JOINT RESEARCH AND DEVELOPMENT: THE LURE OF DOMINANCE

by

D. A. SOBERMAN*

97/48/MKT

* Assistant Professor of Marketing at INSEAD, Boulevard de Constance, Fontainebleau 77305 Cedex, France.

Joint Research and Development: The Lure of Dominance

David Soberman
INSEAD

April 1997

Abstract

In this paper, we examine how the incentives of incumbent firms in an industry to jointly pursue research and development projects are affected by the potential entry of a new competitor who has access to existing production technology. We focus on risky research and development projects which can provide production cost reductions. The tendency of firms to act strategically to prevent the entry of a potential competitor is underlined by the work of Dixit (1979; 1980). The benefits of research joint ventures are also considered by Kamien, Muller and Zang (1992) and Bhattacharya, Glazer and Sappington (1992). A natural extension of this work is the possibility of investing in risky R&D focused on process innovation to manipulate the attractiveness of a market for a potential entrant. This research considers a stable market where competitors are engaged in Cournot (quantity competition). Two symmetric incumbents decide between the individual or joint pursuit of a stylized R&D project and an entrant with existing technology makes a decision whether or not to enter the industry after the completion of these R&D efforts. The key question addressed in this research is how are the incumbents' R&D decisions affected by the threat of entry. To analyze this issue it proves useful to develop a taxonomy for process innovations based on their potential market impact. Borrowing from Arrow (1962), we define a drastic innovation as one of sufficient magnitude that a sole owner can monopolize a market. Conversely, we define as non-drastic, an innovation that simply allows a sole owner to increase both market share and profit, but not force its competitors from the market. In a market with three competitors, there are also innovations of an intermediate nature that are not drastic (i.e. a sole owner cannot monopolize the market) yet are of sufficient magnitude such that two owners of the innovation can force a third firm from the market. We define innovations of this intermediate character as being semi-drastic. The basic finding of Dixit is recovered in this paper in that incumbents will alter their research and development policies to affect the decision of an entrant. Specifically, the threat of entry causes incumbents to increase their tendency to cooperate in the case of non-drastic innovations. With non-drastic innovations, cooperation allows incumbents to share costs and capitalize on the positive externality created by increasing the likelihood that the entrant faces two strong incumbents. Surprisingly however, with R&D projects directed towards

drastic innovations, the incidence of cooperation is unchanged. The reason for this is that another force affects the decisions of incumbents. We call this force the "lure of dominance" and define it as the degree to which profit increases for the sole owner of an innovation as function of the innovation's magnitude. (This force in large part explains why in the absence of a potential entrants many firms prefer to pursue R&D individually). The "lure of dominance" pulls incumbents towards non-cooperation whereas "cost saving" and reduced production by the entrant pulls the incumbents towards cooperation. With the potential of a third participant in the market, the "lure of dominance" is high, most notably with drastic innovations and this reduces the attractiveness of joint R&D.

Key Words: Joint R&D, threat of entry, process innovation, barriers to entry, strategic cooperation, Cournot competition

1.0 Introduction

The objective of this paper is to analyze how the R&D policy of existing firms in an industry can be affected by the threat of potential entry. Specifically we consider the incentives firms have to cooperate on research and development projects (while remaining fully competitive in the product market) when faced with a threat of entry by a new competitor. This is an important issue for two reasons.

First, as noted by Larreché and Weinstein (1988), there is a preponderance of joint R&D activity in industrial markets. Blau (1994) reports that collaborative R&D to develop new products and improve processes is both on the increase and prevalent across industries from chemicals and autos to new materials and microelectronics. Recent examples of joint R&D activity between competitors include the efforts of Digital and Mitsubishi to develop the Alpha chip for personal computers, IBM and Toshiba's joint venture Display Technologies Inc. for the development of thin film transistor liquid crystal displays, and the joint venture of several European airlines to develop *Amadeus*, a reservation system similar to American Airlines' *Sabre* system[1]. The reporting of joint R&D undoubtedly under-represents the extent of this activity due to natural censoring which occurs. Natural censoring occurs because journalists have a tendency to focus on successful research ventures while unsuccessful research initiatives receive minimal coverage. In addition, firms have few reasons to publicize their cooperation given the scrutiny it may stimulate on the part of government and its associated agencies[2].

---

[1] Various references to these projects are found in the popular literature. A specific list of citations is available form the author on request.
[2] These include the FTC in the United States, the Competition Tribunal in Canada and in Europe , the EU antitrust authority.

Second, many reasons are cited as rationales for cooperation with respect to R&D initiatives including risk reduction (by decreasing the overall capital needed to pursue a given line of research) and avoiding capital constraints that prevent a firm from pursuing a project individually. These are all important reasons for joint R&D work (and in the case of high technology industries may be sufficient). However in a vast array of industries from consumer packaged goods to more mundane industrial products, risk and capital constraints do not provide a basis for joint R&D activity because the firms are ostensibly risk neutral and have easy access to capital markets. In spite of this, we observe firms working together to develop process innovations (often through industry associations).

Clearly there are situations where firms cooperate simply because of the economics of the endeavor. This occurs when the probability of the projects being successful is so high that the firms effectively share and (thereby) reduce costs. It also happens when the project is only feasible given that its costs are shared. This being said it is nonetheless apparent that decisions to cooperate may be affected when there is a potential competitor waiting 'in the wings'. Cooperating in such a situation might have two effects. First, it might make a previously unfeasible project attractive, simply because the market is less attractive with the entrant and having the innovation mitigates the decrease in overall market attractiveness. Second, it might make joint research more attractive because it internalizes a positive externality between two incumbents (each incumbent is privately better off because an entrant's actions are less harmful when both incumbents have the process advantage). Given these ideas, the objectives of this research are to develop a game theoretic model that provides insight into three questions:

1. How are the Joint Research Programmes of incumbents affected by the potential entry of a new competitor?

2. What are the major forces that cause the Joint Research Programs of incumbents to change?

3. What normative implications can we gain about the types of R&D where the threat of entry affects the decisions of industry incumbents?

We will focus on R & D, the goal of which is to identify procedures for reducing the marginal cost of producing products in a given market. Similar to Athey and Schmultzer (1995), we define this type of innovation as process innovation. Admittedly, a great deal of funds are spent on product innovation in terms of quality improvement (existing consumers gain increased utility from the product) or attribute modification and addition (new features allow the product or its line extensions to appeal to a broader set of consumers). These are important areas, but as a first step in gaining greater understanding of joint R&D, this research focuses on process innovation.

2.0 Literature Review

The formation of associations in industry have received considerable attention and the objectives of these associations invariably involve the sharing of costs, information, facilities or the adoption of common standards. Bloch (1995) notes that these associations are considered to be major factors in the profitability and technological innovation of many industries. There are a number of papers which examine the benefits of cooperative R&D but before proceeding with a discussion of this literature, it is important to draw attention to the different types of innovation that are commonly pursued through research and development.

Some research is purely speculative (i.e. developing products for markets that do not yet exist) however, a great deal of funds are invested by firms against existing products. Generally, these funds are directed towards identifying innovations that improve the quality or flexibility of existing products or that reduce the cost of producing them. Some innovations provide a combination of performance and cost improvement benefits but in most cases, an R&D project can be categorized based on whether its primary thrust is to affect the benefits that consumers obtain from the product or to provide benefits to the firm in terms of the production of the product (while leaving the product physically unchanged). An early reference to types of innovation is Abernathy and Utterback (1978) who study innovation over the course of the product life cycle. Athey and Schmultzer (1995) draw a clear distinction between process innovation and product innovation. They define process innovation as providing a reduction in the unit cost of production and product innovation as providing an upward shift in the demand curve. This distinction is close to the approach adopted in this paper and we focus our analysis on process innovation. It is important to note however, that product innovation is a richer concept than simply an upward shift in demand. Product innovation can of course, be an improvement in quality (which will generate an upward shift in demand). But it can also relate to the addition of new benefits that broaden the appeal of a product to other consumers. For detailed discussion of this issue refer to Gallini and Eswaran (1996).

Process innovations (i.e. that provide reductions in unit cost) are the focus of d'Aspremont and Jacquemin (1988) who examine the impact that cooperation and spillover effects have on the rate of technological advance in a Cournot duopoly. The model we utilize is similar; however, in contrast to d'Aspremont and Jacquemin, we focus on the strategic role of R&D in the absence of spillover effects. Kamien, Muller and Zang (1992) extend the model of d'Aspremont and Jacquemin to a market where

n-firms can adopt two levels of coordination, the first being a coordination of R&D expenditures and the second being a complete sharing of knowledge gained from R&D activity. The model of Bhattacharya, Glazer and Sappington (1992) considers a unique form of R&D joint venture where the outcome of the joint venture is used as input to firm proprietary R&D programs.

Following the work of Spence (1977), Dixit (1979; 1980) uses a Stackelberg model of sequential capacity choices to demonstrate the power of investment in deterring entry. In this vein, it follows that decisions about R&D can be used the same way. Similar to investment in capacity, R&D clearly has strategic value as incumbents armed with new innovations may make markets less attractive for a potential entrant. Adams and Encaoua (1994) examine the activity of a monopolist faced with a potential entrant and they find that a monopolist might invest in technologies that are socially undesirable in order to prevent the entry of a new competitor. The work to date mentions but does not explicitly consider the strategic benefits of cooperation on R&D projects. One limitation of existing research is that R&D is generally modeled as a benefit function where the benefits are positively related to the allocated investment. A weakness with this approach is that it inadequately reflects the risky nature of research and development. A key objective of this research will be to reflect the uncertain nature of R&D investment in the context of incumbents contemplating cooperation.

