibility (NSR) concern might not be ideal for all socio-economic environments, unless the needs of stakeholders are properly addressed there will be an adverse effect on firm performance, the interaction between corporate success and social welfare is not a zero-sum game. John Egan (CEO of British Airport Authority) had said a firm could not serve the long-term interest of shareholders other than it cooperated with its stakeholders [60]. Carroll and Shabana [10] think that the classical economic view ignores the long-term negative effects in applying profit maximization principle.

An interesting question is whether the SR concern behavior reduces the firm performance or shareholders’ interests, especially, whether NSR concern firms can provide superior interests to the SR concern firms in the long-term. There is a seldom research relating to the question and this paper attempts to redress this situation. We propose a new way to look at the relationship between firm success and SR, suggest an effective strategy for firm’s development. Considering each individual owns bounded rationality, and a firm operation should secure the long-term economic performance, our paper uses the method of evolutionary game theory to discuss the evolutionary stable strategy of a firm, and analyzes the advantage strategy for a firm’s development in the long term.
What is the relationship between SR and firm performance? How a SR concern firm incorporates the SR concern behavior and the profit of the firm? In Section 3, we establish the basic model depending on whether or not the decision makers are SR concern. Considering a SR concern firm cares about the benefit of its stakeholders, we establish the main objective of the firm’s managers is to maximizing the combination of profit of the firm and the stakeholders’ welfare.

In Section 4, we develop two models to study the conditions that firms choose shareholder-oriented strategy (i.e., NSR concern) or stakeholder-oriented strategy (SR concern). In the first model, by comparing the interaction between the shareholder-oriented firms and the stakeholder-oriented firms achieve the shareholder-oriented firm’s profit is lower than the stakeholder-oriented firm’s profit when the stakeholder parameter is less than the threshold. We find that shareholder-oriented strategy is an evolutionary stable strategy when the firm cares about stakeholders very much. The stakeholder-oriented strategy is an evolutionary stable strategy when the firm moderate concerns stakeholders (Proposition 3).

Section 5 investigates the evolution of the firm’s SR preference. We use an indirect evolutionary approach to study the change in the short run, and use adaptive dynamics to study the evolution of firm’s SR preference in the long-term run. We discover that although a NSR concern firm’s profit is higher than a SR concern firm’s when they compete with a NSR or SR concern firm, the zero firm’s SR preference factor is not an evolutionary stable preference (Proposition 5). Furthermore, there is a unique evolutionary stable degree of the firm’s SR preference between zero and one, and using the adaptive dynamics, we get the unique evolutionary stable preference is continuously stable (Proposition 8).

The paper makes two general contributions to the existing literature. Firstly, it is to demonstrate the behavior that concern social responsibility may be evolutionary stable. Secondly, the evolution of the firm’s SR preference is deficiency in the existing literature, we try to complement it and obtain some new managerial insights.

2. Literature review. This paper is related to the literature on corporate governance strategy, corporate social responsibility, evolution of preferences, and adaptive dynamics.

Corporate governance strategy is a topic of discussion worldwide, Krafft et al. [44], Laporta et al. [49], and Jensen and Meckling [40] find that the better corporate governance will result in a higher firm value and more profitable firm performance. The classical perspective in Economics is that the firm managements’ only responsibility is to maximize interest of its owners [27]. However, researchers and practitioners find different results in academic research and survey. Tirole [77] shows that shareholders’ interests maximization is a second-best optimum strategy in certain environments. Nelson and Winter [58], Schaffer [72], Guth and Peleg [33] point out that profit maximization is not necessarily the fittest survival strategy for a firm. Rhode and Stegeman [68], Xiao and Yu [82], Xiao and Chen [81], Chai et al. [12], Yi and Yang [83] show that revenue maximization is an evolutionary stable strategy under some conditions. Denis and McConnell [19], Rieckers and Spindler [69], and Schmidt [73] conclude that shareholders’ interest maximization is not the only objective of firms. Aoki and Jackson [3] point out corporate governance should consider human assets. Allen [1], Allen et al. [2], Magill et al. [52] assert that the strategy to maximize the welfare of all stakeholders is better than shareholders alone. In this paper, we also consider the welfare of stakeholders (consumers).
The concept of SR has developed and evolved in both academic and non-academic worldwide. Those against SR argue that the social issues should be resolved by the free market, and that SR should not be the concern of businesses [6, 76]. Proponents of SR have argued that SR can be consistent with a firm’s strategy and related to its financial sustainability [62]. Lee [51] and Vogel [79] reveal that there is a tight relation between SR and a firm’s financial performance [38, 50]. Kurucz et al. [45] investigate whether a firm can improve financial performance by addressing SR. Many researchers conclude that SR has a positive effect on the firm financial performance [11, 16, 17, 31, 53, 54, 59, 61, 66]. However, Roman et al. [70], Barnett [5], Carroll and Shabana [10] disagree; these works show that the relationship between SR and the firm’s financial performance may be positive, negative or unrelated. Barnett [5] argues that the relationship between SR and firm financial performance depends on stakeholder influence. Waddock and Graves [80] demonstrate a negative relationship between SR and firm performance. McWilliams et al. [56] find neutral impact of SR on the firm financial performance. Previous literature studies SR and its relation to cost, risk, market share change, and the resultant effect on firm’s financial performance.

Our paper is closely related to Goering [30], Panda [64], and Kopel and Brand [43]. Goering [30] and Panda [64] investigate channel coordination and consider consumers as stakeholders of both manufacturers and retailers. Goering [30] demonstrates that a two-part tariff can coordinate the channel when the retailer or manufacturer has a concern in SR. Panda [64] shows the revenue-sharing contract can coordinate the channel if the retailer or manufacturer cares about SR. Kopel and Brand [43] study the relationship between fraction of consumer surplus and the firm’s profit and find that firm profit increases and then decreases as the fraction of consumer surplus increases.

We study firm SR behavior from a novel evolutionary perspective. This paper investigates the effect of the degree of the firm’s SR concern and the type of products of firms on the firm financial performance or interests of shareholders and firm management strategy in the long-term. Our approach enables analysis of the evolutionary stability of equilibrium points.

Our paper is also related to Allen et al. [2], Xiao and Yu [82], Xiao and Chen [81], Chai et al. [12], Yi and Yang [83]. Allen et al. [2] examine benefit of stakeholder concern on firm value and conclude that benefit of stakeholders is constant because it is decided by local environment or law. Our definition of a stakeholder firm is a general notion of SR [30, 71], and is consistent with Jensen’s [39] single-valued objective function requirement for purposeful behavior. A firm’s concern for SR is interpreted as taking consumer surplus into consideration. Xiao and Yu [82], Xiao and Chen [81], Chai et al. [12], Yi and Yang [83] study the evolution of profit maximization or revenue maximization. In our paper, we study the evolution of shareholder-oriented strategy or stakeholder-oriented strategy. Finally, besides the evolutionary stability of production strategies, we further investigate the evolutionary stability of preferences.

