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Abstract

Research and development (R&D) in upstream and downstream markets influence each other. This is because, in assembly industries, when upstream input prices are low, downstream firms can easily introduce or develop new products. The introduction of a new product creates a new final good market, creating an increased demand for inputs. This greater demand for inputs provides an incentive for upstream firms to reduce their costs through R&D. In this study, we consider both downstream R&D for new product introduction and upstream R&D for cost reduction. We show that if upstream R&D is efficient (inefficient), the results of the downstream new product introduction race are strategic complements (substitutes). Furthermore, in terms of timing, the upstream firm determines its input price after observing the downstream firm's investment decision, with the upstream firm extracting benefits from downstream R&D by raising the input price. It is well-known that this behavior by upstream firms impedes downstream investment (the hold-up problem). Despite this timing structure, we show that the more downstream firms invest, the lower the input price.

Keywords: New product introduction; Cost-reducing R&D; Upstream firm; R&D efficiency

JEL classification: L13; D43; O31

Statements and Declarations

The authors declare no conflicts of interest associated with this manuscript.

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Akio Kawasaki, Tomomichi Mizuno, and Kazuhiro Takauchi

Abstract

Research and development (R&D) in upstream and downstream markets influence each other. This is because, in assembly industries, when upstream input prices are low, downstream firms can easily introduce or develop new products. The introduction of a new product creates a new final good market, creating an increased demand for inputs. This greater demand for inputs provides an incentive for upstream firms to reduce their costs through R&D. In this study, we consider both downstream R&D for new product introduction and upstream R&D for cost reduction. We show that if upstream R&D is efficient (inefficient), the results of the downstream new product introduction race are strategic complements (substitutes). Furthermore, in terms of timing, the upstream firm determines its input price after observing the downstream firm's investment decision, with the upstream firm extracting benefits from downstream R&D by raising the input price. It is well-known that this behavior by upstream firms impedes downstream investment (the hold-up problem). Despite this timing structure, we show that the more downstream firms invest, the lower the input price.

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1 Introduction

In a vertical production chain, upstream firms supply various inputs and parts to downstream firms. For example, in the automobile industry, Bridgestone Corp. predominantly supplies tires to downstream firms.[1] In the aircraft industry, Raytheon Technologies Corp. supplies various parts. The cost-reducing research and development (R&D) investment of these input suppliers results in a benefit that occurs because of the price reduction of inputs to downstream firms.

Using various inputs and parts supplied by upstream firms, and assembling final products, downstream firms supply their products to consumers.[2] The time at which downstream firms supply their products, by considering diversity of consumer preferences, gives downstream firms an incentive to introduce various products. Hence, there is an interaction between upstream cost-reducing investment and downstream new product introduction.

In this paper, we consider how upstream cost-reducing R&D affects downstream new product introduction.[3] Thus, we build a model comprising an innovative upstream input supplier and two downstream final-good producers that develop new products in the case in which all final goods are differentiated. Under this vertical structure, we consider a four-stage process: In the first stage, each downstream firm decides whether to introduce a new product. In the second stage, the upstream firm makes a cost-reducing investment. In the third stage, the upstream firm decides its input price. In the final stage, the downstream firms compete on quantity.[4]

We show that if all downstream firms introduce new products, the upstream cost-reducing

[1] See, for example, the following site: https://gyokai-search.com/3-tire.html (accessed 2022-07-23).

[2] In addition to these examples for the assembly industry, we consider an example of a fuel supplier (upstream) and the transportation industry (fuel user: downstream).

[3] Because downstream new product introduction increases the number of final products, it increases input demand. As empirically shown by Fontana and Guerzoni (2008), process innovation (i.e., cost-reducing R&D) becomes a more important innovative activity for firms when the market size is large. Thus, cost-reducing R&D by upstream firms is partly consistent with the empirical evidence.

[4] We consider price competition in Section 5.1.

investment level is maximized, and simultaneously, the input price becomes the lowest. When a downstream firm introduces a new product, input demand rapidly increases. For example, if all downstream firms introduce new products, input demand doubles. This expansion in downstream input demand increases incentives in investment by upstream firms. Because a rise in cost-reducing investment lowers the upstream production cost, the input price falls. Therefore, the input price is lowest when all downstream firms invest.

We also show that a downstream firm's strategic behavior against its rival introducing a new product mainly depends on upstream production efficiency. The production efficiency of the upstream supplier that makes an effort to reduce costs is equivalent to the efficiency of its R&D. Suppose a downstream firm introduces a new product. This behavior increases demand for input; hence, the upstream firm actively invests to reduce its production cost, and thus, the input price falls. Because the price-cost margin of the downstream firm widens as the input price lowers and results in a scenario similar to market expansion, the incentive of the rival firm to introduce a new product becomes strong. Introducing a new product steals a part of the rival's market share; hence, the rival's incentive to introduce a new product weakens. At this time, if upstream R&D efficiency is high, the input price drops because of the introduction of a new product. The fall of the input price facilitates the rival's introduction of a new product; hence, the race to introduce a new product starts to have the nature of a strategic complement. Conversely, if upstream R&D efficiency is low, because the effect of stealing the rival's market share is dominant, the race to introduce a new product starts to have the nature of a strategic substitute.

Our contribution is regarding the relation between the input price and downstream investment. When the upstream agent decides its price after observing the downstream investment decision, the upstream agent extracts downstream R&D benefit by increasing the input price. Under this timing of decision-making, the more the downstream firm invests, the higher the input price. It is well known that this behavior of the upstream agent impedes downstream investment (e.g., Banerjee and Lin 2003; Gilbert and Cvsa 2003; Haucap and Wey 2004). However, in our model, even though the timing of decision-making is the same as that in previous studies, the more downstream firms invest, the lower the input price. Hence, if all downstream firms invest, the input price becomes the lowest. This is because downstream new product introduction expands the demand for input and, in response to this, the upstream supplier increases the level of cost-reducing investment; hence, the input price falls.

This paper is related to two strands in the literature: one is studies on new product introduction in an oligopoly (Basak and Mukherjee 2018)[5] and the other is studies that focus on upstream innovation in vertically related markets (e.g., Chen and Sapppington 2010; Hu, Monden and Mizuno 2022; Macho-Stadler, Matsushima and Shinohara 2021; Pinopoulos 2020; Stefanadis 1997). Basak and Mukherjee (2018) considered new product introduction in a unionized duopoly. They showed that, in their many different settings, the strategic substitute equilibrium in which "one firm only introduces a new product" appears,[6] whereas the strategic complementary equilibrium appears if and only if labor unions are firm-specific (i.e., decentralized labor unions) and product differentiation is *asymmetric*. Our model shows that, when an upstream supplier engages in cost-reducing investment, both the strategic complementary equilibrium and

[5]Additionally, Dawid, Kopel and Kort (2010) considered new product development in a duopoly setting. However, their model has no upstream sector, and the R&D types differ between the two firms: one firm engages in a new product development project and the other firm engages in cost-reducing R&D. Although Dobson and Waterson (1996) and Grossman (2007) also considered a similar scenario in which firms choose their number of differentiated goods, there is no upstream market in these models. Battaggion and Tedeschi (2021) considered both cost-reducing R&D and demand-enhancing R&D in a duopoly, whereas Lin and Zhang (2022) considered product innovation in which the new product entails a safety risk.

[6]This case is the same as the scenario in which "one is a multi-product firm and the other is a single-product firm." Hence, the strategic substitute type of equilibrium in our new product introduction model includes this scenario. Inomata (2018) and Kawasaki, Lin and Matsushima (2014) also considered the coexistence of multi-product and single-product firms.

strategic substitute equilibrium appear. This is in sharp contrast to the results of Basak and Mukherjee (2018).

Although some researchers have also focused on upstream process innovation, their models and purposes differ substantially from ours. Chen and Sappington (2010) considered the effects of vertical integration and separation on upstream innovation. Under a general demand system, Macho-Stadler, Matsushima and Shinohara (2021) considered the relationship between firms' decisions on organizational structures and upstream R&D. Hu, Monden and Mizuno (2022) considered upstream R&D; however, their purpose was to examine the relationship between upstream cost-reducing investment and cross-holdings among downstream firms. Pinopoulos (2020) considered some types of input pricing behaviors, for example, two-part tariffs, by an upstream firm that engages in cost-reducing R&D. Stefanadis (1997) considered R&D competition between two upstream suppliers, and also examined the possibility that the conclusion of exclusive supply contracts with a downstream firm discourages upstream innovation.

This paper is structured as follows: In Section 2, we provide the basic model, and in Section 3, we present the analysis of the model. In Section 4, we perform welfare analysis. In Section 5, we discuss our results and present an extension of our benchmark model. Finally, in Section 6, we draw conclusions.

2 Model

We consider a vertically related market with an upstream firm (U) and two symmetric downstream firms (Di, $i = 1, 2$). Di uses one unit of input to produce one unit of the final product, and it competes on quantity.[7] For simplicity, we omit other production costs for Di. U decides the input price w and makes a take-it-or-leave-it offer. U charges a uniform input price for Di.

