Social Efficiency of Downstream Entry with Technology Choice

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Abstract: We offer a new perspective to the literature analyzing entry in a vertical structure by considering endogenous technology choice. We first show that, entry is socially excessive if either R&D is less costly or knowledge spillover is relatively high when the upstream firm's input price decision is prior to downstream firm's technology choice. In addition, we consider another order of game move between upstream firm's input price and downstream firm's technology choice, and show that entry is socially excessive regardless of the order of game moves. Furthermore, we consider the upstream firm's input price and technology choice, and show that entry is socially excessive. Hence, anti-competitive entry regulation policies in vertical structures are more desirable than suggested by the previous works.

Keywords: Excessive entry; Insufficient entry; Vertical structure; R&D
JEL classifications: L13; L40

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1 Introduction

In an influential work, Mankiw and Whinston (1986) show that entry in oligopolistic markets are socially excessive in the presence of scale economies, thus providing the rationale for anti-competitive entry regulation in oligopolistic markets. This result, often called "excess-entry theorem", has created significant interest in analyzing the welfare effects of entry in oligopolisitc markets.[1] As mentioned by Vives (1988), whether or not entry is socially excessive is not merely an issue of simple academic interest. Governments in many countries take actions to foster or deter entry into particular industries. For example, in the post-war period, preventing excessive entry was a guiding principle in the Japanese industrial policy (Suzumura and Kiyono, 1987, and Suzumura, 1995).

Although it is generally believed for long time that entry is socially excessive in oligopolistic industries with scale economies, Ghosh and Morita (2007a) show concern to the "excess-entry theorem".[2] They show that entry is socially insufficient instead of excessive in a vertical structure where both the downstream and the upstream sectors have market powers. In particular, they demonstrate that excess entry occurs as a special case where neither the upstream sector nor the downstream sector has market power. Thus, they question the applicability of the previous works such as Mankiw and Whinston (1986) in industries with effective vertical relationships.[3]

While the findings of Ghosh and Morita (2007a) are interesting, we show in this paper

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[1] See, Von Weizsäcker (1980), Perry (1984), Suzumura and Kiyono (1987), Okuno-Fujiwara and Suzumura (1993), Anderson et al. (1995) and Fudenberg and Tirole (2000) for other works on excessive entry in the presence of scale economies. Klemperer (1988), Lahiri and Ono (1988) and Ghosh and Saha (2007) suggest that excessive entry can occur without scale economies but in the presence of marginal cost difference.

[2] In a related work, Ghosh and Morita (2007b) show that insufficient entry may occur in bilateral oligopolies.

[3] Several other recent papers also question the "excess-entry theorem". Entry in oligopolistic markets can be socially insufficient in the presence of spatial competition (Matsumura and Okamura 2006), technology licensing (Mukherjee and Mukherjee 2008) and market leaders (Mukherjee, 2011). These works show that along with business stealing effects, entry creates further effects by either affecting the input prices, technologies or the elasticity of demand.

that the applicability of the “excess-entry theorem” in industries with effective vertical relationships is actually more than what has been suggested by them. In a vertical structure with upstream market power, it is certainly in the interest of the downstream firms to reduce the effects of the upstream prices. A natural way to do that is through R&D investments reducing the input coefficients in the production process. Hence, it may be natural to examine how the welfare effects of entry will be affected if the downstream firms can determine their technologies, affecting the input coefficients in the production process, depending on the final goods market structure due to entry.

It is very common for both upstream firms and downstream firms devoting to R&D, especially in technology industries. For example, Intel and AMD, two worldwide competitive hi-tech giants, are the major central processing unit (CPU) designers and producers in the personal computer (PC) industry, which includes both desktop and laptop computers. This is a very typical case for imperfectly competitive market structure because it is hardly to see that a personal computer which is not equipped with one of these two giant’s CPU. The competition between these two enterprises drives them to aggressively proceed with R&D. R&D in the upstream of PC industry primarily focus on the pursuit of lower electric consumption, higher performance and lower working temperature. Therefore, from the viewpoint of personal computer, Intel and AMD are the upstream firms on grounds that CPU is the heart of a computer. The downstream firms are those very often seen computer designers and producers such as Asus, Acer, Lenovo, Dell, Toshiba, Sony and Fujitsu.

