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Social responsibility in a bilateral monopoly with R&D

Abstract

This note examines social responsibility in a linear bilateral monopoly by incorporating a cost-reducing R&D investment and investigates an endogenous timing game. We find that in the presence of R&D, the retailer always adopts social responsibility irrespective of the timing of the game, but the manufacturer adopts only with its leadership in a sequential game where it can take the first-mover advantage. We also show that two sequential choices will be subgame perfect equilibria, but the commitment to the social responsibility by manufacturer is a payoff dominance outcome.

Keywords: social responsibility; R&D investment; fixed-timing game; endogenous-timing game

JEL Classification: D21; L13; L22; M14

1. Introduction

The recent topic on the firm's social responsibility has received increasing attention from broad research in both empirical and theoretical management economics.¹ Numerous studies have also formulated theoretical approaches on the social responsibility in the fields of business management and applied economics. While most research considered horizontal models of market competition where the products are substitutes,² some research examined the vertical model of supply channel where the products are complements.

Goering (2012, 2014) and Brand and Grothe (2013, 2015) considered a linear bilateral monopoly with the upstream manufacturer and the downstream retailer, and showed that the profit-maximizing firm has a strategic motivation to commit social responsibility to reduce double marginalization problem and thus to increase its own profits. Goering (2012) and Brand and Grothe (2013) examined the two-part tariff under perfectly coordinated marketing channel and showed that the manufacturer can induce the retailer to increase total outputs but its rate depends on the firm's concern on the social responsibility. Goering (2014) and Brand and Grothe (2015) also considered the sequencing choice of social responsibility under imperfectly coordinated marketing channel and showed that a sequential choice of the social responsibility with manufacturer leadership yields higher profits than those under pure profit maximization.

In this note, we extend their analysis by incorporating a cost-reducing R&D investment under imperfectly coordinated marketing channel in a linear bilateral monopoly. We show that the retailer always adopts social responsibility irrespective of whether simultaneous game or sequential game, but the manufacturer adopts only with its leadership in

¹For the intensive discussions on the practical and academic issues on social responsibility, see Crifo and Forget (2015) and Kitzmueller and Shimshack (2012).

²As for extensive works with strategic motives for social responsibility, Fanti and Buccella (2016) examined the network effects while Lambertini and Tampieri (2015), Liu et al. (2015), Hirose et al. (2017) and Lee and Park (2018) incorporated environmental concern. See Fanti and Buccella (2016, 2017) and Leal et al. (2018) for more literature on the strategic approaches on social responsibility.

a sequential game. From the strategic viewpoint of the retailer, its social responsibility can induce the manufacturer to undertake more R&D investment, which will reduce the wholesale price. However, the manufacturer will adopt social responsibility only when it is profitable from more R&D investment, which causes higher cost. Thus, the manufacturer will take advantage of its leadership in choosing the social responsibility in a bilateral monopoly where the choices of the social responsibility are strategic complements. These findings also imply that the sequential choice on the social responsibility critically depends on the efficiency of R&D investment of the manufacturer.

We also examine an endogenous timing game, suggested by Hamilton and Slutsky (1990), and show that two sequential choices will be subgame perfect equilibria, but the sequential choice of the social responsibility by manufacturer is a payoff dominance outcome. This finding is also consistent with Brand and Grothe (2015). Hence, we can conclude that the sequential commitment with manufacturer leadership is robust in a linear bilateral monopoly relationship with R&D investment.

The remainder of the paper is organized as follows. Section 2 describes the model of a linear bilateral monopoly with R&D. Section 3 provides the results under the fixed timing of the game and Section 4 provides main findings under the endogenous timing game. Finally, Section 5 concludes and suggests further research directions.

2. Model

We consider a linear demand bilateral monopoly framework where upstream and downstream monopolists exist, respectively, as a manufacturer and a retailer. The retailer is endowed with constant returns to scale technologies that transform one unit of input to one unit of output. This input is sold by the manufacturer for the wholesale price w to produce a final good. The retailer faces the linear (inverse) demand function $p(Q) = a - q$ and no other cost than the input price w where the trading is conducted through linear wholesale price contracts.