U engages in R&D to reduce the constant marginal cost $c \in (0, 1)$. To create demand by

[7] Our main results do not alter in price competition. For more details, see Section 5.1.

introducing a new product, Di chooses whether to conduct R&D by paying a fixed cost f (> 0). Let Di's output of the existing product be $q_{e,i}$ and that of the new product be $q_{n,i}$. When $D1$ and $D2$ introduce new products, inverse demand is[8]

$$\begin{aligned} p_{e,i} &= 1 - q_{e,i} - \gamma(q_{n,i} + q_{e,j} + q_{n,j}), \\ p_{n,i} &= 1 - q_{n,i} - \gamma(q_{e,i} + q_{e,j} + q_{n,j}), \end{aligned} \tag{1}$$

where $p_{e,i}$ $(p_{e,j})$ is the price of the existing product of Di (Dj) and $p_{n,i}$ $(p_{n,j})$ is the price of the new product of Di (Dj), $i \neq j$ and $i, j = 1, 2$.[9] The parameter γ $(0 \leq \gamma < 1)$ measures the degree of product substitutability among final products. Final products are independent if $\gamma = 0$, whereas they are homogeneous if $\gamma = 1$.

The gross profit of Di[10] is

$$\pi_{Di}(q_{e,i}, q_{n,i}) \equiv (p_{e,i} - w)q_{e,i} + (p_{n,i} - w)q_{n,i}. \tag{2}$$

If Di innovates, its profit is $\pi_{Di}(q_{e,i}, q_{n,i}) - f$; otherwise, its profit is $\pi_{Di}(q_{e,i}, 0)$.

The profit of U is

$$\pi_U \equiv (w - (c - x))Q - kx^2, \tag{3}$$

where x is the investment level and kx^2 is the R&D cost. k (> 0) denotes R&D efficiency. Q is the demand for input. $Q = \sum_i q_{e,i}$ if no one innovates. $Q = \sum_i q_{e,i} + q_{n,j}$ if only Dj innovates. $Q = \sum_i q_{e,i} + \sum_i q_{n,i}$ if everyone innovates.

We consider the following four-stage process. In the first stage, $D1$ and $D2$ independently

[8]The other possible setting is that existing and new products are differentiated. The formula in such a case is $p_{e,i} = 1 - (q_{e,i} + q_{e,j}) - \gamma(q_{n,i} + q_{n,j})$, $i, j = 1, 2;$ $i \neq j$. However, our main results do not alter; hence, we use a simpler form (1).

[9]Even if we use a Shubik and Levitan-type demand function, our main result does not alter.

[10]We implicitly assume that downstream firms use Leontief technology. That is, the existing product and the new product are produced using common inputs and inputs purchased from different competing fringe firms, respectively. Here, for simplicity, we normalize the price of inputs purchased from competing fringe firms to zero.

and simultaneously choose whether to conduct R&D by paying the fixed cost (I) or not (N). In the second stage, U decides the investment level. In the third stage, U charges the input price. Finally, the downstream firm competes on quantity.

This timing structure corresponds to the difficulty in R&D. Generally, product development requires a sunk cost, such as a long-term contract with researchers, and it takes a much longer time. Hence, downstream R&D is in the first stage. Effort that produces a prototype and repeatedly tests its safety is not required; hence, upstream R&D is in the second stage. The downstream firm can flexibly adjust its production; hence, the quantity of final products is decided in the final stage. The solution concept is the subgame-perfect Nash equilibrium.

3 Results

Depending on the downstream investment decisions, four regimes can arise: II, IN, NI, and NN. Because downstream firms are symmetric, IN and NI are the same. We call II the *all product-developers regime*, IN and NI the *mixed regime*, and NN the *no one invests regime*. Using (1)–(3), we obtain the equilibrium solutions for each regime. The derivation of equilibrium outcomes in each regime is reported in Appendix B.

In this model, the input price w and the upstream R&D level x play a central role. Hence, we report other equilibrium outcomes in Appendix C.

No one invests regime: $\boldsymbol{NN}$. Each Di only produces the existing product; hence, $q_{n,i} = 0$. Thus, we obtain the following equilibrium outcomes:

$$w^{NN} = \frac{(1+c)(\gamma+2)k-1}{2(\gamma+2)k-1}; \quad x^{NN} = \frac{1-c}{2(\gamma+2)k-1}. \tag{4}$$

Mixed regime: $\boldsymbol{IN}$ or $\boldsymbol{NI}$. When Di invests and Dj does not, because Di produces both existing and new products but Dj only produces its existing product, $q_{e,i} > 0$, $q_{n,i} > 0$, $q_{e,j} > 0$, and $q_{n,j} = 0$ $(i, j = 1, 2$ and $i \neq j)$. From this, we obtain the following:

$$\begin{aligned} w^{IN} = w^{NI} &= \frac{2(1+c)(2+2\gamma-\gamma^2)k-(3-\gamma)}{4(2+2\gamma-\gamma^2)k-(3-\gamma)}, \\ x^{IN} = x^{NI} &= \frac{(1-c)(3-\gamma)}{4(2+2\gamma-\gamma^2)k-(3-\gamma)}. \end{aligned} \tag{5}$$

All product-developers regime: *II*. Four differentiated products are produced in this regime; hence, we obtain the following equilibrium outcomes:

$$w^{II} = \frac{(1+c)(2\gamma+1)k-1}{(4\gamma+2)k-1}; \quad x^{II} = \frac{1-c}{(4\gamma+2)k-1}. \tag{6}$$

To ensure the positive marginal cost of U after investment, we need Assumption 1.

Assumption 1. $k > k_0 \equiv \dfrac{1}{2c(1+2\gamma)}$.

We establish Proposition 1 from Equations (4)–(6).

Proposition 1. *(i) The equilibrium level of the R&D investment of U is largest in the all product-developers regime, intermediate size in the mixed regime, and smallest in the no one invests regime. More precisely,* $x^{II} > x^{IN} = x^{NI} > x^{NN}$. *(ii) In all regimes, the higher R&D efficiency of U increases its investment level. Higher product substitutability decreases the level of R&D investment of U. More precisely,* $\partial x^r/\partial k < 0$ *and* $\partial x^r/\partial \gamma < 0$*, where* $r = II, IN, NI, NN$.

Proof. See Appendix A.

Proposition 1 yields Proposition 2.

Proposition 2. *(i) The equilibrium level of the input price is highest in the no one invests regime, intermediate size in the mixed regime, and lowest in the all product-developers regime. Formally,* $w^{NN} > w^{IN} = w^{NI} > w^{II}$. *(ii) In all regimes, the higher R&D efficiency of U lowers the input price. Higher product substitutability raises the input price. More precisely,* $\partial w^r/\partial k > 0$ *and* $\partial w^r/\partial \gamma > 0$*, where* $r = II, IN, NI, NN$.

Proof. See Appendix A.

The logic behind part (i) of Proposition 1 is as follows: As U engages in cost-reducing investment, it invests a large amount if it can sell a large amount of input. Innovation by Di increases the number of product varieties; hence, the demand for input also expands. If $D1$ and $D2$ innovate, because the input demand is the largest among all regimes and the sales opportunity for input is similarly the largest, the investment level becomes the largest. Hence, when no one innovates, the investment size becomes the lowest among all regimes. If only Di innovates, the investment level becomes intermediate.

Part (ii) is intuitive. The first result is natural. Although larger γ makes competition tougher, in our model, it reduces the downstream market size. The latter effect is dominant; hence, input demand shrinks. This impedes upstream investment.

Proposition 1 immediately yields Proposition 2. Because the larger the investment, the lower the input price, we obtain the ranking of the input price. Part (ii) is a natural one. The effects of γ are similar to those in part (ii) of Proposition 1.

The role of k is important because a larger k raises the input price (Proposition 2). Because a higher input price reduces the benefit obtained from the new product development, the incentive for downstream R&D is reduced. If R&D does not take place downstream, the demand for intermediate goods does not increase, and thus the incentive for upstream firms to invest in cost reduction is reduced (Proposition 1).

To derive the equilibrium of the game, we introduce two threshold functions Φ_I and Φ_N: $\Phi_I \equiv \pi_{D1}^{IN} - \pi_{D1}^{NN} = \pi_{D2}^{NI} - \pi_{D2}^{NN}$ and $\Phi_N \equiv \pi_{D1}^{II} - \pi_{D1}^{NI} = \pi_{D2}^{II} - \pi_{D2}^{IN}$.[11] These thresholds are related to the gain (or loss) that results from the deviation from equilibrium regimes NN and II, respectively.

