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Evolutionary Behavior of Supply Chains: Altruism or Fairness

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Abstract
Basing on the individual behavior preferences, we analyze the evolutionary stable strategies of supply chains, where each chain consists of one manufacturer and one retailer. There are many manufacturers and retailers in the economic system. A retailer and a manufacturer interact with each other randomly. A manufacturer or retailer has two behavioral preferences: fairness concern and altruism concern. We get the evolutionarily stable strategies under linear demand and nonlinear demand. By analyzing, the evolutionary stability of Nash equilibrium is distinct under different demand types. The evolutionarily stable strategies of the manufacturer and retailer depend on their preference parameters.
Keywords: *evolutionary stable strategy; preference; fairness; altruism; selfishness*

1 Introduction

In the experimental economics, objectives often show non-selfish behavior, such as fairness, altruism, etc. Fairness implies that goods or resource should be distributed by a perceived appropriateness in a society, group or organization in economics. While altruism refers to the behavior by an individual that increases the fitness of another individual, even this behavior may decrease the fitness of the actor. Fairness is a popular topic in the behavior research, for instance, some scholars find that there is a strong feelings of fairness about the products' price for the consumers[1,2], hence, consumers are unwilling to buy a product in a monopoly price because they feel it is unfair. Another example has been found in the firm's wage setting for the workers[1,3,4,5], which explain why some employers choose to cut down the number of persons employed rather than cut the wage of their workers. The study of altruistic behavior is another popular topic in the behavior economics. The altruistic behavior of proposers in the Ultimatum game[6,7,8,9], the act of "giving" in the public goods[10,11] has been studied for many years. The investigation of non-selfish behavior, especially, fairness and altruism has attracted many scholars in biology, mathematics, economics, etc.

The study in supply chain management and the dynamics of individual preference has been paid more and more attention recently. *T. H. Cui et al.* [12] investigated the role of fairness in the channel coordination. *K. M. Amaeshi et al.*[13], *S. Panda*[14], *G. E. Goering*[15], *C. F. Hsueh*[16], and *D. Ni et al.*[17] considered the role of social responsibility preference in a supply chain. *G. E. Bolton* and *A. Ockenfels*[18], *E. Fehr* and *K. M. Schmidt*[19], *G. Charness* and *E. Haruvy*[20] studied the effect of fairness, altruism, reciprocity on the strategy of players in the different games, and *E. Dekel et al.* [21], *H. Bester* and *W. Güth*[22], *J. C. Ely* and *O. Yilankaya*[23], *E. A. Ok* and *F. Vega-Redondo*[24], *Y. Shirata*[25] analyze the evolutionary dynamics of the general individual's preference. However, these papers few combine the two fields to examine the effect of preference on the dynamics of supply chains.

Our paper is different with the existing literature at two points. First, we study the dynamics of players' strategies in the long term rather than one-shot game, focus on the evolutionary stability of manufacturers' and retailers' strategies in the supply chains. Second, we study the evolution of strategies with fairness and altruism preferences under different demands, and analyze the effects of individual preferences and demand type on the evolutionarily stable strategies.

2 Model analysis

We assume that there are many (a sufficiently large number of) manufacturers and retailers in the market. They match randomly to play a two-person manufacturer Stackelberg game. Let the unit wholesale price be *w* and the selling price be *p*. The manufacturer and the retailer have two pure pricing strategies: fairness concern and altruism concern.

2.1 Mathematical models

In this section, we examine the effects of fairness concern and altruism concern on a channel with one manufacturer and one retailer. If a player cares about fairness, he maximizes his utility that includes two parts: one is monetary payoff and the other is the disutility due to inequity. If he is altruism concern, he maximizes the combination of his profit and the profit of his opponent. Assuming the market demand is given by $D(p)=1/p^2$, and only the manufacturer incurs a unit production cost *c (0<c<1)* in this channel. We use π_m and π_r to denote the profits of the manufacturer and the retailer in this supply chain, respectively.

First, if only the retailer concerns fairness, the manufacturer is altruistic. Then the retailer will maximize a utility function $u_r(w,p)$ that accounts for the retailer's monetary payoff as well as his concern about fairness when setting his price. We can write

$$u_r(w,p)=\pi_r(w,p)+f_r(w,p),$$

where $f_r(w,p)$ is the disutility due to inequity. We model fairness as inequity aversion as in *E. Fehr* and *K. M. Schmidt*[19]. The algebraic form is $f_r(w,p)=-\alpha_f\max\{\pi_m-\pi_r,0\}-\alpha'_f\max\{\pi_r-\pi_m,0\}$, $\alpha_f\geq 0$ is the fairness parameter of retailer from disadvantage profit, $\alpha'_f\geq 0$ is the fairness parameter of retailer from advantage profit, the parameters imply the degree of fairness for retailers. Similarly, we can define the degree of fairness for manufacturers. As the mention in *T. H. Cui et al.*[12], although the distributive fairness has much more substance than a simple mathematic representation here can capture, we believe that this formulation strikes a reasonable balance between modeling tractability and behavioral complexity.

