

# **Variable Costs, Fixed Costs and Entry Deterrence**

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## **Abstract**

R&D is used by firms to reduce different types of costs including variable production costs and fixed production costs. An incumbent monopolist and a potential entrant can adopt R&D to reduce their costs with bidirectional technological spillovers- spillover from the incumbent to the entrant and from the entrant to the incumbent. Thereby, R&D that affects both variable production costs and fixed production costs has an impact on the profitability of entry. This paper models entry deterrence in the presence of cost reducing R&D. The paper will discuss R&D reducing variable costs and fixed costs. Then, in order to explore the decisions of entry deterrence and entry for an incumbent monopolist and a potential entrant, this paper will focus on two aspects of entry deterrence: fixed production costs as exogenous and fixed production costs as endogenous. Then the paper will focus on the fixed production costs as endogenous to build a model to analyze the strategic behavior of the incumbent.

**Keywords:** Cost reducing R&D; Entry deterrence; Spillovers; Fixed costs; Variable costs; Innovation

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## 1. Introduction

Research and development (R&D) is a general term for activities in connection with corporate or governmental innovation. These activities which are classified as R&D differ from firm to firm, but there are two primary models. The first one is with a R&D department being staffed with industrial scientists and tasked with applied research in scientific or technological fields which may facilitate future product development. The second one is a R&D department staffed by engineers and tasked with directly developing new products. In either case, we can see that R&D is different from the majority of corporate activities in that it does not generate immediate profit, and usually has greater risk and an uncertain return on investment. Therefore, R&D is generally applied by firms to develop new products and reduce different types of costs. According to the definition and properties of R&D, here I will mainly discuss in more detail R&D on the reduction of production costs with spillovers (leakages) from the incumbent to the entrant and from the entrant to the incumbent. A large literature focuses on variable production costs. Other studies focus on the effect of fixed production costs. However, the combined effect of fixed and variable costs on entry deterrence has been neglected.

In this paper, I turn my concern to the effect of both fixed and variable costs on entry deterrence. Something we need to pay attention to is the role of fixed costs in the model. There is a large literature about how fixed costs affect entry deterrence, but most of these studies treated fixed costs as exogenous. This implies that there are many factors which determine the entry decision of the firm. However, very few literatures focused on fixed costs as endogenous. Except for the paper of Hegji (2001), Atallah (2007) introduced fixed production costs, instead of variable production costs, into his model to analyze entry deterrence through fixed cost-reduction R&D.

This paper explores the role of R&D investments reducing fixed and variable production costs in entry deterrence in the presence of technological spillovers. We build a four-stage game-theoretic model to study the effect of these two production costs on entry deterrence. In the first stage, the incumbent makes its investment decisions which are observable. In the second stage, the entrant decides whether to enter or not. In the third stage, if the entrant enters, it invests in R&D. In the last stage, production and sales take place. We find that entry deterrence happens when the R&D spillover from the incumbent to the potential entrant is high, when the spillover from the potential entrant to the incumbent is low, and when fixed and variable costs are intermediate.

There is a large literature about cost reducing R&D with spillovers focusing on variable costs, as mentioned above, but very few papers studied fixed costs. That is what I will study in this paper, which is an extension of the model of Atallah (2007).

The structure of the paper is as follow: section 1 is introduction; section 2 presents the literature review; in section 3, I will build four-stage game model to analyze the strategic behaviour of the incumbent and potential entrant; in section 4, I will mainly discuss the effect of spillover; section 5 concludes.

## **2. Literature Review**

A large number of papers discuss the different kind of factors which have an impact on the decision of entry for a potential entrant and the entry deterrence strategies for the incumbent. Fixed production cost is not the only explanation for this problem. There are many factors which determine the entry decision of a firm. With bidirectional and asymmetric spillovers, R&D is not

only used by firms to introduce new products but also reduce firms' production costs. In what follows, we review some papers from the aspect of variable costs and fixed costs reduction R&D with spillovers.

Schwartz and Thompson (1986) showed that firms can beneficially forestall entry by creating new divisions. Their model gave us a clearer picture of the reason why it is less frequent to enter into profitable oligopolistic industries and why large firms in the high-profit oligopolies often divisionalize, which allows their divisions to freely compete. However, Veendorp (1991) criticized that the model used by Schwartz and Thompson did not explain why divisions are allowed to make their own operating decision but not the investment decision. Veendorp used a simple example to explain this question in the framework of Schwartz and Thompson by providing four scenarios.

Scenario A is that the divisionalized firm chooses the number of divisions, while divisions make all output and input decisions. The divisionalization decision cannot be reversed costlessly, but the capacity decision can. Under this situation, the equilibrium levels of divisional output and total gross profit are:

$$Q_{i,A}^* = f(a - w - r)/(a - f - w - r)$$

$$\pi_{G,A}^* = f(a - 2f - w - r)(a - w - r)^2/(a - f - w - r)^2$$

Scenario B: as A, except that the capacity decision cannot be reversed costlessly. Under this situation, the equilibrium levels of divisional output and total gross profit are:

$$Q_{i,B}^* = K_{i,B}^* = (f + r)(a - w - r)/(a - f - w)$$

$$\pi_{G,B}^* = (f + r)(a - 2f - w - r)(a - w - r)^2/(a - f - w)^2$$

Scenario C: as A, except that the divisionalized firm chooses the capacity level of each division, and this decision can be reversed costlessly. Under this situation, the reversibility of the capacity decision eliminates the firm's ability to deter entry and the rationale for divisionalization.

Scenario D: as A, except that the capacity decision cannot be reversed. Under this situation, the equilibrium levels of divisional output and total gross profit are:

$$Q_{i,D}^* = K_{i,D}^* = f + r$$

$$\pi_{G,D}^* = 2f(a - 2f - w - r)$$

Compared with these four scenarios, it is clear that scenario C is the least profitable one. With costlessly reversible investment decisions and a fixed coefficient production technology, a divisionalized firm should not centralize its decisions.

Pires and Catalão-Lopes (2013) studied the relationship between economies of scope and entry deterrence. They showed that the incumbent expands only when economies of scope are large enough. In other words, expansion is an important signal of scope economies and, for certain parameter values, leads to entry deterrence. Bandyopandhyay and Mukherjee (2014) explored what is the effect of entry by non-innovating firms if they want to cooperate with R&D of innovation firms. They found that entry by non-innovation firms might be more likely to either increase or decrease the incentive of cooperative R&D than no entry. Karaer and Erhun (2015) analyzed the role of quality as a competitive tool in a quality-price setting. They considered the incumbent's entry deterrence strategies using quality as a deterrent when faced by a potential entrant instead of fixed production costs.