Φ_I and Φ_N are given by

[11] Chowdhury (2005) defined Φ_I as a *non-strategic benefit* of R&D and Φ_N as a *strategic benefit* of R&D.

$$\Phi_N(k,\gamma) \equiv \frac{(1-c)^2(1-\gamma)k^2 \left[\begin{array}{l} 1+4\gamma-\gamma^2 + 16(2+6\gamma+6\gamma^2+2\gamma^3-\gamma^4)k^2 \\ -8(2+4\gamma+3\gamma^2-\gamma^3)k \end{array} \right]}{2[(4\gamma+2)k-1]^2[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2} > 0 \quad \text{and}$$

$$\Phi_I(k,\gamma) \equiv \frac{(1-c)^2(1-\gamma)k^2[8(8+8\gamma-4\gamma^4)k^2 - 8(2+2\gamma+\gamma^2-\gamma^3)k - 2\gamma^2+5\gamma-1]}{[2(\gamma+2)k-1]^2[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2} > 0.$$

Di innovates if $f < \min\{\Phi_I(k,\gamma), \Phi_N(k,\gamma)\}$ and does not innovate if $f > \max\{\Phi_I(k,\gamma), \Phi_N(k,\gamma)\}$. Hence, the mixed regime, $IN\&NI$, can appear if $\Phi_N(k,\gamma) < \Phi_I(k,\gamma)$; and the complementary equilibrium, $NN\&II$, can appear if $\Phi_I(k,\gamma) < \Phi_N(k,\gamma)$. These arguments yield Proposition 3.[12]

Proposition 3.

1. Suppose that $k \in (k_0,\ 1/(4\gamma))$. Then, $\Phi_I(k,\gamma) < \Phi_N(k,\gamma)$. (i) If $f < \Phi_I(k,\gamma)$, II appears; (ii) if $f > \Phi_N(k,\gamma)$, NN appears; and (iii) if $\Phi_I(k,\gamma) \le f \le \Phi_N(k,\gamma)$, $NN\&II$ can appear.

2. Suppose $k > 1/(4\gamma)$ or $1/(4\gamma) \le k_0$. Then, $\Phi_N(k,\gamma) < \Phi_I(k,\gamma)$. (i) If $f < \Phi_N(k,\gamma)$, II appears; (ii) if $f > \Phi_I(k,\gamma)$, NN appears; and (iii) if $\Phi_N(k,\gamma) \le f \le \Phi_I(k,\gamma)$, $IN\&NI$ can appear.

Proof. See Appendix A.

[Figure 1 around here]

When fixed cost f is small (large) because I (N) is the dominant strategy, II (NN) appears. If f is an intermediate size, Di's strategy depends on upstream R&D efficiency k: (a) if k is small, $NN\&II$ can appear; and (b) if k is large, $IN\&NI$ can appear (see Figure 1).

The intuition behind Proposition 3 is as follows: (a) When k is small, upstream R&D

[12] We focus on pure-strategy equilibria, but if there is more than one pure-strategy equilibrium, there also exists a symmetric mixed-strategy equilibrium. Each downstream firm chooses I with probability θ. Then, solving $\theta(\pi_{Di}^{II} - f) + (1-\theta)(\pi_{D1}^{IN} - f) = \theta\pi_{D1}^{NI} + (1-\theta)\pi_{Di}^{NN}$ for θ, we obtain the symmetric mixed-strategy equilibrium θ.

is efficient. In this case, if Di deviates from NN, because k is small, the U actively invests. Therefore, the decline in input prices is greater, and thus downstream production costs generally fall. However, this promotes the rival's production and leads to intensified competition in the existing product market. Hence, even if the deviation increases the number of product market, because the benefit of R&D can be canceled, Di does not deviate from NN. Furthermore, if Di deviates from II, its market halves and the input price discontinuously increases. Hence, Di does not deviate from II.

Basak and Mukherjee (2018) found that, in a unionized duopoly, the emergence of the complementary equilibrium needs *asymmetric product differentiation* and *decentralized unions*. Conversely, we show that the complementary equilibrium appears even if there is no asymmetry in product differentiation. This implies that upstream R&D plays an important role in downstream innovation, and therefore, provides a new insight into the literature.

(b) When k is large or γ is large (i.e., $k > 1/(4\gamma)$ or $1/(4\gamma) \leq k_0$), because upstream R&D is inefficient or the downstream market is competitive, the effects of upstream investment on the input price weaken, and the effect of horizontal competition (γ) grows strong. When γ becomes large (closes to 1), competition in the downstream market intensifies. Because of this, the firm's incentive to raise a rival cost to weaken intensive competition strengthens; hence, the equilibrium of strategic substitute appears. If Di deviates from II, its product market halves and the input price rises. However, the input price is relatively high because of the larger k (Proposition 2). Thus, the production cost is also high, and the profit from the new product market becomes relatively small; that is, the R&D benefit is small. As a deviation from II raises the input price, it also increases the rival's cost. This results in a lessening of intensive competition in the existing product market. Because the R&D benefit is small and competition in the existing product market loosens, Di has an incentive to choose N if the rival chooses I. The deviation from NN increases the sales market of products and lowers the input price.

Then, although the R&D benefit is small, the input price is high because k is large. Hence, a fall in production cost through the decrease in input price becomes attractive. Di chooses I when its rival chooses N.

Our study contributes to the relation between the input price and downstream investment. In our model, the upstream input supplier decides its price after observing the downstream investment decision. Despite this, when all downstream firms invest, the input price is the lowest among any other regimes (see Proposition 2).

When the input supplier decides its price after observing the downstream investment decision, it is well known that it raises the input price to snatch the benefit of downstream investment (Banerjee and Lin 2003; Gilbert and Cvsa 2003). Banerjee and Lin (2003) emphasized such hold-up behavior by the upstream supplier. They showed that if the input price is decided after downstream investment, because the upstream input supplier raises its price and snatches the downstream investment benefit, the input price increases and it impedes downstream investment activities.[13] Furthermore, it has been emphasized that opportunistic behavior by the upstream firm appears even if the upstream agent is a labor union (i.e., wage setter) (Haucap and Wey 2004). In Banerjee and Lin's (2003) argument, if the input supplier decides its price after observing downstream investment behavior, because a higher input price occurs, the larger the downstream investment, the higher the input price the downstream firm encounters. By contrast, our result is opposite to this.

This difference is based on the following two points: (i) the upstream input supplier's cost-reducing investment activity, and (ii) downstream product R&D. When the downstream firm invests, the demand for input discontinuously increases. Furthermore, when all downstream firms invest, demand for input doubles. The rapid increase in input demand through down-

[13] Banerjee and Lin (2003) showed that a fixed-price contract (i.e., input price is decided first in the process) that uses the input price resolves this hold-up problem. Conversely, Takauchi and Mizuno (2019) demonstrated that a fixed-price contract can harm upstream and downstream firms.

stream product R&D increases the investment incentives of the upstream supplier. As shown in Proposition 1, upstream investment depends on downstream investment, that is, the size of input demand. Additionally, the upstream cost-reducing investment level decides the level of the input price. Because the cost-reducing investment level is maximized if all downstream firms invest, the input price is lowest among all other regimes when all downstream firms invest. Our result implies that upstream R&D is very influential in vertical structures, and thus, it offers a new insight into studies on innovation and the vertical production chain.

4 Welfare analysis

Even if a downstream firm innovates, it does not capture all the surplus it generates. Therefore, if innovation cost f is large, downstream firms give up on introducing new products, and underinvestment (i.e., welfare loss) occurs. In this section, we provide the conditions that can cause underinvestment.

To avoid unnecessary algebraic complexity and facilitate our welfare analysis, we must set a lower limiting value for k. Therefore, we make Assumption 2.

Assumption 2. $k \geq \dfrac{1}{2}$.

First, we discuss underinvestment in terms of consumer surplus. We define consumer surplus and gross total surplus (excluding downstream R&D cost f) as follows:

$$\begin{aligned} CS = {} & q_{e,1} + q_{e,2} + q_{n,1} + q_{n,2} - \frac{q_{e,1}^2 + q_{e,2}^2 + q_{n,1}^2 + q_{n,2}^2}{2} \\ & - \gamma \left[q_{e,1}(q_{e,2} + q_{n,1} + q_{n,2}) + q_{e,2}(q_{n,1} + q_{n,2}) + q_{n,1} q_{n,2} \right] \\ & - p_{e,1} q_{e,1} - p_{n,1} q_{n,1} - p_{e,2} q_{e,2} - p_{n,2} q_{n,2}, \end{aligned}$$

and $TS = CS + \pi_U + \sum_i \pi_{Di}$. Then, we have the outcomes in each regime: CS^r and TS^r, $r = II, IN, NI, NN$.

In view of consumer surplus, investment cost f is irrelevant; hence, the best regime for consumers is "II." Areas in which other equilibrium regimes appear are underinvestment areas.

