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Strategic Aspects of Supply Chain Relations:

An Interdisciplinary Approach to the Analysis of Inter-Firm Cooperation and Competition

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CONTENTS

Abstract

The last decade has witnessed substantial changes in organizational structure, inter-organizational relations and the nature of competition. In particular, the realization of interdependencies across firm boundaries has brought forth a range of mechanisms for coordination among firms in vertically related stages of production, or among direct competitors in the same industry. Our objective is to study inter-organizational relations in an oligopolistic setting to explore the interactions between efficiency and strategic incentives for organizations to engage in various forms of coordination, vertically or horizontally. Specifically, we employ a game-theoretic approach to analyze organizational structure and coordination incentives in relation to process innovation, transfer pricing, and degree of competition between products. This study is divided into four parts.

In the first part, we look at the impact of manufacturer's investments in process innovation to reduce production costs on distribution channel structure, and vice versa. We show that the optimal channel structure decision depends on interactions between two parameters: degree of product differentiation and the extent of production cost reduction. These parameters represent the two primary 'generic strategies' that most organizations follow in order to gain competitive advantage. Second, we show that decentralized manufacturers invest less in process innovation than integrated manufacturers do. However, manufacturers may prefer decentralized, non-coordinated channels to perfectly coordinated channels when product substitutability is high, contrary to efficiency and transaction-cost based arguments for increased coordination.

In the second part, we relax the assumption that a manufacturer has a choice only between integration (or 'hierarchy') and decentralization (or 'market'). Various means of channel coordination are analyzed, and ownership is assumed to be distinct from the particular coordination mechanism employed. It is shown that the consideration of the competitive environment changes incentives for, and benefits to, coordination in various production, inventory, and pricing decisions among members of a supply chain.

In the third part, we focus on horizontal cooperation among firms, ignoring the vertical relations. We consider the possibility of technological spillovers in the process innovation efforts of the manufacturers, and their incentives to engage in cooperative R&D agreements with rivals in the same industry. We develop a two-stage game model with manufacturers producing differentiated products, and establish fairly general conditions under which different cooperative arrangements would be beneficial both for manufacturers and consumers.

In the fourth part, we merge the above two dimensions, i.e., we investigate the interactions between horizontal cooperative agreements among rival manufacturers and vertical coordination arrangements along the supply chain. The models above are extended to incorporate the triple influence of technological spillovers and research joint ventures, along with demand and cost side parameters, on supply chain coordination incentives. We argue that a better understanding of such interactions is crucial in explicating a more relevant theory of the firm.

(... français en suite)

Résumé

La dernière décennie a été le théâtre de changements profonds dans la structure organisationnelle, les relations interorganisations et la nature de la concurrence. En particulier, la réalisation d'interdépendances au travers de limites organisationelles a donné naissance à tout un éventail de mécanismes de coordination entre les entreprises aux étapes de la production verticales, ou entre des entreprises rivales directes dans la même branche d'activités. Notre objectif est d'étudier les relations interorganisations dans un cadre oligopolistique afin d'analyser les interactions entre l'efficacité et les incitations stratégiques pour les entreprises qui se livrent à diverses formes de coordination, verticalement ou horizontalement. En particulier, nous employons la théorie des jeux pour analyser la structure organisationnelle et les incitations de coordination par rapport à la restructuration des activités, au prix de transfert entre organisations et au niveau de concurrence entre les produits. Cette étude se divise en quatre parties.

Dans la première partie, nous analysons l'impact des investissements des fabricants dans la restructuration des activités visant à réduire les coûts de production sur la structure des circuits de distribution et vice-versa. Nous démontrons que la meilleure décision sur la structure des circuits dépend des interactions entre deux paramètres : le niveau de différenciation des produits et l'ampleur de la réduction des coûts de production. Ces paramètres représentent les deux principales "stratégies génériques" que suivent la plupart des entreprises pour avoir un avantage concurrentiel. Deuxièmement, nous démontrons que les fabricants décentralisés investissent moins dans la restructuration des activités que ne le font les fabricants intégrés. Toutefois, il se peut que les fabricants préfèrent les circuits décentralisés et non coordonnés aux circuits parfaitement coordonnés lorsque la substituabilité des produits est élevée, contrairement aux arguments reposant sur l'efficacité

et les frais de transaction pour une plus grande coordination.

Dans la deuxième partie, nous infirmons l'hypothèse selon laquelle un fabricant n'a de choix qu'entre l'intégration (ou la "hiérarchie") et la décentralisation (ou le "marché"). Divers moyens de coordination des circuits sont analysés et on présume que la propriété est distincte de l'instrument de coordination particulier utilisé. On démontre que le poids attaché au milieu concurrentiel modifie les incitations et les avantages de la coordination dans diverses décisions sur la production, les stocks et les prix entre les membres d'une chaîne d'approvisionnement.

Dans la troisième partie, nous nous concentrons sur la coopération horizontale entre les entreprises, en ignorant les relations verticales. Nous étudions la possibilité d'hémorragies technologiques dans les efforts déployés par les fabricants pour restructurer leurs activités et dans leur incitation à conclure des accords de R-D concertée avec des rivaux du même secteur. Nous élaborons un modèle de jeu en deux temps avec des fabricants qui produisent des produits différenciés et établissons les conditions relativement générales dans lesquelles divers accords de coopération peuvent être bénéfiques à la fois pour les fabricants et les consommateurs.

Dans la quatrième partie, nous fusionnons les deux dimensions ci-dessus, c'est-à-dire que nous étudions les interactions entre les accords de coopération horizontaux entre fabricants rivaux et les accords de coordination verticaux le long de la chaîne d'approvisionnement. Nous élargissons les modèles ci-dessus pour y intégrer la triple influence des hémorragies technologiques et des coentreprises de recherche, les paramètres relatifs à la demande et aux coûts sur les incitations à coordonner la chaîne d'approvisionnement. Nous soutenons qu'une connaissance plus intime de ces interactions est essentielle pour expliquer une théorie plus pertinente de l'entreprise.