An important study is "Sunk capacity costs, long-run fixed costs, and entry deterrence under complete and incomplete information" by Arvan (1986). Arvan showed that there might be

multiple equilibria of the complete information game. If the entrant is incompletely informed about the incumbent's cost, the entrant might use the capacity choice of the incumbent as a signal of the incumbent's cost. The model used in this article is a three-stage, extensive-form game where capacity is sunk but where fixed costs are not sunk. In stage one, the incumbent firm chooses its capacity and acts as a monopolist in the output market. In stage two, the potential entrant decides whether to sink the entry fee. In stage three, the incumbent acts as a monopolist if the potential entrant did not pay the entry fee in stage two. Then Lanny built a long-run cost function given as:

$$C_i(x_i) = f_i + w_i x_i + r_i c_i \text{ when } x_i > 0,$$

$$= 0 \quad \text{when } x_i = 0,$$

and a short- run cost function given by,

$$C_i^s(x_i, k_i) = C_i(x_i) \quad \text{if } x_i \geq k_i,$$

$$= f_i + w_i x_i + r_i k_i \text{ if } k_i > x_i > 0, \text{ and}$$

$$= r_i k_i \quad \text{if } x_i = 0.$$

where  $f_i$  is long-run fixed costs which are not sunk,  $r_i$  is the unit capacity cost which is sunk once installed. From the model Lanny built, we can see that fixed costs act like an endogenous variable and have influence on the level of output, profit and also play a role in entry deterrence. Then Lanny proposed two examples: a) the incumbent prefers a non-informative capacity signal; b) the entrant is incompletely informed. For the first example, the reason is that a non-informative capacity signal has the effect of reducing the scale of entry. The reason for the second example is that the incumbent makes a choice over production technologies that are

unobservable to the entrant. Finally, based on the results of the model, Lanny concluded that entry will occur at a smaller scale when the entrant is uninformed of the incumbent's cost function and the overall welfare effect is ambiguous.

Charles E. Hegji (2001) examined the impact of cost-reducing expenditures on output, profit and the number of firms under both free and blocked entry. At the beginning, the author assumed marginal cost is given, that is, treated the fixed costs as exogenous, and solved the Cournot equilibrium. Then Hegji made the marginal costs as a function of fixed costs, which treat the fixed costs as endogenous to study how cost-reducing expenditure affects output, profit and the number of firms to lead to entry deterrence. In this article, Hegji gave a relationship between fixed costs and marginal costs  $MC = K_1 - K_2 * FC$   $K_1, K_2 > 0$ . This equation implies that if an increase in fixed costs might be the result of new and improved production techniques, such costs may result in a decrease in marginal costs. Then Hegji discussed the optimal fixed costs, output and profits under blocked entry and the number of firms under free entry.

Under blocked entry, the optimal fixed costs for the monopoly and Cournot firms are:

$$FC_{\text{Monop}} = \frac{K_1 - a}{K_2} + \frac{2b}{K_2^2}$$

$$FC_{\text{Cournot}} = \frac{K_1 - a}{K_2} + \frac{(N + 1)^2 b}{2K_2^2}$$

From the above equation, it is shown that for all types of firms, optimal fixed costs decrease with  $a$ . Hegji stated that this implies that a vertical expansion in market size causes fewer fixed costs for all market structures. The author also said that fixed costs for both the monopolist and Cournot firms decrease if the parameter  $b$  decreases. This means that a horizontal expansion in market size reduces fixed costs.

And the output for the monopolist and Cournot firms are:

$$Q_{\text{Monop}} = \frac{1}{K_2}$$

$$Q_{\text{Cournot}} = \frac{N(N+1)}{2K_2}$$

It is clear that output is independent with respect to both parameters “a” and “b” for all market structures. And the profits for the monopolist and Cournot firms are:

$$\pi_{\text{Monop}} = \frac{K_2(a - K_1) - b}{K_2^2}$$

$$\pi_{\text{Cournot}} = \frac{K_2(a - K_1) - b \left[ \frac{N+1}{2} \right]^2}{K_2^2}$$

According to the two last equations, the profits for the monopolist are greater than the profits for the Cournot firms. Also, profits for both firms increase with “a” and decrease with parameter “b”.

Under free entry, the equilibrium number of firms is

$$N_{\text{Cournot}} = 2 \sqrt{\frac{K_2(a - K_1)}{b}} - 1 = 2K_2^{1/2}(a - K_1)^{1/2}b^{-1/2} - 1$$

It is shown that the number of firms in the Cournot situation increases if parameter a increases and parameter b decreases. Therefore, market growth leads to more firms. Finally, Hegji concluded that output and profits under blocked entry are sensitive to both vertical and horizontal market growth. And the optimal choice of fixed costs results in the equilibrium number of firms being more sensitive to vertical market growth.

However, very few studies focused on fixed costs as endogenous. Atallah (2007) stated that the possibility of performing R&D to reduce fixed production costs makes those costs endogenous. And this created a problem of entry deterrence in the presence of those endogenous costs. Atallah explored the role of R&D investment reducing fixed production costs in entry deterrence in the presence of technological spillovers. He found that the only way to deter entry is for the incumbent to underinvest in R&D. More specifically, deterrence is more likely to happen when the fixed cost is intermediate, when the spillover from the incumbent to the potential entrant is high and when the spillover from the potential entrant to the incumbent is low.

Olczak (2005) analyzed the strategic use of fixed costs to deter entry or monopolize a market in a standard Cournot model. Firstly, the author attempted to formalize the possibility of strategically raising the level of fixed costs in an industry. According to the analysis of this model, Olczak found that a strategy of symmetrically raising fixed costs is profitable. However, for the case where both firms can take action to increase fixed costs, it required that firms have either a first mover advantage in production or at least high enough probability to produce first. Then Olczak discussed the possible approaches to the equilibrium selection problems that occur when fixed costs are present which used two applications for a raising fixed cost strategy: regulation and “nuisance” law suits. After comparing these two applications, the author found that the use of regulation would more likely succeed in a dynamic setting if it involves an increase in fixed costs. Finally, Olczak investigated the strategic increase in fixed costs to deter entry or force a rival to exit the industry.

Ashiya (2002) considered a sequential entry game of homogenous firms in a vertically differentiated market. The author found that if the fixed cost is so large that subsequent entry is blocked, then the first firm will choose the highest quality. If the fixed cost decreases, it will

choose an intermediate quality to deter entry of a low quality firm. Therefore, everyone becomes worse off when the entrant is more dangerous. Ashiya indicated the optimal product of the first entrant as a function of fixed costs. And the first mover can choose both high-quality and low-quality products and could screen its consumers if there is no other firm. However, if there are potential entrants, the first mover must converge their products to deter entry in the top-quality range. Then Ashiya also showed that in order to deter the entry of a low-quality firm, the first mover needs to degrade their product quality if the fixed costs decrease.

Arvan (1986) showed that there might be multiple equilibria of the complete information game. If the entrant is incompletely informed about the incumbent's cost, it might use the capacity choice of the incumbent as a signal of the incumbent's cost.

