Cooperative and Non-cooperative R&D in Duopoly Manufacturers with a Common Supplier

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Outline

- Motivation and Research Problem
- Literature Review
- Model Description
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Motivation

- Cooperative R&D strategy is commonly used by technological industries, including electronics and new materials, as well as in many bioengineering areas, including medicine and food fermentation；

“BMW and Mercedes-Benz Will Stop Fighting and Join Forces to Make a Better Autonomous Car”
https://www.caranddriver.com/news/a26572775/bmw-and-mercedes-benz-joint-autonomous-car/

“Ericsson and OPPO sign initial patent license agreement”
Ericsson (NASDAQ:ERIC) and OPPO have signed a global patent license agreement. This initial agreement includes a cross license covering the 2G, 3G and 4G patent portfolios from both companies
https://www.ericsson.com/en/press-releases/2019/2/ericsson-and-oppo-sign-initial-patent-license-agreement

Research Problem

We aim to answer the following research questions:

- What factors will influence the choice of R&D strategy, i.e. cooperative vs. non-cooperative R&D?
- How will different R&D strategies affect the performances of duopoly manufacturers and the supplier and, in turn, the social welfare?
- Whether there exists stability and coordination mechanism of cooperative R&D?

Literature Review

i) Horizontal cooperative R&D among firms

- AJ model

  (D'Aspremont and Jacquemin 1988)
- KMZ model

  (Kamien, Morton I., Muller E., and Zang I. 1992)
- Comparison of the AJ modeland the KMZ model

  (Amir 2000; Stepanova and Tesoriere 2011)
- Dynamic AJ model

  (Cellini and Lambertini 2009; Smrkolj and Wagener 2016)

ii) Vertical cooperative R&D

- Vertical R&D spillovers between upstream and downstream firm

  (Atallah2002)
- Vertically related duopolies

  (Ishii 2004)
- Firms' R&D cooperation behavior in a supply chain

  (Ge et al. 2014; Xu et al. 2015; Zeng et al. 2017)

Literature Review

Our works are significantly different from those of the AJ model, which are mainly shown in the following two aspects:

(1) AJ model points out that, when the level of technology spillovers is small, the firms' equilibrium R&D output levels under the mixed game are lower than the one under the fully non-cooperative game.

Our work indicates that:

- *when the level of technology spillovers is small and the initial marginal production costs of the downstream firms are large, the firms' equilibrium R&D output levels under the mixed game are lower than the one under the fully noncooperative game;*
- *when both the level of technology spillovers and the initial marginal production costs of the downstream firms are large, the firms' equilibrium R&D output levels under the mixed game are greater than the one under the fully noncooperative game;*
- *when the initial marginal production costs of the downstream firms are small, regardless of the level of technology spillovers, the firms' equilibrium R&D output levels under the mixed game are equal to the one under the fully noncooperative game;*

Literature Review

（2） **AJ model points out that, when the level of technology spillovers is large, the social welfare under the mixed game is greater than the one under the noncooperative game.**

Our work indicates that:

- *when both the level of technology spillovers and the initial marginal production costs of the downstream firms are large, the social welfare under mixed game is greater than the one under fully noncooperative game.*
- *when both the level of technology spillovers is large and the initial marginal production costs of the downstream firms are small, the social welfare under mixed game is equal to the one under fully noncooperative game.*

Literature Review

Different from the assumption that the initial marginal production costs of duopoly firms in AJ model are equal, our work also makes a partial discussion for the case of the equal initial marginal production costs of the two downstream firms in the supply chain environment.