The manufacturer has a constant marginal cost, however, it invest in R&D to reduce the initial production costs. In particular, we assume that reducing production costs by x units requires $\frac{kx^2}{2}$ as R&D expenditures where k represents the inefficiency of R&D investment in the followings:

$$c(q; x) = (c - x)q + \frac{kx^2}{2} \quad \text{where} \quad c < a \quad \text{and} \quad k > \underline{k}(a, c) \equiv \frac{3a + c}{8c} > \frac{1}{2}$$

to guarantee interior solutions where $w > 0$ and $0 < x < c$.

Then, the manufacturer's profit π_m and the the retailer's profit π_r are given by

$$\pi_m = wq - c(q; x) \tag{1}$$

$$\pi_r = (p - w)q \tag{2}$$

According to Brand and Grothe (2015), we model social responsibility in the objective functions of the firms and assume that both firms care for consumer surplus CS additionally to their own profits π_i for $i \in \{m, r\}$. Thus, the firms' objective functions can be rewritten by:

$$v_m = \pi_m + \theta_m CS = wq - c(q; x) + \theta_m \frac{q^2}{2} \tag{3}$$

$$v_r = \pi_r + \theta_r CS = (p - w)q + \theta_r \frac{q^2}{2} \tag{4}$$

where v_m and v_r stand for the objectives of the manufacturer and the retailer, and $\theta_i \in [0, 1]$ indicates the weights put on consumer surplus in its objective function. For $\theta_i = 0$ the firm operates like a profit maximizer while for $\theta_i = 1$ the whole consumer surplus is considered in the firm's objectives.

The game runs as follows:³ In the first stage, both firms choose its levels of social concern to maximize its own profits. Given levels of social concern, the manufacturer chooses the R&D investment in the second stage and then fixes the wholesale price per quantity in the third stage to maximize its objectives. In the last stage, the retailer sells the product at the final market to the end-consumers.

3. Results

3.1. Exogenous level of social concern

In the last stage, the retailer maximizes its objectives v_r by choosing the optimal quantity q . As a result, we get the following FOC and the optimal quantity $q(w)$ of this stage:

$$\frac{\partial v_r}{\partial q} = a - w - q(2 - \theta_r) = 0 \Leftrightarrow q(w) = \frac{a - w}{2 - \theta_r} \quad (5)$$

Inserting the retailer's quantity $q(w)$ into the manufacturer's objectives results in the following reduced form expression

$$v_m = \frac{1}{2} \left(\frac{2(a - w)(w - c + x)}{2 - \theta_r} + \frac{(a - w)^2 \theta_m}{(2 - \theta_r)^2} - kx^2 \right) \quad (6)$$

In the second stage, the manufacturer chooses the wholesale price w that maximize its value v_m . Solving this problems gives the following equilibrium price:

$$w(x) = \frac{(a + c - x)(2 - \theta_r) - a\theta_m}{4 - \theta_m - 2\theta_r} \quad (7)$$

A few remarks are in order. First, the effect of each firm's concern on consumer surplus on the wholesale price is negative and thus, the wholesale price decreases as the concern on consumer surplus of each firm increases. That is, $\frac{\partial w}{\partial \theta_m} < \frac{\partial w}{\partial \theta_r} < 0$: the effect of θ_m is more significant to the wholesale price. It implies that the strategic motives of social responsibility will reduce the wholesale price. Second, the wholesale price decreases as the manufacturer's R&D investment increases. That is, $\frac{\partial w}{\partial x} < 0$ and $\frac{\partial(\partial w / \partial \theta_i)}{\partial x} < 0$: R&D outcome will enhance the effect of θ_i on the wholesale price. It also implies that the strategic motives of social responsibility for decreasing the wholesale price will depend critically on the effect on the R&D investment.