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1. INTRODUCTION

"You have to compete and cooperate at the same time."

– Ray Noorda, founder of Novell, Inc.

The last decade has witnessed substantial changes in organizational structure, interorganizational relations and the nature of competition. A few examples include: vertical disintegration and outsourcing, joint ventures and strategic alliances, transformation of buyer-supplier relations from 'adversarial' (characterized by frequent bidding, multiple sourcing, no information sharing and constant bargaining) to 'obligational' (characterized by longer contracts, mutual trust, and collaborative practices). In particular, the increasing realization of interdependencies across firm boundaries has brought forth a range of mechanisms for coordination among firms in vertically related stages of production, or among direct competitors in the same industry. Theoretical explanations for the underlying drivers of such change vary widely across disciplines. In economics, the contractual theories of the firm treat the problem of coordination among different economic entities (individuals or firms) as primarily a problem of incentive alignment, and different organizational forms as governance mechanisms (see Masten, 1996; Williamson, 1996). On the other hand, most studies in management credit the imperatives of operational efficiency and competitiveness (lowering costs, accelerating new product development, and responding to changing market needs) for the accelerated change in organizational forms and interorganizational relations. For example, there is a large and growing body of literature on supply chain management in production/operations (and channel coordination in marketing) that assumes efficiency gains from coordinating production, inventory, and pricing policies among different members of a supply chain, and focuses on devising means of realizing such gains. Such studies, however, ignore the interdependence among organizations that arises in oligopolistic markets with competition among a few organizations, and as such, are applicable only in the context of monopolies or perfect competition. The competitive interactions can have a significant influence on the desirability of various coordination mechanisms or alternative organizational forms, the extent of diversification (Scott, 1991), speed of new product development, and, level of product differentiation or cost leadership incentives (Scherer, 1980; Porter, 1985). A large number of industries from air crafts and automobiles to athletic shoes, cereals, and fast food, can be best described as oligopolies where actions of one organization significantly influence the strategies of another. Moreover, the fast pace of consolidation in a number of industries such as suppliers of various parts and components to automobile manufacturers, auto dealers, entertainment, and banking, implies that competitive influences will play an increasingly important role in determining an organization's behavior.

The broad objective of our research is to study inter-organizational relations in an oligopolistic setting to explore the possibility that different organizations may, in addition to the efficiency incentive, have a strategic incentive as well to engage or not in various forms of coordination or vertical integration. Specifically, we employ a game-theoretic approach where competitors' reactions are explicitly accounted for, and study the interactions between specific organizational and operational decisions such as process innovation and transfer pricing agreements between firms (or divisions of a firm), and the implications thereof for organizational form and coordination incentives. There are three basic themes in this thesis:

1. *Supply chain coordination in the presence of competition:* The joint consideration of vertical coordination along the supply chain and the competitive environment provides a foundation for better understanding the variety of interorganizational coordination mechanisms and the changes in organizational form observed in a large number of industries. The mandate of increasing the efficiency of production and distribution through more coordination among members of a supply chain – a mandate implicit in most of the expanding literature in the increasingly popular field of Supply Chain Management – does not capture

the strategic incentives that play an important part in any intra- or inter-organizational coordination.

2. *Integrating both the demand and the cost side effects:* An interdisciplinary modeling approach that incorporates both the demand and the cost side parameters yields a much more general framework in which to analyze specific firm decisions. Most studies in marketing ignore the cost side effects (eg, manufacturer's investments in cost reduction), whereas most of the operations management literature ignores the demand side effects (eg, retail pricing), and thus, can lead to suboptimal decisions.

3. *Interactions between 'horizontal' and 'vertical' inter-organizational relations:* The problem of coordination among different firms at various stages of a supply chain (from raw materials, to suppliers of intermediate parts and components, manufacturers, wholesalers and retailers) is generally treated as distinct from the problem of cooperation among different organizations (ie, competitors) within the same industry (eg, through strategic alliances and joint ventures). By simultaneously modeling these two dimensions of inter-organizational relations, we intend to show that such interactions are crucial in explicating a more relevant theory of the firm and market structure.

The thesis is divided in four parts. In the first part, we analyze a manufacturer's incentives to integrate or decentralize downstream retailing in relation to his[1] own investments in cost-reducing process innovation. We develop a four-stage game theoretic model with two manufacturers and two retailers where the decisions at successive stages of the game include a choice between integration and decentralization, level of R&D investments, setting the transfer price, and setting the retail price. Results from this model indicate that the optimal channel structure decision depends on two parameters: degree of substitutability between the manufacturers' products, and the extent of investments in production cost reduction. These parameters represent what have been widely interpreted in the management literature as the two primary 'generic

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[1] The masculine gender is used throughout this thesis for simplicity only.

strategies' that most organizations follow in order to gain competitive advantage: cost reduction and product differentiation (Porter, 1981, 1985). Thus, our analysis brings out the strategic and interdisciplinary nature of the channel structure decision that can significantly affect firm profitability. Specifically, we find that manufacturers may prefer decentralized, non-coordinated channels to integration (or perfectly coordinated channels) when product substitutability is high, contrary to efficiency arguments for increased coordination as well as transaction-cost based arguments for integration. Moreover, the range of substitutability over which decentralization is an equilibrium strategy is smaller the easier it is reduce production costs, implying that there is an explicit trade-off between efficiency and strategic incentives in distribution channel design. Second, we show that decentralized manufacturers invest less in process innovation than integrated manufacturers do, because of a vertical 'R&D externality' induced by the imperfect appropriability of the benefits of R&D to the manufacturer in a decentralized channel. Consequently, a decentralized channel with non-coordinated decision-making has higher costs, charges higher prices, and produces lower quantities than an integrated channel does. Lower channel costs, however, do not always benefit the coordinated manufacturer when competitive interactions between channels are accounted for. Profit dominance conditions depend, in general, on interactions between cost reduction and product differentiation parameters. Thus, a joint consideration of both the demand and the cost side parameters allows us to extend many of the existing results on the likelihood of observing integrated or decentralized channels obtained previously in studies that consider only the latter decision, as well as obtain many new results.