The downstream firms of the PC industry are even keener to R&D in view of the Internet age. Internet shortens the information distance between producers and consumers, from technical details to price differences, from product quality to service quality. Moreover, the intensity of competition among producers is stronger. Then those producers have no choice but to provide products that are attractive and powerful enough to keep its original customers and hope that the market share can be broadened further. Accordingly, the only way to create such products by all means is R&D. R&D in downstream of PC industry is easily observed. From the size and the weight or even the outlook of laptops, it can be understood how R&D works because a laptop nowadays is much more powerful than it was but it becomes thinner, yet stronger and the battery endurance is much longer, even the choice of color is more. From ordinary laptop and desktop to finger-touch enabled ones, from keyboard input to handwriting or even voice input, these are all conspicuous evidences for R&D.

Aside from PC industry, smartphone industry is another typical case. The screen is the most important component of smartphones. From traditional TFT-LCD to LED, the electric consumption becomes lower, then to AMLED and Super AMLED, the screen becomes brighter and more breathtaking. This is the upstream. As to the downstream, the smartphone itself, its user interface (UI), weight, thickness and even the quality of the pictures it takes are all keys to the success of smartphones. From the products of the major producers like HTC, Sony Ericsson, Motorola, Samsung and LG, it is not difficult to realize the commitment of these enterprises to R&D.

In steel industry, for example, many different types of R&D activities conducted by the downstream producers that use steel as the input could be classified as: 1. R&D for fasteners of automobiles: The researches included the key technology development of raw material improvement, surface treatment, development of mold and product detection in order to increase the unit price and output value of fasteners; 2. R&D for high performance and light weight hand tools: Developments in material technology, process technology, styling design and validate procedures to improve the quality of hand tools and the technique capability for our customers. These also increase their international competitiveness; 3. R&D for tube hydro-forming technology for automobile parts: To match with the development trend of international tube hydro-forming industry technology, by applying the existing experience and advantage of Taiwan automobile industry, a vertical disintegrated cooperation plan has been settled to develop three tube hydro-forming automobile parts for coping with the design and modification trend of future new generation automobile parts; 4. R&D for advanced high strength steel and forming technology for automobiles: Developing state of the art high strength steels and establishing collaboration between China Steel and auto-OEMs for developing light weight stamping parts and new generation of vehicles; 5. R&D for advanced molding technology for automobile panels: The researches included automotive sheet metal modeling and automotive mold digital, automotive sheet metal forming by the CAE (Computer Aided Engineering) analysis technology, and 3D automotive mold structure design and verification technology etc. The time of automotive parts for R&D is expected to be reduced from eight months to four months.

We could easily find that R&D is significant in other industries using the products of the industries such as petroleum refining, petrochemicals, cement, paper and pulp, and sugar refining as inputs. In fact, in the mentioned industries, R&D investment is significant and vital for those upstream firms as well.

In view of effective vertical oligopoly structure where entry occurs in the downstream sector while R&D investment is significant either for upstream sector or downstream sector, we provide new insights to the welfare effects of entry. We show that entry is socially excessive if either the slope of the marginal cost of R&D is small (which creates large incentive for innovation) or knowledge spillover is large (which helps to reduce the cost of the firms). Our result holds whether or not the downstream firms commit to the technology choice before input price determination. We also show that the entry of downstream firms is socially excessive if the R&D investment is less costly regardless of the degree of knowledge spillover when the R&D is committed by the upstream firms. Hence, while considering the problem of social efficiency of entry in a broader context with endogenous technology choice, the anti-competitive entry regulation policies may be justified even in the vertical structures with market powers of the upstream and downstream sectors.

The remainder of this paper is organized as follows. We present the basic model in Section 2. Section 3 considers the benchmark case with no R&D. Section 4 considers the case where the downstream firms commit to the technology choice before input price determination. Section 5 considers the other case where the downstream firms determine input price before the technology choice. Section 6 shows the welfare effects of downstream entry in the final goods market in the presence of R&D chosen by the upstream firms. Section 7 concludes the paper.

2. The Basic Model

Consider an economy with successive Cournot oligopoly as in Greenhut and Ohta (1976), Salinger (1988), Ghosh and Morita (2007a). We assume that there is large number of firms which produce homogeneous goods by using an intermediate good produced in an imperfectly competitive market with *m* upstream firms, where each upstream firm's marginal cost of production is *c*. We assume that the inverse market demand for the final goods is $p = a - Q$, where P is price and Q is the total output. Each final goods producer decides whether to enter the market. If a final goods producer enters the market, it needs to incur a fixed entry cost, F. The number of final goods producer is determined by the zero profit condition. Hence, entry in the final goods market occurs until the net profit of a final goods producer is zero.