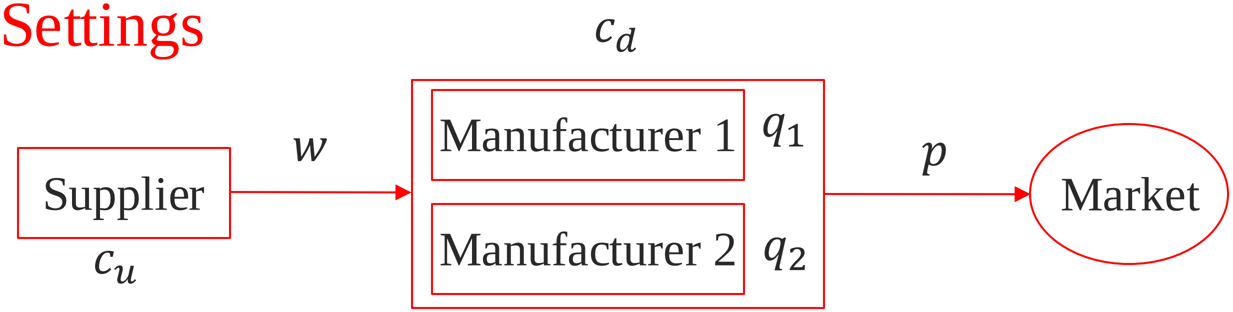
We focus on whether one downstream firm will carry out R&D and the other downstream firm won't carry out R&D. We show that:

when the initial marginal production costs of the two downstream firms are not equal, it is possible that one downstream firm will carry out R&D activity and the other downstream firm won't carry out R&D activity.

This occurs in neither AJ model nor the case of the equal initial marginal production costs of the two downstream firms in the supply chain environment studied in this paper.

Model Description

Basic Model Settings



- One component supplier and two symmetric manufacturers under a Stackelberg setting with the downstream manufacturers being the leaders.
- Supplier produces the component at unit cost c_u and sells it to the downstream at unit price w .
- Inverse demand function

$$p = a - q_1 - q_2.$$

- Marginal production cost of manufacturer i after R&D investments is

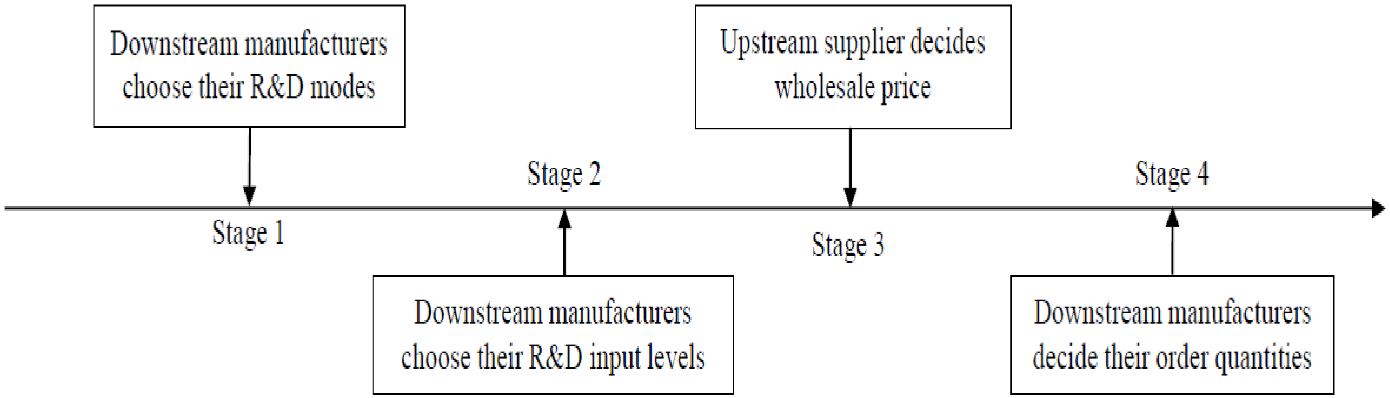
$$c_d - x_i - \beta x_{3-i},\ i = 1, 2.$$

- R&D investment cost incurred by manufacturer i

$$\frac{1}{2}x_i^2,\ i = 1, 2.$$

Sequences

Sequence of events includes four stages



1. **Stage 1**: two downstream manufacturers decide on their R&D strategies, i.e., non-cooperative R&D or cooperative R&D.