Inserting the wholesale price $w(x)$ into (6), we get the following optimization problem and optimal R&D investment

$$\frac{\partial v_m}{\partial x} = \frac{a - c + x(1 - 4k + k\theta_m + 2k\theta_r)}{4 - \theta_m - 2\theta_r} = 0 \Leftrightarrow x^* = \frac{a - c}{\Delta} \quad (8)$$

³One may consider the reverse order that R&D is implemented in the first stage and then both firms choose its levels of social concern to maximize its own profits in the second stage. In this case where the R&D decision takes a long-run process, compared to the decision on social responsibility, the production cost is deterministic at the stage that the manufacturer decides its social responsibility and production outputs. Thus, the analysis becomes the same with Brand and Grothe (2015) and thus the strategic motives of social responsibility toward R&D decisions disappear. We thank to an anonymous referee for this suggestion.

55 where $\Delta = k(4 - \theta_m - 2\theta_r) - 1 > 0$. Note that the effect of each firm's concern on consumer surplus on the R&D investment is positive and thus, the R&D investment increases as the concern on consumer surplus of each firm increases. That is, $\frac{\partial x}{\partial \theta_r} > \frac{\partial x}{\partial \theta_m} > 0$.

The optimal R&D investment yields the following equilibrium wholesale price

$$w^* = \frac{a(k(2 - \theta_m - \theta_r) - 1) + ck(2 - \theta_r)}{\Delta} \quad (9)$$

Inserting the optimal R&D investment x^* and the wholesale price w^* , which is always higher or equal to marginal costs, into (1)-(5) results in the equilibrium quantity, price, profit and payoffs:

$$\begin{aligned} q^* &= \frac{(a-c)k}{\Delta}, & p^* &= \frac{k(a(3 - \theta_m - 2\theta_r) + c) - a}{\Delta} \\ \pi_m^* &= \frac{(a-c)^2 k(k(4 - 2\theta_m - 2\theta_r) - 1)}{2\Delta^2}, & \pi_r^* &= \frac{(a-c)^2 k^2(1 - \theta_r)}{\Delta^2} \\ v_m^* &= \frac{(a-c)^2 k}{2\Delta}, & v_r^* &= \frac{(a-c)^2 k^2(2 - \theta_r)}{2\Delta^2} \end{aligned} \quad (10)$$

60 3.2. Benchmark

As a benchmark, we consider a standard case of pure-profits maximization where $\theta_m = \theta_r = 0$. From the outcomes in (10), we obtain the results in the equilibrium quantity, price, and profit:

$$\begin{aligned} q^B &= \frac{(a-c)k}{4k-1}, & p^B &= \frac{a(3k-1) + ck}{4k-1} \\ v_m^B &= \pi_m^B = \frac{(a-c)^2 k}{2(4k-1)}, & v_r^B &= \pi_r^B = \frac{(a-c)^2 k^2}{(4k-1)^2} \end{aligned} \quad (11)$$

3.3. Timing of social concern

In the followings, we examine three cases according to the timing of the firm's choice on social concern. In each 65 case, firms choose θ_i to maximize its own profits, respectively.

3.3.1. Simultaneous choice of social concern

Firms simultaneously decide on their level of social concern θ_i so as to maximize π_m^* and π_r^* respectively. Then, we obtain the optimal levels of social concern

$$\theta_m^s = 0, \quad \theta_r^s = \frac{1}{2k} \quad (12)$$

It represents that R&D investment can change the outcomes in which the retailer adopts social responsibility in a simultaneous game. This is contrast to the results in Brand and Grothe (2015), who showed that both the manufacturer and the retailer do not adopt social responsibility in a simultaneous game in the absence of R&D where $k \rightarrow \infty$. In 70 our model, the strategic motive of social responsibility by the retailer depends on the efficiency of R&D investment of the manufacturer. In particular, as the inefficiency of R&D increases, which causes more R&D investment of the manufacturer, the effect of decreasing wholesale price is lessen and thus the retailer's social responsibility decreases.