As mentioned above, using R&D for firms can reduce their production costs such as variable and fixed production costs. A large number of literatures about cost-reducing R&D study the reduction of variable production costs. D'Aspremont and Jacquemin (1988) employed variable production costs in their duopoly model of R&D and spillovers to compare several equilibrium concepts. Vandekerckhove and Bondt (2008) analyzed the incentives of firms to invest in R&D when sequential moves are taken into account by using variable production costs in their model. Goel and Haruna (2011) built a model by applying variable production cost to get the results that optimal research subsidies differ under spillovers and no spillovers. However, just few papers focused on the fixed costs reducing R&D.

As for variable production costs reduction R&D, much of the literature about cost-reduction R&D is related to this methodology. Haaland and Kind (2008) examined the effect of policy changes on research subsidies and firm behavior in the context of international trade when there are deterministic process innovations. They found that optimal research subsidies, R&D, and

output can increase in the face of trade liberalization. They built the model from two sides: demand side and supply side. For the demand side, they supposed that there are two identical groups of consumers, and the population group size of each group  $i=1,2$  is equal to 1. There are two goods, A and B, demanded by consumers who have a quadratic utility function  $U_i$ . According to this quadratic utility function, Haaland and Kind expressed the consumer surplus and also the total consumer surplus. In order to find the inverse demand curve for two countries (consumers), they derived consumer surplus for country 1,2 with respect to the price of good A, B in country 1, 2 separately ( $\partial CS_i/\partial P_{Ai}=\partial CS_i/\partial P_{Bi}=0$  where  $P_{ji}$  denotes the price of good  $j$  in country  $i$ ) and let these derivatives equal to 0. For the supply side, they supposed that goods are produced by two independent profit maximizing firms  $j=1,2$ . Each firm might invest in R&D in order to improve the quality of the products it offers, so as to lead to a positive shift in the demand curve. Here, they used a quadratic R&D cost function  $C(X_j)=X_j^2$  where  $j=1,2$ . Then Haaland and Kind wrote the profit function of firm  $j$  as

$$\pi_j = (P_{j1} - c)Q_{j1} + (P_{j2} - c)Q_{j2} - X_j^2 + S_j X_j$$

where  $S_j$  denote the subsidy that firm  $j$  receives for each unit  $X_j$  of R&D.

The first two terms on the right hand side of the profit function represent the operating profit of selling good  $j$  in country 1 and 2, respectively. The third term is variable R&D costs, and the fourth term is the R&D subsidy. They studied the model as a two-stage game where R&D subsidies are set at stage 1, and the firms make decisions on investment in R&D and compete in quantities at stage 2. Then they solved the market equilibrium through backward induction and got four propositions from the relevant results of this market equilibrium.

However, in the paper of Haaland and Kind, they did not consider the effect of research spillovers. Goel and Haruna (2011) extended the previous analysis by incorporating research spillovers, allowing for imperfect appropriability of research returns. The authors introduced the degree of research spillovers  $\beta$  into the model based on the work of Haaland and Kind. Goel and Haruna defined  $0 \leq \beta \leq 1$ , with  $\beta = 0$  denoting no spillovers,  $0 < \beta < 1$  signifying imperfect spillovers, and  $\beta = 1$  denoting perfect spillovers. For the cost function, Goel and Haruna defined that the marginal production costs are constant, denoted by  $C$  and also added trade costs  $\tau$  into the supply side as an exogenous proxy. Thus, taking account of cost reduction by R&D process innovation and R&D spillovers, firm  $i$ 's production cost is reduced to  $C - X_i - \beta X_j$ . They changed the quadratic research cost assumption used in the model of Haaland and Kind, since the marginal production costs of firm  $i$  can be lowered by investing in R&D although these costs are constant in the units of production. Then they modified the total research costs  $C(X_i)$  as the sum of fixed outlays ( $F$ ) and variable outlays ( $X_i$ ), that is  $C(X_i) = X_i^2 + F$  instead of the quadratic research cost function,  $C(X_i) = X_i^2$ , in the paper of Haaland and Kind. Due to changes in the production cost function and R&D cost function, they rewrote the profit function as

$$\begin{aligned}\pi_i &= [P_{ii} - (C - X_i - \beta X_j)]Q_{ii} + [P_{ij} - (C - X_i - \beta X_j) - \tau]Q_{ij} - X_i^2 - F + S_i X_i \\ &= (\alpha - Q_{ii} - bQ_{ij} - C + X_i + \beta X_j)Q_{ii} + (\alpha - Q_{ij} - bQ_{jj} - C + X_i + \beta X_j^2 - \tau)Q_{ij} \\ &\quad - X_i^2 - F + S_i X_i\end{aligned}$$

The first two terms of this profit equation for firm  $i$  represent revenues net of production costs from domestic and foreign sales, the third term is R&D costs and trade costs, and the last term is R&D subsidies and benefits from own and foreign cost reduction. Similarly, Goel and Haruna studied this trade game for two steps where the government chooses optimal subsidy at

stage 1 and the firms choose the level of R&D and production at stage 2. In stage 1, the authors were interested in examining the level of optimal subsidies with spillovers and the effects of trade policy changes. In stage 2, they studied the impacts on R&D and production in the presence of spillovers. Then Goel and Haruna got the market equilibrium through assuming  $b=0$  in the demand relations and thus found several propositions from this new equilibrium.

According to the results, Goel and Haruna found that it differs from the result of Haaland and Kind, where the optimal trade policy of the domestic government is to subsidize domestic R&D with no spillovers. Goel and Haruna stated that Haaland and Kind's assumption did not hold any more if there are spillovers. Goel and Haruna also showed that R&D with spillovers affects the R&D policy of the domestic government. And depending on the level of spillovers, either subsidizing or taxing domestic R&D can be the optimal policy. With the presence of spillovers, the optimal subsidy or tax policy does not exist anymore at some specific level of spillovers although the market is separated into domestic and foreign. Moreover, foreign profits are greater than domestic profits with spillovers, because of an increase in cost reduction and subsequent output. Therefore, Goel and Haruna concluded that the domestic government would like to tax rather than subsidize domestic R&D. However, the domestic government prefers to subsidize domestic R&D if spillovers are modest, because domestic profits are greater than foreign profits. Finally, Goel and Haruna concluded that incorporation of R&D with spillovers in a two-stage game has crucial impacts on both stages.