When the profit of the manufacturer is higher than the profit of the retailer, the equilibrium profit of the manufacturer is always less than that one of the retailer if the retailer is fairness concern. Hence, in this section, we only consider this case that the retailer's profit higher than the manufacturer's, i.e., $\pi_r\geq\pi_m$. So for a fairness concern manufacturer and retailer, the optimization problems are

$$\max_w u'_m=(w-c)/p^2-\beta'_f[(p-w)-(w-c)]/p^2,\quad \max_p u'_r=(p-w)/p^2-\alpha'_f[(p-w)-(w-c)]/p^2,$$

respectively.
Let the first order partial derivative, $\partial u'_r / \partial p = (2w - p)(1 - \alpha'_f) - 2(w - c)\alpha'_f$ equal zero, we get the first order condition $p^*(w) = 2w - 2(w - c)\alpha'_f / (1 - \alpha'_f)$. From the indirect calculation, it is easy to verify that when $p_1 < p^*(w)$, the first order partial derivative at point p_1 is larger than zero, and when $p_2 > p^*(w)$, the first order partial derivative at point p_2 is less than zero, i.e., it is unimodal in p. Thus, this is a unique p_n^{ff}, such that retailers can get the maximal utility at the point p_n^{ff}. Similarly, we can get there exists a unique w_n^{ff} such that at this point, manufacturers can get their maximal utility.
Thus, we get the equilibrium wholesale price and market price is $w_n^{ff} = \frac{c[2(1 + \beta'_f) + \alpha'^2_f(3 - 2\beta'_f) - \alpha'_f(5 + 2\beta'_f)]}{(1 - 2\alpha'_f)[1 - \alpha'_f(1 - 2\beta'_f)]}$, $p_n^{ff} = \frac{4c(1 + \beta'_f - \alpha'_f)}{1 - \alpha'_f(1 - 2\beta'_f)}$, respectively. In order to ensure $\pi_r \geq \pi_m$ is true, let $\alpha'_f < 1/2$ or $\alpha'_f > 1/2$ and $\beta'_f < \frac{5\alpha'_f - 2 - 3\alpha'^2_f}{2(1 - \alpha'_f - \alpha'^2_f)}$, we get the equilibrium profits of manufacturer and retailer are

$$\pi'^{ff}_m = \frac{(1 - \alpha'_f)^2(1 + 2\beta'_f)(1 - \alpha'_f + 2\alpha'_f\beta'_f)}{16c(1 - 2\alpha'_f)(1 - \alpha'_f + \beta'_f)^2},$$

$$\pi'^{ff}_r = \frac{(1 - \alpha'_f + 2\alpha'_f\beta'_f)[2(1 + \beta'_f) + \alpha'^2_f(5 + 2\beta'_f) - \alpha'_f(7 + 6\beta'_f)]}{16c(1 - 2\alpha'_f)(1 - \alpha'_f + \beta'_f)^2}.$$

Otherwise, $\pi'^{ff}_m = \pi'^{ff}_r = \frac{1}{8c}$.
Similarly, under the assumption $\alpha'_f < 1/2$, we get the equilibrium profits for the manufacturer and retailer as Table 1.
Here $0 \leq \beta_a, \beta'_f \leq 1, 0 \leq \alpha_a, \alpha'_f \leq 1$. β_a and α_a denote the degrees of altruism for manufacturers and retailers; β'_f, α'_f denote the degrees of fairness from disadvantage profit for manufacturers and the degree of fairness from advantage profit for retailers, respectively. The superscripts *f* and *a* denote the strategy fairness and altruism, the first one is the strategy of manufacturers, and the second one is the strategy of retailers. Subscripts *m* and *r* denote the profits of manufacturers and retailers. When $\alpha'_f \geq 1/2$, we can similarly analyze the dynamics of the supply chain.

2.2 Evolutionary analysis

We assume the principle of an individual choose his strategy is the strategy that gets a higher profit has the higher probability to be chosen in the further interaction. The change of the shares of the manufacturer and retailer using altruistic strategy satisfy the replicator dynamics. Let *x* denote the share of manufacturers using altruistic strategy, *y* denote the share of retailers using altruistic strategy, then shares of manufacturer and retailer using fair strategy are $1 - x$, $1 - y$, respectively. Two-tuple (*x*, *y*) means that there are manufacturers with proportion *x* using strategy altruism, retailers with proportion *y* using strategy altruism. Thus, basing on the replicator dynamics and the stability of the differential equation, we get the results as follows.

Table 1 - The equilibrium profits of the manufacturer and retailer in the one-shot game