The resulting profits are, respectively:

$$\pi_m^s = \frac{(a-c)^2 k}{4(2k-1)}, \quad \pi_r^s = \frac{(a-c)^2 k}{8(2k-1)} \quad (13)$$

In sum, the retailer chooses positive θ_r and induces the manufacturer to undertake more R&D investment, which leads to reduced wholesale price. Compared to the benchmark case, the profit of both firms increase, but the profit of
75 manufacture is still higher than that of retailer, i.e., $\pi_r^B < \pi_r^s$, $\pi_m^B < \pi_m^s$ and $\pi_r^s < \pi_m^s$.

3.3.2. Sequential choice of social concern with retailer leadership

Using backward induction, the manufacturer chooses its level of social concern to maximize its profit π_m^* . Then we have the following equilibrium level of social concern

$$\frac{\partial \pi_m^*}{\partial \theta_m} = -\frac{(a-c)^2 k^3 \theta_m}{\Delta^3} < 0 \Leftrightarrow \theta_m^{rl} = 0 \quad (14)$$

By inserting $\theta_m^{rl}(\theta_r) = 0$ into the objectives of the retailer, we get the following optimization problem and equilibrium levels of social concern

$$\frac{\partial \pi_r^*}{\partial \theta_r} = \frac{(a-c)^2 k^2 (-1 + 2k\theta_r)}{(1 - 2k(2 - \theta_r))^3} = 0 \Leftrightarrow \theta_r^{rl} = \frac{1}{2k} \quad (15)$$

This finding is the same with simultaneous game in which the strategic motive of social responsibility by the retailer depends on the efficiency of R&D investment of the manufacturer. This is because the reaction of the manufacturer is always to choose $\theta_m = 0$ in either sequential choice game with retailer leadership or simultaneous choice game. Thus,
80 the retailer leadership does not change R&D investment of manufacturer.

The resulting profits are, respectively:

$$\pi_m^{rl} = \frac{(a-c)^2 k}{4(2k-1)}, \quad \pi_r^{rl} = \frac{(a-c)^2 k}{8(2k-1)} \quad (16)$$

Hence, the results in the sequential choice game with retailer leadership are the same with those in simultaneous choice game.

3.3.3. Sequential choice of social concern with manufacturer leadership

Using backward induction, the retailer chooses the profit-maximizing level of social concern.

$$\frac{\partial \pi_r^*}{\partial \theta_r} = -\frac{(a-c)^2 k^2 (1 + k(\theta_m - 2\theta_r))}{\Delta^3} = 0 \Leftrightarrow \theta_r(\theta_m) = \frac{1 + k\theta_m}{2k} \quad (17)$$

In this case, θ_r depends on θ_m positively: θ_r and θ_m are strategic complements in a bilateral monopoly. Note that θ_r ,
85 is always positive as far as θ_m in non-negative.

Inserting $\theta_r(\theta_m)$ into the objectives of the manufacturer, we get the following optimization problem and equilibrium levels of social concern

$$\frac{\partial \pi_m^*}{\partial \theta_m} = \frac{(a-c)^2 k^2 (1 - k(2 - 3\theta_m))}{8(1 - k(2 - \theta_m))^3} = 0 \Leftrightarrow \theta_m^{ml} = \frac{2k-1}{3k} \quad (18)$$

The sequential choice of firms' profit-maximizing level of social concern, whereas the manufacturer determines before the retailer does, yields the following equilibrium values of θ_i

$$\theta_m^{ml} = \frac{2k-1}{3k}, \quad \theta_r^{ml} = \frac{1+k}{3k} \quad (19)$$

Note that $\theta_m^{ml} > 0$ if $k > 1/2$ and $\theta_m^{ml} \geq \theta_r^{ml}$ if $k \geq 2$. Thus, the efficiency of R&D investment determines the relative degree of the social concerns. In particular, if $k \rightarrow \infty$, the results converge to the outcomes in Brand and Grothe (2015) where R&D investment could not be undertaken.