Pan (2005) wrote that, in the presence of spillovers, the private R&D expenditure is lower than the socially desirable level. Spence (1984) concluded that potential performance is significantly better if spillover is high. Spillovers reduce the incentives for cost reduction and also the costs at the industry level of achieving a given level of cost reduction. He found from his

model that even if spillovers have negative effect on cost reduction and performance of firms, it still have other benefits. Firstly, the absence of spillover does not eliminate performance problems. In the first best unregulated market, the highest performance occurred when there are two firms and the spillover rate is 0.25. Secondly, he verified that appropriability increased industry R&D costs associated with a given level of cost reduction. If there is no spillover, then cost reduction would be too expensive. The reason is that each firm in this market would have to invest in its own R&D which leads to overinvestment in R&D. If spillover rate is equal to 1 or firms in the market share all their information with other firms, firms would have higher performance and more effective cost reduction with a small amount of R&D. Therefore, Spence suggested that if a government wants to provide incentives through subsidizing R&D, it would be better to do it at a higher spillover rate.

Moreover, Spence studied the case where a firm might “imperfectly anticipate or even ignore the effect of their own R&D investments on the costs of other firm industry prices”. Underestimating or ignoring spillovers had the impact of making the investment decisions of firms more aggressive. Pan intuitively commented that because of underestimating or ignoring spillovers, more aggressive R&D investments increase the possibility of deterring entry and reducing the number of potential entrants. So ignoring the effect of spillover is equivalent to removing a negative term in the expression for the marginal return on R&D investment. Spence found that if there are high spillovers but firms ignored the effect of spillovers on prices, then the market will perform much better than when firms share all of their information with each other. The advantage on performance comes from the increased efficiency of R&D investments. In addition, Spence found that, in the market with higher spillovers (higher than 0.25), ignoring the effect of spillovers would have a positive impact on the performance of firms. He gave an

positive example of electronic industries with higher spillovers but performing well in terms of dynamic technical efficiency.

However, Nakao (1989) found that if the spillover is high, the R&D equilibrium is not stable anymore. Because the R&D investment of rival firms can affect the firms' profits, the effect of a change in a firm's R&D investments on its own profits is exceeded by the total effect of a change in the R&D investments of the rival firms.

Until now, these two literatures focused on the models of variable costs reduction R&D with spillovers with simultaneous moves. Jan Vandekerckhove and Raymond De Bondt (2008) extended the model to a sequential game where there are leaders and followers in the market. They considered the oligopoly model which includes  $n$  firms competing with each other on the output market with a homogenous product. They defined that, in these  $n$  firms,  $k$  firms perform as leaders and  $n-k$  firms are followers, and assumed that leaders always move before followers in both investment stage and output stage. However, the difference between Jan Vandekerckhove, and Goel and Haruna, and Haaland and Kind is that Jan Vandekerckhove considered a four-stage setting. In the first stage, all  $k$  leaders make decisions on the level of strategic investment and also know that all  $n-k$  followers observe their efforts. In the second stage, followers choose their commitments to innovative efforts. In the third stage, after observing the investment level of the followers and anticipating the  $n$  output choices, leaders commit to an output level. In the fourth stage, followers choose their output based on the observation of the previous stages. Vandekerckhove added spillovers in stages 1 and 2 to consider the change of effects with spillovers or no spillovers between leaders in stage 1 and between followers in stage 2. To clearly analyze the different types of spillovers in different stages, Jan Vandekerckhove classified four types of spillovers: leader-specific spillovers, follower-specific spillovers,

spillover from leaders to followers and spillover from followers to leaders. As for the cost function, he proposed that all firms enter stages 1 and 2 with an ex ante unit cost  $C$ . Then, in stage 3, leaders have an ex post cost  $C_i^L$ . In stage 4, followers have an ex post cost  $C_j^F$ . He wrote the ex post cost function of leaders and followers with spillovers as:

$$C_i^L = C - [X_i^L + \beta_{LL} \sum_{l=1, l \neq i}^k X_l^L + \beta_{FL} \sum_{f=k+1}^n X_f^F] \quad i = 1, \dots, k$$

$$C_j^F = C - [X_j^F + \beta_{FF} \sum_{f=k+1, f \neq j}^n X_f^F + \beta_{LF} \sum_{l=1}^k X_l^L] \quad j = k + 1, \dots, n$$

Also Vandekerckhove defined that the costs as a function of the investment of output level are  $g(X)$  with diminishing return on investment, given by

$$g(X) = (\tau/2)X^2$$

Then he wrote the profit function of leaders and followers as:

$$\pi_i^L = (P - C_i^L)Q_i^L - g(X_i^L) \quad i = 1, \dots, k$$

$$\pi_j^F = (P - C_j^F)Q_j^F - g(X_j^F) \quad j = k + 1, \dots, n$$

Through finding Stackelberg equilibrium in output of stages 3 and 4, Vandekerckhove studied the impact of spillovers on R&D efforts, the impact of leading or following on R&D investments, the impact of cooperation on R&D investments, and the implications for static welfare.

Vandekerckhove showed that symmetric spillovers have a negative impact on cooperative investments of leaders and followers which is due to the spillovers from leaders to followers and the spillovers from followers to leaders. However, as for asymmetric spillovers, the directions are the same as the two-stage models with simultaneous moves. Second, with symmetric

spillovers, leaders always invest more than followers. And with asymmetric spillovers, the spillovers from leaders to followers are important for the comparisons of investments of leaders and followers. Third from the aspect of comparison of R&D cooperation and R&D competition, Vandekerckhove wrote that “With symmetric spillovers, investments of leaders with R&D cooperation are higher than with R&D competition, if the spillover is larger than  $(n - k + 1)/(n - k + 2)$ .” ( p.422)

Khazabi (2011) has used a model of d’Aspremont and Jacquemin type to analyze the impact of R&D spillovers on entry and the resulting equilibrium market structure. He found that the degree of spillovers plays a fundamental role on the number of firms entering the market, their R&D activities, and social welfare. His analysis suggested that social welfare is maximized at some intermediate degree of spillovers. The policy implication of this result is that neither complete protection of intellectual property right nor lax enforcement of patent laws is socially optimal. He realized that uncertainty and risk are important factors in R&D, which merit more attention. Therefore, Khazabi suggested that a more complete modeling of the innovation process should include an examination of the major drivers influencing the degree of spillovers: distance between the innovators, property rights, and the extent of telecommunication networks.

### **3. The Model**

In the market, there exist an incumbent and a potential entrant. The incumbent produces a good with a technology which involves variable and fixed production costs. If the incumbent is a monopolist in this market, the monopoly profit is  $\pi_m$ . The incumbent produces  $y_m$  and sells the product at price  $p_m$  as a monopolist. If the firm spends  $\gamma k_m^2/2$  on R&D, then it gets a cost

reduction  $k_m$  on variable production costs. If the firm spends  $\gamma x_m^2/2$ , then it reduces fixed production costs by  $x_m$ . However, if the incumbent is a non-monopolist in this market, its profit is  $\pi_i$ . The incumbent produces  $y_i$  and sells the product at price  $p$  as a non-monopolist. If the firm spends  $\gamma k_i^2/2$  on R&D, then it gets a cost reduction  $k_i$  on variable production costs. If the firm spends  $\gamma x_i^2/2$ , then it reduces fixed production costs by  $x_i$ .  $F$  is the fixed production cost for the incumbent and it can invest in R&D to reduce it. The subscript  $m$  refers to the monopolist incumbent and  $i$  refers to the non-monopolist incumbent,  $\gamma$  is a cost parameter for variable and fixed production costs – we assume that different kinds of production costs have the same cost parameter  $\gamma$  to enter this market, and the convex R&D cost function reflects a decreasing returns to scale in R&D.