2. **Stage 2**: given the R&D strategy, two manufacturers decide on their R&D output levels x_i, i=1, 2.

3. **Stage 3**: whether the two manufacturers choose to cooperate in R&D or not, they compete in the product market. The upstream supplier decides on the wholesale price w.

4. **Stage 4**: given the wholesale price w of the upstream supplier, two downstream manufacturers act as Cournot duopoly competitors

Optimal Decisions under Non-cooperative R&D

We consider the case when the two manufacturers do not take cooperative R&D activities. We solve the game from Stage 2 to Stage 4 by backward induction.

- Stage 4

$$\max_{q_i \geq 0} \pi_i\left(q_1, q_2 | w, x_1, x_2\right) = \left[a - q_1 - q_2 - w - \left(c_d - x_i - \beta x_{3-i}\right)\right] q_i, \text{ i=1, 2.}$$

- Stage 3

$$\max_{w} \pi_u(w | x_1, x_2) = (w - c_u)\left[q_1^N(w, x_1, x_2) + q_2^N(w, x_1, x_2)\right].$$

- Stage 2

$$\max_{x_i \leq c_d - \beta x_{3-i}} \Pi_i(x_1, x_2) = \pi_i(q_1^N, q_2^N | w^N, x_1, x_2) - \frac{1}{2} x_i^2, \text{ i=1, 2.}$$

Model Analysis

- **Proposition 1**. (Non-cooperative R&D activities) The optimal equilibrium R&D output levels of the two manufacturers satisfy

$$(i)\ \ if\ 0 < c_d \le c_n(\beta),\ then\ x_1^N = x_2^N = \frac{c_d}{1+\beta};$$
$$(ii)\ \ if\ c_n(\beta) < c_d < a - c_u,\ then\ x_1^N = x_2^N = \frac{7-5\beta}{29-2\beta+5\beta^2}(a - c_u - c_d).$$

From the proposition 1 and the equations above, we can get the equilibrium outcomes in Non-cooperative R&D Strategy

Table 1 The Equilibrium Outcomes in Noncooperative R&D Strategy

Scenario	$c_n(\beta) < c_d < a - c_u$	$0 < c_d \le c_n(\beta)$
x_i^N	$\frac{(7-5\beta)k}{29-2\beta+5\beta^2}$	$\frac{c_d}{1+\beta}$
w^N	$\frac{18(a-c_d)+(11-2\beta+5\beta^2)c_u}{29-2\beta+5\beta^2}$	$\frac{a+c_u}{2}$
p^N	$\frac{a(17-2\beta+5\beta^2)+12(c_u+c_d)}{29-2\beta+5\beta^2}$	$\frac{2a+c_u}{3}$
q_i^N	$\frac{6k}{29-2\beta+5\beta^2}$	$\frac{a-c_u}{6}$
π_u^N	$\frac{216k^2}{(29-2\beta+5\beta^2)^2}$	$\frac{(a-c_u)^2}{6}$
π_i^N	$\frac{(23+70\beta-25\beta^2)k^2}{2(29-2\beta+5\beta^2)^2}$	$\frac{(a-c_u)^2(1+\beta)^2-18c_d^2}{36(1+\beta)^2}$