3.0 The Model

The model consists of two incumbent firms who compete in a market characterized by quantity competition. These firms are risk neutral and they are faced with potential entry of a new competitor who has costless access to current production technology. This situation is typical of many traditional industries where the technology of production is well understood and significant numbers of previous employees of the incumbents either work in other industries or are available for hire.

Similar to Adams and Encaoua (1994), we assume that technological expertise is enjoyed more by incumbents than by entrants as they have the advantage of both being operational in the industry and having process lines that are available for research and testing. Thus, it is reasonable to assume that technological advances can be achieved earlier by incumbents than by an entrant. In the spirit of Dixit (1979) where incumbents can pre-invest in capacity, the incumbents in this industry decide both whether or not to cooperate on R&D activities and whether or not to pursue them at all. The idea is that the incumbents can "prepare themselves for battle with the new competitor" and the question they must answer is whether or not to do this together.

As with all R&D projects, there is potential for both failure and success. We assume without loss of generality that the results of the projects are both:

1. Available to the incumbents before the entrant makes a decision whether or not to enter and,

2. Known to the entrant in the sense that the actions of the incumbents provide information to the entrant about their production capabilities.

After the completion of the research projects, the incumbents and entrant make production decisions and outcomes are realized in the market contingent on these decisions. The game is one of imperfect, complete and uncertain information. It is imperfect because the incumbents are assumed to make simultaneous decisions about whether or not to cooperate but complete because the players have all relevant information about each other at each stage (including Nature's move). We now consider the details of market competition.

The Firms and the Market

The market is characterized by simple linear demand as follows:

$$D = 1 - p \tag{1}$$

Where D is overall market demand and p is the market clearing price. Consistent with Cournot competition, n competitors in market choose quantities (q_n) and an auctioneer chooses the market clearing price. While this model of competition is frequently criticized due to the paucity of auctioneers across markets, Kreps and Scheinkman (1983) note that the outcome of the Cournot model is also the outcome in a market where firms first choose capacities and then compete on a basis of price. Thus, the implications of Cournot competition are not restricted to markets with auctioneers. Cournot models have relevance for many situations where firms make decisions before pricing that can reduce price competition[3].

Each competitor has the following objective function for the quantity setting subgame:

$$\Pi_n = (p - c_n)q_n - k_n \tag{2}$$

Where c_n is the marginal cost of production specific to the *n-th* company, q_n is his production decision, and k_n is the amount he invests in R&D. Firms 1 and 2 are the incumbents and Firm 3 is the entrant. When Firms 1 and 2 pursue joint R&D, the cost k_n is equivalent to $\frac{K}{2}$ where K is the capital cost of the R&D project (costs are evenly

[3] For more discussion of this issue, refer to Tirole (1990).

shared between the incumbents). Of course, when an incumbent pursues a project individually, the cost k_n is K (he pays the full cost of pursuing the project).

We assume there are two incumbents who possess a marginal cost of production c_1 when research has not been pursued or has been pursued but has been unsuccessful. To ensure that the incumbents are operational (and thus justified in being called incumbents), we assume that the production cost c_1 is less than 1. Firms that have successful R&D projects achieve a production cost c_2 and we assume that $c_2<c_1$. The entrant has a cost of production equal to c_1 and does not have the opportunity to pursue research projects. It should be noted that the *n-th* firm will choose zero production if for all $q_n > 0$, $\Pi_n < 0$.

Characterizations of Research Projects

In this model, research projects are risky endeavors that are available to incumbent firms to reduce the per unit cost of producing the product. This approach has some similarity to the characterization used by Bhattacharya, Glazer and Sappington (1992). Any project is represented by three dimensions: the expected likelihood of the project's success, the capital cost of the project, and the new marginal cost associated with the project (σ, K, c_2). In other words, we characterize both the benefit (i.e. the cost reduction) and the optimal investment for the project as known quantities a priori. In addition, we assume that both incumbents have symmetric beliefs about the probability of the project being successful. This formulation allows us to capture the risky nature of different R&D projects through the parameter σ. Many R&D projects involve a decision about how much to invest against a given concept with both the magnitude of the investment and the probability of the project's success being a function of the level of investment. Our formulation does not preclude this conceptualization of the R&D process (in general, an optimal level of investment can be specified ex ante for any project which has a risk of failing). It simply implies that firms go through the process of determining the optimal level of investment (and the corresponding magnitude of associated benefits and likelihood of the project being successful) prior to making decisions about whether or not they wish to pursue the project jointly with their competitor, alone or not at all.

Informational Assumptions

The firm's cost structures, market demand, and the result of R&D projects (if undertaken) are assumed to be common knowledge. In addition, the incumbents are assumed to have symmetric research projects to consider and both are assumed to have the same prior beliefs about the project's likelihood of success.

Extensive Form of the Game

The game is modeled as a 3 stage game. In the initial stage, the incumbents first make a decision about whether or not to cooperate on an R&D project. Contingent on this decision, the incumbents may also make a second decision about whether to pursue the R&D project individually. These decisions are then followed by R&D activity, the results of which are revealed to all firms. In the second stage, the entrant makes a decision about whether or not to enter and in the final stage, all firms in the market set production quantities.

Because we are trying to understand the impact that an entrant has on the decision of whether or not to cooperate, we consider two different games: one in which the incumbents are not faced with the threat of entry (Figure 1) and one in which they are (Figure 2). The incumbents cannot determine the outcomes of their actions precisely (because nature moves after the first decision by incumbents), so they base their decisions on expected outcomes using the likelihood of success for the project which is known a priori.

Solution Procedure

This game is solved by determining the expected profit for the incumbents in three different cases. The first case is that incumbents cooperate, the second case is that incumbents pursue research individually, and the final case is one in which one incumbent pursues research and the other does not (this is an asymmetric market outcome). We represent the expected profit from cooperation as $E(\pi_c)$ and the expected profit from doing research individually (when both incumbents pursue it) as $E(\pi_{ibo})$. When only one incumbent pursues research and the other does not, we represent their respective profits as π_{ir} and π_{nr}. Using the game tree in Figure 1 and 2, we can make the following statements:

1. Incumbents will only cooperate when $E(\pi_c)>E(\pi_{ir})$. $E(\pi_{ir})>E(\pi_{ibo})$ for all projects because an incumbent is always better off when his competitor is weaker.
2. Incumbents will both pursue the research project on an individual basis if $E(\pi_{ibo})>E(\pi_{nr})$ and $E(\pi_{ibo})>E(\pi_c)$.
3. An asymmetric outcome will result when $E(\pi_{ibo})<E(\pi_{nr})$ and $E(\pi_{ir})>E(\pi_c)$.

We now proceed with the detailed solution of the model.

4.0 Results

First, we consider the problem when there is no threat of entry (Figure 1). This will be used as a basis for understanding the results when there is a threat of entry (Figure 2).

No threat of entry

When the innovation associated with a research project is sufficiently large (i.e. c_2 is much lower than c_1), a market situation where one firm has the innovation and the other does not may result in monopoly. In the table below, we present the variable profit for the each possible market situation after market research (these expressions are obtained by simultaneously solving the first order conditions for the objective functions of the incumbents under each market condition). We then derive the cutoff point below which an innovation becomes drastic. This will enable us to identify zones for the feasibility of each strategy in the parameter space (σ,K) for the family of R&D projects directed towards achieving a marginal cost c_2.

Table 1
End Market Variable Profit without Entry

Market Situation	Non-drastic Innovation	Drastic Innovation
Both Firms have Innovation	$\frac{(1-c_2)^2}{9}$	$\frac{(1-c_2)^2}{9}$
Neither Firm has Innovation	$\frac{(1-c_1)^2}{9}$	$\frac{(1-c_1)^2}{9}$
Firm has Innovation and Competitor does not	$\frac{(1-2c_2+c_1)^2}{9}$	$\frac{(1-c_2)^2}{4}$
Firm does not have Innovation and Competitor does	$\frac{(1-2c_1+c_2)^2}{9}$	0

PROPOSITION 1: An innovation is drastic when $c_2<2c_1-1$ and when $c_1<0.5$ drastic innovations do not exist.

PROOF: Set the relevant profit function to zero and this result obtains easily. The range is only positive when $c_1>½$. Q.E.D.

This intuition for this proposition is that when an innovation is of sufficient magnitude, a sole owner of an innovation will adopt production quantities that make the market unfeasible for the competitor. However, when existing costs in a market are sufficiently low, such an innovation does not exist (i.e. even if one of the firms obtains an innovation that reduces production costs to zero, the market is still sufficiently attractive that the competitor continues to operate).

We now determine the feasibility limits for each strategy (cooperate and pursue R&D on an individual basis) as a function of the exogenous variables. For purposes of presentation, we provide a proposition and proof that relates to the limit for the symmetric pursuit of research individually. The other key boundaries are shown in Table 2.