We assume that each downstream firm requires one unit of the intermediate good to produce one unit of the final goods. Each downstream firm purchases the intermediate goods from the upstream sector at a price, *w*, and incurs a cost *d* to covert the intermediate goods to the final goods. However, each final good producer, which enters the market, invests *x* amount in R&D to reduce the cost of converting the intermediate goods to the final goods to $(d - x)$. We have considered for analytical convenience that investment in R&D reduces the cost of converting the intermediate goods to the final goods. However, our qualitative results hold if R&D reduces input coefficient in the final goods producers' production technology, instead of reducing the cost of converting the intermediate goods to the final goods.

We assume knowledge spillover under R&D. If there are n final goods producers, we assume that knowledge spillover to the ith final goods producer, $i = 1, 2, ..., n$, is $\gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s$, where $\gamma \in [0,1]$ shows the degree of knowledge spillover. Hence, the total cost reduction of the ith firm, $i = 1, 2, ..., n$, through R&D is $(x_i + \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s)$.[4] We also assume that R&D is costly and the cost of R&D to each final goods producer is $R(x) = \frac{gx^2}{2}$.

Before analyzing the effects of R&D in the downstream sector, we show the welfare effects of entry in the next section without R&D in the downstream sector.

3. Benchmark: Equilibrium Outcomes without R&D

We consider the following game in this section. At stage 1, the final goods producers decide whether to enter the market. At stage 2, the upstream firms take their output decisions simultaneously, and the price of the intermediate goods is determined from the derived demand for the intermediate goods. At stage 3, the final goods producers, which have entered the market, produce like Cournot oligopolists, and the profits are realized. We solve the game through backward induction.

If n final goods producers enter the market, the ith final goods producer, $i = 1, 2, ..., n$, maximizes the following expression to determine its output:

$$\pi_i = (a - Q - w - d)q_i . \tag{1}$$

The equilibrium output of the ith final goods producer can be found as

[4] This concept of knowledge spillover is similar to D'Aspremont and Jacquemin (1988).

$$q_i^* = \frac{a-w-d}{1+n}, \quad i = 1, 2, ..., n. \tag{2}$$

The derived demand for the intermediate good is

$$w = a - d - \frac{(1+n)q_I}{n}, \tag{3}$$

where $q_I = \sum_{i=1}^{n} q_i^* = \sum_{j=1}^{m} q_j$ and q_j is the output of the *j*th upstream firm.

The *j*th upstream firm maximizes the following expression to determine its output:

$$\pi_j = (w-c)q_j, \quad j = 1, 2, ..., m. \tag{4}$$

The equilibrium output of the *j*th intermediate goods producer is

$$q_j^* = \frac{An}{(1+m)(1+n)}, \tag{5}$$

where $A = (a-c-d)$.

The equilibrium price of the intermediate good is

$$w^* = \frac{a-d-cm}{1+m}. \tag{6}$$

The net profit of the *i*th final goods producer and *j*th intermediate goods producer are

$$\pi_i^* = \frac{A^2 m^2}{(1+m)^2 (1+n)^2} - F, \quad i = 1, 2, ..., n. \tag{7}$$

and

$$\pi_j^* = \frac{A^2 n}{(1+m)^2 (1+n)}, \quad j = 1, ..., m. \tag{8}$$

The free entry equilibrium number of final goods producers is $\pi_i^* = 0$, or

$$\frac{A^2 m^2}{(1+m)^2 (1+n)^2} = F. \tag{9}$$

Now we consider welfare-maximizing number of downstream firms. Welfare is given by $SW = CS + \sum_{j=1}^{m} \pi_j + \sum_{i=1}^{n} \pi_i$, where $CS = Q^2 / 2$. Hence, welfare is

$$SW = \frac{A^2 mn[2(1+n)+m(2+n)]}{2(1+m)^2(1+n)^2} - nF \, . \qquad (10)$$

The welfare-maximizing number of downstream firms is given by

$$\frac{A^2 m(1+m+n)}{(1+m)^2(1+n)^3} = F \, . \qquad (11)$$

Comparing (9) and (11), we get that left hand side (LHS) of (11) is greater than LHS of (9), which gives the following result immediately.

Proposition 1: *The free entry equilibrium number of downstream firms is lower than the welfare- maximizing number of downstream firms, suggesting entry is socially insufficient.*

Proposition 1 shows the result in Ghosh and Morita (2007a).[5]

4. Input Price-R&D-Quantity Competition

Now we want to show the welfare effects of entry in the final goods market in the presence of R&D chosen by the downstream firms. We consider in this section that the downstream firms do not commit to the technology choice before input price determination.