Optimal Decisions under Cooperative R&D

Since given the R&D input levels, decisions in Stages 3 and 4 are exactly the same as in the non-cooperative game, we thus focus on the joint R&D investments of manufacturers in Stage 2, the objective function of which can be expressed as follows:

$$\max_{x_1,x_2} \Pi(x_1,x_2) = \sum_{i=1}^{2} \Pi_i(x_1,x_2) = \sum_{i=1}^{2} \left\{ \frac{1}{144}\left[2(a-c_u-c_d)+(7-5\beta)x_i-(5-7\beta)x_{3-i}\right]^2 - \frac{1}{2}x_i^2 \right\}$$

$$\text{s.t. } x_1+\beta x_2 \le c_d$$

Model Analysis

- **Proposition 2**. (Cooperative R&D activities)The optimal joint R&D output levels under coop- erative R&D strategy satisfy

$$(i)\ \ if\ 0 < c_d \le c_o(\beta),\ then\ x_1^C = x_2^C = \frac{c_d}{1+\beta};$$

$$(ii)\ \ if\ c_o(\beta) < c_d < a - c_u,\ then\ x_1^C = x_2^C = \frac{1+\beta}{17-2\beta-\beta^2}(a - c_u - c_d).$$

From the proposition 2 and the equations above, we can get the equilibrium outcomes in Cooperative R&D Strategy

Table 2 The Equilibrium Outcomes in Cooperative R&D Strategy

Scenario	$c_o(\beta) < c_d < a - c_u$	$0 < c_d \le c_o(\beta)$
x_i^C	$\frac{k(1+\beta)}{17-2\beta-\beta^2}$	$\frac{c_d}{1+\beta}$
w^C	$\frac{9(a-c_d)+(8-2\beta-\beta^2)c_u}{17-2\beta-\beta^2}$	$\frac{a+c_u}{2}$
p^C	$\frac{a(11-2\beta-\beta^2)+6(c_u+c_d)}{17-2\beta-\beta^2}$	$\frac{2a+c_u}{3}$
q_i^C	$\frac{3k}{17-2\beta-\beta^2}$	$\frac{a-c_u}{6}$
π_u^C	$\frac{54k^2}{(17-2\beta-\beta^2)^2}$	$\frac{(a-c_u)^2}{6}$
π_i^C	$\frac{k^2}{2(17-2\beta-\beta^2)}$	$\frac{(a-c_u)^2(1+\beta)^2-18c_d^2}{36(1+\beta)^2}$

R&D Strategies: Cooperative vs. Non-cooperative

Lemma 1. Comparing the optimal decisions under cooperative and noncooperative R&D strategies, we have

$$(i)\ q_i^C < q_i^N,\ x_i^C < x_i^N,\ i = 1, 2,\ \text{and}\ w^C < w^N,\ \text{if}\ (2 - \sqrt{2})/2 < \beta < 5/7\ \text{and}\ c_d \geq c_o(\beta);$$

$$(ii)\ q_i^C > q_i^N,\ x_i^C > x_i^N,\ i = 1, 2,\ \text{and}\ w^C > w^N,\ \text{if}\ 5/7 < \beta < 1\ \text{and}\ c_d \geq c_n(\beta);$$

$$(iii)\ q_i^C = q_i^N,\ x_i^C = x_i^N,\ i = 1, 2,\ \text{and}\ w^C = w^N,\ \text{otherwise}.$$

Based on Lemma 1, the decisions under cooperative and noncooperative R&D strategies could be different, which mainly depends on the two key factors, *the magnitude of spillover effect* and *the initial marginal production cost*.

R&D Strategies: Cooperative vs. Non-cooperative

Theorem 1. (Optimal R&D Strategy)

(i) If $\beta \neq 5/7$ *and* $c_d \geq min\{c_n(\beta), c_o(\beta)\}$, *then cooperative R&D strategy dominates;*