PROPOSITION 2: When an innovation is non-drastic, firms cannot feasibly pursue projects on an individual basis when

$$K > \frac{-4(\sigma c_1 c_2 + \sigma c_2 - \sigma c_2^2 - \sigma c_1 - 2\sigma^2 c_1 c_2 + \sigma^2 c_2^2 + \sigma^2 c_1^2)}{9}.$$

PROOF: When the incumbents both pursue research individually, their profits are given by calculating their expected profit using the extensive form shown in Figure 1. It easy to show that this profit is:

$$\pi_{gia} = \frac{8}{9}\sigma^2 c_2 c_1 - \frac{2}{9}c_1 + \frac{1}{9} - \frac{8}{9}\sigma c_2 c_1 - \frac{4}{9}\sigma^2 c_2^2 + \frac{1}{9}c_1^2 - \frac{2}{9}\sigma c_2 + \frac{2}{9}\sigma c_1 + \frac{5}{9}\sigma c_2^2 + \frac{1}{3}\sigma c_1^2 - \frac{4}{9}\sigma^2 c_1^2 - K$$

Similarly, the expected profit for an incumbent that does not pursue research is:

$$\pi_{nr} = \frac{-2}{9}\sigma c_1 + \frac{2}{9}\sigma c_2 + \frac{1}{3}\sigma c_1^2 - \frac{4}{9}\sigma c_1 c_2 + \frac{1}{9}\sigma c_2^2 + \frac{1}{9} - \frac{2}{9}c_1 + \frac{1}{9}c_1^2.$$ Simply solving the inequality $\pi_{nr} > \pi_{gia}$ yields the condition on K as given above. Q.E.D.

The critical boundaries for the feasibility of strategies are provided in Table 2.

Table 2
Critical Boundaries without Entrant

Description of Boundary	**Maximum Value for K as a function of exogenous variables** non-drastic innovation	**Maximum Value for K as a function of exogenous variables** drastic innovation
Individual Pursuit (asymmetric equilibrium)	$\frac{4\sigma}{9}(c_1 - c_2)(1 - c_2)$	$\frac{\sigma}{36}(1 - 3c_2 + 2c_1)(5 - 3c_2 - 2c_1)$
Cooperative Pursuit	$\frac{2\sigma}{9}(c_1 - c_2)(2 - c_1 - c_2)$	$\frac{2\sigma}{9}(c_1 - c_2)(2 - c_1 - c_2)$
Individual Pursuit (both firms pursue research)	$\frac{-4\sigma c_1 c_2 - 4\sigma c_2 + 4\sigma c_2^2 + 4\sigma c_1}{9} + \frac{8\sigma^2 c_1 c_2 - 4\sigma^2 c_2^2 - 4\sigma^2 c_1^2}{9}$	$\frac{-\sigma^2 + 10\sigma^2 c_2 - 5\sigma^2 c_2^2 + 5\sigma - 18\sigma c_2}{36} + \frac{9\sigma c_2^2 + 8\sigma c_1 - 4\sigma c_1^2 - 8\sigma^2 c_1 + 4\sigma^2 c_1^2}{36}$

The general appearance of these boundaries in (σ,K) space is shown in Figure 3 and is similar for both non-drastic and drastic innovations. It should be noted that a comparison of cooperation to the individual pursuit of research is only relevant in the area where cooperation is feasible (the shaded area of Figure 3).

Determination of Optimal R&D Strategy

A simulation has been conducted in the no entrant game to identify the optimal strategies for the two types of innovation considered when there is no entrant. We use an existing cost of c_1=0.7 and c_2=0.5 to analyze optimal strategies with non-drastic innovation and c_2=0.2 for drastic innovation. The optimal strategies for non-drastic innovation are shown in Figure 4 (the findings for drastic innovation are similar). The findings of the simulation basically indicate that cooperation is preferred to the individual pursuit of research when projects are expensive and have a high probability of success. In contrast, when projects have a low probability of success, the preferred strategy is for both firms to pursue the R&D project individually. The exception to this rule occurs when the individual pursuit of research by both incumbents is not feasible and cooperation is (this area is labeled A in Figure 3). In this area, a firm that pursues the project individually has expected profit that exceeds the profit associated with cooperation. An explicit but long proof is available to show that $\pi_{ir}>\pi_c$ for both drastic and non-drastic innovations. Of course this does not rule out cooperation in (σ, K) space (for a given innovation) because π_{ir} is only relevant when the asymmetric market outcome is an equilibrium.

With a Potential Entrant

We now analyze the decisions of incumbents when they are faced with the potential entry of a new competitor (Figure 2). Similar to the situation where there is no threat of entry, when an innovation is sufficiently large (i.e. full drastic), a monopoly results when one incumbent has the innovation and neither the other incumbent nor the entrant do. There is also an intermediate situation in which the entrant may decide not to enter the market if both incumbents possess a new innovation (i.e. semi-drastic). A priori, we might expect that a larger innovation is required to sustain a monopoly than to keep an entrant out when both incumbents possess the innovation. Similar to the *no threat of entry* analysis, we present the variable profit for the each possible market situation after market research in Table 3. We then derive the cutoff points that determine when an innovation qualifies as being semi-drastic or drastic. This will enable us to identify the optimal strategies in the parameter space (σ,K) for the family of R&D projects directed towards achieving any marginal cost improvement.

innovation (i.e. semi-drastic). A priori, we might expect that a larger innovation is required to sustain a monopoly than to keep an entrant out when both incumbents possess the innovation. Similar to the *no threat of entry* analysis, we present the variable profit for the each possible market situation after market research in Table 3. We then derive the cutoff points that determine when an innovation qualifies as being semi-drastic or drastic. This will enable us to identify the optimal strategies in the parameter space (σ,K) for the family of R&D projects directed towards achieving any marginal cost improvement.

Table 3
End Market Variable Profit with Entrant
(in all cases entrant does not have access to the innovation)

Market Situation	Non-drastic Innovation	Semi-drastic Innovation	Drastic Innovation
Both Firms have Innovation	$\frac{(1-2c_2+c_1)^2}{16}$	$\frac{(1-c_2)^2}{9}$	$\frac{(1-c_2)^2}{9}$
Neither Firm has Innovation	$\frac{(1-c_1)^2}{16}$	$\frac{(1-c_1)^2}{16}$	$\frac{(1-c_1)^2}{16}$
Firm has Innovation and Competitor does not	$\frac{(1-3c_2+2c_1)^2}{16}$	$\frac{(1-3c_2+2c_1)^2}{16}$	$\frac{(1-c_2)^2}{4}$
Firm does not have Innovation and Competitor does	$\frac{(1-2c_1+c_2)^2}{16}$	$\frac{(1-2c_1+c_2)^2}{16}$	0

PROPOSITION 3: An innovation is semi-drastic when $c_2 < \frac{3}{2}c_1 - \frac{1}{2}$ and when $c_1 < \frac{1}{3}$, drastic innovations do not exist.

PROOF: The profit function for the entrant must be used. When all three firms are operational and the incumbents have cost c_2 and the entrant has cost c_1, the profit of the entrant is $\frac{1-3c_1+2c_2}{16}$. Setting this equal to zero, the result obtains easily. The range is only positive for values of $c_1 > \frac{1}{3}$. Q.E.D.

It is easy to show (using the profit expression for an incumbent without the innovation) that the boundary for drastic innovation is unchanged by the threat of entry.

PROPOSITION 4: When drastic innovations exist (i.e. $c_1>½$), the boundary for semi-drastic innovation is always greater than the boundary for drastic innovation.

PROOF: Using Proposition 3, the boundary for semi-drastic innovation is $c_2=\frac{3}{2}c_1-\frac{1}{2}$. Similarly, the boundary for drastic innovation is $c_2=2c_1-1$. Assume that $2c_1-1>\frac{3}{2}c_1-\frac{1}{2}$. This implies that $\frac{c_1}{2}>\frac{1}{2}$ or that $c_1>1$ which is outside the allowable range. Therefore $2c_1-1<\frac{3}{2}c_1-\frac{1}{2}$. Q.E.D.

The importance of Propositions 3 and 4 is that innovations follow a natural progression depending on their magnitude. A small innovation has no effect on the entrant's decision to enter the market. An intermediate (or semi-drastic) innovation only affects the entrant's decision if both incumbents possess it. A large (or drastic) innovation not only affects an entrant's decision to enter the market if both incumbents have it, it also affects an entrant's decision if just one of the incumbents has it. A unique (and perhaps unrealistic) characteristic of this model, due to the absence of fixed costs, is that if one incumbent possesses a drastic innovation, it forces the other incumbent from the market. Adding small fixed costs would eliminate this problem and would leave the results otherwise unchanged.

Similar to the case with entry, the feasibility limits for each strategy (cooperate, concurrent or individual pursuit of research) as a function of the exogenous variables. The key boundaries for the case with the threat of entry are shown in Table 4.