If n final goods producers enter the market, the ith final goods producer, $i = 1, 2, ..., n$, maximizes the following expression to determine its output:

$$\pi_i = (a - Q - w - d + x_i + \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) q_i - \frac{g x_i^2}{2} \, , \qquad (12)$$

where $\gamma \in [0,1]$ shows the degree of knowledge spillover.

The equilibrium outputs are

[5] See footnote 1 of Ghosh and Morita (2007a). They argued that with a fixed number of upstream firms and free entry in the downstream sector, insufficient entry can occur in the downstream sector. They also find that insufficient entry can occur in an alternative setup in which there is free entry in the downstream sector as well as in the upstream sector.

$$q_i^* = \frac{a - n(w + d - x_i - \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) + \sum_{\substack{s=1 \\ i \neq s}}^{n} (w + d - x_s - \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j)}{1 + n}, \tag{13}$$

where $(w + d - x_i - \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s)$ is the marginal cost of the ith firm and $(w + d - x_s - \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j)$ is the marginal cost of the other $(n-1)$ firms. Note that $(w + d - x_s - \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j)$ also involves x_i.

The ith final goods producer, $i = 1, 2, ..., n$, maximize the following expression to determine the R&D investment:

$$\pi_i = (a - \sum_{i=1}^{n} q_i^* - w - d + x_i + \gamma \sum_{\substack{s=2 \\ i \neq s}}^{n} x_s) q_i^* - \frac{g x_i^2}{2} \tag{14}$$

where q_i^* is given in (13).

The equilibrium R&D investments are

$$x_i^* = \frac{2(a - d - w)[n(1-\gamma) + \gamma]}{B_1 - 2[n(1-\gamma) + \gamma][1 + (n-1)\gamma]}, \quad i = 1, 2, ..., n, \tag{15}$$

where $B_1 \equiv g(1+n)^2$. $B_1 - 2[n(1-\gamma) + \gamma][1 + (n-1)\gamma] > 0$ if $g > \tilde{g}_1 \equiv \frac{2[n(1-\gamma) + \gamma][1 + (n-1)\gamma]}{(1+n)^2}$, which guarantees that the R&D investment is positive. The second order condition $g > \tilde{g}_2 \equiv \frac{2(n + \gamma - n\gamma)^2}{(1+n)^2}$ makes $d - x_i^* > 0$. To assure $d - x_i^* > 0$, $\tilde{g}_1 > \tilde{g}_2$ for $\gamma > \frac{1}{2}$ while if $\gamma < \frac{1}{2}$, $\tilde{g}_1 < \tilde{g}_2$. Hence, $g > \max[\tilde{g}_1, \tilde{g}_2]$ is needed for finding a positive interior solution of the equilibrium R&D investment.

The derived demand for the intermediate goods follows from (13) and (15), and it is given by

$$w = a - d - \frac{\{B_1 + 2[1 + (n-1)\gamma][(n-1)\gamma - n] q_I\}}{gn(n+1)}. \tag{16}$$

The equilibrium output of the *j*th intermediate goods producer is

$$q_j^* = \frac{Agn(1+n)}{(1+m)\{B_1 + 2[n(\gamma-1)-\gamma][1+(n-1)\gamma]\}}. \tag{17}$$

The equilibrium price of intermediate good is computed as

$$w^* = \frac{a-d-cm}{1+m}. \tag{18}$$

The net profit of the *i*th final goods producer, $i = 1,...,n$ is

$$\pi_i^* = \frac{A^2gm^2[B_1 - 2(n+\gamma-n\gamma)^2]}{(1+m)^2\{B_1 - 2[n(1-\gamma)+\gamma][1+(n-1)\gamma]\}^2} - F. \tag{19}$$

Free entry equilibrium number of final goods producers is given by $\pi_i^* = 0$, or

$$\frac{A^2gm^2[B_1 - 2(n+\gamma-n\gamma)^2]}{(1+m)^2\{B_1 + 2[n(1-\gamma)+\gamma][1+(n-1)\gamma]\}^2} = F. \tag{20}$$

Now we determine the welfare-maximizing number of final goods producers. Social welfare is

$$SW = \frac{A^2gmn\{B_1[2(1+n)+m(2+n)] - 4[n(1-\gamma)+\gamma][1+n+mn+(n-1)(1-m+n)\gamma]\}}{2(1+m)^2\{B_1 + 2[n(\gamma-1)-\gamma][1+(n-1)\gamma]\}^2} - nF. \tag{21}$$

The welfare-maximizing number of downstream firms is given by

$$dSW/dn = f(a,c,d,g,m,n,\gamma) - F = 0. \quad \Rightarrow \quad f(\cdot) = F \tag{22}$$

Due to the complicated expression in (21), let us consider two extreme case of $\gamma = 0$ and $\gamma = 1$. Defining Δ = [LHS of (21) – LHS of (19)] and let $\gamma = 0$, we get that

$$\Delta(\gamma = 0) = \frac{A^2gmH_1}{(1+m)^2[B_1 - 2n]^3}, \tag{23}$$

where $H_1 = 4n^3 - B_1 g(1+n)[n(m-1)-1] - 2gn[(1+n)^3 + m(-2+n^2-n^3)]$.