We also tap into the concepts introduced in the literature on evolution of preferences and adaptive dynamics. Besides the SR concern behavior, sometimes people have SR concern preferences [8]. The preferences are not always identical, it changes with the environment. Experimental evidence suggest that people may choose fair behavior at one time, and unfair behavior at another [13, 37]. Güth and Yaari
introduce the indirect evolutionary approach to study the evolution of preference. The indirect evolutionary approach is based on the assumption that the players behave rationally for given preferences but that their preferences change through an evolutionary process [37]. Another approach to study frequency dependent selection is the adaptive dynamics, which sets out to provide additional insights into long-term dynamics of evolutionary process [20, 63]. The adaptive dynamics approach extends classification scheme for evolutionary stable strategies, and links the evolutionary models to replicator models. Many researchers study the evolution of specific preference, such as fairness [36, 37, 75], reciprocity [7, 74], altruism [8, 9, 22, 32, 35], vengeance [26], and the conspicuous [24]. Recently, Li et al. [47], Chen et al. [14] analyze the effect of overconfidence on management strategy of firms. However, the existing literature does not study the evolution of firms’ SR concern preferences. We consider evolution of a novel preference-firm’s SR preference, and seek for the evolutionary stable SR factor.

3. The basic model. We consider an economic system consisting of many firms that produce and sell substitutable products in oligopolistic market. A firm randomly competes with another firm in a given market. All firms are symmetric in position so that the interaction between a pair of firms can be described by a symmetric game. Each firm is an individual of firm population. In this game, one of the firms is labeled as firm 1 and the other is labeled as firm 2. A firm with no SR concern is shareholder-oriented, and a firm concerned with SR is stakeholder-oriented. Each firm picks one of two pure production strategies: shareholder-oriented (H) and stakeholder-oriented (T). In an one-shot game, two firms first determine their production strategies, and then decide quantities according to their production strategies. Assuming that the individuals are bounded rational, we study the distribution of the individuals’ strategies in the single population using evolutionary game theory. There are four possible strategy profiles: (i) both firms are shareholder-oriented (HH); (ii) both firms are stakeholder-oriented (TT); (iii) firm 1 is shareholder-oriented and firm 2 is stakeholder-oriented (HT); and (iv) firm 1 is stakeholder-oriented and firm 2 is shareholder-oriented (TH). We denote each strategy profile by a superscript; e.g., superscript TT denotes case (ii). We refer to TT as symmetric stakeholder-oriented strategy, HH as symmetric shareholder-oriented strategy, HT and TH as asymmetric strategy profiles.

This is a single population game. The single population model assumes that all individuals are homogenous and focuses on evolution of the fraction playing a particular strategy in the population. Symmetry of individuals is a common assumption in the single population model [4, 23, 25, 41, 55, 65]. We consider the linear duopoly inverse demand function, like others in this literature [8, 67, 81, 82].

\[ p_i = a - q_i - dq_j, 0 < d < 1. \]  

Where \( p_i \) is the retail price of firm \( i \), \( c \) is the unit production cost of a firm, \( q_i \) is the production quantity of firm \( i \), \( i = 1, 2 \). \( q_j \) is the production quantity of firm \( j \), \( (j = 1, 2, j \neq i) \), the parameter \( a \) denotes the price cap, (with \( a > c \)), and \( d \) represents substitutability between two products.

Consumers are the objective of corporate services, and consumer demand is the source of corporate profits. Consumers will reward firms for their social responsibility behaviors. McWilliams and Siegel [57] argue there are two major demands for social responsibility from the firm perspective: consumer demand and the demand from other stakeholders. Consumers concern is the most basic manifestation
of corporate social responsibility, for instance, the case that Samsung mobile phone recall recently, the event that IKEA furniture recall. In the social responsibility report of some international firms, such as Canon, Lenovo, Ford, GELI, the services for consumers accounts for an important place. Social responsibility means that a firm should consider the social welfare rather than the interests of shareholders. Social welfare is the sum of the consumer surplus and the producer surplus. So in the paper, refer to Goering [30] and Panda [64], we consider consumer surplus is the exhibition of corporate social responsibility. Thus, following Goering [30], and Salehi and Azary [71], in modeling and analysis we regard concerning the surplus of its own consumers (stakeholders) as the exhibiting of a firm’s SR. Specifically, the objective of a SR concern firm is to maximize the traditional pure profit plus a share of the surplus of its own consumers [28, 29, 30, 42, 46, 48, 58, 64].

Consumer surplus is the difference between maximum price that consumers are willing to pay for a product and market price that they actually pay for the product. Following Panda [64], the total surplus of the consumers buying from firm $i$ is

$$\int_{p_{min}}^{p_{max}} q_i dp_i = \int_{a-q_i-dq_j}^{a-dq_j} (a-dq_j-p_i) dp_i = \frac{1}{2}q_i^2.$$  

The profit of firm $i$ is $\pi_i = (p_i-c)q_i$. A SR concern firm not only cares its own interest, but the benefit of its consumers. Hence the optimization problem of firm $i$ with strategy $T$ is

$$\max q_i \left( (a-q_i-dq_j-c)q_i + \frac{\alpha}{2}q_i^2 \right),$$

and the optimization problem of firm $i$ with strategy $H$ is

$$\max q_i = \max (a-q_i-dq_j-c)q_i,$$

where the parameter $\alpha \in [0, 1]$ is consumer surplus factor, reflecting the degree of firm $i$ cares about SR. We also call $\alpha$ as the SR preference factor. A higher $\alpha$ means that firm $i$ has higher social responsibility. $\alpha = 1$ means that all consumers’ benefit is interest of firm $i$, i.e., the firm has full social responsibility; whereas, on the contrary, $\alpha = 0$ indicates that the firm has no social responsibility.

4. Evolutionary analysis. In this section, we study evolutionary stable strategy (ESS). We first discuss the price and quantity in the one-shot game, then study the production strategy.

4.1. Equilibrium outcome in the one-shot game. According to Eqs. (2) and (3), we get for the strategy profile $HT$, the objective functions of firms 1 and 2 are respective

$$\max q_1 (a-q_1-dq_2-c)q_1, \quad \max q_2 [(a-q_2-dq_1-c)q_2 + \frac{\alpha}{2}q_2^2].$$

From $0 < d < 1$ and $0 \leq \alpha \leq 1$, it follows that the second-order conditions are satisfied. Solving their first-order conditions, we can obtain

$$q_1^{HT} = \frac{(a-c)(2-d-\alpha)}{4-d^2-2\alpha}, \quad q_2^{HT} = \frac{(a-c)(2-d)}{4-d^2-2\alpha}.$$  

Corresponding, the optimizing prices are respective

$$p_1^{HT} = a - q_1^{HT} - dq_2^{HT} = \frac{a(2-d-\alpha) + c(2+d-d^2-\alpha)}{4-d^2-2\alpha},$$

and
The profits of firms 1 and 2 are respective

\[ \pi_1^{HT} = (a - q_1^{HT} - dq_1^{HT})q_1^{HT} = \frac{(a - c)^2(2 - d - \alpha)^2}{(4 - d^2 - 2\alpha)^2}, \]

\[ \pi_2^{HT} = (a - q_2^{HT} - dq_2^{HT})q_2^{HT} = \frac{(a - c)^2(2 - \alpha)(1 - \alpha)}{(4 - d^2 - 2\alpha)^2}. \]

Similarly, we get the equilibrium outcomes for the other strategy profiles. Table 1 summarizes the equilibrium outcomes for the one-shot game.