In the second part, we expand on the above model by relaxing the assumption that a manufacturer has a choice only between integration (or 'hierarchy', with common ownership and centralized control over all decisions) and decentralization (or 'market', with separate ownership and control of respective decisions, transfer pricing being the only coordination mechanism). Various means of channel coordination are analyzed, and ownership is assumed to be distinct from the particular coordination mechanism employed. This is in agreement with the framework adopted by Langlois and Robertson (1995), as well as by Mattsson (1965) who considers integration along three dimensions: institutional, decision, and executional. The expanding body of literature on channel coordination mechanisms in marketing and operations management typically ignores the institutional dimension, the former focusing on transfer and retail pricing decisions, and the latter on production and inventory costs. We show that consideration of operational parameters such as production costs alongwith the pricing decisions has important implications on the desirability for a firm to engage in various forms of decision or ownership integration. For example, certain existing results on franchising agreements as a means of channel coordination do not hold when variation in production costs are taken into account: two-part tariffs (a fixed fee plus a per-unit charge) do not always guarantee that a manufacturer would always prefer to distribute his products through an independent retailer, contrary to existing results. Similarly, benefits of offering quantity discounts are expected to be much less pronounced than those shown by most analyses in the literature that ignores competition.

Note that in the above two parts, the horizontal interaction between firms is only through competition between their products in the final market. In practice, inter-organizational relations among firms in an industry are more varied: through externalities imposed on the competitors of one firm's investments, or various kinds of strategic alliances and joint ventures. We incorporate such horizontal relations in the third part of this thesis. We consider the possibility that intellectual property rights do not provide perfect protection for process innovation efforts of a manufacturer, and that rivals can benefit from his R&D investments at no cost to them. Such involuntary R&D spillovers have been the subject of intensive study over the last few years and have prompted many government policy changes as well. In keeping with the literature on R&D spillovers, we ignore the vertical aspects in this part and focus instead on various forms of horizontal cooperative arrangements and their effects on R&D levels, prices, and firm profits. To this end, we develop a two-stage game model, where n firms in an industry produce differentiated products and commit to a certain level of R&D expenditures. Four different arrangements for horizontal cooperation are analyzed (depending on whether the firms share cost or results of R&D or both), and conditions are provided under which different forms of research joint ventures are preferable (to other alternatives such as intellectual property rights or subsidies) in alleviating the old trade-off between provision of incentives and dissemination of

R&D. This model allows us to extend many existing models in the literature (eg, d'Aspremont and Jacquemin, 1988; Kamien et al, 1992; Suzumura, 1992).

In the fourth part, we merge the above two strands and consider the joint effects of horizontal cooperative arrangements in the presence of R&D spillovers, and vertical channel structure. That is, four different games are analyzed, each corresponding to a particular horizontal arrangement, where each game is similar to that analyzed in part I above with the added generality of involuntary R&D spillovers. The optimal channel structure is now shown to depend on three crucial parameters: degree of product differentiation, ease of production cost reduction, and level of R&D spillovers. Thus, the model integrates both the demand and the cost side effects, horizontal and vertical dimensions, as well as strategic and efficiency incentives in determining the channel structure. Thus, the problem of supply chain/channel coordination is shown to be much more complex and multi-faceted than a simple emphasis on reducing costs of production and distribution as is traditionally assumed in most of the operations management literature. Specific results for this part indicate that the threshold value of the R&D spillovers required for determining the nature of strategic interaction between the R&D level decision variables, and hence in evaluating the benefits of allowing competitors in an industry to cooperate on their R&D decisions, is dependent on the vertical structure of the industry: at any given level of product substitutability, a relatively larger level of spillovers is required to induce strategic complementarity between the R&D levels (which reduces incentives of a firm to unilaterally increase R&D investments) if manufacturers are integrated than if they are decentralized. Thus, even in the presence of spillovers, the strategic incentive persists for the manufacturers to decentralize retailing in order to limit their own R&D investments. This point has not been recognized in numerous analyses of research joint ventures, and government policies encouraging such cooperative arrangements ought to take into account the downstream integration level of the firms involved.

The thesis is organized as follows: in the next chapter, we summarize the research questions we address in our study and the methodology employed. In Chapter 3, we briefly review economic theories of the firm and some economic models relating to vertical integration incentives. This serves as a general backdrop against which we position our models. Accordingly, a more detailed review of the literature closely related to each of the four parts is handled separately alongwith the models in subsequent chapters. The first part appears in Chapter 4, where we present our basic model structure. In Chapter 5, we first provide a brief overview of the different channel coordination policies prevalent in the literature as well as in practice, and then consider these policies in the context of our model. In Chapter 6, we start with a review of the basic arguments and models proposed to study horizontal cooperation in research and development. These models typically ignore vertical channel relations, which we consider in conjunction with horizontal cooperative arrangements in Chapter 7. Chapter 8 concludes this thesis, and provides some directions along which we hope to extend this work.

2. RESEARCH QUESTIONS AND METHODOLOGY

2.1. Research Questions

The research questions that we wish to address in this thesis are summarized below:

(1) What are the determinants of incentives for an organization to engage in vertical integration or various forms of cooperative arrangements along its supply chain[1]?

(2) Are there any strategic incentives for a firm to engage (or not) in coordinated decision making along its supply chain? Is there any strategic value for an integrated firm to decentralize internally and delegate decision-making power to autonomous, profit-maximizing divisions? Can lack of coordination be beneficial for organizations?

(3) What effects do the level of integration or the cooperative agreements of a firm have on its internal operational parameters, such as incentives to invest in process improvements? Conversely, how do operational parameters such as production costs affect organizational incentives for cooperation?

(4) Is there a trade-off between cost-leadership and product differentiation incentives of manufacturers in an oligopolistic industry?