For the potential entrant, it is able to enter this market before competition in the product market occurs. If the potential entrant decides to enter, then the incumbent will get profit  $\pi_i$ , with  $\pi_m > \pi_i > 0$ . Also, the entrant must afford the entry sunk cost  $S$  if it enters. Here  $S$  is assumed to be small enough so as not to make entry unprofitable:  $S < \pi_i$ . And once it enters, the entrant produces  $y_e$ , and must also incur the fixed production cost  $F$ . If the entrant spends  $\mu k_e^2/2$ , then it gets a cost reduction  $k_e$  on variable production costs; if it spends  $\gamma x_e^2/2$ , then it reduces fixed production costs by  $x_e$ .

We assume that firms can learn from each other's R&D which means R&D efforts are complementary. And the R&D investment of each firm produces R&D spillovers which reduce both variable and fixed production costs of the other firm.  $\beta_i \in (0,1]$  refers to the outgoing spillover from the incumbent to the potential entrant, and  $\beta_e \in (0,1]$  refers to the outgoing spillover from the potential entrant to the incumbent. All R&D investments are made before

product market competition occurs. The market is assumed to be always profitable for at least one firm in the absence of entry and R&D:  $\pi_m > F$ .

In the first stage of the game, the incumbent makes its investment decisions which are observable. In the second stage, the entrant decides whether to enter or not. In the third stage, if the entrant enters, it invests in R&D. In the last stage, production and sales take place.

If there is no entry, the incumbent performs as a monopolist, the profit of the monopolist incumbent is given by

$$\pi_m = p_m y_m - (\alpha - k_m) y_m - (F - x_m) - \gamma k_m^2 / 2 - \gamma x_m^2 / 2 \quad (1)$$

$$\text{where } p_m = a - b y_m$$

If entry occurs, then the profits of the incumbent and the entrant are given by

$$\pi_i = p y_i - (\alpha - k_i - \beta_e k_e) y_i - (F - x_i - \beta_e x_e) - \gamma k_i^2 / 2 - \gamma x_i^2 / 2 \quad (2)$$

$$\pi_e = p y_e - (\alpha - k_e - \beta_i k_i) y_e - (F - x_e - \beta_i x_i) - \gamma k_e^2 / 2 - \gamma x_e^2 / 2 - S \quad (3)$$

$$\text{where } p = a - b(y_i + y_e)$$

We can see that if there is no entry the incumbent will have higher operational profits, but cannot get any benefit from investment in R&D of the potential entrant. However, if entry occurs, the incumbent benefits through spillovers from the investment in R&D of the potential entrant, but it loses from product market competition. Both cases reflect that the profit of the incumbent is affected by the fact that the threat of entry will influence the choice of R&D investment. R&D investment allows the incumbent to reduce both its variable and fixed production costs. However, at the same time, reducing these costs may give the potential entrant

a chance to get into the market. Therefore, the incumbent may want to use its R&D investment to deter entry.

Because the optimal outputs of the incumbent and potential entrant are unknown, we need to find their values by maximizing their profit under two situations: blocking and entry. If there is no entry, then the profit-maximizing output of the incumbent is given by

$$y_m = (a + k_i - \alpha)/2b \quad (4)$$

If entry occurs, then the profit-maximizing output of the incumbent is given by

$$y_i = (a + 2k_i - k_e - \alpha - k_i\beta_i + 2k_e\beta_e)/3b \quad (5)$$

If entry occurs, then the profit-maximizing output of the entrant is given by

$$y_e = (a - k_i + 2k_e - \alpha + 2k_i\beta_i - k_e\beta_e)/3b \quad (6)$$

After we get the optimal outputs of the incumbent and the potential entrant under these two scenarios, we can substitute them into their profit functions and get their optimal investments in R&D. Thus, substituting (4), (5) and (6) into (1), (2) and (3), we get the optimal investments in R&D separately as following.

If there is no entry, then the profit-maximizing investments in R&D of the incumbent are given by

$$k_m = (a - \alpha)/(2b\gamma - 1) \quad (7)$$

$$x_m = 1/\gamma \quad (8)$$

We can get the above answers simply through equating the marginal revenues from investment to the marginal costs of R&D. If entry occurs, then the profit-maximizing investments in R&D of the incumbent are given by

$$k_i = \frac{-\{2(a-\alpha)(-2+\beta_i)[4+2(-3+\beta_e)\beta_e-3b\gamma]\}}{4(-2+\beta_i)(-2+\beta_e)(-1+\beta_i\beta_e)+6b[8+(-4+\beta_i)\beta_i+(-4+\beta_e)\beta_e]\gamma-27b^2\gamma^2} \quad (9)$$

$$x_i = 1/\gamma \quad (10)$$

If entry occurs, then the profit-maximizing investments in R&D of the entrant are given by

$$k_e = \frac{-\{2(a-\alpha)(-2+\beta_e)(4+2(-3+\beta_i)\beta_i-3b\gamma)\}}{\{4(-2+\beta_i)(-2+\beta_e)(-1+\beta_i\beta_e)+6b(8+(-4+\beta_i)\beta_i+(-4+\beta_e)\beta_e)\gamma-27b^2\gamma^2\}} \quad (11)$$

$$x_e = 1/\gamma \quad (12)$$

These solutions are the privately optimal investments. When there is no entry, only (8) will be the socially optimal investment, because the monopolist incumbent generates all the benefits from R&D.

The four-stage game is solved backwards to ensure subgame perfection. In the first stage, the incumbent makes its investment decisions which are observable. In the second stage, the entrant decides whether to enter or not. In the third stage, if the entrant enters, it invests in R&D. In the last stage, production and sales take place.

### 3.1 Strategic Behaviour

Now we discuss the incentives for entry and entry deterrence.