Given the above, we note the areas of "II" or "$II\&NN$" (see Fig. 1). When f is smaller than $\Phi_N(k,\gamma)/(1-c)^2$, either II or $II\&NN$ appear. Suppose that II appears in $II\&NN$. Then, underinvestment occurs in the area $f > \Phi_N(k,\gamma)/(1-c)^2$. Conversely, if NN appears, underinvestment occurs in the area $f > \min\{\Phi_N(k,\gamma)/(1-c)^2, \Phi_I(k,\gamma)/(1-c)^2\}$.

Next, we discuss underinvestment in terms of total surplus. We do not present an algebraic proof, only intuitive discussions.

We assume $k > \max\{1/2, k_0\}$. To consider the best regime that maximizes the total surplus, we define the gross benefits of an increase in the number of downstream firms conducting R&D: $\Psi_{21}^{TS} \equiv TS^{II} - TS^{IN} = TS^{II} - TS^{NI}$, $\Psi_{10}^{TS} \equiv TS^{IN} - TS^{NN} = TS^{NI} - TS^{NN}$, and $\Psi_{20}^{TS} \equiv (TS^{II} - TS^{NN})/2$. More precisely, a rise in the number of downstream firms conducting R&D increases the total surplus if the following conditions are satisfied: $\Psi_{21}^{TS} > f$, $\Psi_{10}^{TS} > f$, or $\Psi_{20}^{TS} > f$.

No downstream firm conducts R&D if the R&D cost is large: $f > \max\{\Phi_I, \Phi_N\}$. Then, underinvestment in terms of total surplus occurs when the gross benefits Ψ_{10}^{TS} and Ψ_{20}^{TS} are larger than $\max\{\Phi_I, \Phi_N\}$. By calculating the threshold ranking between Φ_I, Φ_N, Ψ_{10}^{TS}, and Ψ_{20}^{TS}, we can show $\max\{\Psi_{10}^{TS}, \Psi_{20}^{TS}\} > \max\{\Phi_I, \Phi_N\}$. Hence, if $\max\{\Psi_{10}^{TS}, \Psi_{20}^{TS}\} > f > \max\{\Phi_I, \Phi_N\}$, the downstream firms do not conduct R&D, which turn into underinvestment.

To confirm this result, we use a numerical example to illustrate the total surplus benefit from downstream R&D, which yields Figures 2 and 3. In these Figures, the horizontal axis represents the fixed cost f of introducing a new product. For Figure 2 (or Figure 3), we assume $c = 2/5$, $k = 1$, and $\gamma = 1/5$ (or $2/5$, $k = 5$, and $\gamma = 1/5$). Each figure has three lines. The bold gray, dashed black, and solid black lines represent $TS^{II} - 2f$, $TS^{IN} - f (= TS^{NI} - f)$, and TS^{NN}, respectively. Each figure has four vertical dotted lines: Φ_I, Φ_N, Ψ_{10}^{TS}, and Ψ_{20}^{TS}. From

Proposition 2, Φ_I and Φ_N determine the investment decision for downstream firms. Additionally, at $f = \Psi_{10}^{TS}$ and $f = \Psi_{20}^{TS}$, $TS^{IN} - f = TS^{NI} - f = TS^{NN}$ and $TS^{II} - 2f = TS^{NN}$, respectively. From Figures 2 and 3, we confirm that underinvestment occurs if f takes the intermediate value.

[Figures 2 and 3 around here]

We explain the intuition behind the result for underinvestment in Figures 2 and 3. First, we consider a case with small f. At $f = 0$, downstream firms always invest. Additionally, the total surplus increases with the number of investing downstream firms because downstream investment increases final demand. From the continuity of the total surplus function, both $D1$ and $D2$ invest, and this investment decision is socially optimal if f is small.

Second, we consider a case with large f. When no downstream firm invests, the total surplus is independent of f; when at least one downstream firm invests, the total surplus decreases with f. Hence, we obtain two threshold values: Ψ_{10}^{TS} and Ψ_{20}^{TS}. Because from Proposition 2, no downstream firm invests if f is large, the equilibrium number of investing downstream firms is socially optimal.

Finally, we consider a case in which f takes an intermediate value. In our model, $\max\{\Phi_I, \Phi_N\} < \max\{\Psi_{10}^{TS}, \Psi_{20}^{TS}\}$. Hence, for any $\max\{\Phi_I, \Phi_N\} < f < \max\{\Psi_{10}^{TS}, \Psi_{20}^{TS}\}$, no downstream firm invests while it is socially desirable for both downstream firms to invest. In the case with $\Phi_I < f < \Phi_N$ in Figure 2, equilibrium investment decisions are $II\&NN$. Hence, whether the underinvestment of downstream firms occurs depends on the manner in which the equilibrium is refined. If NN (or II) is realized under $\Phi_I < f < \Phi_N$, downstream investment is insufficient (or socially optimal).

5 Discussion and Extension

5.1 Downstream price competition

Here, we discuss the case in which downstream firms compete on price to show the robustness of the main result obtained in the previous sections. In differentiated price competition, the demand function depends on whether downstream firms introduce a new product. Revising Equation (1), the following demand functions are obtained in each regime.

No one invests regime: $\boldsymbol{NN}$. In this regime, the demand function is

$$q_{e,i} = \frac{(1-\gamma) - p_{e,i} + \gamma p_{e,j}}{1-\gamma^2}; \quad q_{e,j} = \frac{(1-\gamma) - p_{e,j} + \gamma p_{e,i}}{1-\gamma^2}, \quad i \neq j.$$

Mixed regime: $\boldsymbol{IN}$ or $\boldsymbol{NI}$. Because only Di introduces a new product, the demand function is

$$\begin{aligned} q_{e,i} &= \frac{(1-\gamma) - (\gamma+1)p_{e,i} + \gamma(p_{n,i} + p_{e,j})}{(1-\gamma)(2\gamma+1)}, \\ q_{e,j} &= \frac{(1-\gamma) - (\gamma+1)p_{e,j} + \gamma(p_{e,i} + p_{n,i})}{(1-\gamma)(2\gamma+1)}, \\ q_{n,i} &= \frac{(1-\gamma) - (\gamma+1)p_{n,i} + \gamma(p_{e,i} + p_{e,j})}{(1-\gamma)(2\gamma+1)}. \end{aligned}$$

All product-developers regime: $\boldsymbol{II}$. In this regime, the demand function is

$$\begin{aligned} q_{e,i} &= \frac{(1-\gamma) - (2\gamma+1)p_{e,i} + \gamma(p_{n,i} + p_{n,j} + p_{e,j})}{(1-\gamma)(3\gamma+1)}, \\ q_{n,i} &= \frac{(1-\gamma) - (2\gamma+1)p_{n,i} + \gamma(p_{n,j} + p_{e,i} + p_{e,j})}{(1-\gamma)(3\gamma+1)}. \end{aligned}$$

The timing of the process is similar to that of the quantity competition case. By applying the same procedure as that used in the previous setting, we obtain each regime's equilibrium outcomes, which are shown in Appendix D. Using their equilibrium outcomes, we can derive the best response of downstream firms.

Suppose that Dj introduces a new product. If $f < \hat{\Phi}_I$, Di introduces a new product;

otherwise, it does not, and

$$\hat{\Phi}_I \equiv (1-c)^2(\gamma-1)k^2\left[\tfrac{\gamma+1}{(2(\gamma-2)(\gamma+1)k+1)^2} - \tfrac{2(2\gamma+1)(3\gamma+2)^2}{(\gamma(\gamma+5)+4(2\gamma+1)((\gamma-2)\gamma-2)k+3)^2}\right].$$

Suppose that Dj does not introduce a new product. If $f < \hat{\Phi}_N$, Di introduces a new product; otherwise, it does not, and

$$\hat{\Phi}_N \equiv \frac{1}{2}(1-c)^2(\gamma-1)(\gamma+1)k^2\left[\tfrac{8(\gamma+1)^2(2\gamma+1)}{(\gamma(\gamma+5)+4(2\gamma+1)((\gamma-2)\gamma-2)k+3)^2} - \tfrac{3\gamma+1}{(\gamma-2(3\gamma+1)k+1)^2}\right].$$

These two thresholds, $\hat{\Phi}_I$ and $\hat{\Phi}_N$, have similar properties to those in the quantity competition case; that is, even if the downstream firm has a different competition form, we obtain similar results.[14] The logic behind the results in the price competition case is very similar to that of Proposition 3. Hence, we conclude that the complementary equilibrium appears without asymmetry in product differentiation and verify that Proposition 3 has a certain robustness.

5.2 Timing of the R&D decision

In this subsection, we examine the timing of the R&D decision of firms. First, we consider the situation in which the initial decision is made regarding upstream cost-reducing investment. Thus, in the second stage of the game, each Di chooses either I or N. All other conditions are the same as those outlined in the previous section. We consider the Nash equilibrium of the second stage, and eliminate the cost-reducing investment variable x from Di's profit. Hence, the strategic variable U is a scale parameter for Di, and thus we can derive the second-stage equilibrium by omitting x.