$\alpha'_f < \frac{1+\beta_a}{1+3\beta_a} \le \frac{1}{2},\ \beta_a > \frac{5\alpha'_f - 4\alpha'^2_f - 1}{1+4\alpha'^2_f - 3\alpha'_f},\ \beta'_f < \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)},\ 0 < \alpha_a < 1/3$
$\pi'^{ff}_m = \frac{(1-\alpha'_f)^2(1+2\beta'_f)(1-\alpha'_f+2\alpha'_f\beta'_f)}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2},\ \pi'^{ff}_r = \frac{(1-\alpha'_f+2\alpha'_f\beta'_f)[2(1+\beta'_f)+\alpha'^2_f(5+2\beta'_f)-\alpha'_f(7+6\beta'_f)]}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2}$ $\pi'^{af}_m = \frac{(1-\alpha'_f)^2(1-\beta_a)[1+\beta_a-\alpha'_f(1+3\beta_a)]}{16c(1-2\alpha'_f)(1-\alpha'_f-\alpha'_f\beta_a)^2},\ \pi'^{af}_r = \frac{[1+\beta_a-\alpha'_f(1+3\beta_a)][2-\alpha'_f(7+\beta_a)+\alpha'^2_f(5+3\beta_a)]}{16c(1-2\alpha'_f)(1-\alpha'_f-\alpha'_f\beta_a)^2}$ $\pi'^{fa}_m = \frac{(1+2\beta'_f)(1+2\alpha_a\beta'_f)}{16c(1-\alpha_a)(1+\beta'_f+\alpha\beta'_f)^2},\ \pi'^{fa}_r = \frac{(1+2\alpha_a\beta'_f)[{}_f2(1+\beta'_f)-2\alpha_a^2\beta'_f-\alpha_a(3+2\beta'_f)]}{16c(1-\alpha_a)(1+\beta'_f+\alpha_a\beta'_f)^2}$ $\pi'^{aa}_m = \frac{(1-\beta_a)[1+\beta_a(1-2\alpha_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2},\ \pi'^{aa}_r = \frac{[1+\beta_a(1-2\alpha_a)][2+2\alpha_a^2\beta_a-\alpha_a(3+\beta_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2}$
$\alpha'_f < \frac{1+\beta_a}{1+3\beta_a} \le \frac{1}{2},\ \beta_a < \frac{5\alpha'_f - 4\alpha'^2_f - 1}{1+4\alpha'^2_f - 3\alpha'_f},\ \beta'_f < \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)},\ 0 < \alpha_a < 1/3$
$\pi'^{ff}_m = \frac{(1-\alpha'_f)^2(1+2\beta'_f)(1-\alpha'_f+2\alpha'_f\beta'_f)}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2},\ \pi'^{ff}_r = \frac{(1-\alpha'_f+2\alpha'_f\beta'_f)[2(1+\beta'_f)+\alpha'^2_f(5+2\beta'_f)-\alpha'_f(7+6\beta'_f)]}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2}$ $\pi'^{af}_m = \frac{1}{8c},\ \pi'^{af}_r = \frac{1}{8c}$ $\pi'^{fa}_m = \frac{(1+2\beta'_f)(1+2\alpha_a\beta'_f)}{16c(1-\alpha_a)(1+\beta'_f+\alpha\beta'_f)^2},\ \pi'^{fa}_r = \frac{(1+2\alpha_a\beta'_f)[{}_f2(1+\beta'_f)-2\alpha_a^2\beta'_f-\alpha_a(3+2\beta'_f)]}{16c(1-\alpha_a)(1+\beta'_f+\alpha_a\beta'_f)^2}$ $\pi'^{aa}_m = \frac{(1-\beta_a)[1+\beta_a(1-2\alpha_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2},\ \pi'^{aa}_r = \frac{[1+\beta_a(1-2\alpha_a)][2+2\alpha_a^2\beta_a-\alpha_a(3+\beta_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2}$
$\alpha'_f < \frac{1+\beta_a}{1+3\beta_a} \le \frac{1}{2},\ \beta_a < \frac{5\alpha'_f - 4\alpha'^2_f - 1}{1+4\alpha'^2_f - 3\alpha'_f},\ \beta'_f > \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)},\ 0 < \alpha_a < 1/3$
$\pi'^{ff}_m = \frac{(1-\alpha'_f)^2(1+2\beta'_f)(1-\alpha'_f+2\alpha'_f\beta'_f)}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2},\ \pi'^{ff}_r = \frac{(1-\alpha'_f+2\alpha'_f\beta'_f)[2(1+\beta'_f)+\alpha'^2_f(5+2\beta'_f)-\alpha'_f(7+6\beta'_f)]}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2}$ $\pi'^{af}_m = \frac{1}{8c},\ \pi'^{af}_r = \frac{1}{8c}$ $\pi'^{fa}_m = \frac{1}{8c},\ \pi'^{fa}_r = \frac{1}{8c}$ $\pi'^{aa}_m = \frac{(1-\beta_a)[1+\beta_a(1-2\alpha_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2},\ \pi'^{aa}_r = \frac{[1+\beta_a(1-2\alpha_a)][2+2\alpha_a^2\beta_a-\alpha_a(3+\beta_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2}$
$\alpha'_f < \frac{1+\beta_a}{1+3\beta_a} \le \frac{1}{2},\ \beta_a > \frac{5\alpha'_f - 4\alpha'^2_f - 1}{1+4\alpha'^2_f - 3\alpha'_f},\ \beta'_f > \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)},\ 0 < \alpha_a < 1/3$
$\pi'^{ff}_m = \frac{(1-\alpha'_f)^2(1+2\beta'_f)(1-\alpha'_f+2\alpha'_f\beta'_f)}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2},\ \pi'^{ff}_r = \frac{(1-\alpha'_f+2\alpha'_f\beta'_f)[2(1+\beta'_f)+\alpha'^2_f(5+2\beta'_f)-\alpha'_f(7+6\beta'_f)]}{16c(1-2\alpha'_f)(1-\alpha'_f+\beta'_f)^2}$ $\pi'^{af}_m = \frac{(1-\alpha'_f)^2(1-\beta_a)[1+\beta_a-\alpha'_f(1+3\beta_a)]}{16c(1-2\alpha'_f)(1-\alpha'_f-\alpha'_f\beta_a)^2},\ \pi'^{af}_r = \frac{[1+\beta_a-\alpha'_f(1+3\beta_a)][2-\alpha'_f(7+\beta_a)+\alpha'^2_f(5+3\beta_a)]}{16c(1-2\alpha'_f)(1-\alpha'_f-\alpha'_f\beta_a)^2}$ $\pi'^{fa}_m = \frac{1}{8c},\ \pi'^{fa}_r = \frac{1}{8c}$ $\pi'^{aa}_m = \frac{(1-\beta_a)[1+\beta_a(1-2\alpha_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2},\ \pi'^{aa}_r = \frac{[1+\beta_a(1-2\alpha_a)][2+2\alpha_a^2\beta_a-\alpha_a(3+\beta_a)]}{16c(1-\alpha_a)(1-\alpha_a\beta_a)^2}$