We get that $\Delta(\gamma = 0) > 0$ as $H_1 > 0$. Since H_1 is decreasing in g, a lower g increases the possibility of $H_1 > 0$ or $\Delta(\gamma = 0) > 0$, suggesting excessive entry when knowledge spillovers is not existed.

Proposition 2: *The free entry number of downstream firms is greater than the number of firms in the welfare-maximizing equilibrium if the R&D investment without spillover is less costly when* $g < \hat{g}_1$ *, entry is socially excessive. However, if* $g > \hat{g}_1$ *, entry is socially insufficient.*

Proof:

$$g < \hat{g}_1 \equiv \frac{n\{m[2+(n-2)n] + \sqrt{2m(n-1)(n+1)[2-(n-2)n] + m^2[2+(n-2)n]^2 + (n^2-1)^2} - (n+1)^2\}}{(1+n)^2[n(m-1)-1]}$$

and then $\Delta(\gamma = 0) > 0$.

The economic reasoning for excessive entry is that with a high cost-reducing efficiency of R&D investment, marginal and incumbent firms are able to reduce the marginal cost of production, and also due to the competition prevailed in the upstream market, the fraction of the profits of the downstream firms is less extracted by the upstream producers. Hence, the marginal entrant is able to extract the benefits from entry, thus increasing the incentive for entry.

Next we consider the case of $\gamma = 1$. We get that

$$\Delta(\gamma = 1) = \frac{A^2 gmH_2}{(1+m)^2[B_1 - 2n]^3}. \qquad (23')$$

where $H_2 = 4n^3 - 8mn - B_1 g(1+n)[n(m-1)-1] - 2gn(1+n)[(1+n)^2 + m(n^2-6)]$. Since H_2 decreases with g, a lower g increases the possibility of $\Delta(\gamma = 1) > 0$, suggesting excessive entry even if knowledge spillovers is existed. In the case of $\gamma = 1$, the critical value of g for $\Delta(\gamma = 1) > 0$ is

$$\hat{g}_2 \equiv \frac{\sqrt{n}\sqrt{n - 2n^3 + n^5 + m^2 n[28 + n(n^3 - 12n - 8)] + 2m(n^2-1)\{[n(n+4)-2]-4\}} - n[(1+n)^2 + m(n^2-6)]}{(1+n)^2[n(m-1)-1]}$$

and then $\Delta(\gamma = 1) > 0$.

In the following Figure 1, letting $\Delta g = \hat{g}_1 - \hat{g}_2$, we can get $\Delta g = \hat{g}_1 - \hat{g}_2 > 0 \quad \forall$ $m, n > 0$.

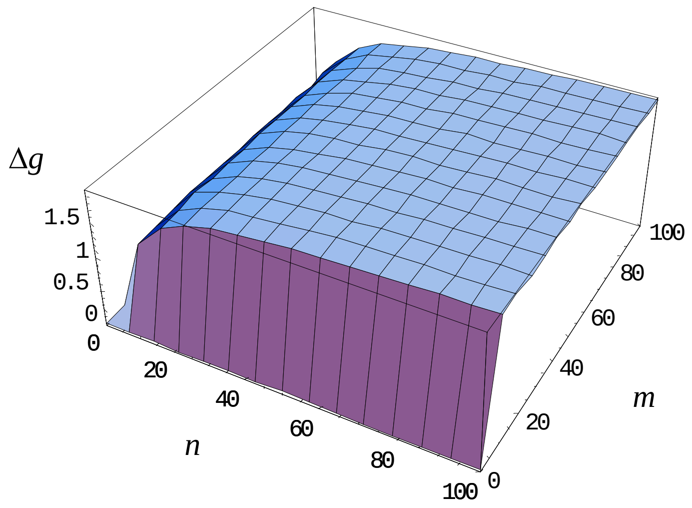

Figure 1

In the presence of knowledge spillovers, excessive entry result still holds even if a lower $\hat{g}$ indicating a relatively higher efficiency in the R&D technology. Accordingly, Proposition 2 is robust.

5. R&D-Input Price-Quantity Competition

We next will consider the scenario where the final goods producers invest in R&D firstly, then the upstream firms decide the input price.