Suppose a rival chooses I. If $f < \delta_N$, Di introduces a new product; otherwise, it does not. Here, δ_N is defined by

$$\delta_N \equiv \bar{\Pi}_1^{II} - \bar{\Pi}_1^{NI} = \frac{(1-(c-x))^2(\gamma-1)(\gamma^4-2\gamma^3-6\gamma^2-6\gamma-2)}{8(2\gamma+1)^2\left(\gamma^2-2\gamma-2\right)^2},$$

[14] Because the figure for equilibrium in the differentiated price competition case is almost the same as that in the quantity competition case, we omit it.

where $\bar{\Pi}_1^{II} = \bar{\Pi}_2^{II}$ and $\bar{\Pi}_1^{NI} = \bar{\Pi}_2^{IN}$.

Suppose a rival chooses N. If $f < \delta_I$, Di introduces a new product; otherwise, it does not. Here, δ_I is defined by

$$\delta_I \equiv \bar{\Pi}_1^{IN} - \bar{\Pi}_1^{NN} = \frac{(1-(c-x))^2(\gamma-1)(\gamma^4-8\gamma-8)}{8(\gamma+2)^2\,(\gamma^2-2\gamma-2)^2},$$

where $\bar{\Pi}_1^{IN} = \bar{\Pi}_2^{NI}$ and $\bar{\Pi}_1^{NN} = \bar{\Pi}_2^{NN}$.

Summarizing the above argument and $\delta_I \geq \delta_N$ for all $\gamma \in [0,1]$, $II\&NN$ disappears.

Second, we also consider the situation in which upstream R&D and downstream R&D are simultaneously conducted. That is, in the first stage of the game, U decides x and Di $(i = 1, 2)$ chooses either I or N. All other conditions are the same as those outlined in the previous section.

We focus on the conditions related to two equilibria, $II\&NN$ and $IN\&NI$, and find that these equilibria can emerge in the case of simultaneous R&D.

Suppose k is sufficiently small. Then, if $\phi_I < f < \phi_N$, $II\&NN$ can appear. In addition, if $\psi_N < f < \psi_I$, $IN\&NI$ can appear.[15]

Hence, we find that Proposition 3 is not necessarily robust in terms of timing.

5.3 Pricing in the upstream market

In the previous section, we assumed a uniform linear contract between upstream and downstream firms. Here, we consider other types of contracts: input price discrimination and a two-part tariff.

Input price discrimination Because the downstream firms are symmetric, there is no difference between the outcomes under uniform input prices and input price discrimination if either both downstream firms or neither firm invest: that is, the II and NN cases. Therefore, we consider only the case where only one downstream firm invests.

Without loss of generality, we consider only the IN case. Calculating input prices under

[15] These thresholds are given by $\psi_I \equiv \frac{2(1-c)^2(\gamma^5-\gamma^4-8\gamma^2+8)k^2}{(\gamma+2)^2[\gamma+(-4\gamma^2+8\gamma+8)k-3]^2}$, $\psi_N \equiv \frac{2(1-c)^2(\gamma^5-3\gamma^4-4\gamma^3+4\gamma+2)k^2}{(2\gamma+1)^2[\gamma+(-4\gamma^2+8\gamma+8)k-3]^2}$, $\phi_I \equiv \frac{(1-c)^2(\gamma^5-\gamma^4-8\gamma^2+8)k^2}{2(\gamma^2-2\gamma-2)^2(1-2(\gamma+2)k)^2}$, and $\phi_N \equiv \frac{(1-c)^2(\gamma^5-3\gamma^4-4\gamma^3+4\gamma+2)k^2}{2(\gamma^2-2\gamma-2)^2((4\gamma+2)k-1)^2}$.

price discrimination, we obtain $w_i = w_i^{IN}$, which is equal to the uniform input price in (5). Therefore, the equilibrium R&D decision of the downstream firms is exactly the same because the outcomes of each subgame are the same as those in the uniform input price case.

The reason why the input price under price discrimination is the same as that under uniform prices is as follows. Regardless of whether or not the downstream firms invest in R&D, the choke price of the demand function for the upstream firm is constant. That is, at $w_1 = w_2 = 1$, the output of the downstream firms in each subgame is zero. Thus, the R&D of the downstream firms affects only the slopes of the demand functions faced by the upstream firm. This result implies that the input prices chosen by the upstream firm are independent of the R&D of the downstream firms.

Two-part tariff The fixed fee depends on the other options available to the downstream firms. Because we assume that the investment by the downstream firms is a sunk cost, the external investment option of the downstream firms is $-f$, and zero if the downstream firms make no external investment.

If either both or neither of the downstream firms invest, the upstream firm extracts all of the downstream firms' surplus using the fixed fee. Thus, the downstream firms' profit is $-f$ if both downstream firms invest and zero if neither downstream firm invests. If one downstream firm invests in R&D and the other does not, there are two candidates for the fixed fee. First, the upstream firm equates the fixed fee to the profit of the downstream firm that did not engage in R&D and sells to both downstream firms. Second, the upstream firm equates its fixed fee to the surplus of the downstream firm that engages in R&D and sells only to that downstream firm. Regardless of which of these two fixed rates is chosen, downstream firms that do not engage in R&D will earn zero profit. Thus, the case where both downstream firms engage in R&D, that is, case II, will never be in equilibrium.

To show whether case IN or case NN is in equilibrium, we consider which of the fixed fees in case IN is chosen by the upstream firm. We denote the fixed fee as F. If both downstream firms accept the two-part tariff, the upstream firm chooses the following outcome.

$$
\begin{aligned}
w^{IN,duo} &= \frac{2k[\gamma^3 - 5\gamma^2 + c\left(\gamma^3 - 5\gamma^2 + 4\gamma + 6\right) + 4\gamma + 2] - (\gamma - 3)^2}{4k\left(\gamma^3 - 5\gamma^2 + 4\gamma + 4\right) - (\gamma - 3)^2}, \\
F^{IN,duo} &= \frac{4(1-c)^2(\gamma - 3)^2 k^2}{[4k\left(\gamma^3 - 5\gamma^2 + 4\gamma + 4\right) - (\gamma - 3)^2]^2}, \\
x^{IN,duo} &= \frac{(1-c)(\gamma - 3)^2}{4k\left(\gamma^3 - 5\gamma^2 + 4\gamma + 4\right) - (\gamma - 3)^2},
\end{aligned}
$$

where the superscript 'IN, duo' represents the case where both downstream firms accept the two-part tariff in case IN. Substituting the outcomes into the profits of the upstream and downstream firms, we obtain the following:

$$
\begin{aligned}
\pi_U^{IN,duo} &= \frac{(1-c)^2(\gamma - 3)^2 k}{4k\left(\gamma^3 - 5\gamma^2 + 4\gamma + 4\right) - (\gamma - 3)^2}, \\
\pi_{D1}^{IN,duo} &= \frac{2(1-c)^2(\gamma - 3)^2\left(\gamma^3 - 3\gamma^2 + 2\right)k^2}{\left[4k\left(\gamma^3 - 5\gamma^2 + 4\gamma + 4\right) - (\gamma - 3)^2\right]^2} - f, \quad \pi_{D2}^{IN,duo} = 0.
\end{aligned}
$$

Next, we consider the case where one downstream firm accepts the two-part tariff and the other does not. The upstream firm then makes the following decision:

$$
w^{IN,mono} = \frac{2c(\gamma+1)k - 1}{2(\gamma+1)k - 1}, \quad F^{IN,mono} = \frac{2(c-1)^2(\gamma+1)k^2}{(1 - 2(\gamma+1)k)^2}, \quad x^{IN,mono} = \frac{1-c}{2(\gamma+1)k - 1},
$$

where the superscript '$IN, mono$' represents the case where downstream firm 1 accepts the two-part tariff and downstream firm 2 does not in case IN. Substituting the outcomes into the profits of the upstream and downstream firms, we obtain the following:

$$
\pi_U^{IN,mono} = \frac{(1-c)^2 k}{2k(1+\gamma) - 1}, \quad \pi_{D1}^{IN,mono} = -f, \quad \pi_{D2}^{IN,mono} = 0.
$$

Comparing $\pi_U^{IN,duo}$ with $\pi_U^{IN,mono}$, the optimal two-part tariff for the upstream firm is $(w^{IN,duo}, F^{IN,duo})$ if $0 \leq \gamma < 2 - \sqrt{3}$ (≈ 0.268); that is, $(w^{IN,mono}, F^{IN,mono})$ otherwise. This result leads to the strategic form game in the first stage, as shown in Table 1. Solving this game, we obtain the following proposition.

[Table 1 around here]

Proposition 4. *Suppose that the upstream firm uses a two-part tariff contract. (i) IN&NI appear if the downstream products are sufficiently differentiated and the downstream R&D cost is small:* $0 \leq \gamma < 2 - \sqrt{3}$ *and* $\pi_{D1}^{IN,duo} > 0$*; (ii) otherwise, NN appears:* $2 - \sqrt{3} \leq \gamma < 1$ *or* $\pi_{D1}^{IN,duo} \leq 0$.