Proposition 1 *(1) When* $\beta_a > \frac{(1-\alpha'_f)\beta'_f}{1-\alpha'_f+\beta'_f+\alpha'_f\beta'_f}$, $\beta'_f < \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)}$, $0 < \alpha_a < 1/3$ *and* α'_f *is small (less than 1/5), the point (0, 0), i.e., the strategy (fairness, fairness) is an evolutionarily stable strategy;*

(2) When $\beta_a > \max\{\frac{5\alpha'_f-4\alpha'^2_f-1}{1+4\alpha'^2_f-3\alpha'_f}, \frac{\beta'_f}{1+\beta'_f+2\alpha_a\beta'_f}\}$, $\beta'_f < \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)}$, $0 < \alpha_a < 1/3$ *and* α'_f *is relative large (*$2(1+\beta'_f)-\alpha'_f(7+6\beta'_f)+\alpha'^2_f(5+2\beta'_f)<0$*), the equilibrium (0, 1), i.e., strategy (fairness, altruism) is an evolutionarily stable strategy;*

(3) When $\frac{5\alpha'_f-4\alpha'^2_f-1}{1+4\alpha'^2_f-3\alpha'_f} < \beta_a < \frac{\beta'_f}{1+\beta'_f+2\alpha_a\beta'_f}$, $\beta'_f < \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)}$, $0 < \alpha_a < 1/3$*, and* α'_f *is relative large (*$2-\alpha'_f(7+\beta_a)+\alpha'^2_f(5+3\beta_a)<0$*), the equilibrium (1, 1), i.e., strategy (altruism, altruism) is an evolutionarily stable strategy;*

(4) When $\beta_a < \frac{(1-\alpha'_f)\beta'_f}{1-\alpha'_f+\beta'_f+\alpha'_f\beta'_f}$, $\beta'_f < \frac{1-3\alpha_a}{2\alpha_a(1+\alpha_a)}$, $0 < \alpha_a < 1/3$ *and* α'_f *is small (less than 1/4), the equilibrium point (1, 0), i.e., strategy (altruism, fairness) is an evolutionarily stable strategy.*

The proof is a straightforward computation. For describing the dynamics of Proposition 2, we give Figs. 1-4 as follows, where c=1.

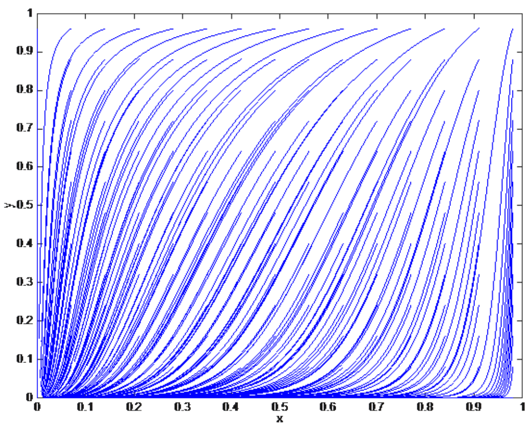

Fig. 1 - The portrait of Proposition 2(1) ($\alpha_a = 0.3, \alpha'_f = 0.2, \beta_a = 0.3, \beta'_f = 0.2$)

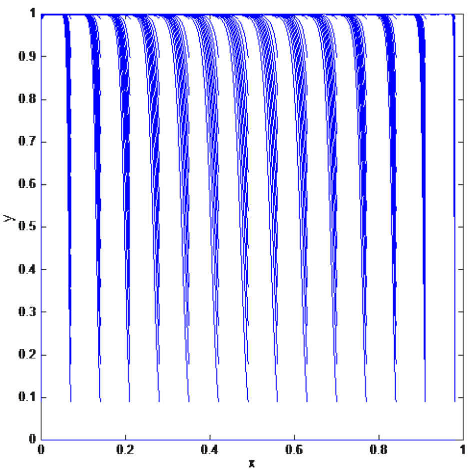

Fig. 2 - The portrait of Proposition 2(2) ($\alpha_a = 0.3, \alpha'_f = 0.45, \beta_a = 0.5, \beta'_f = 0.4$)