### Table 1. The equilibrium expressions under given strategy for one-shot game

| Strategy | Quantity \((q_1, q_2)\) | Price \((p_1, p_2)\) | Profit \((\pi_1, \pi_2)\) |
|----------|-----------------|-----------------|-----------------|
| **TT**   | \[
\begin{align*}
q_1 &= \frac{a - c}{2 + d}, \\
q_2 &= \frac{a - d}{2 + d}.
\end{align*}
\]
| \[
\begin{align*}
p_1 &= \frac{c(1 + d) + a(1 - \alpha)}{2 + d}, \\
p_2 &= \frac{c(1 + d) + a(1 - \alpha)}{2 + d}.
\end{align*}
\]
| \[
\begin{align*}
\pi_1 &= \frac{(a - c)^2(1 - \alpha)^2}{(4 - d^2 - 2\alpha)^3}, \\
\pi_2 &= \frac{(a - c)^2(1 - \alpha)^2}{(4 - d^2 - 2\alpha)^3}.
\end{align*}
\]
| **HH**   | \[
\begin{align*}
q_1 &= \frac{a - c}{2 + d}, \\
q_2 &= \frac{a - d}{2 + d}.
\end{align*}
\]
| \[
\begin{align*}
p_1 &= \frac{a + c(1 + d)}{2 + d}, \\
p_2 &= \frac{a + c(1 + d)}{2 + d}.
\end{align*}
\]
| \[
\begin{align*}
\pi_1 &= \frac{(a - c)^2}{(2 + d)^2}, \\
\pi_2 &= \frac{(a - c)^2}{(2 + d)^2}.
\end{align*}
\]
| **TH**   | \[
\begin{align*}
q_1 &= \frac{(a - c)(2 - d)}{4 - d^2 - 2\alpha}, \\
q_2 &= \frac{(a - c)(2 - d)}{4 - d^2 - 2\alpha}.
\end{align*}
\]
| \[
\begin{align*}
p_1 &= \frac{c[2 - d^2 + d(1 - \alpha)] + a(2 - d)(1 - \alpha)}{4 - d^2 - 2\alpha}, \\
p_2 &= \frac{c[(2 - d - \alpha) + c(2 + d - d^2 - \alpha)]}{4 - d^2 - 2\alpha}.
\end{align*}
\]
| \[
\begin{align*}
\pi_1 &= \frac{(a - c)^2(2 - d)^2(1 - \alpha)}{(4 - d^2 - 2\alpha)^2}, \\
\pi_2 &= \frac{(a - c)^2(2 - d^2)(1 - \alpha)}{(4 - d^2 - 2\alpha)^2}.
\end{align*}
\]
| **HT**   | \[
\begin{align*}
q_1 &= \frac{(a - c)(2 - d)}{4 - d^2 - 2\alpha}, \\
q_2 &= \frac{(a - c)(2 - d)}{4 - d^2 - 2\alpha}.
\end{align*}
\]
| \[
\begin{align*}
p_1 &= \frac{(a - d)(2 - d)}{4 - d^2 - 2\alpha}, \\
p_2 &= \frac{(a - d)(2 - d)}{4 - d^2 - 2\alpha}.
\end{align*}
\]
| \[
\begin{align*}
\pi_1 &= \frac{(a - c)^2(2 - d)^2(1 - \alpha)}{(4 - d^2 - 2\alpha)^2}, \\
\pi_2 &= \frac{(a - c)^2(2 - d^2)(1 - \alpha)}{(4 - d^2 - 2\alpha)^2}.
\end{align*}
\]}

From Table 1, the equilibrium quantity of a SR concern firm is higher than that of a NSR concern firm, i.e., more consumers are willing to buy the products of a firm who cares about SR. Furthermore, we find that the profit of a NSR concern firm is higher than that of a SR concern firm when it competes with a NSR concern firm and the SR concern firm competes with a SR concern firm. These results seem to mean that for a firm, it gets the less profit when it more cares about SR. However, under the strategy profile TH, when \(\alpha < 2d - d^2\), the profit of the SR concern firm is higher than the profit of the NSR concern firm. Thus, the firm should appropriately take SR into account. That means that although the SR concern decreases the SR concern firm’s profit but decreases the profit of the NSR concern firm even more. For example, as \(d = 1/2, \alpha < 3/4\), the reduced profit of a SR-oriented firm is \((a - c)^2[\frac{4}{25} - \frac{9(1 - \alpha)}{(7 - 4\alpha)^2}]\), that of a NSR concern firm is \((a - c)^2[\frac{4}{25} - \frac{3 - 2\alpha}{(7 - 4\alpha)^2}]\). Obviously, \((a - c)^2[\frac{4}{25} - \frac{9(1 - \alpha)}{(7 - 4\alpha)^2}] < (a - c)^2[\frac{4}{25} - \frac{3 - 2\alpha}{(7 - 4\alpha)^2}]\).

Next, we study the retail price at the Nash equilibrium. We write \(p_i^{HT}\) denotes the retail price of firm \(i\) when both firm 1 and firm 2 use strategy \(T\), and \(p_i^{HH}\) represents the retail price of firm \(i\) when both firms use strategy \(H\).
Proposition 1. The retail price under strategy $T$, i.e.,

$$p_i^{HH} \geq p_i^{TT} \quad \text{and} \quad p_i^{HH} \geq p_i^{TH}(p_i^{HT}), \ i = 1, 2.$$ 

Proof. From Table 1, we have

$$p_i^{HH} - p_i^{TT} = \frac{(a - c)(1 + d)\alpha}{(2 + d)(2 + d - \alpha)},$$

which is nonnegative because $0 \leq \alpha \leq 1$, $a > c$, and $0 < d < 1$. Similarly, we have

$$p_i^{HH} - p_i^{TH} = \frac{(a - c)(2 - d^2)\alpha}{(2 + d)(4 - d^2 - 2\alpha)} \geq 0, \quad p_i^{HH} - p_i^{HT} = \frac{(a - c)d\alpha}{(2 + d)(4 - d^2 - 2\alpha)} \geq 0.$$

So Proposition 1 is true.

From Proposition 1, we know that considering SR will decrease the retail price and increase the consumer surplus. Intuitively, when a firm cares about SR, it is willing to sacrifice its own interest to set a lower retail price, which is beneficial to its consumers. Corresponding, after its consumers feel about the firm’s concern, they are more willing to buy the firm’s product rather than the product of a NSR concern firm. This result also explains why the profit of a SR concern firm is higher than the profit of a NSR concern firm when they compete with each other.

Let the fraction of firms who choose strategy $H$ be $x$, then the fraction of firms who choose strategy $T$ be $1 - x$. Without loss of generality, we assume that the population’s strategy evolves following the Malthusian dynamic system (or replicator dynamic system), which is a very general dynamic system in evolutionary game theory [15, 23, 82]. In a replicator dynamic system, the growth rate $\dot{x}/x$ equals the difference between the strategy $H$’s fitness $x_1\mathbf{M}(x, 1 - x)^T$ and the average fitness $(x, 1 - x)\mathbf{M}(x, 1 - x)^T$ of the population, where $\dot{x} = dx/dt$. $x_1 = (1, 0)$ denotes all firms choose strategy $H$. The material payoff matrix of firm 1 is

$$\mathbf{M} = \begin{pmatrix} 
\frac{(a-c)^2}{(2+d)^2} & \frac{(a-c)^2(2-d-\alpha)^2}{(4-d^2-2\alpha)^2} \\
\frac{(a-c)^2(1-\alpha)(2-d)^2}{(4-d^2-2\alpha)^2} & \frac{(a-c)^2(1-\alpha)^2}{(2+d-\alpha)^2} 
\end{pmatrix}$$

Hence, the replicator dynamics for the population is

$$\dot{x} = x(x_1 - (x, 1 - x))\mathbf{M}(x, 1 - x)^T$$

$$= (a - c)^2(1 - x)x\left\{ \frac{x\alpha(-4d^2 + d^4 + 4\alpha)}{(2 + d)^2(4 - d^2 - 2\alpha)^2} 
+ (1 - x)\left\{ \frac{-1 + \alpha}{(2 + d - \alpha)^2} + \frac{(2 - d - \alpha)^2}{(4 - d^2 - 2\alpha)^2} \right\} \right\}$$

(4)

System (4) is the continuous frequency dynamic systems for the population consisting of firms. It describes the growth rate of the firm using strategy $H$ to its relative fitness.