(5) Do intellectual property rights provide adequate protection to process innovation efforts

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[1] In this thesis, we will use the terms 'channel' and 'supply-chain' interchangeably, although the marketing literature generally employs the former term and focuses only on the manufacturer-retailer relations, whereas the operations management literature uses the term supply chain to refer to a more general network of interrelated activities consisting of raw material and components suppliers, intermediate and final product plants, distribution centers, warehouses, and retailers. For simplicity, we focus on the manufacturer-retailer relations in our discussions, though similar incentives exist at other stages as well.

of a manufacturer? Under what conditions should competitors in an industry be allowed to cooperate in their R&D efforts? How do these cooperative arrangements compare to other policy alternatives such as subsidies in restoring the divergence between social and private incentives to conduct R&D? Do they aid or restrict the dissemination of R&D results?

(6) In industries with technological spillovers and various institutional alternatives to R&D cooperation, under what conditions will the manufacturers prefer to integrate or decentralize the retailing function? Does the level of spillovers have an impact on the downstream integration incentive and the retail channel structure? Does the integration level of a firm affect its incentives to participate in a particular form of R&D cooperation? What effects do vertical cooperative arrangements of a firm have on its incentives to engage in horizontal R&D cooperation? Do government policies on vertical restraints and cooperative R&D need to be modified?

As mentioned in the Introduction, we have broken down this study into four related parts, and in each part we study a subset of the above questions in detail, as will be clear in the following chapters.

2.2. Methodology

In order to answer the questions listed above, we adopt an economic model-based approach. Since the competitive context of an organization is one of the central characteristics underlying our analysis, we develop a series of game-theoretic models in which competitive reactions are explicitly accounted for. Most models in the operations management literature typically ignore the competitive context, and focus instead on ways of minimizing production costs or coordinating production and inventory decisions across a (single) supply chain (eg, Cohen and Lee, 1988; Lee and Billington, 1992, 1995; Cachon and Fisher, 1997). On the other hand, models of oligopoly have been studied in the economics and industrial organization literature for a long time (eg, Cournot in 1838; Bertrand in 1883; Edgeworth in 1925), though these models typically abstract away from the detailed operational decisions of manufacturers. Issues of vertical restraints and channel coordination have been extensively studied within the disciplines of both economics (eg, see Blair and Kaserman, 1983; Mathewson and Winter, 1984; Rey and Tirole, 1986) and marketing (eg, McGuire and Staelin, 1983; Jeuland and Shugan, 1983; Coughlan and Wernerfelt, 1989), also at the expense of production decisions. Thus, none of these disciplines provides adequate answers to the questions listed above. We borrow insights, models and results from each of these disciplines and seek to integrate them in our models; that is, we study the competitive environment, channel coordination practices, and operational parameters simultaneously. A discussion of why we choose *noncooperative game theory* as our preferred methodology and the specific assumptions employed in our models follows.

We base our analysis on the observation that in industries with a handful of firms, strategic decision making requires a careful consideration of the competitive environment and anticipated reactions of the competitors. Firms are assumed to act as rational decision-makers who make their operational and structural decisions to maximize their own profits, while being aware of the impact that the competitors' decisions will have on their own profitability, and conversely. Game theory provides an ideal tool for analyzing decision making in such a setting. Pioneered by von Neumann and Morgenstern in the 1940s, it has proved to be an invaluable tool in analyzing competitive and cooperative interactions among rational decision makers in situations where their respective well-being depends on actions taken by all the players involved (Rubinstein, 1991). The level of theoretical developments in this field has been remarkable[2], and practical applications span the fields of economics, management, biology, political science and international relations.

We treat organizations as players in a game where the profitability of each is dependent on the actions taken by all the players, reflecting their interdependence through the markets in which the organizations compete.

> "If the essence of a game of strategy is the dependence of each person's proper choice of action on what he expects the other to do, it may be useful to define a 'strategic

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[2] The Noble Prize for Economics for 1994 was awarded to three game theorists: John Harsanyi, John Nash, and Reinhard Selten.

> move' as follows: A strategic move is one that influences the other person's choice, in a manner favorable to one's self, by affecting the other person's expectations of how one's self will behave." [Schelling, 1960]

> "Game theory is particularly effective when there are many interdependent factors and no decision can be made in isolation from a host of other decisions." ... "The real value of game theory for business comes when the full theory is put into practice: when game theory is applied to the interplay between competition *and* cooperation." [Brandenburger and Nalebuff, 1996]

We take the example of an operational decision involving the level of investments in process innovation as a strategic commitment by the manufacturers whereby they expect to alter the outcome of competition between independent, profit-maximizing firms to their own advantage. The method employed can be used to analyze other types of strategic commitments as well. The example chosen enables us to analyze the strategic interaction effects of the cost leadership incentive of manufacturers in industries with only a few producers. Moreover, since we assume manufacturers to be producing differentiated products, our analysis provides an explicit account of the trade-offs between cost leadership and product differentiation incentives.[3] Porter (1985) has convincingly argued that firms should (and often do) choose between the 'generic strategies' of cost-leadership *or* product differentiation, but not both. Though this framework has been widely adopted within strategic research and practice in management, and a lot of anecdotal evidence and some empirical data exist supporting this view, there has not been much systematic quantitative examination of the trade-off posited in this framework.