#### 3.1.1 Blocking

Entry is blocked when the entrant has no profits to gain in this market even though the incumbent does not behave strategically. In this case, the monopolist incumbent chooses (4) and

(5) as R&D investments on variable and fixed production costs. Substituting (4) and (5) into (1) generates the profit of the monopolist incumbent when entry is blocked, which is

$$\pi_m = \{-1 + 2(b + F)\gamma + (-4bF + (a - \alpha)^2)\gamma^2\} / 2\gamma(-1 + 2b\gamma)$$

This profit of the incumbent occurs if the entrant finds that there is no benefit to gain in this market, even if it optimally invests in R&D, as given by (11) and (12). Substituting (7), (8), (11) and (12) into (3) gives us the condition for blocking:

$$\pi_e^1 \leq 0$$

Solving for F yields the minimal value of F allowing blocking  $F_B$ . The subscript B refers to the critical value of F which separates deterrence from blocking. If  $F < F_B$ , then entry is not blocked, and the entrant would find a way to make a profit in this market, so it would choose to enter, given the investment levels of the incumbent (7) and (8). Now the only method which the incumbent can use to deter entry is through its R&D investments, the  $k_m$  and  $x_m$  as innovation. We know that because of the existence of  $\beta_i$ , the entrant would get benefits from the incumbent's investments. Therefore, the incumbent should invest less in R&D than when there is no entry. However, the lower investment would reduce the profit of the incumbent, so it might choose the highest level of R&D investment ( $k_m$  and  $x_m$ ) which does not exceed (7) and (8) and also makes entry unprofitable for the entrant.

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<sup>1</sup> Some expressions are not shown due to their analytical complexity.

### 3.1.2 Deterrence

In this case,  $k_i$  and  $x_i$  represent the R&D investments of the incumbent on variable and fixed production costs under entry deterrence. If the entrant decides to enter, then its privately optimal R&D investments would be (11) and (12). Substituting (11) and (12) into (3), we get the profit of the entrant if it enters:  $\pi_e$ .

Then we solve for  $k_i$  and  $x_i$  by setting  $\pi_e=0$  to get the entry deterrence level of R&D investment of the incumbent. Since there are two variables ( $k_i$  and  $x_i$ ) and one equation ( $\pi_e = 0$ ), the solution of the entry deterrence level of R&D investment will be a relationship between the R&D investment on variable production costs  $k_i$  and the R&D investment on fixed production costs  $x_i$ :  $x_i^D$ .

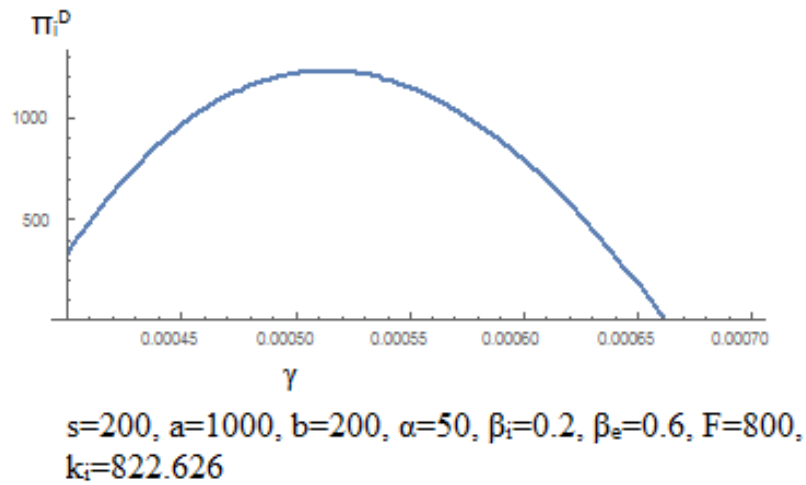
The R&D investment on fixed production costs  $x_i$  decreases as the R&D investment on variable production costs  $k_i$  increases:  $\frac{\partial x_i}{\partial k_i} < 0$  which means that  $x_i$  and  $k_i$  are substitutes; the incumbent can raise one and decrease the other while still deterring entry. The incumbent would choose the combination of  $x_i$  and  $k_i$  which gives it maximum profit. Here the question is whether the incumbent is indifferent between all combinations or not. Figure 2 illustrates the relationship between  $k_i$  and the profit of the incumbent. We can see that the incumbent is not indifferent between the different combinations. There is a unique (intermediate) value of  $k_i$  which maximizes the incumbent's profit.

Substituting  $x_i$  into (2) generates the deterrence profit of the incumbent which is a function of  $k_i$ :  $\pi_i^D(x_i(k_i), k_i)$ . Moreover, from figure 1, we can see that deterrence profits first increase with the cost of R&D and then decrease with it. Deterrence profits increase with the cost of R&D because higher  $\gamma$  makes deterrence easier by reducing  $x_e$ , which will increase the  $x_i$  of the

incumbent under entry deterrence. Thus, entry deterrence has a lower distortion on R&D investment. However, if the cost of R&D increases further and further, then the deterrence profit will decrease with  $\gamma$  because of the dominant negative effect on  $\pi_i^D$ .

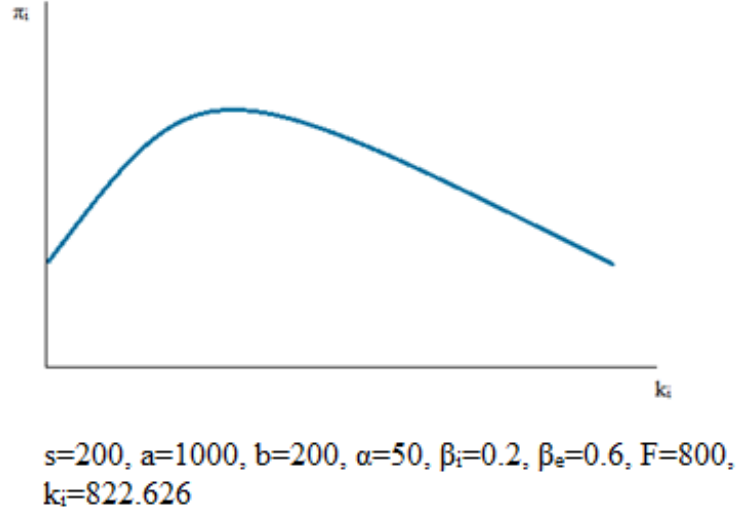
**Figure 1**

**Incumbent's Deterrence Profits as a Function of the Cost of R&D**



**Figure 2**

**Incumbent's Deterrence Profits as a Function of The R&D Investments on Variable  
Production Cost**



*3.1.3 Accommodation*

We solve the game by using backward induction, so first we maximize the profit of the entrant (3) to get the optimal private R&D investments for the entrant, which are given by (11) and (12). If the incumbent accommodates entry, then the R&D investments of the incumbent and the entrant would be the same  $k_v = -\{2(a - \alpha)(-2 + \beta_v)(4 + 2(-3 + \beta_v)\beta_v - 3b\gamma)\} / \{4(-2 + \beta_i)(-2 + \beta_e)(-1 + \beta_i\beta_e) + 6b(8 + (-4 + \beta_i)\beta_i + (-4 + \beta_e)\beta_e)\gamma - 27b^2\gamma^2\}$  and  $x_v = 1/\gamma$ . The subscript v represents the R&D investment both of incumbent and of entrant. By substituting these levels of R&D investments into (2) we get the accommodation profit of the incumbent:  $\pi_i^A$