The intuition behind this proposition is as follows. The introduction of new products through downstream R&D has three effects on the profit of the upstream firm. The first is a positive effect. A new product launch makes the downstream market larger. Hence, the upstream firm can choose a higher fixed fee. The second and third effects are negative. The new product launch incurs investment costs for the downstream firm and intensifies competition in the downstream market, resulting in a lower fixed fee. Therefore, the upstream firm prefers a two-part tariff contract that results in a new product launch if γ and f are small, which mitigates these negative effects.

6 Conclusion

In vertically related markets, such as assembly industries, the key input price is important. This is because the price of the key input highly effects final-good production. If the key input is cheap, because the downstream production cost is low, downstream firms can easily introduce a new product. Hence, upstream cost-reducing R&D investment has an important role. Using the upstream monopoly and downstream duopoly model, in this paper, we considered both upstream cost-reducing R&D and downstream new product introduction. We found that upstream R&D efficiency (or production efficiency) determines the downstream behavior of introducing a new product. If the upstream firm is efficient, the downstream new product introduction race is a strategic complement; however, if the upstream firm is less efficient, it is a strategic substitute.

In this paper, we did not consider a price bargaining problem between upstream and downstream firms. However, if bargaining power shifts from the upstream firm to the downstream firm in the Nash bargaining problem, the change in the input price decreases (or closes to a constant). In this case, because the strategic effect is banished, it is expected that the pattern of multiple equilibria in Figure 1 will be banished.

Furthermore, we could consider the case of competitive vertical chains by introducing a new upstream firm. That is, upstream firm 1 (2) provides its input to only downstream firm 1 (2). Differing from the monopolistic upstream case because this involves competition among the upstream firms, each input price declines even when cost-reducing R&D is insufficient. Although the incentive to develop a new product remains, the benefits are reduced. Rather, by developing a new product, the downstream firm might face more intense competition. Consequently, the downstream firm develops a new product if its rival does not, and the downstream firm does not develop a new product if its rival does. In other words, the equilibria of NN & II disappear in the case of competitive vertical chains.

Although we considered a simple vertical structure in this paper, its analysis is limited to a domestic or single region's market. When downstream firms have two options, that is, "produce the product for domestic consumers" and "introduce a new product for foreign consumers," it would be interesting to consider what equilibrium patterns arise. Additionally, we did not consider the effect of vertical integration/separation on upstream and downstream innovation. When upstream and downstream firms are integrated, because their organizational forms alter, we expect that innovation activities would be affected. However, this consideration is beyond the scope of this study. Hence, we leave it to future research.

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Appendix A. Proofs

Proof of Proposition 1. (i) $x^{II}-x^{IN}=\frac{2k(1-c)(1-\gamma)}{L_N}>0$ and $x^{IN}-x^{NN}=\frac{2k(1-c)(1-\gamma)(2-\gamma)}{L_I}>0$, where $L_N\equiv[(4\gamma+2)k-1][4(2+2\gamma-\gamma^2)k-(3-\gamma)]$ and $L_I\equiv[2(\gamma+2)k-1][4(2+2\gamma-\gamma^2)k-(3-\gamma)]$. (ii) The partial derivative of x^r with respect to k yields $\partial x^{II}/\partial k=-\frac{2(1-c)(2\gamma+1)}{[(4\gamma+2)k-1]^2}<0$, $\partial x^{IN}/\partial k=-\frac{4(1-c)(3-\gamma)(2+2\gamma-\gamma^2)}{[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2}<0$, and $\partial x^{NN}/\partial k=-\frac{2(1-c)(\gamma+2)}{[2(\gamma+2)k-1]^2}<0$. The partial derivative of x^r with respect to γ yields $\partial x^{II}/\partial\gamma=-\frac{4(1-c)k}{[(4\gamma+2)k-1]^2}<0$, $\partial x^{IN}/\partial\gamma=-\frac{4(1-c)(\gamma^2-6\gamma+8)k}{[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2}<0$, and $\partial x^{NN}/\partial\gamma=-\frac{2(1-c)k}{[2(\gamma+2)k-1]^2}<0$. □

Proof of Proposition 2. (i) $w^{NN}-w^{IN}=\frac{k(1-c)(2-\gamma)(1-\gamma)}{L_I}>0$ and $w^{IN}-w^{II}=\frac{k(1-c)(1-\gamma)}{L_N}>0$. (ii) The partial derivative of w^r with respect to k yields $\partial w^{II}/\partial k=\frac{(1-c)(2\gamma+1)}{[(4\gamma+2)k-1]^2}>0$, $\partial w^{IN}/\partial k=\frac{2(1-c)(3-\gamma)(2+2\gamma-\gamma^2)}{[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2}>0$, and $\partial w^{NN}/\partial k=\frac{(1-c)(\gamma+2)}{[2(\gamma+2)k-1]^2}>0$. The partial derivative of w^r with respect to γ yields $\partial w^{II}/\partial\gamma=\frac{2(1-c)k}{[(4\gamma+2)k-1]^2}>0$, $\partial w^{IN}/\partial\gamma=\frac{2(1-c)k(4-\gamma)(2-\gamma)}{[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2}>0$, and $\partial w^{NN}/\partial\gamma=\frac{(1-c)k}{[2(\gamma+2)k-1]^2}>0$. □

Proof of Proposition 3. By comparing Φ_N with Φ_I, we obtain

$$\Phi_N-\Phi_I=\frac{(1-c)^2(1-\gamma)^2k^2(1-4\gamma k)\ g(k,\gamma)}{2[1-2(\gamma+2)k]^2[(4\gamma+2)k-1]^2\left[\gamma+\left(-4\gamma^2+8\gamma+8\right)k-3\right]^2}$$

$$\text{and}\quad g(k,\gamma)\equiv16(3\gamma^4+5\gamma^3+16\gamma^2+22\gamma+8)k^3-12(5\gamma^3+5\gamma^2+8\gamma+6)k^2+24\gamma^2k-3\gamma+3.$$

We show that $g(k,\gamma)>0$ and $\text{sign}\{\Phi_N-\Phi_I\}$ depend only on $1-4\gamma k$. To prove $g(k,\gamma)>0$, it is sufficient to show that $g(k,\gamma)$ has its minimum value at $k=k_0$ and $c=1$, and that its value is positive.

First, we show that $g(k,\gamma)$ is an increasing function of k; that is, $g(k,\gamma)$ is smallest at $k=k_0$. The first derivative $g(k,\gamma)$ with respect to k is $\partial g(k,\gamma)/\partial k=24[2(3\gamma^4+5\gamma^3+16\gamma^2+22\gamma+8)k^2-(5\gamma^3+5\gamma^2+8\gamma+6)k+\gamma^2]$. $\partial g(k,\gamma)/\partial k$ is a quadratic function of k and the coefficient of k^2 is positive. Hence, by solving $\partial g(k,\gamma)/\partial k > 0$ for k, we obtain $k < k_1$ and $k > k_2$, where k_1 and k_2 are roots of $g(k,\gamma) = 0$ for k and $k_1 < k_2$.

[Figure 4 around here]

As $k_0 = 1/[2c(2\gamma + 1)]$ decreases with c, k_0 has its minimum value at $c = 1$. We illustrate k_1, k_2, and k_0 at $c = 1$ in Figure 4. Using numerical calculation, we find that for $\gamma \in [0, 1]$, the unique root of $k_2 - k_0|_{c=1} = 0$ is $\gamma = 1$. Hence, $\partial g(k,\gamma)/\partial k > 0$ for any $k > k_0$. Therefore, $g(k,\gamma)$ has its minimum value at $k = k_0$.

Second, we show $\partial g(k_0,\gamma)/\partial c < 0$. The derivation yields

$$\frac{\partial g(k_0,\gamma)}{\partial c} = \frac{\partial g(k_0,\gamma)}{\partial k} \times \frac{\partial k_0}{\partial c} = \frac{\partial g(k_0,\gamma)}{\partial k}\left[\frac{-1}{2c^2(2\gamma+1)}\right] < 0.$$

The last inequality is satisfied because $\partial g(k,\gamma)/\partial k > 0$. Hence, $g(k_0,\gamma)$ is a decreasing function for c and it has its minimum value when $c = 1$.

From the above discussion, $g(k_0,\gamma)$ has the following minimum value at $k = k_0$ and $c = 1$: $g(k_0,\gamma)\big|_{c=1} = \frac{(1-\gamma)^2(\gamma+1)}{(2\gamma+1)^3} > 0$. Because $g(k_0,\gamma)\big|_{c=1}$ is positive, $\forall k > k_0$, $g(k,\gamma) > 0$. This result implies that $\operatorname{sign}\{\Phi_N - \Phi_I\}$ depends only on "$1 - 4\gamma k$." Hence, $\Phi_N > \Phi_I$ iff $k < 1/(4\gamma)$. $\square$

Appendix B. Derivation of Equilibrium Outcomes

In this appendix, we derive the equilibrium outcomes in each regime.