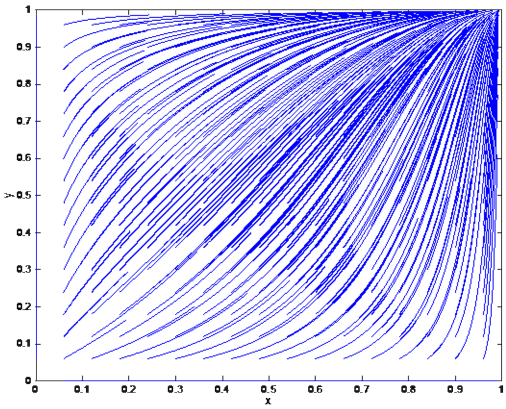

Fig. 3 - The portrait of Proposition 2(3)
($\alpha_a = 0.2, \alpha_f' = 0.2, \beta_a = 0.3, \beta_f' = 0.8$)

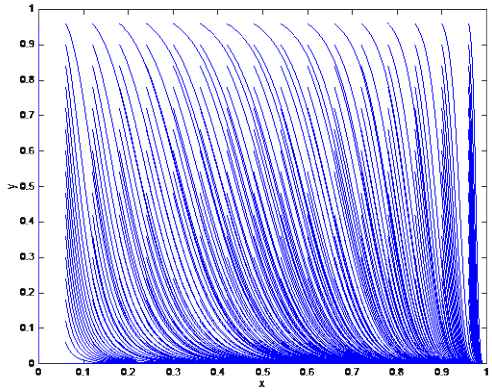

Fig. 4 - The portrait of Proposition 2(4)
($\alpha_a = 0.3, \alpha_f' = 0.2, \beta_a = 0.2, \beta_f' = 0.4$)

From Proposition 1 and Figs. 1-4, the four strategy profiles: two symmetry strategy profiles and two asymmetry strategy profiles, specially, both manufacturer and retailer use strategy altruism or fairness, manufacturers use strategy fairness and retailers use strategy altruism, and manufacturers use strategy altruism and retailers fairness may be evolutionarily stable strategy depend on their preference parameters. When the degree of fairness to the manufacturer is high, the manufacturer should use altruistic strategy; correspondingly, when the degree of fairness for the retailer is high, then he should use altruistic strategy. The degree of the retailer is relatively low, when the degree of altruism to the manufacturer is relative high, the manufacturer should use fair strategy, when the degree of altruism to the manufacturer is relatively low, he should use altruistic strategy. The evolutionary stability of strategy depends on the relative values of individual preference parameters.

3 The impact of demand type

For analyzing the effect of demand type on the evolutionarily stable strategies in the supply chain, we discuss the case that the demand is a linear function of price in this section. Assuming the demand is given by $D(p) = 1 - p$, we study the evolutionarily stable strategies.

3.1 Equilibrium outcomes under linear demand function in the one-shot game

First, we consider the case that the profit of the manufacturer is higher than the retailer's. So in the case where the manufacturer is an altruist and the retailer cares about fairness, the optimization problems of the manufacturer and retailer are

$$\max_w u_m = (w-c)(1-p) + \beta_a(p-w)(1-p), \ \max_p u_r = (p-w)(1-p) - \alpha_f[(w-c)-(p-w)](1-p),$$

respectively. Here $0 \le \beta_a \le 1$ denotes the degree of altruism of the manufacturer.

From $\partial^2 u_r / \partial p^2 = -2(1+\alpha_f) < 0$, we get the second order condition is true. Similarly, we can get the second order condition for u_m also is true. Thus we obtain the equilibrium outcomes of manufacturers and retailers in the one shot game. The specific outcomes are shown in Appendix.

Basing on the calculation, we get five payoff matrices depend on the values of the preference parameters. We focus on one case in our paper, the others can be analyzed using the similar method. We get payoff matrix when $\alpha_f \le \frac{1}{2}, \beta_f < \frac{1-\alpha_f - 2\alpha_f^2}{3+2\alpha_f}, \beta_a \le \frac{(1+\alpha_f)(1-2\alpha_f)}{2+3\alpha_f+2\alpha_f^2}, 0 \le \alpha_a, \beta_a < 1$ as Table 2.

Table 2 - The material payoff with altruism and fairness

M \ R	altruism	fairness
altruism	π_m^{aa}, π_r^{aa}	π_m^{af}, π_r^{af}
fairness	π_m^{fa}, π_r^{fa}	π_m^{ff}, π_r^{ff}

Where α_f, β_f are the fairness parameters of the retailer and manufacturer, respectively. α_a, β_a are the altruism parameters of the retailer and manufacturer, respectively. The superscripts *f* and *a* denote the strategy fairness and altruism, the first one is the strategy of manufacturers, and the second one is the strategy of retailers. Subscripts *m* and *r* denote the equilibrium profits of the manufacturer and retailer.

3.2 Evolutionarily stable strategy under linear demand function

In this subsection, we analyze the evolutionary stable strategies. Let s_a be the fraction of manufacturers who are altruism concern, and s'_a be the fraction of retailers who are altruism concern, we get the replicator dynamics

$$\begin{cases} \dot{s}_a = s_a(1-s_a)[s'_a \pi_m^{aa} + (1-s'_a)\pi_m^{af} - (s'_a \pi_m^{fa} + (1-s'_a)\pi_m^{ff})] \\ \dot{s}'_a = s'_a(1-s'_a)[s_a \pi_r^{aa} + (1-s_a)\pi_r^{fa} - (s_a \pi_r^{af} + (1-s_a)\pi_r^{ff})] \end{cases} \quad (1)$$

By calculating, we have the results.