### 3.1.4 Comparison

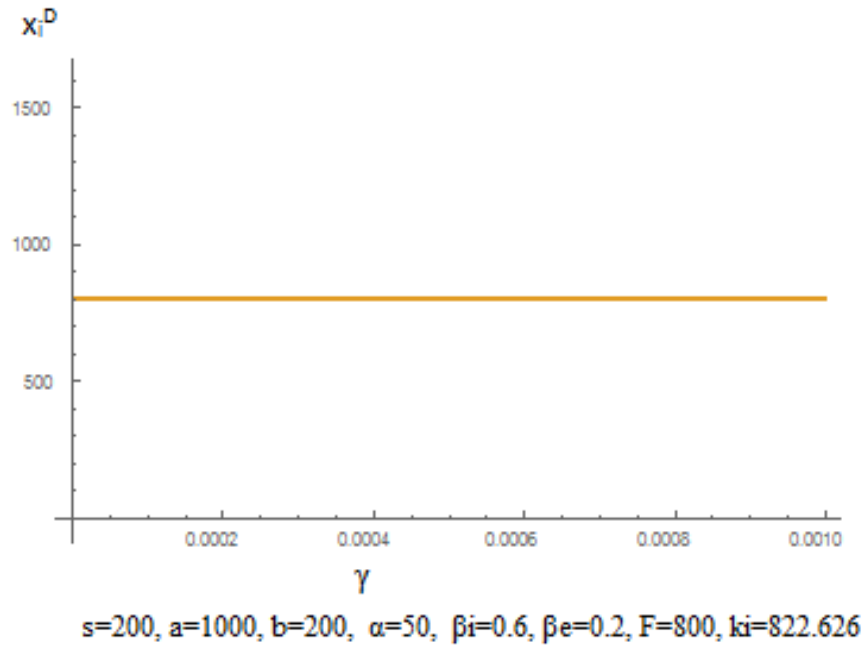
Until now, we analyzed the profits of the incumbent and the potential entrant under three situations: blocking, deterrence and accommodation. In this section we analyze which strategic behaviour the incumbent will choose between entry deterrence and accommodation. Therefore, we need to compare the profits of the incumbent under entry deterrence and under accommodation. If  $\pi_i^A > \pi_i^D$ , the incumbent would choose to accommodate; otherwise, it will choose to deter entry. When  $\pi_i^A = \pi_i^D$ , the fixed production cost  $F_{AD}$  is given by  $F_{AD}$ .

Because  $\frac{\partial \pi_i^D}{\partial F} < 0$ , this means that a lower  $F$  generates a higher profit and less distortion in R&D investment. Entry deterrence is more likely to happen in this case. Therefore, when  $F < F_{AD}$ , the incumbent would prefer entry deterrence to accommodation. However, if  $F_B > F > F_{AD}$ , the incumbent prefers accommodation.

Another restriction is that we need to verify that  $x_i^D > 0$ . Figure 3 illustrates the relationship between  $x_i^D$  and  $\gamma$ . From the figure we can see that, irrespective of the value of  $\gamma$ ,  $x_i^D$  is always positive. In other words, no matter what is the cost of R&D, the investments in R&D are always positive. Therefore, we do not have to explicitly impose  $x_i^D > 0$ .

**Figure 3**

**The Relationship Between the Cost of R&D and the R&D Investment on Fixed Cost Under Deterrence**

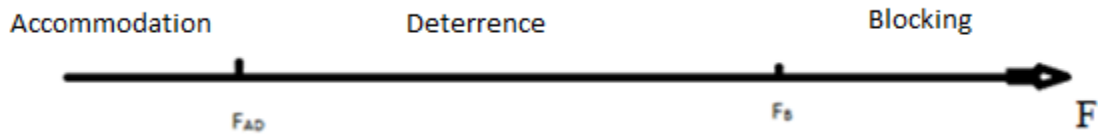


*3.1.5 Summary of strategic behaviours*

According to the analysis of the three cases considered above, figure 4 illustrates the different behaviours as a function of  $F$ .

**Figure 4**

**Fixed costs and equilibrium outcomes**



As discussed in section 2.1.4, if  $F < F_{AD}$ , the incumbent prefers entry deterrence to accommodation. This relationship is clearly reflected in figure 4

Figures 5 and 6 show the relationship between the profits of the incumbent and  $F$  and  $k_i$  corresponding to figure 4. As we can see, the profit of the incumbent always decreases with  $F$  whether it is under blocking, accommodation or deterrence. And the profit of the incumbent takes its maximum value under blocking, then decreases under accommodation and increases under entry deterrence.

Therefore, we can say the following about the strategic behaviour of the incumbent:

- When  $F > F_B$ , entry is blocked and  $x_i = 1/\gamma$ ;
- When  $F_B > F > F_{AD}$ , entry is accommodated because  $\pi_i^A > \pi_i^D$ . Moreover,  $x_i = 1/\gamma$ ;
- When  $F < F_{AD}$ , the incumbent deters entry by investing  $x_i < 1/\gamma$ ;

with  $F_B$ ,  $F_{AD}$  and  $x_i^D$  given by (13), (15) and (14).