Though the specifics of the models employed in different chapters below differ somewhat, the common assumptions and their methodological implications are summarized below:

First, we illustrate the concepts of a multi-stage game and the different equilibrium notions utilized, ie, Nash, Stackelberg and subgame perfect equilibria, due respectively to Nash,

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[3] In the models that we have developed so far, product differentiation is treated as an exogenous parameter. More ambitious models may formalize the choice between cost leadership and product differentiation explicitly.

von Stackelberg, and Selten (see Shubik, 1980; Friedman, 1977; or, Fudenberg and Tirole, 1992, for a full description). Let $\Gamma = [N, \{S_i\}_{i \in N}, \{\pi_i\}_{i \in N}]$ denote a game between n players played in m stages, where $N = \{1, 2, \ldots n\}$ is the set of players; S_i is the set of strategies of player $i \in N$, $S_i = S_i(1) \times S_i(2) \times \ldots S_i(m)$, where $S_i(\varsigma)$ represents the strategy set of player i at stage ς (ie, $S_i = \prod_{\varsigma=1}^{m} S_i(\varsigma)$, the Cartesian product of the strategy sets at each stage); and, π_i is the payoff function of player $i \in N$ that maps every strategy-tuple $\mathrm{s} = (\mathrm{s}(1), \mathrm{s}(2), \ldots \mathrm{s}(m)) \in \{\prod_{i=1}^{n} S_i(1)\} \times \{\prod_{i=1}^{n} S_i(2)\} \times \ldots \times \{\prod_{i=1}^{n} S_i(m)\}$ into the set of real numbers (where $\mathrm{s}(\varsigma) = (s_1(\varsigma), s_2(\varsigma), \ldots s_n(\varsigma))$ is the strategy n-tuple at stage ς, $s_i(\varsigma) \in S_i(\varsigma)\ \forall i$, and $\mathrm{s}(\varsigma) \in \prod_{i \in N} S_i(\varsigma)$; we also write $\mathrm{s}(\varsigma) = (s_i(\varsigma), s_{-i}(\varsigma))$, where $s_{-i}(\cdot)$ denotes the vector of strategies of all players except player i). At any stage $\varsigma = 1, 2, \ldots m-1$, players simultaneously and non-cooperatively choose a strategy n-tuple $\mathrm{s}(\varsigma)$ that induces a subgame $\Gamma(\mathrm{s}(\varsigma)) = [N, \{S_i(\varsigma+1)\}_{i \in N}, \{\pi_i(\mathrm{s}(\varsigma), \cdot)\}_{i \in N}]$, and so on. The strategy profile $\mathrm{s}(\varsigma)$ is a *Nash equilibrium* of the game (in pure strategies[4]) at stage ς if no player has an incentive to deviate from it, ie, for all players $i \in N$, $\pi_i(s_i(\varsigma), s_{-i}(\varsigma)) \geq \pi_i(\tilde{s}_i(\varsigma), s_{-i}(\varsigma))$, for all $s_i(\cdot), \tilde{s}_i(\cdot) \in S_i(\cdot)$. On the other hand, a *Stackelberg equilibrium* applies to situations where players move sequentially at each stage (and hence the game reduces to one with perfect information). Thus, a Stackelberg equilibrium is consistent with backward induction (Schelling, 1960; Fudenberg and Tirole, 1992). Finally, a *subgame perfect equilibrium* extends the idea of backward induction to extensive form games where players move simultaneously at several stages (Selten, 1965; Fudenberg and Tirole, 1992). A subgame perfect equilibrium of the multi-stage game described above is a strategy profile s such that $\mathrm{s}(\varsigma)$ is a Nash equilibrium of the subgame $\Gamma(\mathrm{s}(\varsigma))$ for each ς. To illustrate, assume the game Γ as above, but with only two stages, $\varsigma = 1, 2$. Specification of $\mathrm{s}(1)$ induces a subgame $\Gamma(\mathrm{s}(1))$, and let $\mathrm{s}^N(\mathrm{s}(1)) \in \prod_{i \in N} S_i(2)$ be the Nash equilibrium of the subgame $\Gamma(\mathrm{s}(1))$.[5] Then, assuming that the outcome of the second stage game will correspond to the Nash equilibrium, the game to be analyzed at the first stage can be represented by $\Gamma^N = [N, \{S_i(1)\}_{i \in N}, \{\Omega_i\}_{i \in N}]$,

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[4] That is, probabilistic (or mixed) actions are not considered.

[5] The existence and uniqueness of such equilibria are assumed here; see Friedman (1977) or Fudenberg and Tirole (1992) for a detailed discussion.

where $\Omega_i(\mathrm{s}(1)) = \pi_i(\mathrm{s}(1), \mathrm{s}^N(\mathrm{s}(1)))$, $i \in N$, for each $\mathrm{s}(1) \in \prod_{i \in N} S_i(1)$. If $\mathrm{s}^N(1) \in \prod_{i \in N} S_i(1)$ is the Nash equilibrium of game Γ^N, then $\left\{\mathrm{s}^N(1), \mathrm{s}^N(\mathrm{s}(1))\right\}$ is the subgame perfect equilibrium of the two stage game Γ (Suzumura, 1995). We will use these concepts in subsequent chapters to analyze various multi-stage games.

Secondly, we assume throughout that consumers value diversity in the products that they consume. We follow the "non-address" approach to model the consumer preferences [Spence, 1976; Dixit and Stiglitz, 1977]. That is, a predetermined set of all possible products in an industry is assumed, over which the consumer preferences are defined.[6] This approach is quite flexible, allows easy welfare analysis [Eaton and Lipsey, 1989], and has been recently used by a number of authors (eg, Roller and Tombak, 1990, 1993; Coughlan and Wernerfelt, 1989; McGuire and Staelin, 1983).

Let the typical consumer's utility function be [Shubik, 1980; Shaked and Sutton, 1990]:

$$U(q_1, q_2, y) = \frac{M(q_1 + q_2)}{b(1-\theta)} - \frac{q_1^2 + 2\theta q_1 q_2 + q_2^2}{2b(1-\theta^2)} + y \tag{2.1}$$

where q_i is the amount of good i ($i = 1, 2$) and y the amount of income spent on some numeraire good consumed by the representative individual ($y = I - \sum_i p_i q_i$, I being the consumer's income, and p_i the unit price for product i); parameters M, b, and θ are all positive, and $0 \leq \theta < 1$ implying that goods are demand substitutes. Then, assuming I to be sufficiently large so that the consumer's optimal purchases are obtained as an interior solution by setting the marginal utility equal to the unit price ($\partial U/\partial q_i = p_i$) for each product i, we obtain the following system of demand functions:

$$q_i = M - bp_i + b\theta p_j, \quad j = 3 - i,\ i = 1, 2 \tag{2.2}$$

Thus, M can be interpreted as the total market size (when both prices are zero), and θ

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[6] This is in contrast to the "address" approach where the assumed diversity of consumers' tastes is captured through a distribution of tastes over some continuous space of parameters describing the nature of products (see Eaton and Lipsey, 1989, for a summary of the two approaches).

as a substitutability parameter: $\theta = 0$ implies that each manufacturer is a monopolist in his respective market, and products become maximally substitutable as θ approaches unity.