No one invests regime: *NN*. First, we derive the equilibrium quantity of the final product. Because each firm decides the quantity of the final product that maximizes profit, the first-order condition (FOC) to maximize profit is

$$\frac{\partial \pi_{Di}}{\partial q_{e,i}} = 1 - w - 2q_{e,i} - \gamma q_{e,j} = 0.$$

Consequently, we obtain $q_{e,i} = \dfrac{1}{2}(1 - w - q_{e,j})$. From this reaction function, we obtain

$$q_{e,i} = q_{e,j} = \frac{1-w}{2+\gamma}. \tag{7}$$

Substituting eq. (7) into the upstream firm's profit function, we obtain

$$\pi_U = \frac{2(1-w)(w-(c-x))}{\gamma+2} - kx^2.$$

Because the upstream firm decides w and x to maximize its profit, the FOCs are

$$\frac{\partial \pi_U}{\partial w} = \frac{2(1-2w+(c-x))}{\gamma+2} = 0,$$
$$\frac{\partial \pi_U}{\partial x} = \frac{2(1-w)}{2+\gamma} - 2kx = 0.$$

Thus, we obtain the equilibrium outcomes listed in the paper.

Mixed regime: *IN* or *NI*. Without loss of generality, we assume that only D_i invests. First, we derive the equilibrium quantity of final products. Because each firm decides the quantity of final products that maximizes the profit, the FOCs to maximize the profit are

$$\frac{\partial \pi_i}{\partial q_{e,i}} = 1 - w - 2q_{e,i} - 2\gamma q_{n,i} - \gamma q_{e,j} = 0,$$
$$\frac{\partial \pi_i}{\partial q_{n,i}} = 1 - w - 2q_{n,i} - 2\gamma q_{e,i} - \gamma q_{e,j} = 0,$$
$$\frac{\partial \pi_j}{\partial q_{e,j}} = 1 - w - 2q_{e,j} - \gamma(q_{e,i} + q_{n,i}) = 0.$$

Consequently, we obtain

$$q_{e,i} = q_{n,i} = \frac{1}{2(1+\gamma)}(1 - w - q_{e,j}),$$
$$q_{e,j} = \frac{1}{2}(1 - w - \gamma(q_{e,i} + q_{n,i})).$$

From the above reaction functions, we obtain

$$q_{e,i} = q_{n,i} = \frac{(1-w)(2-\gamma)}{2(2+2\gamma-\gamma^2)}; \quad q_{e,j} = \frac{1-w}{2+2\gamma-\gamma^2}. \tag{8}$$

Substituting eq. (8) into the upstream firm's profit function, we obtain

$$\pi_U = \frac{(1-w)(2-\gamma)(w-(c-x))}{2+2\gamma-\gamma^2} - kx^2.$$

Because the upstream firm decides w and x to maximize its profit, the FOCs are

$$\frac{\partial \pi_U}{\partial w} = \frac{(3-\gamma)(-2w+1+(c-x))}{2+2\gamma-\gamma^2} = 0,$$
$$\frac{\partial \pi_U}{\partial x} = \frac{(1-w)(3-\gamma)}{2+2\gamma-\gamma^2} - 2kx = 0.$$

Thus, we obtain the equilibrium outcomes listed in the paper.

All product-developers regime: *II*. First, we derive the equilibrium quantity of the final product. Because each firm decides the quantity of final products that maximizes the profit, the FOCs to maximize the profit are

$$\frac{\partial \pi_{Di}}{\partial q_{e,i}} = 1 - w - 2q_{e,i} - 2\gamma q_{n,i} - (q_{e,j} + q_{n,j})\gamma = 0,$$
$$\frac{\partial \pi_{Di}}{\partial q_{n,i}} = 1 - w - 2q_{n,i} - 2\gamma q_{e,i} - (q_{e,j} + q_{n,j})\gamma = 0.$$

Consequently, we obtain $q_{e,i} = q_{n,i} = \dfrac{1-w-(q_{e,j}+q_{n,j})\gamma}{2(1+\gamma)}$. From this, we obtain

$$q_{e,i} = q_{n,i} = q_{e,j} = q_{n,j} = \frac{1-w}{2(2\gamma+1)}. \tag{9}$$

Substituting eq. (9) into the upstream firm's profit function, we obtain

$$\pi_U = \frac{2(1-w)(w-(c-x))}{2\gamma+1} - kx^2.$$

Because the upstream firm decides w and x to maximize its profit, the FOCs are

$$\frac{\partial \pi_U}{\partial w} = \frac{2(-2w+1+(c-x))}{2\gamma+1} = 0,$$
$$\frac{\partial \pi_U}{\partial x} = \frac{2(1-w)}{(1+2\gamma)} - 2kx = 0.$$

Thus, we obtain the equilibrium outcomes listed in the paper.

Appendix C. Other Equilibrium Outcomes.

No one invests regime: *NN*

$$\pi_U^{NN} = \frac{(1-c)^2 k}{2(\gamma+2)k-1}; \quad q_{e,i}^{NN} = \frac{(1-c)k}{2(\gamma+2)k-1}; \quad \pi_{Di}^{NN} = \left(q_{e,i}^{NN}\right)^2 \text{ for } i = 1, 2,$$

$$CS^{NN} = \frac{(1-c)^2(\gamma+1)k^2}{[1-2(\gamma+2)k]^2}; \quad TS^{NN} = \frac{(1-c)^2k[(3\gamma+7)k-1]}{[1-2(\gamma+2)k]^2}.$$

Mixed regime: *IN* or *NI*

$$\pi_U^{IN} = \frac{(1-c)^2(3-\gamma)k}{4(2+2\gamma-\gamma^2)k-(3-\gamma)},$$
$$q_{e,1}^{IN} = q_{n,1}^{IN} = \frac{(1-c)(2-\gamma)k}{4(2+2\gamma-\gamma^2)k-(3-\gamma)}; \quad q_{e,2}^{IN} = \frac{2(1-c)k}{4(2+2\gamma-\gamma^2)k-(3-\gamma)},$$
$$\pi_{D1}^{IN} = \frac{2(1-c)^2(2-\gamma)^2(1+\gamma)k^2}{[4(2+2\gamma-\gamma^2)k-(3-\gamma)]^2}; \quad \pi_{D2}^{IN} = \left(q_{e,2}^{IN}\right)^2,$$

$$CS^{IN} = \frac{(1-c)^2(\gamma^3-7\gamma^2+8\gamma+6)k^2}{[\gamma+(-4\gamma^2+8\gamma+8)k-3]^2},$$
$$TS^{IN} = \frac{(1-c)^2k[(7\gamma^3-33\gamma^2+24\gamma+42)k-(\gamma-3)^2]}{[\gamma+(-4\gamma^2+8\gamma+8)k-3]^2}.$$

Note that $q_{e,2}^{NI} = q_{n,2}^{NI} = q_{e,1}^{IN} = q_{n,1}^{IN}$, $q_{e,2}^{IN} = q_{e,1}^{NI}$, $\pi_{D2}^{NI} = \pi_{D1}^{IN}$, $\pi_{D1}^{NI} = \pi_{D2}^{IN}$, $CS^{IN} = CS^{NI}$, and $TS^{IN} = TS^{NI}$.

All product-developers regime: *II*

$$\pi_U^{II} = \frac{(1-c)^2k}{(4\gamma+2)k-1},$$
$$q_{e,i}^{II} = q_{n,i}^{II} = \frac{(1-c)k}{2\left[(4\gamma+2)k-1\right]}; \quad \pi_{Di}^{II} = \frac{(1-c)^2(\gamma+1)k^2}{2\left[(4\gamma+2)k-1\right]^2} \quad \text{for } i=1,2,$$
$$CS^{II} = \frac{(1-c)^2(3\gamma+1)k^2}{2[(4\gamma+2)k-1]^2}; \quad TS^{II} = \frac{(1-c)^2k[(13\gamma+7)k-2]}{2[(4\gamma+2)k-1]^2}.$$

Appendix D. SPNE Outcomes in Downstream Price Competition.

To identify Bertrand rivalry, we attach "ˆ" to the variables of the equilibrium solutions.

No one invests regime: *NN*

$\hat{w}^{NN} = \frac{1-(c+1)(2-\gamma)(\gamma+1)k}{1-2(2-\gamma)(\gamma+1)k}$, $\hat{x}^{NN} = \frac{1-c}{2(2-\gamma)(\gamma+1)k-1}$, $\hat{\pi}_U^{NN} = \frac{(1-c)^2k}{2(2-\gamma)(\gamma+1)k-1}$,

$\hat{p}_{e,i}^{NN} = \frac{1-(\gamma+1)k(c-2\gamma+3)}{2(\gamma^2-\gamma-2)k+1}$, and $\hat{\pi}_{Di}^{NN} = \frac{(1-c)^2(1-\gamma)(\gamma+1)k^2}{(2(\gamma^2-\gamma-2)k+1)^2}$.