In the last stage, the equilibrium outputs are

$$q_i^* = \frac{a - n(w + d - x_i - \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) + \sum_{\substack{s=1 \\ i \neq s}}^{n} (w + d - x_s - \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j)}{1 + n}. \tag{13}$$

In the second stage, the derived demand for the intermediate goods follows from (13), and it is given by

$$w = a - d + n(x_i + \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) - \sum_{\substack{s=1 \\ i \neq s}}^{n} (x_s + \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j) - \frac{(1+n)q_I}{n}$$

$$= a - d + n(x_i + \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) - \sum_{\substack{s=1 \\ i \neq s}}^{n} (x_s + \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j) - \frac{(1+n)mq_j}{n}. \tag{24}$$

The equilibrium output of the *j*th intermediate goods producer is

$$q_j = \frac{a - d + n(x_i + \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) - \sum_{\substack{s=1 \\ i \neq s}}^{n} (x_s + \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j) - cn}{(1+m)(1+n)}. \tag{25}$$

The equilibrium price of intermediate good is computed as

$$w^* = a - d + n(x_i + \gamma \sum_{\substack{s=1 \\ i \neq s}}^{n} x_s) - \sum_{\substack{s=1 \\ i \neq s}}^{n} (x_s + \gamma \sum_{\substack{j=1 \\ j \neq s}}^{n} x_j) + \frac{cm}{1+m}. \tag{26}$$

The *i*th final goods producer, $i = 1, 2, ..., n$, then maximize the following expression to determine the R&D investment:

$$\pi_i = (a - \sum_{i=1}^{n} q_i^* - w^* - d - x_i + \gamma \sum_{\substack{s=2 \\ i \neq s}}^{n} x_s) q_i^* - \frac{g x_i^2}{2}, \tag{27}$$

where q_i^* is given in (13).

The equilibrium R&D investments are

$$x_i^* = \frac{2(a-c-d)m^2[n(1-\gamma)+\gamma]}{B_2 - 2m^2[n(1-\gamma)+\gamma][1+(n-1)\gamma]}, \quad i = 1, 2, ..., n, \tag{28}$$

where $B_2 \equiv g(1+m)^2(1+n)^2$. $B_2 - 2m^2[n(1-\gamma)+\gamma][1+(n-1)\gamma] > 0$ if $g > \tilde{g}_3 \equiv \frac{2m^2[n(1-\gamma)+\gamma][1+(n-1)\gamma]}{(1+m)^2(1+n)^2}$, which guarantees that the R&D investment is positive. The second order condition $g > \tilde{g}_4 \equiv \frac{2m^2[n(1-\gamma)+\gamma]^2}{(1+m)^2(1+n)^2}$ makes $d - x_i^* > 0$. To assure $d - x_i^* > 0$, $\tilde{g}_3 > \tilde{g}_4$ for $\gamma > \frac{1}{2}$ while if $\gamma < \frac{1}{2}$, $\tilde{g}_3 < \tilde{g}_4$. Hence, $g > \max[\tilde{g}_3, \tilde{g}_4]$ is needed for finding a positive interior solution of the equilibrium R&D investment.

The net profit of the *i*th final goods producer, $i = 1,...,n$ is

$$\pi_i = \frac{A^2 g m^2 \{B_2 - 2m^2[n(1-\gamma)+\gamma]^2\}}{\{B_2 - 2m^2[n(1-\gamma)+\gamma][1+(n-1)\gamma]\}^2} - F . \tag{29}$$

Free entry equilibrium number of final goods producers is given by $\pi_i^* = 0$, or

$$\frac{A^2 g m^2 \{B_2 - 2m^2[n(1-\gamma)+\gamma]^2\}}{\{B_2 - 2m^2[n(1-\gamma)+\gamma][1+(n-1)\gamma]\}^2} = F . \tag{30}$$

Now we find the welfare-maximizing number of downstream firms. Social welfare is

$$SW = \frac{A^2 gmn[B_2(2+2m+2n+mn) - 4m^3(n+\gamma-n\gamma)^2]}{2\{B_2 - 2m^2[n(1-\gamma)+\gamma][1+(n-1)\gamma]\}^2} - nF . \tag{31}$$

The welfare-maximizing number of downstream firms is given by

$$dSW/dn = f(a,c,d,g,m,n,\gamma) - F = 0. \quad \Rightarrow \quad f(\cdot) = F \tag{32}$$