4.2. Evolutionary stable strategy. In this section, we consider ESS. A population is said to be at an ESS, if it cannot be invaded by a small (relative to the number in the initial population) subpopulation of individuals using another individual strategy. In order to study the dynamic characteristics of an evolutionary game, a dynamic system such as replicator dynamic system is often incorporated. An equilibrium of the replicator dynamics (4) is a point $x \in [0, 1]$ such that $\dot{x} = 0$. From system (4), we get the results as follows.
Proposition 2. System (4) has steady states \( x_1 = 0; x_2 = 1; \) and if \((2-\alpha)(1-\sqrt{1-\alpha}) < d^2 < 2(1-\sqrt{1-\alpha}), \) there is an interior equilibrium
\[
x^* = \frac{(2+d^2)[d^4 - 2d^2(2-\alpha) + (2-\alpha)^2]}{da[2d^4 + d^3(6-\alpha) - 4(2-\alpha)d - d(8-\alpha^2)]}.
\]
Proof. From the replicator dynamics (4), we see that \( x_1 = 0 \) and \( x_2 = 1 \) are the solutions of \( \dot{x} = 0. \) Solving \[
\frac{\alpha}{(2+d^2)(4-d^2-2\alpha)} + (1-x)\left[\frac{1}{(2+d^2-2\alpha)} + (2-d^2)^2\right] = 0,
\]
we can obtain
\[
x^* = \frac{(2+d^2)[d^4 - 2d^2(2-\alpha) + (2-\alpha)^2]}{da[2d^4 + d^3(6-\alpha) - 4(2-\alpha)d - d(8-\alpha^2)]}.
\]
Further, we have \( x^* \in (0,1) \) if \( (2-\alpha)(1-\sqrt{1-\alpha}) < d^2 < 2(1-\sqrt{1-\alpha}) \).

So Proposition 2 is true.

The point \( x = x^* \) becomes the equilibrium \( x_2 = 1 \) if \( 2(1-\sqrt{1-\alpha}) = d^2; \) the point \( x = x^* \) becomes \( x_1 = 0 \) if \( (2-\alpha)(1-\sqrt{1-\alpha}) = d^2. \) From Proposition 2, we know that if the firms care about SR to a certain extent, then some firms choose stakeholder-oriented strategy and the other firms choose shareholder-oriented strategy, i.e., strategies \( H \) and \( T \) coexist. Otherwise, all firms use shareholder-oriented strategy or stakeholder-oriented strategy for getting their own optimal values. The result shows that under the competition between the moderate SR concern firms, firms take into account SR and profit maximization can be the best profits; under the competition between higher or lower SR concern firms, firms use the similar strategy can be the best profits, the higher SR concerns induce firms sacrifice their own profits to increase the social welfare. This result is a short-run term result. What is the situation in a long-run term, i.e., which one is stable for the three equilibria? Proposition 3 gives the answer.

Proposition 3. The interior equilibrium \( x = x^* \) is not an ESS. The stability of both pure strategies is as following:

(i) When \( 2(1-\sqrt{1-\alpha}) \leq d^2, \) strategy \( T \) is dominant, the equilibrium \( x_1 = 0 \) is an ESS;

(ii) When \( (2-\alpha)(1-\sqrt{1-\alpha}) \geq d^2, \) strategy \( H \) is a dominant strategy, the equilibrium \( x_2 = 1 \) is an ESS;

(iii) When \( (2-\alpha)(1-\sqrt{1-\alpha}) < d^2 < 2(1-\sqrt{1-\alpha}), \) there is no dominant strategy, and both \( x_1 = 0 \) and \( x_2 = 1 \) are ESSes.

Proof. We use \( \Delta w \) to denote the payoff difference between strategy \( H \) and strategy \( T, \) i.e., \( \Delta w = (1,0)M(x,1-x)^T - (0,1)M(x,1-x)^T. \)

Let \( s = (x^*,1-x^*) \), we have
\[
\frac{d\Delta w(s)}{dx} = -\frac{(a-c)^2da^2[2d^4 + d^3(6-\alpha) - 4(2-\alpha)d - d(8-\alpha^2)]}{(2+d^2)(2+d-\alpha)^2(4-d^2-2\alpha)^2} > 0,
\]
i.e., the interior equilibrium \( x = x^* \) is not a downcrossing. This means that the fitness advantage of strategy \( H \) is not downward sloping, so the interior equilibrium \( x^* \) is unstable, the mixed strategy is not an ESS.

Part (i). From the payoff matrix, we have
\[
\pi^{H,H}_1 - \pi^{T,H}_1 = \frac{(a-c)^2a(d^4 - 4d^2 + 4\alpha)}{(2+d^2)(4-d^2-2\alpha)^2},
\]
\[
\pi^{H,T}_1 - \pi^{T,T}_1 = \frac{(a-c)^2a[d^4 - 2d^2(2-\alpha) + (2-\alpha)^2\alpha]}{(2+d-\alpha)^2(4-d^2-2\alpha)^2}.
\]
As $2(1 - \sqrt{1 - \alpha}) \leq d^2$, obviously, $\pi_1^{HH} \leq \pi_1^{TH}$ and $\pi_1^{HT} < \pi_1^{TT}$, so strategy $T$ is a dominant strategy, according to Traulsen and Hauert [78], the equilibrium $x_1 = 0$ is an ESS.

**Part (ii).** From the proof of Part (i), we see that if $(2 - \alpha)(1 - \sqrt{1 - \alpha}) \geq d^2$, then $\pi_1^{HH} > \pi_1^{TH}$ and $\pi_1^{HT} \geq \pi_1^{TT}$, so strategy $H$ is a dominant strategy and the equilibrium $x_2 = 1$ is an ESS.

**Part (iii).** Let $\pi(\vec{x}, \vec{y})$ means the payoff to strategy $\vec{x}$ when played against strategy $\vec{y}$, then at the point $x_1 = 0$,

$$
\pi((0, 1), (0, 1)) = \pi((y, 1 - y), (0, 1)) = -\frac{(a - c)^2 y \alpha (d^4 - 2d^2 (2 - \alpha) + (2 - \alpha)^2 \alpha)}{(2 + d - \alpha)^2 (4 - d^2 - 2\alpha)^2},
$$

as $(2 - \alpha)(1 - \sqrt{1 - \alpha}) \leq d^2$, $\pi((0, 1), (0, 1)) \geq \pi((y, 1 - y), (0, 1))$ for all $y \in (0, 1]$.