Mixed regime: IN or NI

$\hat{w}^{IN} = \frac{2(c+1)(2\gamma+1)((2-\gamma)\gamma+2)k-(\gamma(\gamma+5)+3)}{4(2\gamma+1)((2-\gamma)\gamma+2)k-(\gamma(\gamma+5)+3)}$,

$\hat{x}^{IN} = \frac{(1-c)(\gamma(\gamma+5)+3)}{4(2\gamma+1)((2-\gamma)\gamma+2)k-(\gamma(\gamma+5)+3)}$, $\hat{\pi}_U^{IN} = \frac{(1-c)^2(\gamma(\gamma+5)+3)k}{4(2\gamma+1)((2-\gamma)\gamma+2)k-(\gamma(\gamma+5)+3)}$,

$\hat{p}_{e,i}^{IN} = \frac{-(2\gamma+1)k(c(\gamma+1)(\gamma+2)+5(1-\gamma)\gamma+6)+\gamma(\gamma+5)+3}{\gamma(\gamma+5)-4(2\gamma+1)((2-\gamma)\gamma+2)k+3}$, $\hat{p}_{n,i}^{IN} = \frac{-(2\gamma+1)k(c(\gamma+1)(\gamma+2)+5(1-\gamma)\gamma+6)+\gamma(\gamma+5)+3}{\gamma(\gamma+5)-4(2\gamma+1)((2-\gamma)\gamma+2)k+3}$,

$\hat{p}_{e,j}^{IN} = \frac{-2(2\gamma+1)k(2\gamma c+c+2(1-\gamma)\gamma+3)+\gamma(\gamma+5)+3}{\gamma(\gamma+5)-4(2\gamma+1)((2-\gamma)\gamma+2)k+3}$, $\hat{\pi}_{Di}^{IN} = \frac{2(1-c)^2(1-\gamma)(2\gamma+1)(3\gamma+2)^2k^2}{(4(2\gamma+1)((2-\gamma)\gamma+2)k-(\gamma(\gamma+5)+3))^2}$,

and $\hat{\pi}_{Dj}^{IN} = \frac{4(1-c)^2(1-\gamma)(\gamma+1)^3(2\gamma+1)k^2}{(4(2\gamma+1)((2-\gamma)\gamma+2)k-(\gamma(\gamma+5)+3))^2}$.

All product-developers regime: II

$\hat{w}^{II} = \frac{(c+1)(3\gamma+1)k-(\gamma+1)}{(6\gamma+2)k-(\gamma+1)}$, $\hat{x}^{II} = \frac{(1-c)(\gamma+1)}{(6\gamma+2)k-(\gamma+1)}$, $\hat{\pi}_U^{II} = \frac{(1-c)^2(\gamma+1)k}{(6\gamma+2)k-(\gamma+1)}$, $\hat{q}_{e,i}^{II} = \frac{(3\gamma+1)k(\gamma c+c-\gamma+3)-2(\gamma+1)}{4(3\gamma+1)k-2(\gamma+1)}$,

and $\hat{\pi}_{Di}^{II} = \frac{(1-c)^2(1-\gamma)(\gamma+1)(3\gamma+1)k^2}{2[2(3\gamma+1)k-(\gamma+1)]^2}$.

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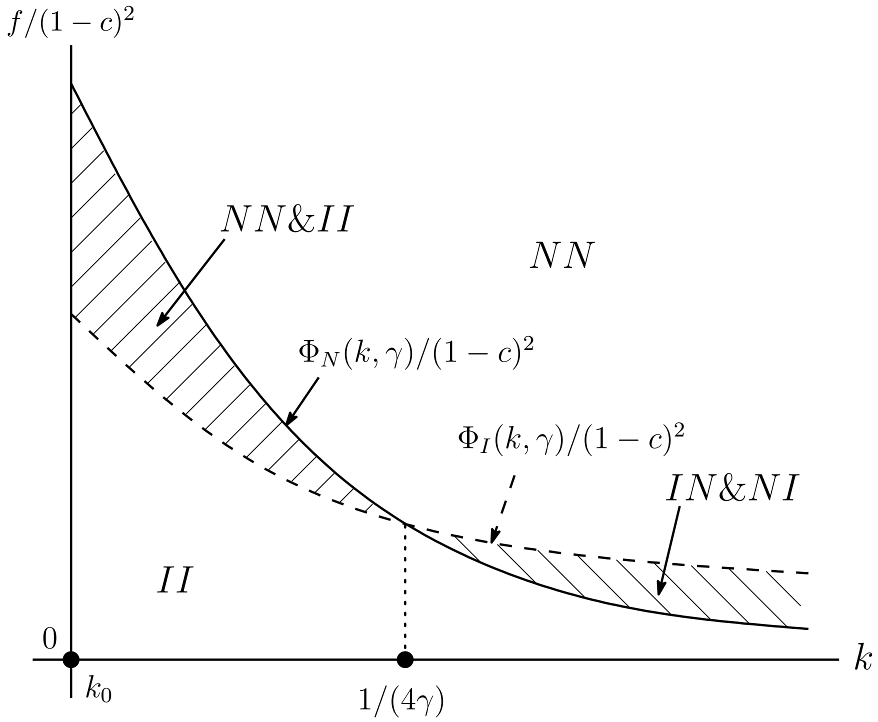

Figure 1: Equilibrium of the new product introduction game in $(k, \frac{f}{(1-c)^2})$-space $(k_0 < 1/(4\gamma))$

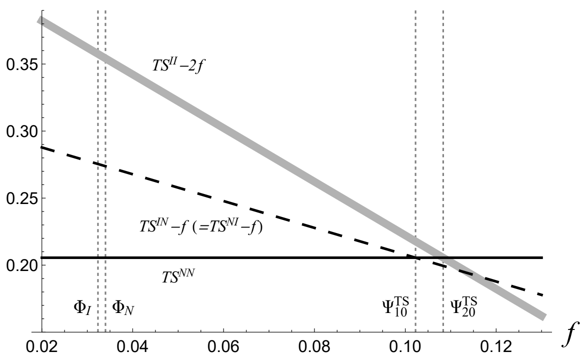

Figure 2: Total welfare comparison: $\boldsymbol{k=1}$

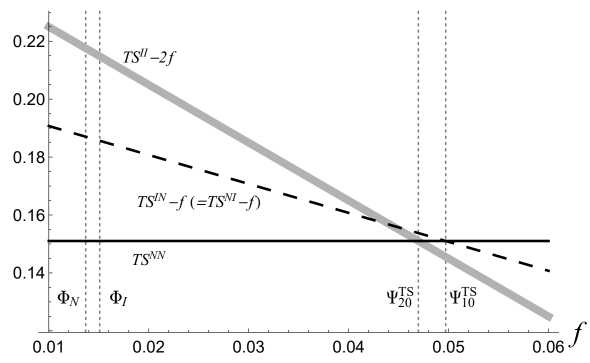

Figure 3: Total welfare comparison: $\boldsymbol{k=5}$

Note: In both Figures 2 and 3, $c = 2/5$ and $\gamma = 1/5$.

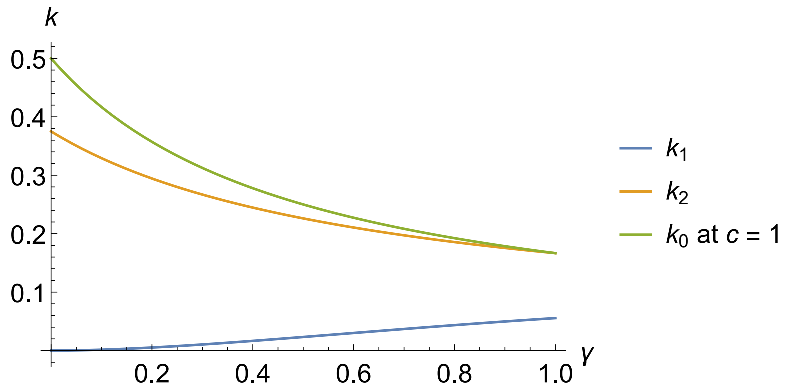

Figure 4: k_0 at $c = 1$ and the two roots of $g(k, \gamma) = 0$

		D2	
		I	N
$D1$	I	$-f, -f$	$-f, 0$
	N	$0, -f$	$0, 0$

Case with $0 \leq \gamma < 2 - \sqrt{3}$.

		D2	
		I	N
$D1$	I	$-f, -f$	$\pi_{D1}^{IN,duo}, 0$
	N	$0, \pi_{D1}^{IN,duo}$	$0, 0$

Case with $2 - \sqrt{3} \leq \gamma < 1$.

Table 1: Strategic form game in the first stage