For all the models except those in Chapter 6, the following structure is assumed: there are two manufacturers, each of who produces a single product, and can distribute his product through one of the two retailers in each geographical region. Each retailer carries the product of only one manufacturer. While this structure may appear somewhat restrictive, it adequately captures the reality in a large number of industries (eg, automobiles, gasoline, and fast food chains). Moreover, this structure has been used by a number of authors (eg, McGuire and Staelin, 1983, 1986; Coughlan, 1985; Moorthy, 1988). The sequence of actions obeyed is as follows[7]: first, manufacturers choose whether to integrate or decentralize the retailing of their products, and then decide on investments in process innovation to reduce their unit production costs. Then, transfer prices are set at which the products will be sold by the manufacturer to the retailer (whether internally within two divisions of a firm, or between separately owned firms). Finally, retailers set the prices at which they will sell their products to final consumers. At each stage, the players are assumed to make their decisions simultaneously, taking the other player's actions as given, and in full knowledge of all the actions taken by all the players at previous stages. The structure is illustrated in Figure 2.1.[8]

With regard to the timing of actions assumed, we believe it is reasonable. For most manufacturers, channel integration is a longer-term decision and precedes those on R&D and transfer pricing, both of which are on-going, short-term decisions. Also, manufacturers' investments in process improvements are anterior to their own production and setting of prices for the retailers. Second, by postulating simultaneous decisions at each stage, we are in effect assuming that firms at each level are symmetric (with their competitor in the other channel); there is no industry leader in any of the actions. While an alternative formulation with a leader/follower structure

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[7] The particular decision rule followed at each of these stages will be different in different models, depending on the institutional assumptions.

[8] On the other hand, models described in Chapter 6 ignore the vertical structure decision and assume the manufacturers to be vertically integrated, in accord with the existing literature on R&D spillovers. This simplification allows us to to extend the model to a general oligopoly with n manufacturers.

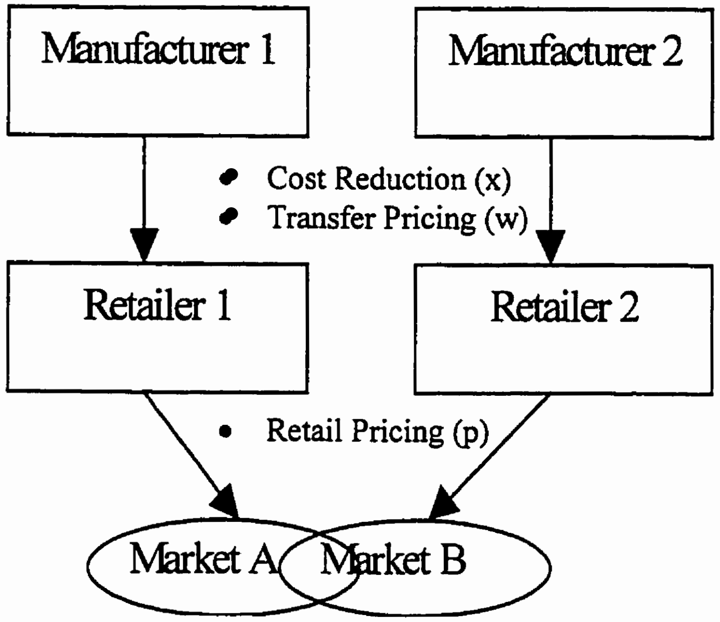

Figure 2.1: A Differentiated Products Duopoly: Channel Structure and Sequence of Decisions

is also possible (and requires determination of Stackelberg equilibria instead of Nash), it is an empirical question as to which of the two is most prevalent; a priori, both would seem to be of equal importance. However, loss of simultaneity of decisions in a leader/follower formulation simplifies the model to one of perfect information. Moreover, the assumption of symmetry also implies that competitors in an industry have equal access to various means of cost reduction. This is quite reasonable given the fact that new ideas and technologies (eg, JIT, FMS, EDI, SCM) get diffused very quickly, especially if they have the potential to affect an organization's cost structure. Third, it can be argued that our assumption that all the decisions are observable to all the players at subsequent stages is somewhat restrictive, as firm- or channel-specific decisions such as R&D investments and transfer pricing contracts may not be observable to competitors. While this may or may not be true, we need to remember that one of our main interests is identifying the effects of strategic interactions; lack of observability of intra-channel decisions may dampen (or nullify) these effects (eg, Coughlan and Wernerfelt, 1989; Katz, 1991). While the latter may be a better description of some empirical settings, that would certainly be a loss in identification of underlying strategic incentives. If such incentives do exist, firms may take measures to *purposively reveal* their operational and channel-specific information.