Furthermore, we have

$$
\pi((0, 1), (y, 1 - y)) - \pi((y, 1 - y), (y, 1 - y)) = (a - c)^2 y \alpha \times
$$

$$
\frac{y (4d^2 - d^4 - 4\alpha) (2 + d - \alpha)^2 - (1 - y) (d^4 - 2d^2 (2 - \alpha) + (2 - \alpha)^2 \alpha) (2 + d)^2}{(4 - d^2 - 2\alpha)^2 (2 + d - \alpha)^2}.
$$

As $2(1 - \sqrt{1 - \alpha}) > d^2$, $\pi((0, 1), (y, 1 - y)) > \pi((y, 1 - y), (y, 1 - y))$. Then $x_1 = 0$ is an ESS. Similarly, we can prove that the point $x_2 = 1$ is also an ESS.

Proposition 3 implies that if the product substitutability is relatively high ($d^2 > 2(1 - \sqrt{1 - \alpha})$), firms should choose stakeholder-oriented strategy such that the firms using stakeholder-oriented strategy get a higher profit than the firms with shareholder-oriented strategy; if the product substitutability is relatively low ($d^2 < (2 - \alpha)(1 - \sqrt{1 - \alpha})$), firms should choose shareholder-oriented strategy rather than stakeholder-oriented strategy for getting higher profit; if the product substitutability is moderate ($2 - \alpha)(1 - \sqrt{1 - \alpha} < d^2 < 2(1 - \sqrt{1 - \alpha})$), all the firms use the same strategy $T$ or $H$ can get the optimal profit. ESS reveals the profit of the firm using evolutionary stable strategy higher than the mean profit of the population, cannot be invaded by the other strategy even the equilibrium state is broken occasionally, is the optimal strategy in the long run competition for firms. Hence, Proposition 3 provides a suggestion for firms to choose their production strategy in the long-term competition.

The dynamics in Proposition 3 is shown in Figs. 1-3.

\[
\begin{array}{c}
\text{T} \\
\bullet
\end{array}
\begin{array}{c}
H \\
\bullet
\end{array}
\begin{array}{c}
x=0 \\
\text{x=1}
\end{array}
\]

**Figure 1.** Evolutionary dynamics when $2(1 - \sqrt{1 - \alpha}) \leq d^2$

To better understand the evolutionary path of the behavior of firms in this case with $(2 - \alpha)(1 - \sqrt{1 - \alpha}) < d^2 < 2(1 - \sqrt{1 - \alpha})$, we depict Fig. 4, where the values of parameters are used as: $\alpha = 4, c = 1.2, d = 0.5$. When $(2 - \alpha)(1 - \sqrt{1 - \alpha}) < d^2 < 2(1 - \sqrt{1 - \alpha})$, the evolutionary path depends on the initial distribution of
firms' strategies. For different values of parameters, the evolutionary paths often are different.

From Fig. 4, it is clear that the convergence of two pure strategies $H$ or $T$ depends on the initial state of the population. When the initial value of the population use strategy $H$ over the interior equilibrium $x^*$, then the trajectory will converge to $x = 1$, i.e., strategy $H$ is evolutionary stable and NSR firms will occupy the market, firms should use shareholder-oriented strategy; when the initial value is less than $x^*$, then the trajectory of the system (4) converges to $x = 0$, i.e., strategy $T$ will spread and become stable, the SR concern firms will be prevalent over the market, firms should use stakeholder-oriented strategy.

From Proposition 3, we have the next corollary.

**Corollary 1.** As firms sell homogenous products, the interior equilibrium $x = \frac{9(3-6\alpha+4\alpha^2-\alpha^3)}{\alpha^2(9-5\alpha)}$ is unstable. Furthermore, the following results hold.

(i) When $\alpha \leq 3/4$, strategy $T$ is dominant, the equilibrium $x = 0$ is an ESS;
(ii) When $\alpha > 3/4$, there is no dominant strategy, and both $x_1 = 0$ and $x_2 = 1$ are ESSes.
From Corollary 1, we know that if the products between two firms are identical, when the firms care about SR less than three forth, then strategy \( T \) will be selected by firms, strategy \( H \) will die out in a long time; if the SR concern is over three forth, then all firms use strategy \( T \) or strategy \( H \) can spread in the market. Corollary 1 implies that when the SR factor is relatively low, firms with stakeholder-oriented can get a higher profit in the long term, but when the SR factor is high enough, the stakeholder-oriented strategy maybe get a lower profit if firms using stakeholder-oriented strategy relatively small in the population at the initial state.

This section considers the evolutionary stability of the pure production strategies. The two strategies may be an ESS, depending on product substitutability and the SR preference factor. We are also interested in the change of SR preference factor in the long time.

5. Evolutionary preference. Individual’s choice is motivated by well-defined, stable preferences over the outcomes of its decisions. In this section, we consider the evolution of SR preference factor. Why the SR preference appears and how the SR preference changes in a long time. The preference determines the players’ behavior and their effective successes via its effects on the outcome of strategic interactions. By assuming rational behavior and applying the concepts of evolutionary stability and continuously stability to the evolution of preferences.

5.1. Indirection evolution. We assume the SR preference factor of a firm is \( \alpha \) and the SR preference factor of the other firm is \( \beta \). Obviously, SR preference influences the strategic interactions between the firms even though it does not directly affect their martial payoffs as defined by Eq. (3). SR preference has an indirect impact on the firms’ material payoffs because their behavior depends on the parameters \( \alpha \) and \( \beta \). Each firm seeks to maximize its subjective objective so that

\[ q_1^* \in \text{argmax}_{q_1} [(a - q_1 - dq_2 - c)q_1 + \frac{\alpha}{2}q_1^2], \]

\[ q_2^* \in \text{argmax}_{q_2} [(a - q_2 - dq_1 - c)q_2 + \frac{\beta}{2}q_2^2]. \]

From the first-order conditions for preference maximization, we can derive the players’ best response functions:

\[ q_1(q_2) = (a - c - dq_2)/(2 - \alpha), \quad q_2(q_1) = (a - c - dq_1)/(2 - \beta). \]

SR preferences shift a firm’s best response function upwards, it is illustrated in Fig. 5. Fig. 5 depicts the firm 1’s best response for given values \( \alpha = 0 \) and \( \alpha > 0 \). Similarly, the firm 2’s behavior is represented for two different values of \( \beta \).

The equilibria of the game between two firms with preference factors \( \alpha \) and \( \beta \) are respective

\[ q_1^*(\alpha, \beta) = \frac{(a - c)(2 - d - \beta)}{(2 - \alpha)(2 - \beta) - d^2}, \quad q_2^*(\alpha, \beta) = \frac{(a - c)(2 - d - \alpha)}{(2 - \alpha)(2 - \beta) - d^2}. \]

In Fig. 5, the equilibrium is determined as the intersection of the firms’ best response function. For \( \alpha = \beta = 0 \), the point \((q_1^{HH}, q_2^{HH})\) is the equilibrium of the game between two firms who have no SR preference. The equilibrium in the game between two SR preference firms \((q_1^*, q_2^*)\) is realized as \( \alpha, \beta > 0 \).