$\mathrm{sgn}(\pi_m^{af} - \pi_m^{ff})$ depends on the value of β_a. If the value of β_a is small, then $\pi_m^{af} - \pi_m^{ff}$ is positive; if the value of β_a is large, $\pi_m^{af} - \pi_m^{ff}$ is negative. And basing on the Figs. 5-10, we see that $\pi_r^{fa} - \pi_r^{ff}$ and $\pi_r^{aa} - \pi_r^{af}$ are negative.

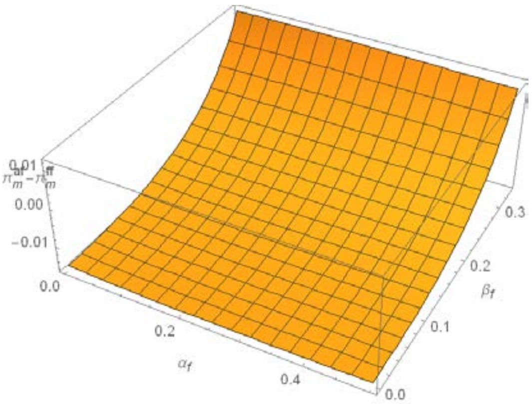

Fig. 5- $\pi_m^{af} - \pi_m^{ff}$ versus α_f and β_f with $\beta_a = 0.4$

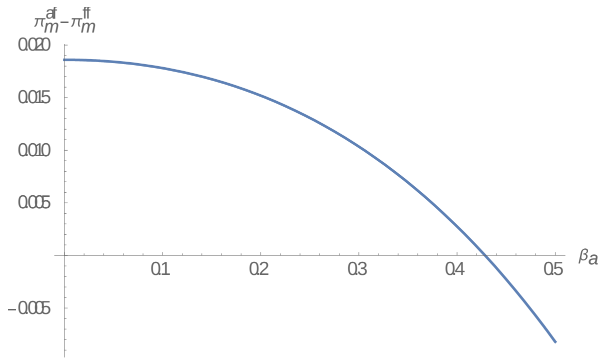

Fig. 6- $\pi_m^{af} - \pi_m^{ff}$ versus β_a with $\beta_f = 0.3, \alpha_f = 0.48$

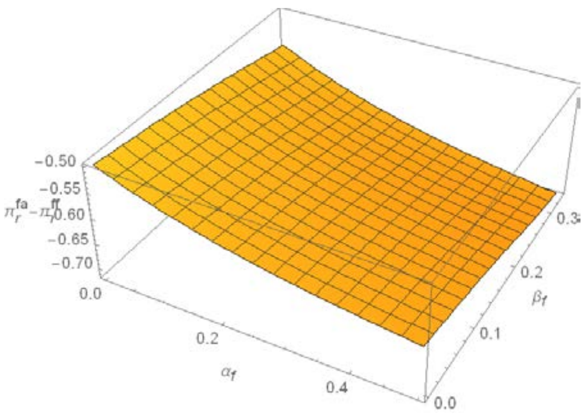

Fig. 7- $\pi_r^{fa}-\pi_r^{ff}$ vs. α_f and β_f with $\alpha_a=0.5$

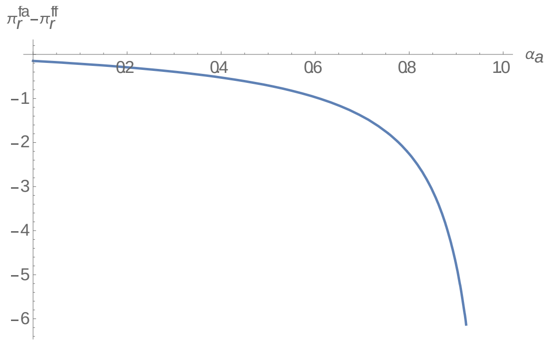

Fig. 8- $\pi_r^{fa}-\pi_r^{ff}$ *vs.* α_a *with* $\beta_f=0.3,\alpha_f=0.48$

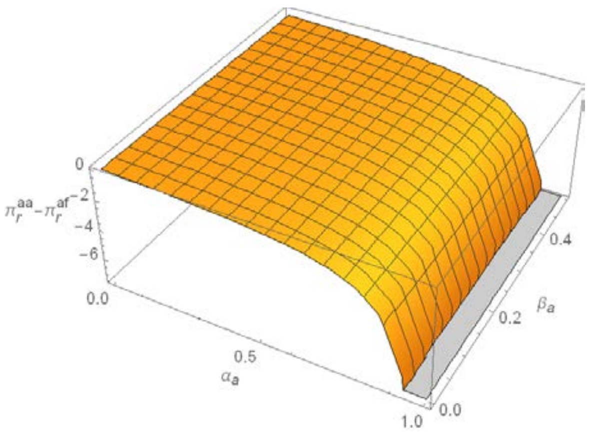

Fig. 9- $\pi_r^{aa}-\pi_r^{af}$ vs. α_a and β_a with $\alpha_f=0.4$

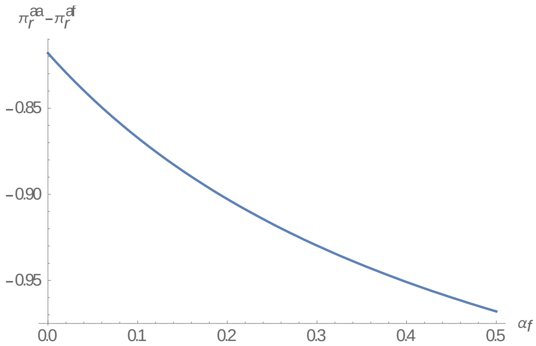

Fig. 10- $\pi_r^{aa}-\pi_r^{af}$ vs. α_f with $\beta_a=0.4,\alpha_a=0.6$

Hence, we have results as below basing on the numerical simulation.