Table 4
Critical Boundaries with Entrant

Description of Boundary	**Maximum Value for K as a function of exogenous variables**		
	non-drastic innovation	semi-drastic innovation	drastic innovation
Individual Pursuit (asymmetric equilibrium)	$\frac{3\sigma}{16}(c_1-c_2)(2-3c_2+c_1)$	$\frac{3\sigma}{16}(c_1-c_2)(2-3c_2+c_1)$	$\frac{\sigma}{16}(1-2c_2+c_1)(3-2c_2-c_1)$
Cooperative Pursuit	$\frac{\sigma}{2}(c_1-c_2)(1-c_2)$	$\frac{\sigma}{72}(1-4c_2+3c_1)(7-4c_2-3c_1)$	$\frac{\sigma}{72}(1-4c_2+3c_1)(7-4c_2-3c_1)$
Individual Pursuit (both firms pursue research)	$-\frac{3}{8}\sigma^2c_2^2-\frac{3}{8}\sigma^2c_1^2+\frac{3}{4}\sigma^2c_2c_1-\frac{3}{4}\sigma c_2c_1$ $+\frac{9}{16}\sigma c_2^2-\frac{3}{8}\sigma c_2+\frac{3}{8}\sigma c_1+\frac{3}{16}\sigma c_1^2$	$\frac{1}{144}\sigma^2+\frac{1}{36}\sigma^2c_2-\frac{1}{8}\sigma^2c_1-\frac{37}{72}\sigma^2c_2$ $-\frac{7}{16}\sigma^2c_1^2+\sigma^2c_2c_1-\frac{3}{4}\sigma c_2c_1+\frac{9}{16}\sigma^2c_2^2$ $-\frac{3}{8}\sigma c_2+\frac{3}{8}\sigma c_1+\frac{3}{16}\sigma c_1^2$	$-\frac{11}{144}\sigma^2+\frac{5}{18}\sigma^2c_2-\frac{5}{36}\sigma^2c_2^2+\frac{3}{16}\sigma$ $-\frac{1}{2}\sigma c_2+\frac{1}{4}\sigma c_2^2-\frac{1}{16}\sigma c_1^2+\frac{1}{8}\sigma c_1$ $+\frac{1}{16}\sigma^2c_1^2-\frac{1}{8}\sigma^2c_1$

The appearance of these boundaries for non-drastic innovations in (σ,K) space is shown in Figure 5. In contrast to Figure 3, the boundary for the feasibility of cooperation lies above the boundary for the individual pursuit of research by one firm. In the case of non-drastic innovations, cooperation effectively opens up more of the strategy space for firms. The appearance of these boundaries for semi-drastic and drastic innovations is similar to the boundaries observed when there is no threat of entry (the boundary for the feasibility of cooperation lies *within* the area of feasibility for pursuing research individually).

Determination of Optimal R&D Strategy

We now conduct a simulation when there is the threat of entry to identify the optimal strategies for the three types of innovation discussed above. We use an existing cost of c_1=0.7 and c_2=0.6 to analyze optimal strategies with non-drastic innovation, c_2=.47 to analyze optimal strategies for semi-drastic innovation and c_2=0.2 for drastic innovation. The optimal strategies for non-drastic innovation are shown in Figure 6. While the individual pursuit of research is still preferred for low probability/low cost projects, cooperation is preferred in all other areas of the feasible space. In contrast, to the situation without an entrant, even when the individual pursuit of research results in an asymmetric market outcome, cooperation is the preferred strategy. As previously noted, cooperation increases the feasible space both by reducing the capital investment and by making the market more attractive for both incumbents. The incumbents derive mutual benefit from a lower production quantity chosen by the entrant when both incumbents (as opposed to just one) have the innovation. Specifically, an incumbent, who has access to a non-drastic innovation, can benefit from a reduction in production of $\frac{c_1 - c_2}{4}$ by the entrant if the second incumbent also has access to the innovation. This increases price by $\frac{c_1 - c_2}{4}$ to the benefit of both incumbents. Thus, for non-drastic innovations, we recover the result of Dixit (1979) in that an incumbent may act strategically to alter the decision of an entrant.

We might expect this result to be strengthened in situations where the action of incumbents has the potential to keep an entrant out of the market (as in the case of semi and full drastic innovation). Interestingly, this is not the case. The results for the simulation associated with a drastic innovation are shown in Figure 7. Similar to the results obtained when there is no threat of entry, cooperation is only optimal in a wedge shaped area associated with projects that are expensive and have a high probability of success. The individual pursuit of research is preferred for projects with a low probability of success and for projects that are expensive and of high probability. As in the situation without the threat of entry, when the individual pursuit of research of is not feasible for both incumbents but one incumbent has an incentive to pursue the project individually (expensive/high probability projects in area A of Figure 3), cooperation is not preferred.

5.0 Discussion

The simulation and preceding analysis shows that the family of R&D projects associated with a given cost innovation can be divided into a number of zones in (σ,K) space based on the feasibility of R&D strategies available to industry incumbents. When there is no threat of entry, the zones have relatively stable geography for all cost innovations. However, when there is a threat of entry, the geography of the zones changes depending on whether the innovation is non-drastic or semi/full drastic.

For non-drastic innovation, the geography of the zones changes from the geography observed in the absence of a potential entrant. Specifically, cooperation enlarges the feasible zone for R&D projects (as opposed to being a subset of the feasible zone). The feasible boundary for pursuing R&D on an individual basis is contained within the feasible zone for cooperation. In contrast, when innovations are either semi-drastic or full drastic, the geography of the zones is similar to the geography observed in the absence of a potential entrant.

Interestingly, this change in zones caused by the threat of an entrant corresponds to a significant change in optimal strategies. Specifically, an R&D project associated with a non-drastic innovation creates a situation where incumbents have a greater likelihood of cooperating. This is strong evidence for the positive externality that exists for incumbents in terms of increasing the likelihood of a non aggressive entry by the new competitor. It follows then that incumbents should have greater benefits to cooperate when they can keep the new entrant out (as in the case of semi-drastic or full drastic innovations). However, we observe the opposite. With R&D projects directed towards semi-drastic or full drastic innovations, the incumbents have no more incentive to cooperate with the threat of a potential entrant than in its absence. We must provide an explanation for this given the evidence that we have of the positive externality observed in the case of non-drastic innovation.

The explanation obtains from another force that affects the optimal decisions of incumbents in an industry. We call this force the "lure of dominance". The "lure of dominance" is a function of how attractive it is for an incumbent to be the sole owner of an innovation. Consider the strategy of pursuing research individually and assume that σ lies in the open interval (0,1). This implies that there is a probability of $\sigma(1-\sigma)$ being the sole owner when both incumbents pursue R&D and a probability of σ of being the sole owner when only the focal incumbent pursues research. Clearly, the payoffs in this situation have a significant impact on the payoffs of pursuing research individually and the decision about whether or not to cooperate.

When a third firm is considering entry into an industry and it decides not to enter, the payoffs of incumbents are the same as if there had been no entrant. However, with respect to R&D, the entrant affects the decisions of the incumbents because the payoffs in states where the entrant does enter are significantly lower i.e. the relative attractiveness of having the innovation is significantly altered. When we examine the relative advantage of being the sole owner of an innovation, we find that there is a significant reversal when the incumbents are faced with a potential entrant.

In Figure 8, for non-drastic innovations, we plot the relative advantage of being the sole owner of an innovation when there is no threat of entry and compare it to the relative advantage when there is (the advantage is plotted for a range of cost reductions consistent with non-drastic innovation). In Figure 9, we plot the same relative advantages for drastic innovations. In Figure 8, there is more advantage to being the sole owner of a non-drastic innovation in the absence of a potential entrant. In contrast when we consider a drastic innovation (see Figure 9), we find that being the sole owner of an innovation is more attractive when there is an entrant. In spite of both the 50% reduction in investment and the positive externality enjoyed by both incumbents under cooperation, this reversal explains why incumbents will choose to pursue research individually when innovations are semi or full drastic. The "lure of dominance" drives the incumbents away from the strategy of cooperation. Since σ is exogenous, it is important to note that the *attractiveness* and not the *likelihood* of being dominant (or being the sole owner) is affected by the presence of a potential entrant.

6.0 Conclusions

The main result of this paper is that the degree of R&D cooperation exhibited by incumbents faced with the threat of entry, only increases for projects directed towards non-drastic innovations (i.e. that do not have the potential to prevent entry). Thus, while the decisions of incumbents about cooperation on R&D policy are affected by the potential entry of a new competitor, we do not find that cooperation becomes more prevalent due to its potential to reduce the likelihood of entry by a new competitor. Simply, for R&D projects that have the potential to prevent the entry of a new competitor, the degree of cooperation in the feasible space is relatively unaffected by the presence of a potential entrant.

This is explained by the existence of three forces that affect the decision of an incumbent. The first two, the need to share costs and the benefit of reduced production by the entrant (due to higher production by the other incumbent) push an incumbent towards cooperation. In contrast, the "lure of dominance" or the attractiveness of being the only firm in the market with a given innovation pushes him towards the individual pursuit of research. When incumbents are faced with a project that does not have the potential to keep the entrant out of the market the first two forces are stronger and this makes cooperation a preferred strategy (except for a limited set of low probability/low cost projects). In contrast, when an innovation has the potential to keep a new entrant out of the market, a third force, the "lure of dominance" is stronger and this explains why the degree of cooperation is relatively unaffected by the presence of an entrant.