Defining Δ = [LHS of (32) – LHS of (30)], we get that

$$\Delta(\gamma=0) = \frac{A^2 gm\{-2g^2(1+m)^4(1+n)^3[n(m-1)-1] + 4g(m+m^2)^2 n[1+2m-(3+m)n^2+(m-2)n^3]\}}{2[B_2 - 2m^2 n]^3} \quad \text{and}$$

$$\Delta(\gamma=1) = \frac{A^2 gm\{-16m^5 n - 2g^2(1+m)^4(1+n)^3[n(m-1)-1] - 4gm^2(1+m)^2 n(1+n)[-1-6m+n+(2+m)n^2]\}}{2[B_2 - 2m^2 n]^3} .$$

Again, we have $\Delta(\gamma=0) > 0$ as $g < \hat{g}_3$, and $\Delta(\gamma=1) > 0$ as $g < \hat{g}_4$, where

$$\hat{g}_3 \equiv \frac{2m^2 n\left[1+2m-(1+2m)n+(m-2)n^2\right]}{(1+m)^2(1+n)^2[n(m-1)-1]} \quad \text{and,}$$

$$\hat{g}_4 \equiv \frac{m^2\sqrt{n}\sqrt{n(-1+n+2n^2)^2 + m^2 n[28+n(n^3-12n-8)] + 2m(n-2)(n+1)\{[n(2n+3)-6]-2\}} - m^2 n[-1-6m+n+(2+m)n^2]}{(1+m)^2(1+n)^2[n(m-1)-1]}$$

suggesting excessive entry still holds whether knowledge spillovers is prevailed or not.

Proposition 3: *The free entry number of downstream firms is greater than the number of downstream firms in the welfare-maximizing equilibrium if the R&D investment is less costly, and entry is socially excessive regardless of the order of R&D and input price decisions.*

Proof:

(i) $g < \hat{g}_3$ and then $\Delta(\gamma = 0) > 0$.

(ii) $g < \hat{g}_4$ and then $\Delta(\gamma = 1) > 0$.

6. R&D in the upstream sector

Now we want to show the welfare effects of downstream entry in the final goods market in the presence of R&D chosen by the upstream firms.

If n final goods producers enter the market, the ith final goods producer, $i = 1, 2, ..., n$, maximizes the following expression to determine its output:

$$\pi_i = (a - Q - w - d)q_i \ , \tag{33}$$

The equilibrium outputs are

$$q_i^* = \frac{a - w - d}{1 + n} \ . \tag{34}$$

The derived demand for the intermediate goods follows from (34), and it is given by

$$w = a - d - \frac{(1+n)}{n} q_I \ . \tag{35}$$

The equilibrium output of the jth intermediate goods producer is

$$q_j^* = \frac{n\{a - m(c - x_j - \gamma \sum_{\substack{k=1 \\ j \neq k}}^{m} x_k) + \sum_{\substack{k=1 \\ i \neq k}}^{m} [c - x_k - \gamma \sum_{\substack{j=1 \\ j \neq k}}^{m} x_j]\}}{(1+m)(1+n)} \ . \tag{36}$$

The equilibrium R&D investments are

$$x_j^* = \frac{2(a-c)n^2[m(1-\gamma)+\gamma]}{B_3 - 2n^2[m(1-\gamma)+\gamma][1+(m-1)\gamma]}, \quad j = 1,2,...,m \ , \tag{37}$$

where $B_3 \equiv g(1+m)^2(1+n)^2 m^2$. $B_3 - 2n^2[m(1-\gamma)+\gamma][1+(m-1)\gamma] > 0$ if $g > \tilde{g}_5 \equiv \frac{2n^2[m(1-\gamma)+\gamma][1+(m-1)\gamma]}{m^2(1+m)^2(1+n)^2}$, which guarantees that the R&D investment is positive. The second order condition $g > \tilde{g}_6 \equiv \frac{2n^2[m(1-\gamma)+\gamma]^2}{m^2(1+m)^2(1+n)^2}$ makes $d - x_i^* > 0$. To assure $d - x_i^* > 0$, $\tilde{g}_5 > \tilde{g}_6$ for $\gamma > \frac{1}{2}$ while if $\gamma < \frac{1}{2}$, $\tilde{g}_5 < \tilde{g}_6$. Hence, $g > \max[\tilde{g}_5, \tilde{g}_6]$ is needed for finding a positive interior solution of the equilibrium R&D investment.