3. ECONOMIC THEORIES OF THE FIRM: A BRIEF REVIEW OF VERTICAL INTEGRATION

"A firm can be described as vertically integrated if it encompasses two single-output production processes in which either (1) the *entire* output of the 'upstream' process is employed as *part or all* of the quantity of one intermediate input into the 'downstream' process, or (2) the *entire* quantity of one intermediate input into the 'downstream' process is obtained from *part or all* of the output of the 'upstream' process" [Perry, 1989]. This definition thus characterizes vertical integration as dependence between two related stages of production, while ruling out the case where *most* of the output of upstream process is used as *most* of the input in the downstream process. The notion of the substitution of market exchange by internal mechanism (within a firm) is inherent in this definition, though it is not limited to this view, as are definitions adopted by the proponents of transaction cost approach (see section 3.2) that sees vertical integration as "... an alternative to contracting where the hazards of market exchange are severe" (Masten, 1996). However, as is readily apparent, it does not directly address the important questions of ownership and control: that is, delineating the range of decisions (eg, investments, employment, deployment of assets in production and distribution) over which partners in an exchange have full authority, and the change in bargaining power or governance capabilities of one party due to ownership. Somewhat different positions are held by Williamson (1975) and Grossman and Hart (1986). (We will discuss these separately below.) In brief, the former argument relies on relationship specific investments in physical assets and human capital as an important element in integration decision, as such specificities expose the parties to opportunism especially because of the lack of ex-post competition. Difficulties in guarding against such possibilities and resulting increase in contracting costs provides incentive to integrate — to internalize these transactions. The second argument considers vertical integration as gaining ownership of the assets of another firm, which gives residual rights of control over all aspects that cannot be contracted (in an incomplete contract) to the owner [Grossman and Hart, 1986]. In this view, no distinction is made between "employees" and "outside contractors" as long as the ownership of the assets used is not changed — that is, nature of the firm's relationship with labor is irrelevant in vertical integration decision — and moreover, rights to a return stream (generated by the acquired firm) are considered to be distinct from ownership of physical assets, in contrast to the literature on property rights that explicitly identifies ownership with rights to a residual return stream [Holmstrom and Tirole, 1989].

It will be useful to recall why, in the economic perspective, does the problem of organization arise in the first place. "Problems of organization arise wherever the benefits of specialization lead to trade" and "with trade ... comes the need to coordinate" [Masten, 1996, p.5]. The contractual perspective sees markets and firms as two polar modes of governance, with the necessary coordination provided by the price system in the former (as assumed in neo-classical economics) and by managerial fiat in the latter. A large number of alternatives exist, however, in the form of institutional or contractual arrangements that are a hybrid between pure (anonymous) spot market exchange and complete vertical integration, sometimes referred to as "vertical controls" or "vertical restraints". Perry (1989) defines vertical control as "a contract between two firms at different stages which transfers control of some, but not all, aspects of production and distribution". Examples of such arrangements include vertical quasi-integration, input-tying, output royalties, requirements contracts and exclusive dealing, and resale price restraints [Katz, 1989][1]. Blair and Kaserman (1983) argue that certain contractual arrangements such as input-tying, royalty, or lump-sum entry fee can be used by an intermediate-product monopolist to yield economically equivalent outcomes to ownership integration, and hence should be similarly treated in a legal sense. Alternative forms of organization such as franchising and joint ventures will be an important part of our study, and a detailed discussion of these is deferred to later chapters.

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[1] See section 3.4.2 for brief definitions.

We now turn to a brief discussion of some of the explanations usually provided for incentives of a firm to integrate. The broad categories are: technological economies, transactional economies, and market imperfections [Perry, 1989]. The first two are "efficiency" arguments [Tirole, 1988]; the former focuses on integration as a way of minimizing costs of production, while the latter relates to minimization of the costs of organizing and governing the exchange process itself between two firms. This might lead one to the erroneous conclusion that integration will always enhance social welfare. In this context, Blair and Kaserman (1983) emphasize the importance of distinguishing between (1) the underlying incentives of a firm to exercise control over another vertically related firm, and (2) the choice of a specific control instrument (ie, ownership integration or contractual arrangements) — such a distinction would help separate out profit motives from efficiency motives for integration. Moreover, Perry (1989) argues that market imperfections remain an important determinant of vertical integration, even if firms have integrated to economize on technological and transactional factors. Integration in response to market imperfections may increase or decrease welfare, hence the importance of government policy.

3.1. Technological Economies

In the past, the predominant economic theories of firm size used to be technology based. In this view, beginning with Viner's (1932) analysis of long-run average cost curves, concentration of production within a single firm is explained by economies of scale, and the optimum firm size is determined by the minimum average costs [Holmstrom and Tirole, 1989]. Higher levels of output allow investments in efficient techniques, new technologies, and specialization of labor.

A related argument is economies of massed reserves [Robinson, 1958] — "a plant with a larger number of machines can support a flow of output proportionally higher than one with a small number" [Tirole, 1989], as random breakdowns have less of an impact in the former case. A similar argument could be used in terms of pooling of various product markets with variable demand to reduce uncertainty. Economies could also be realized in a variety of other activities

— such as marketing, distribution, research and development, procurement of components, and sharing of production techniques among multiple products.

However, limits exist to scale advantages. As firm size grows, these advantages become smaller and smaller, as savings associated with pooling of risk and law of large numbers also become smaller and smaller. Other reasons may include lack of managerial talent and limits to managerial capability. A related development in production management literature is the concept of "focused manufacturing" [Skinner, 1974]. Here it is argued that an expansion in the size of the plant based on economies of scale arguments, as well as widening of product range being manufactured in response to marketing-led strategies of higher differentiation, leads to increased complexity and confusion in the plant [Hill, 1994]. Coordination problems and conflicting requirements of different products make production costs rise as size and complexity increases.

Technological reasons for determination of limits of a firm have almost been abandoned in economic theories of the firm, in favor of transaction cost based arguments which are viewed as "the more interesting economic reasons for vertical integration" [Perry, 1989, p.187]. It is argued [Tirole, 1989] that the technological view is inadequate as a theory of the firm because: (a) it does not explain why economies of scale should be exploited within a firm, instead of through contracting between two legally separate entities; and, (b) diseconomies of scale (ie, average cost curves rising at higher outputs) is not a convincing argument for explaining limits to firm size. In particular, technological view does not explain Williamson's "puzzle of selective intervention" [Williamson, 1975, 1985; Tirole, 1989; Holmstrom and Tirole, 1989]: Why can't one merge two firms into a single one, and by selective intervention (from the top), accomplish more in the integrated case than in the decentralized case?