This research suggests that when incumbents are faced with potential entry, they will increase their degree of cooperation on R&D projects which have the potential to increase efficiency but not foreclose the market to new entrants. In the case of airline deregulation in Europe, this might explain why airlines have recently cooperated in terms of integrating their reservation and data management systems. Airline deregulation which took place in April 1997 had been imminent for some time and the more cooperative stance of the existing airlines is to some extent explained by their desire to "prepare for battle" with new competitors.

This research also provides insight about then types of projects on which we are most likely to observe cooperation. In general, we should expect greater cooperation to occur on projects that have a relatively low rate of return and a high likelihood of success. In contrast, we should expect to see greater individual pursuit of R&D for projects with a low likelihood of success and a relatively high rate of return. This provides some insight regarding the topics that might dominate the activities of industry associations (projects pursued are essentially low risk/low return for all members). In contrast, little cooperation would be expected between firms on process innovations that have the potential to knock firms out of an industry.

The research also provides insight about why certain industries have significant asymmetry with respect to process technology. As identified in the research (regardless of whether there is a threat of entry), a significant part of the strategy space is dominated by the asymmetric outcome where only one incumbent pursues research. In fact, the only time when the asymmetric outcome does not occur is in the case of non-drastic innovations when there is threat of entry. A byproduct of the asymmetric R&D equilibrium is frequently insufficient competition in the market after the research has been conducted. In fact, the sole owner of an innovation may be able to create a monopoly due to its advantage in terms of production costs.

From a public policy perspective, this raises an interesting issue. In general, the competition agencies of government regard industry associations with skepticism. Government's dubious view of industry associations obtains from their occasional use as a tool to facilitate collusion. This research provides a counterpoint to this skepticism. To the extent that trade associations facilitate inter-firm R&D and cooperation, they can reduce the likelihood of market concentration due to a restricted dissemination of process technology innovation. In markets where the likelihood of collusion is low, this provides government with an argument to encourage and perhaps fund the formation of strong industry associations.

An important question is left unanswered by this research. This research focuses uniquely on innovations that are process related and, as previously mentioned, significant R&D is related to product innovation. An interesting extension to this work would be to evaluate the tendency of incumbents to cooperate in the context of innovations which increase demand or the willingness to pay for a given product.

Figure 1

"No Entrant" Game Tree

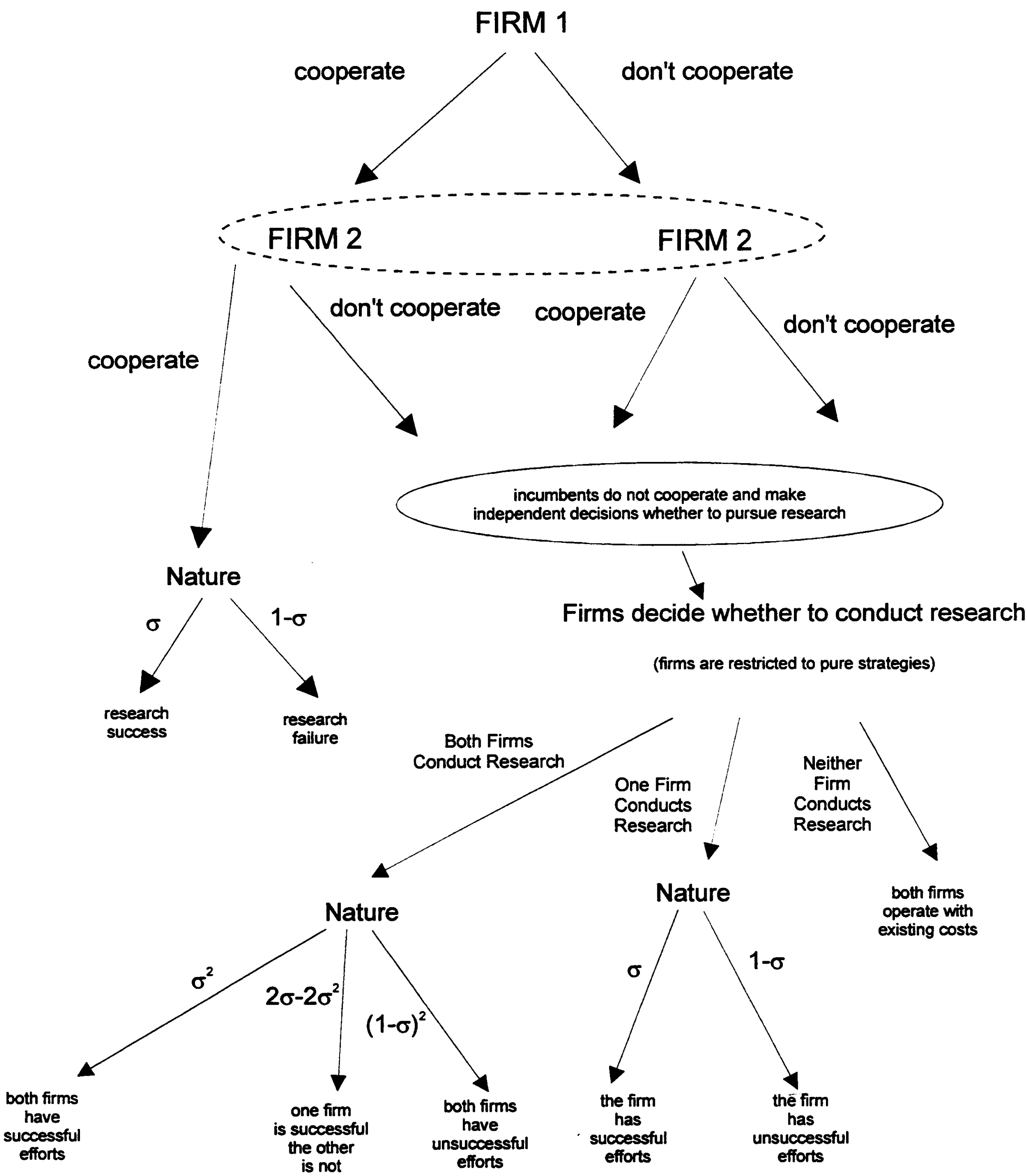


Figure 2

Game Tree "with Entrant"

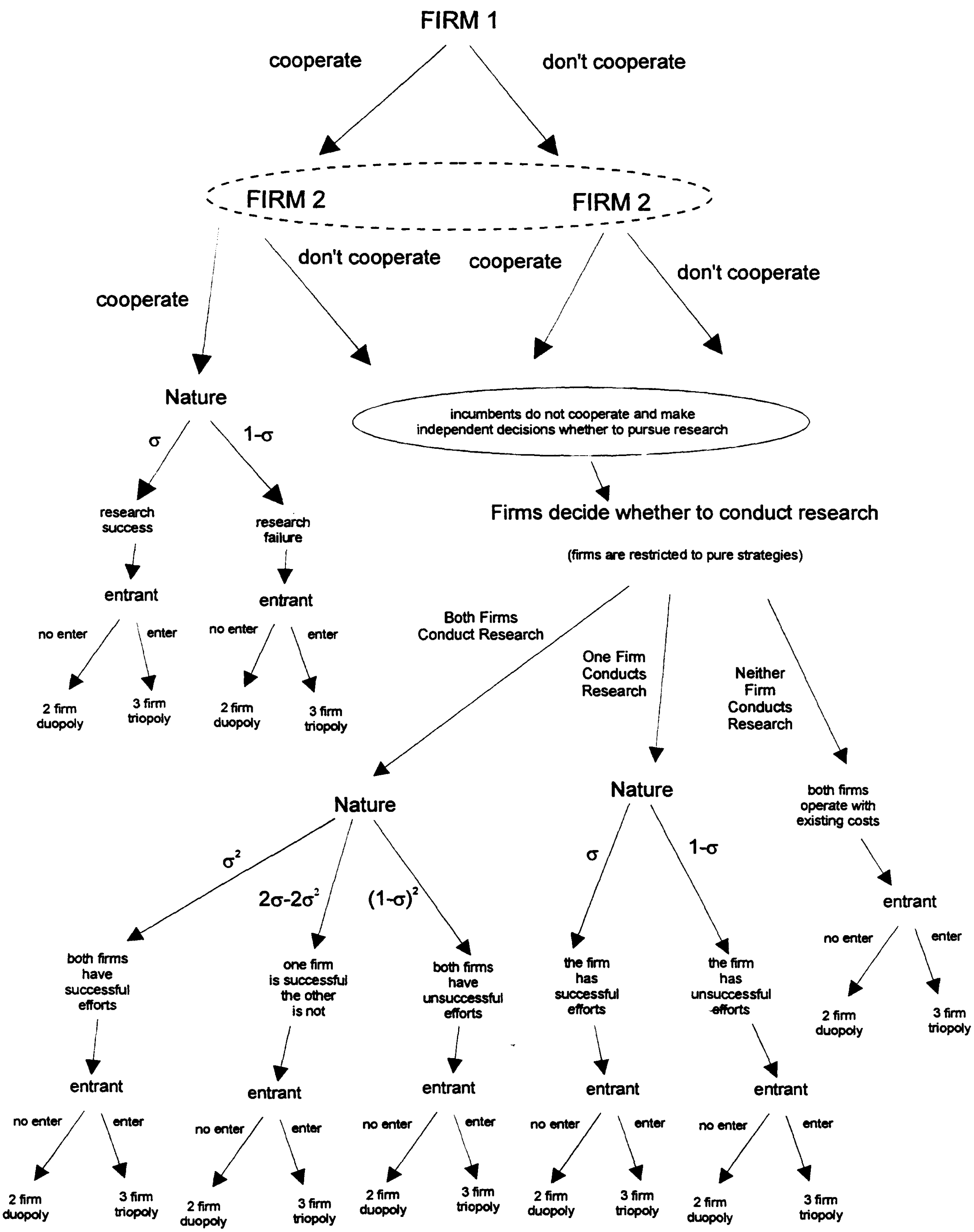


Figure 3

The Feasibility Boundaries for Strategies
(absent the threat of entry)