Proposition 2 The points (0, 1) and (1, 1) are unstable. While the point (0, 0) is asymptotically stable as the value of β_a is large, the point (1, 0) is asymptotically stable as the value of β_a is small.

From Proposition 2, we know that if the manufacturer does not care a lot about altruism, then he decides his wholesale price by maximizing his function of altruism and the retailer decides his market price by maximizing his fair utility is the evolutionary stable strategy; if the manufacturer cares a lot about altruism, then the strategy profile where both manufacturer and retailer decide their prices by maximizing the function of their fair utilities is the evolutionary stable strategy.

3.3 The impact of demand type on evolutionarily stable strategy

In the above analysis, we get the evolutionarily stable strategies of manufacturers and retailers under linear demand and non-linear demand. From the Propositions 1 and 2, although the conditions of parameters to the evolutionarily stable strategies are independent of the demand parameters, the results are distinct under different demand type. Under the non-linear demand, when the retailer is fairness concern, the equilibrium profit of manufacturers is always less than the equilibrium profit of retailers, and the equilibrium outcomes in the one shot game under linear demand are richer than those under non-linear demand.

Basing on Proposition 2, when the degree of altruism of the manufacturer is high, he chooses the fair strategy, and when the degree is relative low, he chooses the altruistic strategy. Those results are similar to those in Proposition 1. However, in Proposition 2, retailers always use fair strategy under linear demand, while according to Proposition 1, under non-linear demand, when the degree of fairness of retailers relatively high, retailers use strategy altruism is a better strategy in the long term interaction. The possible reason is that if the retailer cares about fairness very much, the disutility from inequity will hurt his benefit. Furthermore, from Proposition 1 and Proposition 2, the strategy profile that both the manufacturer and the retailer use strategy altruism can be an evolutionarily stable strategy under non-linear demand, while the result is not true under linear demand. Hence, though the conditions of individual preference parameters that satisfy the evolutionarily stable strategies do not depend on the demand function directly, the demand type is an important factor to the evolutionarily stable strategies of the manufacturer and the retailer.

4 Conclusions

In this paper, we analyze the evolutionary stable strategy in the supply chain consists of many manufacturers and retailers. We assume that each manufacturer or retailer has two kinds of strategies to choose: fairness, altruism. We get that the evolutionary stable strategy depends on the values of fairness or altruism parameters. Furthermore, the market demand also affects the strategy choice of manufacturers and retailers. However, we get some results about individual's preference fairness or altruism by numerical examples, next we will continue to analyze the situation completely.

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Appendix

The computation of the equilibrium outcomes under linear demand

First, we consider that the manufacturer is an altruist and the retailer cares about fairness, the objective functions of the manufacturer and retailer are

$$\max_w (w-c)(1-p)+\beta_a(p-w)(1-p),\ \max_p (p-w)(1-p)-\alpha_f[(w-c)-(p-w)](1-p)$$

By calculating, we have the equilibrium is

$$w^{af}=\frac{1+c-\beta_a+\alpha_f(2+4c-2\beta_a)+\alpha_f^2[1+3c-(1-c)\beta_a]}{(1+2\alpha_f)(2+2\alpha_f-\beta_a)},$$

$$p^{af}=\frac{3+c-2\beta_a+\alpha_f[3+c-(1-c)\beta_a]}{2(2+2\alpha_f-\beta_a)}.$$

And the profits are

$$\pi_m^{af}=\begin{cases}\dfrac{(1-c)^2(1+\alpha_f)^2(1-\beta_a)[1+\alpha_f(1+\beta_a)]}{2(1+2\alpha_f)(2+2\alpha_f-\beta_a)^2}, & \text{if } 0\le\alpha_f\le\dfrac{1}{2},\beta_a\le\dfrac{(1+\alpha_f)(1-2\alpha_f)}{2-3\alpha_f+2\alpha_f^2}\\[2ex] \dfrac{(1-c)^2(1+\alpha_f)}{(3+2\alpha_f)^2}, & \text{otherwise}\end{cases}$$

$$\pi_r^{af}=\begin{cases}\dfrac{(1-c)^2[1+4\alpha_f^2+\alpha_f(5-\beta_a)][1+\alpha_f(1+\beta_a)]}{4(1+2\alpha_f)(2+2\alpha_f-\beta_a)^2}, & \text{if } 0\le\alpha_f\le\dfrac{1}{2},\beta_a\le\dfrac{(1+\alpha_f)(1-2\alpha_f)}{2-3\alpha_f+2\alpha_f^2}\\[2ex] \dfrac{(1-c)^2(1+\alpha_f)}{(3+2\alpha_f^2)}, & \text{otherwise}\end{cases}$$