Basing on Eq. (6), we can judge the direction of the strategy effect. As \( \partial q_1^*/\partial \beta = \frac{(a-c)d(2-d-\alpha)}{(d^2-(2-\alpha)(2-\beta))^2} < 0 \) and \( \partial q_2^*/\partial \alpha = -\frac{(a-c)d(2-d-\beta)}{(d^2-(2-\alpha)(2-\beta))^2} < 0 \) for all \( \alpha \neq 1 \) and \( \beta \neq 1 \), the opponent’s equilibrium action will be lower as the SR preference increases. That
is, firm 1’s (2’s) SR preference induces firm 2 (1) to use a lower action (produce less quantity of product), and this decreases player 2’s (1’s) payoff. The results are showed in Fig. 6, where the values of parameters are used as: \( a = 4 \) and \( c = 1.2 \).

It is important to note that each firm’s preference factor not only affects its own behavior but also the opponent’s behavior. Since the firms are engaged in a non-cooperative game, each of them bases its decision on its knowledge about the other firm’s attitudes. Form Table 1, it is clear that the profits of both firms using strategy \( T \) are less than the profits of both firms using strategy \( H \), but that does not mean that the more SR inclined actor is less successful than a player who acts less SR preference. We have the following result.

**Proposition 4.** (i) If \((1 - \alpha)(1 - \beta) > (1 - d)^2\), then \(\pi_1^*(\alpha, \beta) > \pi_2^*(\alpha, \beta)\) for all \(\alpha > \beta\);

(ii) If \((1 - \alpha)(1 - \beta) < (1 - d)^2\), then \(\pi_1^*(\alpha, \beta) < \pi_2^*(\alpha, \beta)\) for all \(\alpha > \beta\);

(iii) If \((1 - \alpha)(1 - \beta) = (1 - d)^2\), then \(\pi_1^*(\alpha, \beta) = \pi_2^*(\alpha, \beta)\).
Proof. From Eq. (6), we get then the equilibrium profit of the $\alpha$-firm when it
competes with a $\beta$-firm is
\[
\pi^*_1(\alpha, \beta) = \frac{(a-c)^2(1-\alpha)(2-d-\beta)^2}{[(2-\alpha)(2-\beta)-d^2]^2},
\]
the equilibrium profit of the $\beta$-firm is
\[
\pi^*_2(\alpha, \beta) = \frac{(a-c)^2(1-\beta)(2-d-\alpha)^2}{[(2-\alpha)(2-\beta)-d^2]^2},
\]
then if $(1-\alpha)(1-\beta) > (1-d)^2$, $\pi^*_1 - \pi^*_2 = \frac{(a-c)^2(\alpha-\beta)(1-\alpha)(1-\beta)-(1-d)^2}{[(2-\alpha)(2-\beta)-d^2]^2} > 0$
for $\alpha > \beta$; if $(1-\alpha)(1-\beta) < (1-d)^2$, $\pi^*_1 < \pi^*_2$ for all $\alpha > \beta$; and $\pi^*_1 = \pi^*_2$ for
$(1-\alpha)(1-\beta) = (1-d)^2$.

So Proposition 4 is true. $\square$

From Proposition 4, when $(1-\alpha)(1-\beta) = (1-d)^2$, both firms’ profits are equal no
matter what the relative values of preference factors; when $(1-\alpha)(1-\beta) < (1-d)^2$, a firm will get a less profit if it more cares about SR; when $(1-\alpha)(1-\beta) > (1-d)^2$, a firm can get more profit if it more concerns its SR, it seems that the SR preference firm has a higher survival value than non SR preference firm under this condition.

Proposition 4 implies the higher SR concern does not mean a higher profit. Whether is there a appropriate SR preference so that a firm can get optimal profit or not?

Let $R(\alpha, \beta)$ denote a firm’s payoff when it has the SR parameter $\alpha$ while its
opponent has the parameter $\beta$. Since the interaction between these firms results in
the equilibrium $(q^*_1, q^*_2)$, we get
\[
R(\alpha, \beta) = \pi^*_1(q^*_1(\alpha, \beta), q^*_2(\alpha, \beta)), \alpha, \beta \in [0, 1].
(7)
\]

From Proposition 4(i), we know that a firm will increase the SR factor in order
to get a higher payoff than its opponent when it cares about SR not very much. However, from Proposition 4(ii), we know that when the degree of SR preference is high, the payoff decreases with the more SR inclined. As Figs. 7 and 8 show that $R(\alpha, \beta)$ first increases then decreases with $\alpha$, and there are maximum $R(\alpha, \beta) = \frac{(a-c)^2(2-d-\beta)^2}{4(2-\beta)(2-d^2-\beta)}$ at $\alpha = d^2/(2-\beta)$. Figs. 7-8 describe how $R(\alpha, \beta)$ depends on $\alpha$ and $\beta$. The values of parameters are used as: $a = 4, c = 1.2$, and $d = 0.5$.

Figure 7. Profit of a firm versus $\alpha$ ($\beta = 0.6$)
Then why the SR preference exists and whether there is a preference factor so that the firm can get the optimal profit? Next we consider the stability of the preference factor. According to the definition of evolutionary stable for a preference factor [8], we study the stability of SR preference.

**Definition 5.1.** [8] A preference factor \( \alpha^* \in [0, 1] \) is called evolutionary stable if

\[
R(\alpha^*, \alpha^*) \geq R(\alpha, \alpha^*) \quad \text{for all } \alpha \in [0, 1];
\]

and

\[
R(\alpha^*, \alpha) > R(\alpha, \alpha) \quad \text{whenever } R(\alpha^*, \alpha^*) = R(\alpha, \alpha^*).
\]

Definition 5.1 is coincidence with the classical definition of ESS: From the first requirement, an evolutionary stable parameter \( \alpha \) is a best reply against itself. Basing on the second conditions, an alternative best reply \( \beta \neq \alpha \) cannot spread in the population.

From Table 1, we know \( R(\alpha, \alpha) < R(0, 0) \) for all \( \alpha \in (0, 1] \), it seems that a non SR preference firm is more successful than a SR preference firm. However it does not necessarily mean the non SR preference is evolutionary stable. When a SR preference firm invades the population of non SR preference firms and performs better than its opponent, then the non SR preference firm will be eliminated in the process of evolution. In fact, according to Definition 5.1, a preference will be chosen if it can produce more material payoff, we have the following result.

**Proposition 5.** The parameter \( \alpha^* = 0 \) is not evolutionary stable.

**Proof.**

\[
R(0, 0) - R(\alpha, 0) = \frac{(a-c)^2}{(d^2+\alpha)} - \frac{(a-c)^2(2-d)^2(1-\alpha)}{(4-d^2-4\alpha)^2} = \frac{(a-c)^2(\alpha(d^4-4d^2+4\alpha)}{(d^2+2\alpha)(d^2+4\alpha)}
\]

is non-negative only for \( \alpha \geq (2-d)(2+d)d^2/4 \). It doesn’t satisfy the first requirement of the stability.

So Proposition 5 is true. 

From Proposition 5, we know that although the profit of non SR preference firm is higher than that of SR preference with intra competition, the non SR preference is not evolutionary stable, the firm who does not care about SR will failure in the competition. Firms should have SR preference in the long-term competition, what degree of SR preference will emerge in the evolutionary process?
Proposition 6. The parameter $\alpha^* = 1 - \sqrt{1 - d^2}$ is the unique evolutionary stable.