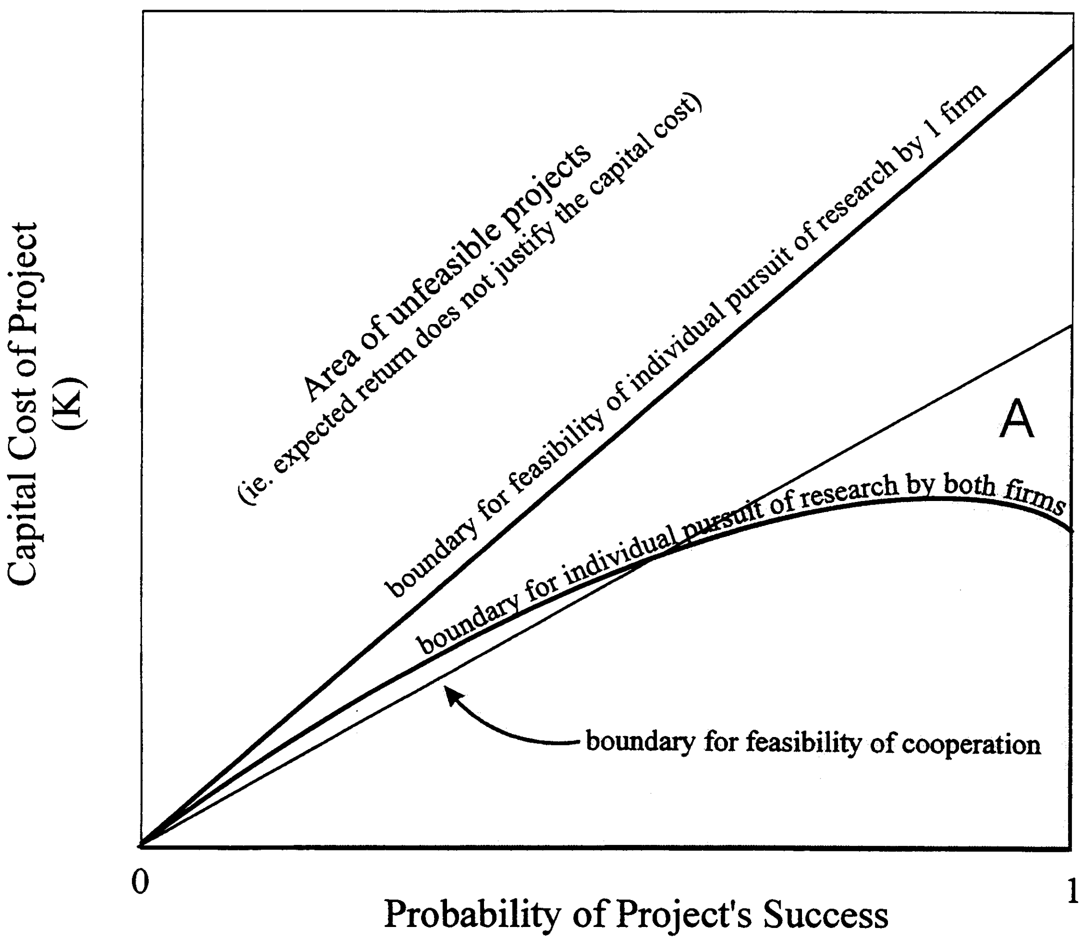


Figure 4

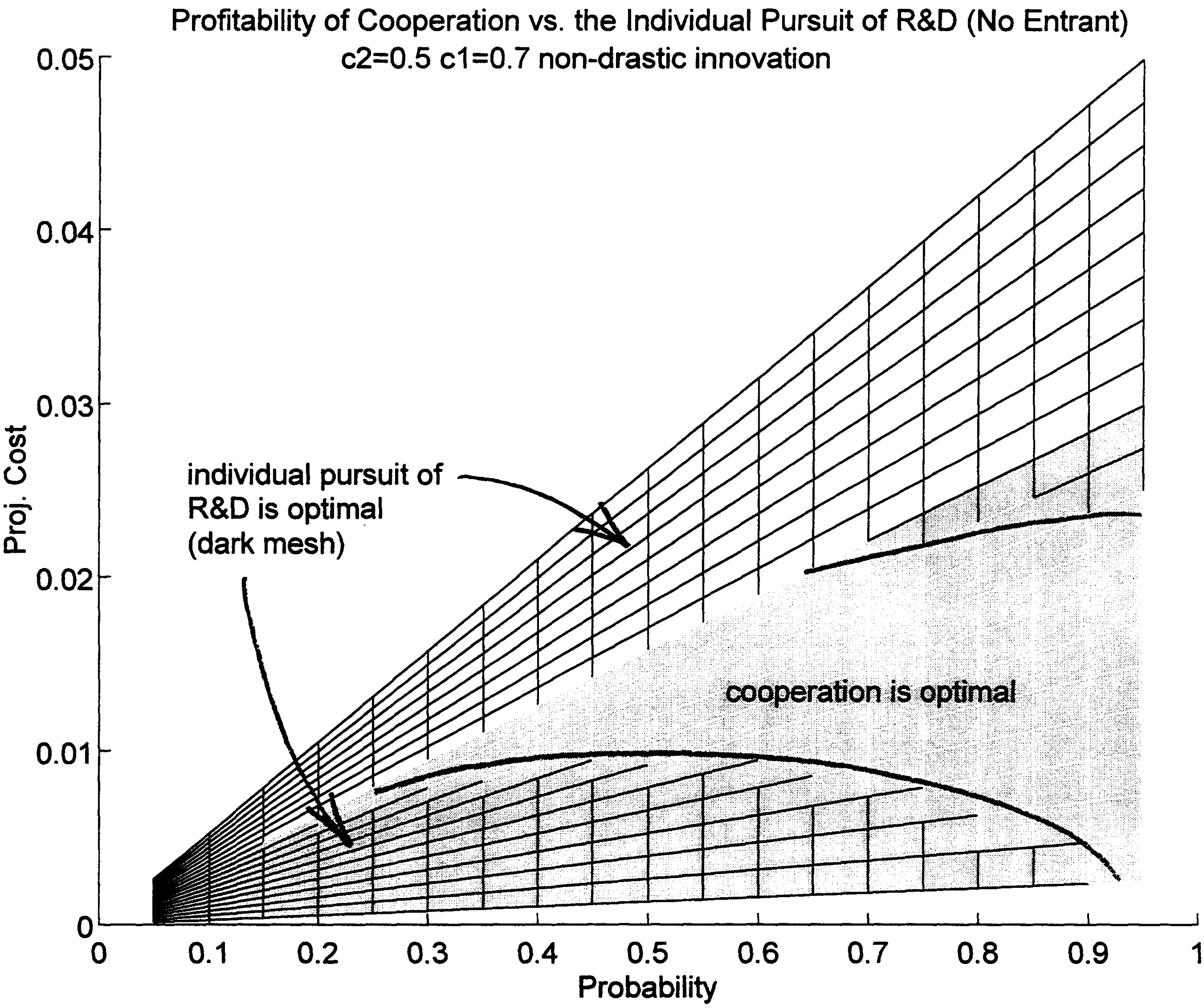

Profitability of Cooperation vs. the Individual Pursuit of R&D (No Entrant)
c2=0.5 c1=0.7 non-drastic innovation
0.05
0.04
0.03
0.02
0.01
0
Proj. Cost
individual pursuit of
R&D is optimal
(dark mesh)
cooperation is optimal
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Probability

Figure 5

The Feasibility Boundaries for Strategies

(non drastic innovation with the threat of entry)