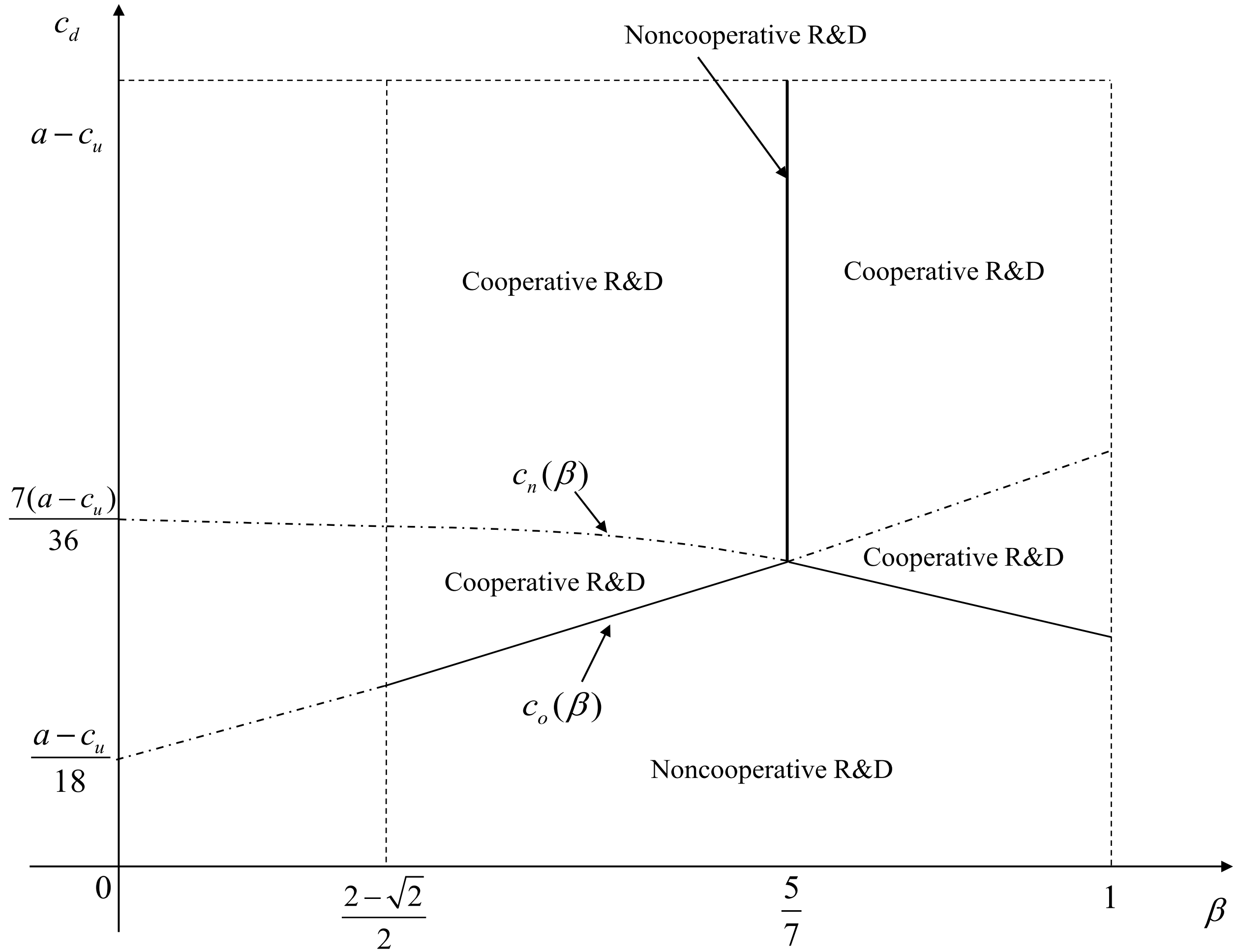
(ii) Otherwise, noncooperative R&D strategy dominates.

- Theorem 1(i) shows that, when R&D spillover effect is either relatively small or relatively large while the initial marginal production cost is large, coordinative R&D take more benefits for the two manufacturers.

- Theorem 1(ii) shows that if the initial marginal production cost is lower enough, then no matter how high the spillover effect is, there is no extra benefit for the two manufacturers to cooperate in R&D activities.

R&D Strategies: Cooperative vs. Noncooperative

Optimal R&D Strategies for Downstream Manufacturers



Stability Analysis of Cooperative R&D

Proposition 3 shows the results on the stability of cooperative R&D of the two manufacturers.