Proof. Solving $\frac{\partial R(\alpha, \beta)}{\partial \alpha} = \frac{(a-c)^2 d^2 - \alpha(2-\alpha)(2-d-\beta)^2}{(2-\alpha)(2-\beta)-d^2} = 0$, then we have $\alpha(\beta) = d^2/(2-\beta)$. Let $\alpha = \beta = \alpha^*$, we get $\alpha^* = 1 - \sqrt{1 - d^2}$.

According to the expression of $R(\alpha, \beta)$, we have

$$R(\alpha^*, \alpha^*) = \frac{(a-c)^2 \sqrt{1 - d^2}}{(1 + d + \sqrt{1 - d^2})^2}, \quad R(\alpha, \alpha^*) = \frac{(a-c)^2 (1 - d + \sqrt{1 - d^2})^2 (1 - \alpha)}{[d^2 - (1 + \sqrt{1 - d^2})(2 - \alpha)]^2}.$$

Hence, we have

$$R(\alpha^*, \alpha^*) - R(\alpha, \alpha^*) = (a-c)^2 \left\{ \frac{\sqrt{1 - d^2}}{(1 + d + \sqrt{1 - d^2})^2} - \frac{(1 - d + \sqrt{1 - d^2})^2 (1 - \alpha)}{[d^2 - (1 + \sqrt{1 - d^2})(2 - \alpha)]^2} \right\}$$

$$= (a-c)^2 \frac{\sqrt{1 - d^2}(1 + \sqrt{1 - d^2})^2 (1 - \alpha - \sqrt{1 - d^2})^2}{(1 + d + \sqrt{1 - d^2})^2[d^2 - (1 + \sqrt{1 - d^2})(2 - \alpha)]^2}.$$

Obviously, $R(\alpha^*, \alpha^*) - R(\alpha, \alpha^*) > 0$ for all $\alpha \neq 1 - \sqrt{1 - d^2}$.

According to Definition 5.1, $\alpha^* = 1 - \sqrt{1 - d^2}$ is evolutionary stable. \hfill \Box

From Proposition 6, the evolutionary stable preference factor is $\alpha^* > 0$, so it exhibits some degree of SR preference. The level of SR preference is positively related to product substitutability $d$. SR preference becomes more important when the interdependence of products between the two firms is relatively high. Actually, the SR preference factor $\alpha \to 1$ as $d \to 1$. Most of studies on SR believe that the SR emerges because of the pressure from the government and the public. Proposition 6 implies that SR preference still emerges even there is no any pressure, and if the products of competing firms are homogenous, the evolutionary stable preference tends to full social responsibility concern.

5.2. Adaptive dynamics. In this subsection we further study the global stability of SR preference. Stability analysis takes a different twist when we consider the long run adaptive process. A long run approach to frequency dependent selection, dubbed adaptive dynamics, gained prominence in the 1990s [25]. We assume that the population consists of all firms is mostly monomorphic: at almost all times, there is a single preference used by 100% of the population. From Proposition 6, although immune to local invasion, there is no guarantee that long run evolutionary dynamics would actually take us to an evolutionary stable $\alpha^*$ if we start with a nearby monomorphism.

We normalize the fitness function as the following form.

$$f(m, \alpha) = (a-c)^2 \left( \frac{(1-m)(2-d-\alpha)^2}{d^2 - (2-m)(2-\alpha)^2} - \frac{1-\alpha}{(2+d-\alpha)^2} \right),$$

then we have $f(\alpha, \alpha) = 0$, that is, fitness is measured as the long run the expected growth rate of the trait’s share is zero when the share remains at 1. For slight mutants $m$, i.e., for $|m - \alpha|$ is small, let

$$g(\alpha) \equiv \frac{\partial f(m, \alpha)}{\partial m} \Big|_{m=\alpha} = \frac{(a-c)^2 [d^2 - (2-\alpha)\alpha]}{(2 + d - \alpha)^3(2-d-\alpha)}$$

be the selection gradient, then if the selection gradient is positive, mutant $m$ with trait value slightly higher than $\alpha$ can invade, and if the selection gradient is negative,
then mutants with slightly lower $\alpha$ can invade since, due to $f(m, \alpha) \approx (m-\alpha)g(\alpha) > 0 = f(\alpha, \alpha)$. Long run steady states, where neither sort of nearby mutant can invade, can only occur at critical points of the selection gradient, i.e., at the roots $\alpha^*$ of $g(\alpha)$.

For analyzing the long run dynamics of the SR factor, we follow Dieckmann and Law [21], consider the following canonical equation.

$$\dot{\alpha} = \frac{(a-c)^2[d^2 - (2 - \alpha)\alpha]}{(2 + d - \alpha)^2(2 - d - \alpha)}.$$  \hspace{1cm} (10)

Obviously, the equilibria for the canonical equation are the critical points of the selection gradient $g(\alpha)$. According to Friedman and Sinervo [25], we have Definition 5.2-5.4.

**Definition 5.2.** A monomorphism $\alpha^* \in [0, 1]$ is called to be convergence stable if it is a downcrossing of the selection gradient, i.e., $g'(\alpha^*) < 0$.

The condition means that starting at some $\alpha$ near the critical point $\alpha^*$, small mutations can invade only if they are closer than $\alpha$ to $\alpha^*$.

**Proposition 7.** An interior critical point $\alpha^*$ is convergence stable if and only if $f_{11}(\alpha^*, \alpha^*) < f_{22}(\alpha^*, \alpha^*)$.

**Proof.** For $f(\alpha, \alpha) = 0$, basing on the implicit function theorem, twice differentiate the equation about $\alpha$, we have

$$f_{11}(\alpha, \alpha) + 2f_{12}(\alpha, \alpha) + f_{22}(\alpha, \alpha) = 0.$$  \hspace{1cm} (11)

Hence if $f_{11}(\alpha^*, \alpha^*) < f_{22}(\alpha^*, \alpha^*)$, we have $2f_{11}(\alpha^*, \alpha^*) + 2f_{12}(\alpha^*, \alpha^*) < 0$ due to Eq. (11), $g'(\alpha^*) = \frac{\partial f_1(\alpha^*, \alpha^*)}{\partial \alpha} = f_{11}(\alpha^*, \alpha^*) + f_{12}(\alpha^*, \alpha^*) < 0$, i.e., $\alpha^*$ is convergence stable based on Definition 5.2. The sufficiency is true.

If $\alpha^*$ is convergence stable, then

$$g'(\alpha) = f_{11}(\alpha^*, \alpha^*) + f_{12}(\alpha^*, \alpha^*) \equiv \frac{\partial^2 f(m, \alpha)}{\partial m^2} \bigg|_{m=\alpha=\alpha^*} + \frac{\partial^2 f(m, \alpha)}{\partial \alpha \partial m} \bigg|_{m=\alpha=\alpha^*} < 0,$$

according to Eq. (11). $f_{11}(\alpha^*, \alpha^*) + f_{12}(\alpha^*, \alpha^*) < 0 < f_{12}(\alpha^*, \alpha^*) + f_{22}(\alpha^*, \alpha^*)$, so $f_{11}(\alpha^*, \alpha^*) < f_{22}(\alpha^*, \alpha^*)$. The necessary is true.

Proposition 7 implies that the SR preference $\alpha^*$ is the attractor of canonical Eq. (10), which means the SR preference of firms will converge to $\alpha^*$ initially. But the subsequent evolutionary fate depends on whether $\alpha^*$ is a maximum or minimum of the fitness $f(m, \alpha)$, i.e., the advantage profit of resident the firm with SR preference $\alpha$ against the firm with SR preference $m$.