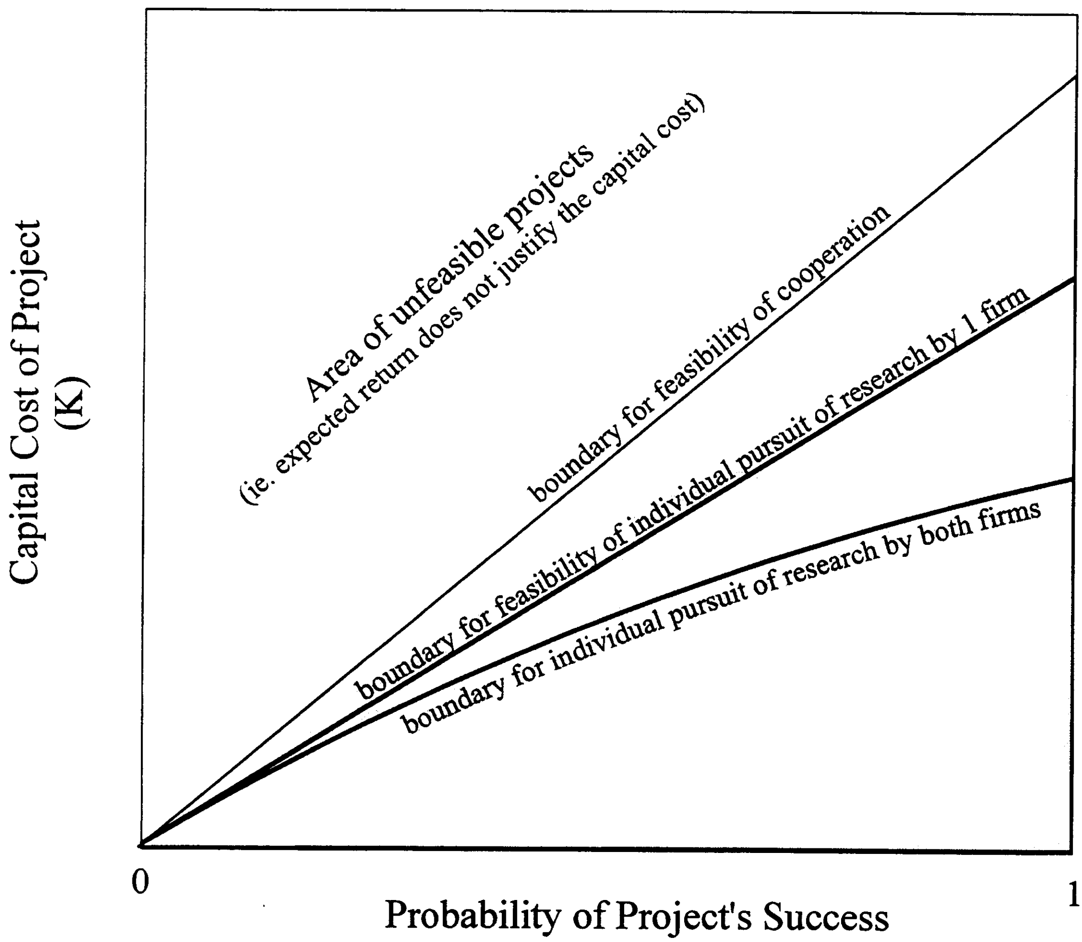
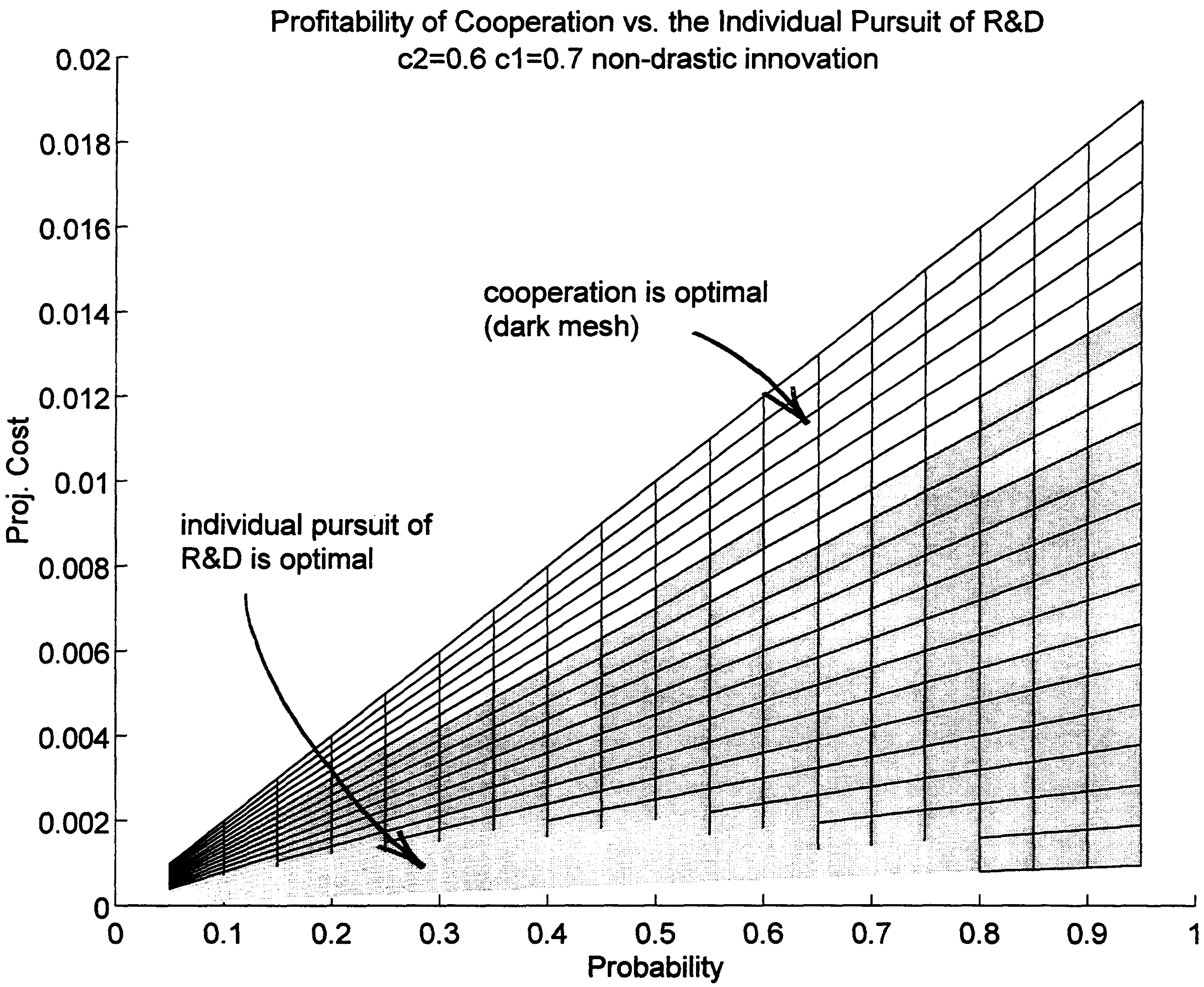


Figure 6



Profitability of Cooperation vs. the Individual Pursuit of R&D
c2=0.6 c1=0.7 non-drastic innovation
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Proj. Cost
cooperation is optimal
(dark mesh)
individual pursuit of
R&D is optimal
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Probability

Figure 7

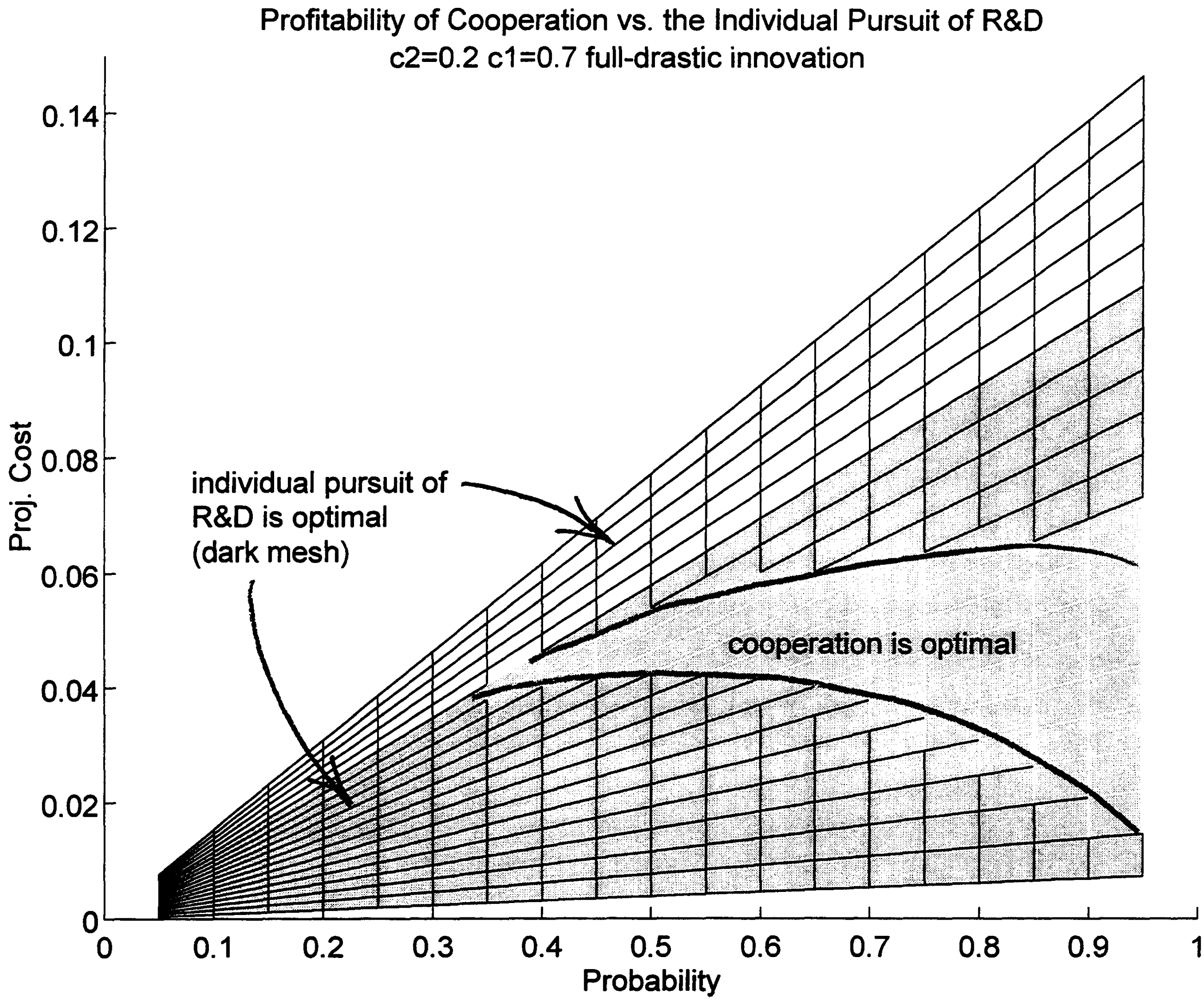

Profitability of Cooperation vs. the Individual Pursuit of R&D
c2=0.2 c1=0.7 full-drastic innovation
Proj. Cost
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
individual pursuit of
R&D is optimal
(dark mesh)
cooperation is optimal
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Probability