PROPOSITION 3. *Suppose* $\beta \neq 5/7$ *and* $c_d > min\{c_o(\beta), c_n(\beta)\}$ *hold. The cooperative R&D strategy in equilibrium is not stable.*

Proposition 3 shows that if the initial marginal production cost is high, although cooperative R&D investments of the two manufacturers can improve the profitability of each, the cooperative R&D strategy itself is unstable. In the absence of other coordination mechanisms, each manufacturer will not adhere to the equilibrium (R&D input levels under cooperation) and choose to betray. In other words, the cooperative R&D of downstream manufacturers are more likely to fall into the prisoners' dilemma.

Stability Analysis of Cooperative R&D

The following Proposition 4 gives the coordination mechanism of cooperative R&D of downstream firms.

Proposition 4. From stability analysis and coordination mechanism of cooperative R&D, we have

(i) when $\beta \in ((2-\sqrt{2})/2, 5/7)$ *and* $c_o(\beta) < c_d \le c_s(\beta)$, *if* $F > t_1$, *then each downstream firm would prefer to cooperate rather than betray in the cooperative R&D stage;*

(ii) when $\beta \in ((2-\sqrt{2})/2, 5/7)$ *and* $c_s(\beta) < c_d < a - c_u$, *or* $\beta \in (5/7, 1)$ *and* $c_o(\beta) < c_d < a - c_u$, *if* $F \ge t_2$ *then each downstream firm would prefer to cooperate rather than betray in the cooperative R&D stage;*

(iii) when $\beta \in (5/7, 1)$ *and* $c_n(\beta) < c_d \le c_o(\beta)$, *if* $F \ge t_3$ *then each downstream firm would prefer to cooperate rather than betray in the cooperative R&D stage.*

Social Comparisons

The following Propositions 5 and 6 characterize the impacts of noncooperative and cooperative R&D on consumer surplus and social welfare, respectively.

$$CS = \int_0^{q_1+q_2} (a-Q)dQ - p^N(q_1+q_2) \qquad SW = \pi_u + \sum_{i=1}^{2} \pi_i + CS$$

PROPOSITION 5. *Compare the consumer surplus under noncooperative and cooperative R&D, we can obtain*

(i) if $\beta \in ((2-\sqrt{2})/2, 5/7) \cup (5/7, 1)$ *and* $c_d \le min\{c_o(\beta), c_n(\beta)\}$, *or* $\beta = 5/7$, *then* $CS^N = CS^C$;

(ii) if $\beta \in ((2-\sqrt{2})/2, 5/7)$ *and* $c_o(\beta) < c_d < a - c_u$, *then* $CS^N > CS^C$;

(iii) if $\beta \in (5/7, 1)$ *and* $c_n(\beta) < c_d < a - c_u$, *then* $CS^N < CS^C$.

PROPOSITION 6. *Compare the social welfare under noncooperative and cooperative R&D, we have*

(i) if $\beta \in ((2-\sqrt{2})/2, 5/7) \cup (5/7, 1)$ *and* $c_d \le min\{c_o(\beta), c_n(\beta)\}$, *or* $\beta = 5/7$, *then* $SW^N = SW^C$;

(ii) if $\beta \in ((2-\sqrt{2})/2, 5/7)$ *and* $c_o = min\{c_o(\beta), c_n(\beta)\} < c_d < a - c_u$, *then* $SW^N > SW^C$;

(iii) if $\beta \in (5/7, 1)$ *and* $c_n = min\{c_o(\beta), c_n(\beta)\} < c_d < a - c_u$, *then* $SW^N < SW^C$.