When the manufacturer cares about fairness and the retailer is an altruist, then the objective functions are respective

$$\max_w (w-c)(1-p)-\beta_f[(w-c)-(p-w)](1-p),\quad \max_p (p-w)(1-p)+\alpha_a(w-c)(1-p).$$

By calculating, we obtain the equilibrium are

$$w^{fa}=\frac{1+c-2c\alpha_a(1-\beta_f)-(2+c)\beta_f+c\alpha_a^2\beta_f}{(1-\alpha_a)[2-(3+\alpha_a)\beta_f]},\quad p^{fa}=\frac{3+c-[5+c+(1+c)\alpha_a]\beta_f}{2[2-(3+\alpha_a)\beta_f]}.$$

And when $w>\bar{w}$, $\bar{w}=\dfrac{1+2c+c\alpha_a}{3+\alpha_a}$, i.e., $\beta_f>\dfrac{2}{3+\alpha_a}>1/3$ or $\beta_f<\dfrac{1+3\alpha_a}{(3+\alpha_a)(1+\alpha_a)}$, the equilibrium profits are

$$\pi_m^{fa}=\frac{(1-c)^2(1-2\beta_f)[1-(1+\alpha_a)\beta_f]}{2(1-\alpha_a)[2-(3+\alpha_a)\beta_f]^2},\quad \pi_r^{fa}=\frac{(1-c)^2[1-(1+\alpha_a)\beta_f][1-\beta_f+\alpha_a^2\beta_f+\alpha_a(4\beta_f-3)]}{4(1-\alpha_a)[2-(3+\alpha_a)\beta_f]^2}.$$

Otherwise,

$$w^{fa}=\bar{w},\quad p^{fa}=\frac{2a+b(1+\alpha_a)}{b(3+2\alpha_a)},\quad \pi_m^{fa}=\pi_r^{fa}=\frac{(a-bc)^2(1+\alpha_a)}{b(3+\alpha_a)^2}.$$

So the profit of the manufacturer and the retailer are, respectively

$$\pi_m^{fa} = \begin{cases} \dfrac{(1-c)^2(1-2\beta_f)[1-(1+\alpha_a)\beta_f]}{2(1-\alpha_a)[2-(3+\alpha_a)\beta_f]^2}, \text{if } \beta_f > \dfrac{2}{3+\alpha_a} \text{ or } \beta_f < \dfrac{1+3\alpha_a}{(3+\alpha_a)(1+\alpha_a)} \\ \dfrac{(1-c)^2(1+\alpha_a)}{(3+\alpha_a)^2}, \text{otherwise} \end{cases}$$

$$\pi_r^{fa} = \begin{cases} \dfrac{(1-c)^2[1-(1+\alpha_a)\beta_f][1-\beta_f+\alpha_a^2\beta_f+\alpha_a(4\beta_f-3)]}{4(1-\alpha_a)[2-(3+\alpha_a)\beta_f]^2}, \quad \text{if } \beta_f > \dfrac{2}{3+\alpha_a} \text{ or } \beta_f < \dfrac{1+3\alpha_a}{(3+\alpha_a)(1+\alpha_a)} \\ \dfrac{(1-c)^2(1+\alpha_a)}{(3+\alpha_a)^2}, \quad \text{otherwise} \end{cases}$$

Similarly, when both the manufacturer and retailer are fairness concern, the profit of manufacturer and retailer are as follows

$$\pi_m^{ff} = \begin{cases} \dfrac{(1-2\beta_f)(1+\alpha_f-\beta_f)(1+\alpha_f)^2(1-c)^2}{2(1+2\alpha_f)(2\alpha_f-3\beta_f-2\alpha_f\beta_f+2)^2}, \quad \text{if } 0 \le \beta_f < \dfrac{1-\alpha_f-2\alpha_f^2}{3+2\alpha_f} \text{ and } \alpha_f \le \dfrac{1}{2} \\ \dfrac{(1-c)^2}{8}, \quad \text{othewise} \end{cases}$$

$$\pi_r^{ff} = \begin{cases} \dfrac{(1+\alpha_f-\beta_f)(5\alpha_f-\beta_f-6\alpha_f\beta_f-4\alpha_f^2\beta_f+4\alpha_f^2+1)(1-c)^2}{4(1+2\alpha_f)(2\alpha_f-3\beta_f-2\alpha_f\beta_f+2)^2}, \quad \text{if } 0 \le \beta_f < \dfrac{1-\alpha_f-2\alpha_f^2}{3+2\alpha_f} \text{ and } \alpha_f \le \dfrac{1}{2} \\ \dfrac{(1-c)^2}{8}, \quad \text{otherwise} \end{cases}$$

When both the manufacturer and retailer are altruism concern, the profits of the manufacturer and retailer are

$$\pi_m^{aa} = \frac{(1-c)^2(1-\beta_a)(1-\alpha_a\beta_a)}{2(1-\alpha_a)[2-(1+\alpha_a)\beta_a]^2}, \quad \pi_r^{aa} = \frac{(1-c)^2(1-\alpha_a\beta_a)(1+\alpha_a(\beta_a-3)+\alpha_a^2\beta_a)}{4(1-\alpha_a)[2-(1+(1+\alpha_a)\beta_a]^2},$$

respectively.

Similarly, we can get the equilibrium outcome when the profit of retailers higher than that one of manufacturers.