The equilibrium price of intermediate good is computed as

$$w^* = \frac{a - d - cm}{1 + m} . \tag{38}$$

The net profit of the *i*th final goods producer, $i = 1,...,n$ is

$$\pi_i^* = \frac{(a-c)^2 g^2 m^4 (1+m)^2 (1+n)^2}{\{B_3 - 2n^2[m(1-\gamma)+\gamma][1+(m-1)\gamma]\}^2} - F . \tag{39}$$

Free entry equilibrium number of final goods producers is given by $\pi_i^* = 0$, or

$$\frac{(a-c)^2 g^2 m^4 (1+m)^2 (1+n)^2}{\{B_3 - 2n^2[m(1-\gamma)+\gamma][1+(m-1)\gamma]\}^2} = F . \tag{40}$$

Now we determine the welfare-maximizing number of downstream firms. Social welfare is

$$SW = \frac{(a-c)^2 gmn\{B_3(2m+2n+mn) - 4n^3[m(1+\gamma)+\gamma]^2\}}{2\{B_3 - 2n^2[m(1+\gamma)+\gamma)][1+(m-1)\gamma]\}^2} - nF . \tag{41}$$

The welfare-maximizing number of downstream firms is given by

$$dSW / dn = f(a,c,d,g,m,n,\gamma) - F = 0 . \quad f(\cdot) = F \tag{42}$$

Due to the complicated expression in (42), let us consider two extreme case of $\gamma = 0$ and $\gamma = 1$. Defining Δ = [LHS of (42) – LHS of (40)] and let $\gamma = 0$, we get that

$$\Delta(\gamma = 0) = \frac{(a-c)^2 g^2 m(1+m)^2 n(1+n) H_3}{[B_2 m - 2n^2]^3} . \tag{43}$$

where $H_3 = 2[m(n-4) - 2n]n - B_2 m(m-2)$.

We get that $\Delta(\gamma = 0) > 0$ as $H_3 > 0$. Since H_3 is decreasing in g, a lower g increases the possibility of $H_3 > 0$ or $\Delta(\gamma = 0) > 0$, suggesting excessive entry when knowledge spillovers is not existed.

Proposition 4: *The free entry number of downstream firms is greater than the number of downstream firms in the welfare-maximizing equilibrium if the R&D investment in the upstream sector without spillover is less costly when* $g < \hat{g}_5$*, entry is socially excessive. However, if* $g > \hat{g}_5$*, entry is socially insufficient.*

Proof:

$g < \hat{g}_5 \equiv \dfrac{2n[2n - m(n-4)]}{(1+m)^2(1+n)^2(m-2)m}$ and then $\Delta(\gamma = 0) > 0$.

Next we consider the case of $\gamma = 1$. We get that

$$\Delta(\gamma = 1) = \frac{(a-c)^2 g^2 (1+m)^2 n(1+n) H_4}{[B_2 m - 2n^2]^3}, \tag{43'}$$

where $H_4 = B_3(m-2) - 2n[-4n + 2mn + m^2(4+3n)]$. We get that $\Delta(\gamma = 1) > 0$ as $H_4 > 0$. Since H_4 is decreasing in g, a lower g increases the possibility of $H_4 > 0$ or $\Delta(\gamma = 1) > 0$, suggesting excessive entry when knowledge spillovers is existed.

Proposition 5: *The free entry number of downstream firms is greater than the number of downstream firms in the welfare-maximizing equilibrium if the R&D investment in the upstream sector with spillover is less costly when* $g < \hat{g}_6$*, entry is socially excessive. However, if* $g > \hat{g}_6$*, entry is socially insufficient.*

Proof:

$g < \hat{g}_6 \equiv \dfrac{2n[-4n + 2mn + m^2(4+3n)]}{(m+m^2)^2(1+n)^2(m-2)}$ and then $\Delta(\gamma = 1) > 0$.

From Propositions 4 and 5, we see that the entry of downstream firms is socially excessive if the R&D investment is less costly regardless of the degree of knowledge spillover when the R&D is committed by the upstream firms. The reasoning is that the strong profit-enhancing effect that results from the lower input price reflecting the low-cost R&D investment of the upstream firms exceeds the profit-reducing effect due to intensive competition in the final goods market.

7. Conclusion

In this paper, we offer a new perspective to the literature analyzing entry in a vertical structure by considering endogenous technology choice. We first show that, entry is socially excessive if either R&D is less costly or knowledge spillover is relatively high when the upstream firm's input price decision is prior to downstream firm's technology choice. In addition, we consider another order of game move between upstream firm's input price and downstream firm's technology choice, and show that entry is socially excessive regardless of the order of game moves; Furthermore, the entry of downstream firms is socially excessive if the R&D investment is less costly regardless of the degree of knowledge spillover when the R&D is committed by the upstream firms, thus justifying the anti-competitive regulation suggested by Mankiw and Whinston (1986).

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