Model Extensions

In the above noncooperative and cooperative R&D model, we assume that the initial marginal production costs of the two downstream firms are equal. In this part, we relax the assumption: suppose that the initial marginal production costs of the two downstream firms are not equal. Let c_i denote the initial marginal production cost of the downstream manufacturers i, $i = 1, 2$. Without loss of generality, c_1 and c_2 are assumed to satisfy $c_2 = 2c_1$. We assume that $\beta > \frac{1}{10}(17 - \sqrt{129})$. The remaining assumptions of extended model are the same as that of the basic assumptions.

Model Extensions

Let λ^* denote the proportion of the profit allocated to downstream manufacturer 1 to the largest joint profit in R&D cooperation, $1-\lambda^*$ the proportion of the profit allocated to downstream manufacturer 2 to the largest joint profit in R&D cooperation and $\Lambda = \{\lambda \,|\, 0<\lambda<1,\ \lambda(\pi_1^{eo}+\pi_2^{eo}) > \pi_1^{en},\ (1-\lambda)(\pi_1^{eo}+\pi_2^{eo}) > \pi_2^{en}\}$. Then we have the following proposition.

PROPOSITION 7. *When $(\beta, c_1) \in S$ and $\lambda^* \in \Lambda$, each downstream manufacturer will choose cooperative R&D. Under cooperative R&D, the equilibrium R&D level of downstream manufacturer 1 is $x_1^{eo} = \frac{2(a-c_u)(1+\beta)+(33-39\beta)c_1}{70\beta-37\beta^2-1}$, and the equilibrium R&D level of downstream manufacturer 2 is $x_2^{eo}=0$.*

Proposition 7 shows that, for $(\beta, c_1) \in S$ and $\lambda^* \in \Lambda$, two downstream firms will choose cooperative R&D. However, the equilibrium R&D output level of downstream firm 2 is 0, that is, downstream firm 2 enjoys free ride in R&D.

Conclusion

Based on the two downstream firms with equal initial marginal costs of production in the supply chain, the study done in this paper and relevant conclusions are as follows:

- First, we study the downstream firms R&D strategies.

When the level of technology spillovers is medium or the initial marginal production costs of downstream firms are small, the optimal R&D strategies for downstream firm are non-cooperative R&D.

When the level of technological spillovers is small or large and the initial marginal production costs of downstream firms are large, the optimal R&D strategies for downstream firms are cooperative R&D.

Conclusion

- Second, we examine the impact of spillover level on the R&D level and profitability of downstream firms under the optimal R&D strategies.

when the initial marginal production costs of the downstream firms are small, the equilibrium R&D levels of the downstream firms decrease in the level of technology spillovers, and the equilibrium profits increase in the level of technology spillovers.

when the initial marginal production costs of the downstream firms are large, the equilibrium R&D levels and equilibrium profits of the downstream firms increase in the level of technology spillovers.

Conclusion

Third, we study the impact of noncooperative and cooperative R&D on consumer surplus and social welfare.

Compared to noncooperative R&D, when the level of technology spillovers is medium or the initial marginal production costs of the downstream firms are small, cooperative R&D has not changed consumer surplus and social welfare.

when the level of technology spillovers is small and the initial marginal production costs of the downstream firms are large, cooperative R&D reduces consumer surplus and social welfare.

when the level of technology spillovers and the initial marginal production costs of the downstream firms are large, cooperative R&D can increase consumer surplus and social welfare.

Conclusion

- Finally, we study the stability and coordination mechanism of cooperative R&D. when the level of technological spillovers is small or large and the initial marginal production costs of the downstream firms are large, although the cooperative R&D of downstream firms can improve their own profitability, in the absence of other coordination mechanism of cooperative R&D, the cooperative R&D of downstream firms is unstable. In other words, the cooperative R&D of downstream firms will fall into the prisoners dilemma. We propose a coordination mechanism to solve the instability problem of cooperative R&D.

In addition, different from the case of two downstream firms with equal initial marginal production costs, when the initial marginal production costs of the two downstream firms are not equal, it is possible that one downstream firm will carry out R&D and the other downstream firm wont carry out R&D.

Q&A

Thank You