Figure 8

Advantage in Gross Profit by being the Sole Owner of a non-drastic innovation

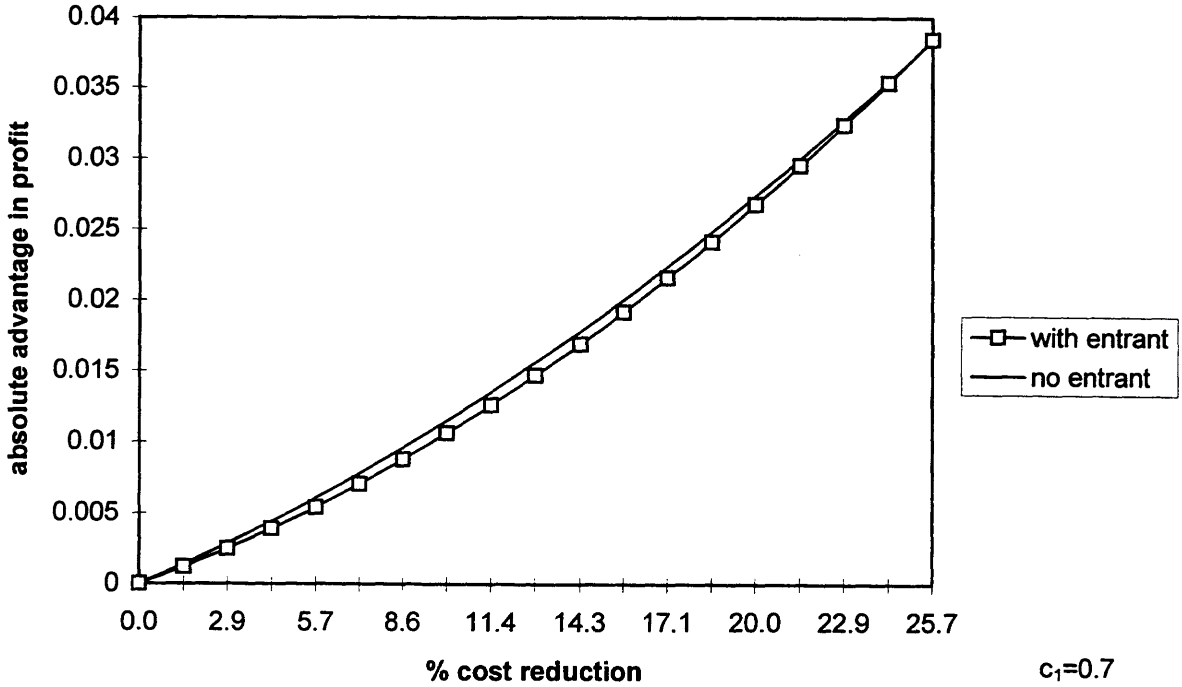
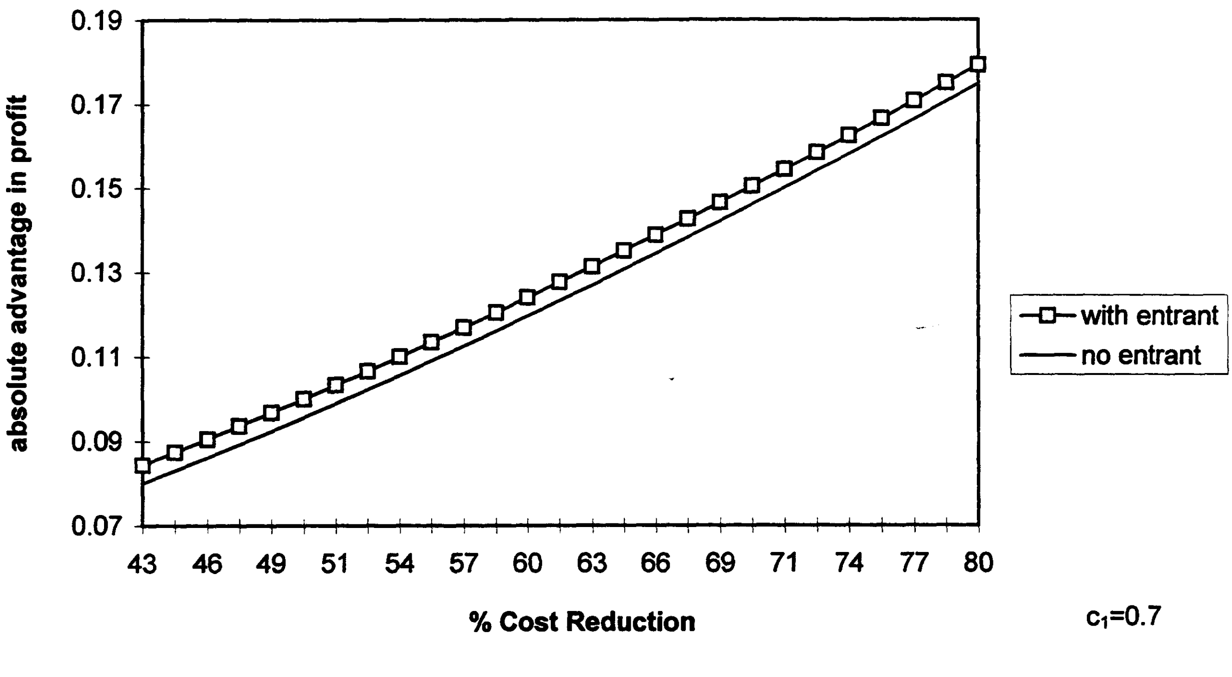


Figure 9

Advantage in Gross Profit by being the Sole Owner of a drastic innovation



References

Abernathy, W. and J.M. Utterback (1978), "Patterns of Industrial Innovation", *Technology Review*, Vol. 80, 41-47.

Adams, William and David Encaoua (1994), "Distorting the direction of technological change", *European Economic Review*, Vol. 38, 663-673.

Arrow, Kenneth J. (1962), "Economic Welfare and the Allocation of Resources for Invention", in *The Rate and Direction of Inventive Activity*, ed. R. Nelson, Princeton University Press, 609-626.

Athey, S. and A. Schmultzer (1995), "Product and Process Flexibility in an Innovative Environment", *Rand Journal of Economics,* Vol. 26, 557-574.

Bhattacharya, S., J. Glazer and D.E.M. Sappington (1992), "Licensing and the Sharing of Knowledge in Research Joint Ventures", *Journal of Economic Theory*, Vol. 56, 43-69.

Blau, John (1994), "Collaborative R&D Sweeps European Industry As Firms Stive To Innovate while Cutting Costs", *Research Technology Management*, November-December, 2-3.

d'Aspremont, Claude and Alexis Jacquemin (1988), "Cooperative and Noncooperative R&D in Duopoly with Spillovers", *American Economic Review*, Vol. 78 (December), 1133-1137.

Dixit, A.(1979), "A Model of Duopoly Suggesting a Theory of Entry Barriers", *Bell Journal of Economics*, Vol. 10, 20-32.

Dixit, A. (1980), "The Role of Investment in Entry Deterrence", *Economic Journal*, Vol. 90, 95-106.

Kamien, Morton I., E. Muller and I. Zang (1992), "Research Joint Ventures and R&D Cartels", *American Economic Review*, Vol. 82, 1293-1306.

Kreps D. and J. Scheinkman (1983), "Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes", *Bell Journal of Economics*, Vol. 14, 326-337.

Larreché, Jean Claude and David Weinstein (1988), *Industrat: The Strategic Industrial Marketing Simulation*, Prentice Hall, Englewood Cliffs, New Jersey, 1-3.

Spence, Michael (1977), "Entry, Capacity, Investment and Oligopolistic Pricing", *Bell Journal of Economics*, Vol. 8, 534-544.

Tirole, Jean (1990), *The Theory of Industrial Organization*, The MIT Press, Cambridge, Mass., 209-238.