**Definition 5.3.** The critical point $\alpha^*$ is evolutionary stable if $0 > f_{11}(\alpha^*, \alpha^*) \equiv \frac{\partial^2 f(m, \alpha)}{\partial m^2} \bigg|_{m=\alpha=\alpha^*}$.

Differing from convergence stability, evolutionary stability requires the first partial derivative of the selection gradient, not the total derivative, is negative.

The idea is that an evolutionary stable critical point is dynamically stable in the short run sense, it is immune to invasion from nearby mutants because it is a local fitness maximum. It is easy to verify that $\alpha^* = 1 - \sqrt{1 - d^2}$ satisfies Definition 5.3.

**Definition 5.4.** The critical point $\alpha^*$ is continuously stable if it is both evolutionary stable and convergence table.
Proposition 8. The preference factor \( \alpha^* = 1 - \sqrt{1 - d^2} \) is continuously stable.

Proof. For Proposition 6, the \( \alpha^* = 1 - \sqrt{1 - d^2} \) is evolutionary stable, and we have

\[
\begin{align*}
 f_{11}(\alpha^*, \alpha^*) &= \left. \frac{\partial^2 f(m, \alpha)}{\partial m^2} \right|_{m=\alpha=\alpha^*} = -\frac{(a-c)^2(1-d^2+\sqrt{1-d^2})}{(1-d)(1+d+\sqrt{1-d^2})^4}, \\
 f_{22}(\alpha^*, \alpha^*) &= \left. \frac{\partial^2 f(m, \alpha)}{\partial \alpha^2} \right|_{m=\alpha=\alpha^*} = \frac{2(a-c)^2[2(1+\sqrt{1-d^2})-d^2(2+3\sqrt{1-d^2})]}{(1-d+\sqrt{1-d^2})^2(1+d+\sqrt{1-d^2})^4}.
\end{align*}
\]

So \( f_{11}(\alpha^*, \alpha^*) - f_{22}(\alpha^*, \alpha^*) = -\frac{4(a-c)^2(1+d)}{(1+d+\sqrt{1-d^2})^4} < 0 \), i.e., \( f_{11}(\alpha^*, \alpha^*) < f_{22}(\alpha^*, \alpha^*) \), according to Proposition 7, the critical point \( \alpha^* = 1 - \sqrt{1 - d^2} \) is convergence stable. According to Definition 5.4, the critical point \( \alpha^* = 1 - \sqrt{1 - d^2} \) is continuously stable.

Proposition 8 implies that the SR preference \( \alpha^* \) is a maximum of the advantage profit of resident the firm with SR preference \( \alpha \) against the firm with SR preference \( m \). Hence, the population consisting of firms with SR preference \( \alpha \) will converge to SR preference \( \alpha^* \), the firm with SR preference \( \alpha^* \) can get an optimal profit in the long-term evolutionary process. Furthermore, combining the results in Proposition 3, we find that when firms’ SR preference is the continuously stable SR preference, the shareholder-oriented strategy is evolutionary stable only if the fraction that firms using shareholder-oriented in the initial state is relatively large (larger than the interior equilibrium).

From Proposition 8, we know that the SR preference factor \( 0 < \alpha^* < 1 \) is stable in the long run. The result explains the existence of firms SR preference even there is no enforcement, the social responsibility may have evolved in humans through a process of natural or cultural selection. According to the canonical equation, we simulate the dynamics as showed in Fig. 9, where the values of the parameters are used as: \( a = 4, c = 1.2, d = 0.8 \), and the initial values of SR preference are \( 1, 0.6, 0.2, 0 \), respectively, which can be clearly seen in the Fig. 9.

![Figure 9. The dynamics of firm’s SR preference](image-url)

From Fig. 9, we know whatever the initial state of the population is, the SR preference will arise and keep in a stable state, that is, the SR preference will tend to \( \alpha^* = 1 - \sqrt{1 - d^2} \) over time.
EVOLUTIONARY STABILITY OF SOCIAL RESPONSIBILITY STRATEGY

Why NSR firms with $\alpha > \alpha^*$ can not invade a population of $\alpha^*$-firms. According to Proposition 4, when $(1 - \alpha)(1 - \beta) > (1 - d)^2$, a mutant has a higher success than the firm of the population with whom it interacts. In fact, the low payoff of an $\alpha^*$-firm against an invading mutant is less important for the evolutionary considerations. Because the probability of the firms interacting with the mutant is small, mostly they interact with each other. The SR preference factor $\alpha^* = 1 - \sqrt{1 - d^2}$ is continuously stable because the game between a pair of $\alpha^*$-firms each of them gets a higher material payoff than the NSR firm against an $\alpha^*$-firm when $(2 - \alpha)(1 - \sqrt{1 - \alpha}) < d^2$.

6. Conclusions. In this paper, we first consider the strategic decisions of firms selling substitutable products from the evolutionary perspective. Firms with SR concern make decisions being stakeholder-oriented, NSR concern firms make them being shareholder-oriented. Then we investigate the evolution of SR preference. The selection of SR preference is in a continuous space.

In the basic model, we consider the case where the SR concern factor is exogenous. Our analysis of individual interactions yields two insights: First, a comparison of the interaction between shareholder-oriented firms and the interaction between stakeholder-oriented firms reveals that the shareholder-oriented firms achieve a higher material payoff than the stakeholder-oriented firms. The main cause is that stakeholder-oriented firms are willing to sacrifice some of their own interests for their stakeholders between the players. Second, when a stakeholder-oriented firm interacts with a moderately concerned shareholder-oriented firm, the shareholder-oriented firm has the lower material payoff. The intuition is that SR concern leads it to a lower price, which impacts the rivals’ profits more than its own profit.

The analysis of the population dynamics reveals that being the stakeholder-oriented or shareholder-oriented may be an evolutionary stable strategy, based on the SR factor and product substitutability. The finding is consistent with the fact that there are some companies are stakeholder-oriented and the other companies are shareholder-oriented. When the product substitutability is relatively high, the firms choose strategy $T$; if the substitutability is relatively low, strategy $H$ does better than strategy $T$; if the substitutability is moderate, all the firm use the same strategy for maximal utility; whether firms use strategy $T$ or $H$ depends on the initial fraction of firms using strategy $H$ in the population.

Furthermore, we investigate the stability of SR preference factor using indirect evolutionary approach and adaptive dynamics. The evolutionary process selects the more successful firm, the firm with a lower material payoff will be eliminated in the market. In this way, the preference with adding material payoff will be selected [8, 18]. We find that there is a unique positive evolutionary stable preference factor that is also continuously stable. The results show that the SR preference exists over the long run, i.e., SR preference appears and becomes more and more important. In our model, the SR preferences are common knowledge, so our results imply that the moderate SR preference is more likely to emerge in the society where firms are not anonymous. For instance, the famous firms are more likely to express their SR preferences.

One can extend this research further in several directions. First, we assume that the firms’ SR preferences are common knowledge. The incomplete information game is also interesting. Second, we assume that each firm has two pure production strategies. This assumption could be relaxed to the case where each firm has more
than two strategies. Finally, we assume that the market demand/cost is deterministic. It would be interesting to study the impact of uncertainty, such as demand shocks or cost shocks, on the stability of equilibrium points.

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