Figure 5

Equilibrium Profits on Fixed Production Costs

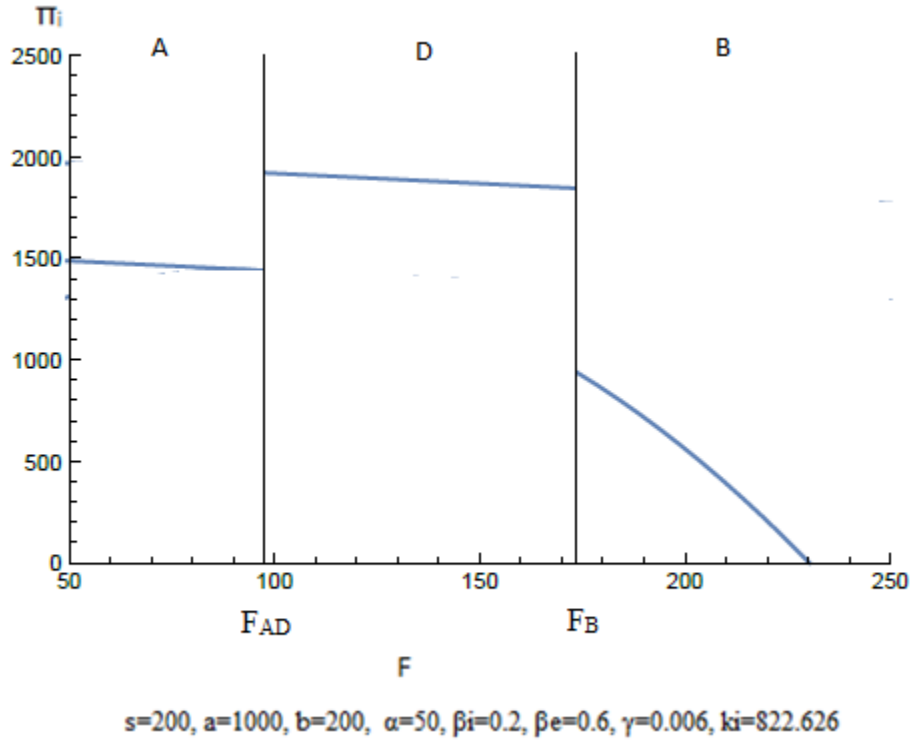
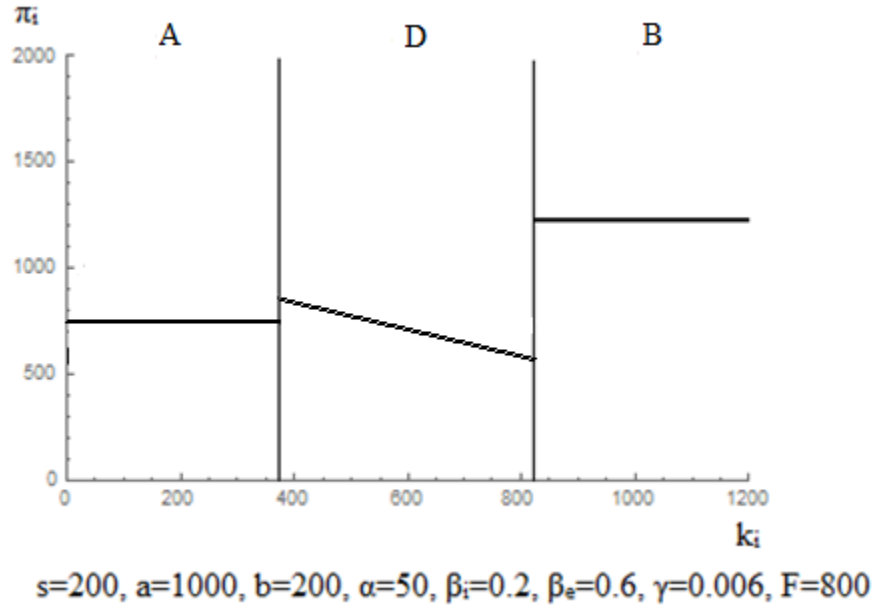


Figure 6

Equilibrium Profits and Variable Production Costs



#### 4. The effect of spillovers

Spillovers play an important role in our model. Until now, we mainly discussed the impact of  $F$  on the strategic behavior of the incumbent. It is also essential to analyze how spillovers influence the decision-making of the incumbent.

There are three situations the incumbent can be in: blocking, deterrence and accommodation. As for the spillover under blocking, solving  $\pi_e^B$  for  $\beta_i$  yields the critical value for blocking ( $\beta_i^B$ ).

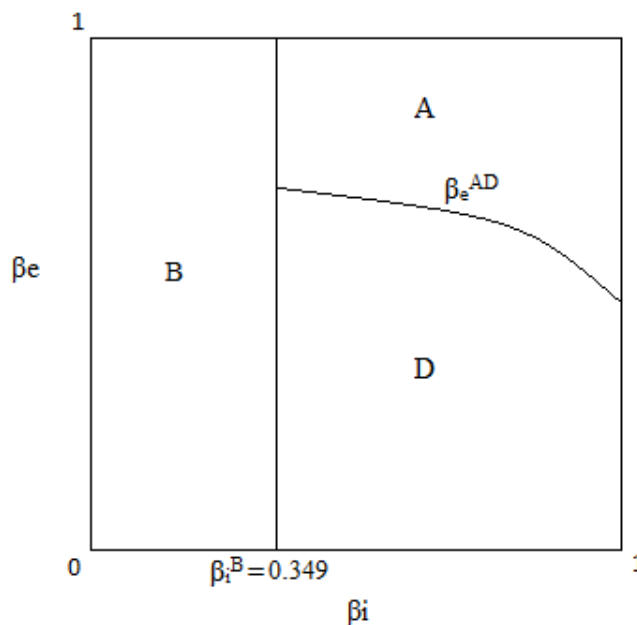
As for the spillover under deterrence and accommodation, the incumbent needs to choose between them by comparing the value of spillover  $\beta_e$ . Equating  $\pi_i^D$  and  $\pi_i^A$  and solving for  $\beta_e$  gives us  $\beta_e^{AD}$ .

Given the above results, we can conclude that, entry is blocked if  $\beta_i < \beta_i^B$ ; when  $\beta_i < \beta_i^B$ , entry is deterred if  $\beta_e < \beta_e^{AD}$ , and is accommodated if  $\beta_e > \beta_e^{AD}$ . This clearly reflects how the strategic behavior of the incumbent depends on spillovers. And it is also easy to verify that  $\frac{\partial \beta_e^{AD}}{\partial \beta_i} < 0$ .

It is helpful to illustrate these results graphically. We can study the effect of spillovers by fixing other variables in the model and varying  $\beta_i$  and  $\beta_e$ . Figure 7 shows the relationship between spillovers  $\beta_i$  and  $\beta_e$  under the three types of equilibrium.

**Figure 7**

**Equilibrium Outcomes**



We can see from the figure that blocking occurs when  $\beta_i$  is low. And when  $\beta_i$  is moderate or high (higher than  $\beta_i^B$ ), the incumbent would not block entry anymore. It has to choose between deterrence and accommodation. When  $\beta_e$  is high (higher than  $\beta_e^{AD}$ ), the incumbent would prefer accommodation. When  $\beta_e$  is low (lower than  $\beta_e^{AD}$ ), the incumbent prefers deterrence. Therefore,

the value of  $\beta_i$  mostly influences the degree of blocking, a higher  $\beta_i$  decreases blocking and facilitates both accommodation and deterrence. However,  $\beta_e$  does not have any impact on the blocking decision. A higher  $\beta_e$  increases accommodation, decreases deterrence and has no effect on blocking; it has no effect on blocking because it only affects the extent to which the incumbent benefits from  $x_e$ .

#### **4. Conclusion**

This paper shows how R&D investments on both variable and fixed production costs can be used by an incumbent to deter entry. From the above results, we can see that entry deterrence happens when the spillover from the incumbent to the potential entrant is high, when the spillover from the potential entrant to the incumbent is low and when fixed and variable costs are intermediate.

A large number of studies treat fixed production costs as exogenous. This means that most of researchers thought that fixed costs have no significant influence on the entry decision of a potential entrant or on the entry deterrence behavior of an incumbent. However, there are still a few literatures which treat fixed production costs as endogenous. The results derived here imply that fixed costs play an important role in entry deterrence.

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