The resulting profits are, respectively:

$$\pi_m^{ml} = \frac{9(a-c)^2k}{32(2k-1)}, \quad \pi_r^{ml} = \frac{3(a-c)^2k}{16(2k-1)} \quad (20)$$

Note that $\pi_m^{ml} > \pi_r^{ml}$. It implies that the manufacturer can take the first-mover advantage in the sequential choice game with its leadership in a bilateral monopoly where the products are complements and the choices of the social responsibility are also strategic complements. A higher choice of θ_m encourages the strategic choice of θ_r , which also encourages higher R&D investment. Thus, the sequential choices of the social responsibility critically depend on the efficiency of R&D investment of the manufacturer. The manufacturer can increase total production outputs with lower production costs even though the wholesale price decreases, but the output effects outweigh the price effects. It also represents that the double marginalization problem can be softened by the manufacturer's social concern.

Proposition 1. *In the fixed timing game, the retailer always adopts social responsibility irrespective of the sequencing of the game, but the manufacturer adopts only under its leadership.*

4. Endogenous Timing Game

We consider an endogenous timing game in the context of Hamilton and Slutsky (1990).⁴ Using the equilibrium results in the fixed-timing game, two comparisons are noteworthy. First, from (13) and (16), we have $\pi_m^s = \pi_m^{rl}$ and $\pi_r^s = \pi_r^{rl}$. Thus, both the manufacturer and the retailer are indifferent between a simultaneous game and a sequential game with the retailer's leadership. Second, from (13) and (20), we have $\pi_m^s < \pi_m^{ml}$ and $\pi_r^s < \pi_r^{ml}$ for any $k > \frac{3a+c}{3a+5c}$. Thus, in the presence of R&D, a sequential game with the manufacturer's leadership is preferable to both firms if the inefficiency of R&D investment is not too low.

Proposition 2. *In the endogenous timing game, (i) both sequential choices are the equilibria, but simultaneous choice is not an equilibrium and (ii) a sequential choice with manufacturer leadership is a payoff dominant equilibrium.*

⁴The endogenous timing game in the context of social responsibility was examined by Kopel and Brand (2012) and Fanti and Buccella (2017). It is also recently expanded to the other context in a mixed oligopoly. See, for example, Matsumura and Ogawa (2014) and Lee and Xu (2018).

It represents that sequential choices of the social responsibility by the manufacturer's leadership increases the
110 manufacturer's profits as well as the retailer's profits.⁵ This finding also consistent with Brand and Grothe (2015)
and thus we can conclude that the sequential commitment with manufacturer leadership is robust in a linear bilateral
monopoly relationship with R&D investment.

5. Concluding Remarks

We examined the strategic motives of social responsibility in a linear bilateral monopoly and emphasized its
115 relationship with R&D decision of the manufacturer. We showed that the retailer always adopts social responsibility
irrespective of the timing of the game, but the manufacturer adopts only with its leadership in a sequential game
where the choices of the social responsibility are strategic complements. We also showed that the sequential choice on
the social responsibility critically depends on the efficiency of R&D investment of the manufacturer.

As future research, it is needed to examine two-part tariffs under perfectly coordinated marketing channel and
120 compare with the results under imperfectly coordinated marketing channel. In this case, as Chen et al. (2016) proposed,
a bilateral duopoly model is also an important research direction. Finally, as Matsumura and Matsushima (2015)
worked, not only the manufacturers but the retailers often engage in R&D investments such as service innovation and
quality management.⁶ Thus, the interplay between the strategic motives of social responsibility will be affected by
the bargaining power because both the manufacturer and the retailer can be main players in the game. We leave it as
125 further research.

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⁵As Matsumura and Ogawa (2009) showed, note that payoff dominance implies risk dominance in the endogenous timing game.

⁶In Appendix, we consider the case that the retailer also undertakes service R&D to promote its sales and, using a numerical example,
show that our findings can be changed.

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165 timing game. *Southern Economic Journal* 81, 457–473.

Appendix A. The case where the retailer engages in the service R&D of sales promotion

In this case the retailer faces the linear (inverse) demand function $p(Q) = a + y - q$ where y is demand-enhancing effect from the service R&D of sales promotion and the innovative service effort is given by $\frac{y^2}{2}$. Then, the retailer's profit π_r becomes

$$\pi_r = (a + y - q - w)q - \frac{y^2}{2} \quad (\text{A.1})$$

In the last stage, the retailer maximizes its objective v_r by choosing the optimal quantity q . As a result, we get the following optimal quantity $q(w)$ of this stage:

$$q(w) = \frac{a - w + y}{2 - \theta_r} \quad (\text{A.2})$$

Inserting (A.2) in eq.(3) we obtain the following reduced form of the manufacturer's objective:

$$v_m = \frac{(a - w + y)^2 \theta_m}{2(2 - \theta_r)^2} + \frac{(-c + w + x)(a - w + y)}{2 - \theta_r} - \frac{kx^2}{2} \quad (\text{A.3})$$

In the third stage, the manufacturer chooses the wholesale price w that maximize its value v_m . Solving this problem gives the following equilibrium price:

$$w(x, y) = \frac{(a + c - x + y)(2 - \theta_r) - (a + y)\theta_m}{4 - \theta_m - 2\theta_r} \quad (\text{A.4})$$

Note that the wholesale price increases as the retailer's R&D in service increases. That is, $\frac{\partial w}{\partial y} > 0$.

In the second stage, making use of (A.4), both firms choose, simultaneously and independently the level of its R&D investment, x and y , that maximizes v_m and v_r respectively. Then, we obtain the optimal levels of R&D investment:

$$x^* = \frac{(a - c)(4 - \theta_m - 2\theta_r)}{\Delta}; \quad y^* = \frac{(a - c)k(2 - \theta_r)}{\Delta} \quad (\text{A.5})$$

where $\Delta = k(14 + \theta_m^2 - 4\theta_m(2 - \theta_r) - 15\theta_r + 4\theta_r^2) - 4 + \theta_m + 2\theta_r$. Note that both manufacturer and retailer's R&D levels increases as the concern on consumer surplus of each firm increases. That is $\frac{\partial x^*}{\partial \theta_i} > 0$ and $\frac{\partial y^*}{\partial \theta_i} > 0$.

The optimal R&D investments levels yield the following equilibrium wholesale price

$$w^* = \frac{ck(2 - \theta_r)(3 - \theta_m - 2\theta_r) + a(4 - \theta_m - 2\theta_r)(2k - k\theta_m - k\theta_r - 1)}{\Delta} \quad (\text{A.6})$$

170 Inserting the optimal R&D investment levels x^* and y^* and the wholesale price w^* , into eq.(1) and (A.1) results in the equilibrium profits:

$$\begin{aligned} \pi_m^* &= \frac{(a - c)^2 k (4 - \theta_m - 2\theta_r)^2 (4k - 2k\theta_m - 2k\theta_r - 1)}{2\Delta^2}; \\ \pi_r^* &= \frac{(a - c)^2 k^2 (2\theta_m^2 (1 - \theta_r) + (2 - \theta_r)^2 (7 - 8\theta_r) - 8\theta_m (2 - 3\theta_r + \theta_r^2))}{2\Delta^2} \end{aligned} \quad (\text{A.7})$$

Finally, we examine the timing of social responsibility between the manufacturer and the retailer in the case that both firms undertake R&D investments. For the sake of easy comparisons, we will use a numerical example where $a = 100$ and $c = 10$ and $k = 1$ and compare with our original results.

Table A.1: Optimal levels of social responsibility (θ_m^*, θ_r^*)

| Timing of social concern | Simultaneous choice | Retailer leadership | Manufacturer leadership |
|--------------------------|---------------------|---------------------|------------------------------|
| with retailer's service | $(0.734, 0.723)$ | $(0.738, 0.712)$ | $(0.739, 0.723)$ |
| original results | $(0, 0.5)$ | $(0, 0.5)$ | $(\frac{1}{3}, \frac{2}{3})$ |