3.2. Transaction Cost Approach

Another definition of vertical integration is whereby a firm "... (internally) transmits a good or service which could, without major adaptation, be sold in the market" [Adelman, 1949; Blair and Kaserman, 1983]. Thus, *markets* and *hierarchies* (or *firms*) are viewed as two alternative mechanisms of coordinating the allocation of productive resources in an economy [Coase, 1937; Williamson, 1975]. The former relies on "the market supply of and demand for the intermediate product" at the aggregate level and "the bilateral negotiation and contracting process that occurs between individual buyers and sellers" at the disaggregate level [Blair and Kaserman, 1983]. Vertical integration suppresses the price mechanism of the market and replaces it with "unilateral administrative decisions of the managers of the firm and the bureaucratic or hierarchical processes through which these decisions are implemented" [ibid]. In this view, credited to Coase, the fundamental reason for the existence of firms is to economize on the costs of using the price mechanism, widely referred to as the transaction costs: "Transaction costs refer to any expenditure of resources associated with the use of the market in transferring a good or service from one party to another" [ibid]. Thus, an incentive to vertically integrate exists whenever internalizing the transfer of an intermediate product leads to reduction in transaction costs.

A question naturally arises then as to the underlying sources of transaction costs. Such a determination would be necessary in order to predict the relative efficacy of markets and hierarchies in organizing economic transactions and how it changes over time [Williamson, 1975; Blair and Kaserman, 1983]. A thorough analysis of such determinants was provided first by Williamson, which we briefly summarize below.

3.2.1. Determinants of Transaction Costs

First of all, it would be useful to recall Williamson's own summary of his approach to economic organization [Williamson, 1975, p. 8]:

"(1) Markets and firms are alternative instruments for completing a related set of transactions;
(2) whether a set of transactions ought to be executed across markets or within a firm depends on the relative efficiency of each mode;
(3) the costs of writing and executing complex contracts across a market *vary with the characteristics of the human decision makers who are involved with the transaction on the one hand,*

and the objective properties of the market on the other; and
(4) although the human and environmental factors that impede exchanges between firms (across a market) manifest themselves somewhat differently within the firm, the same set of factors apply to both."

Williamson identifies "uncertainty" and "small numbers exchange relations" as the two environmental factors, and "bounded rationality" and "opportunism" as the two human factors. It is argued that interactions among these factors are primarily responsible for increasing the costs of market exchange, by impeding the "negotiation and enforcement of contractual agreements between buyers and sellers of an intermediate product". Thus, all economic activity is seen as a series of contracts. Hierarchies replace markets when the contractual costs of the market mechanism become too large. Therefore, the theory explains the shift from many small organizations to a few large ones as a pursuit of efficiency in costs of transacting business – "efficiency of organizational forms, not the efficiency of specific practices, machines, sales techniques, or transportation devices" [Perrow, 1986, p.236]. "I argue that efficiency is the main and only systematic factor responsible for the organizational changes that have occurred" [Williamson, 1975]. Let us look briefly now into each of the four factors central to the Transaction Cost Economics (based on Blair and Kaserman, 1983; Williamson, 1975):

1. Uncertainty: Uncertainty refers to future environmental changes that cannot be foreseen or controlled — for example, uncertainty regarding future market demand, price or quality of the product, ability to produce a new product, technological innovations that may reduce production costs and/or enhance quality, availability of required quantities at any price/quality combination (ie, possibility of rationing). Existence of uncertainty increases the chances of contractual reneging by either party to an exchange. Therefore, a higher degree of uncertainty requires that more lengthy and complex contracts be negotiated to safeguard the interests of both parties, which, in turn, increases the costs of negotiating and enforcing the contracts. However, by locking the parties in a longer, more rigid contract, it also reduces the flexibility to adapt to changing market conditions.

2. Small Numbers Bargaining: This situation arises when parties involved in a trade find their options for seeking alternative partners severely limited. Specifically, this problem could arise even when a large number of potential bidders are involved at the outset. Once the contract is awarded, the winner of original bid may enjoy non-trivial cost advantages over others at the contract renewal time, due either to specific investments in plant and equipment made by the bidder, or investments in firm-specific human capital that result by carrying out the original contract (investments in routines and experience with that firm's supplies, procedures, and idiosyncracies). In either case, firms, by engaging in a contractual exchange over a certain period of time, have created a form of *asset specificity* — specialized assets that are most useful only when employed in an exchange relation with a specific firm.

3. Bounded Rationality: Limits on the capacity of human decision makers have been recognized for a long time, though not explicitly considered especially in economic models that accord human agents a "superrational calculating behavior" [Blair and Kaserman, 1983], or a "preposterously omniscient rationality" [Simon, 1976]. Simon proposed a theory of human behavior and decision-making that "aims to accommodate both those rational aspects of choice that have been the principal concern of the economists and those properties and limitations of the human decision-making mechanism that have attracted the attention of psychologists and practical decision-makers" [Simon, 1976, p. xi]. Simon distinguished between the "economic man" — who *maximizes* (ie, selects the best alternative from all possible actions) and deals with the 'real world' in all its complexity — and the "administrative man" who, instead, *satisfices* (ie, looks for a course of action that is "good enough" without first trying to ascertain *all* possible choices), and, moreover, makes his choices "using a simplified picture of the situation that takes into account just a few of the factors that he regards as most relevant" while ignoring others [ibid]. The latter characteristic allows him to use relatively simple rules of thumb that mitigate the unreasonable requirements on his mental capacity that would otherwise be placed while making decisions. It is in this context that "bounded rationality" is used by Simon as referring to human behavior that is "intendedly rational, but only limitedly so". Thus, in complex situations, bounded rationality may result in individual uncertainty regarding choices available or the consequences thereof, even when the situation itself does not exhibit any such uncertainty — a common example that is often cited in this context is the game of chess (eg, von Neumann and Morgenstern, 1953; Simon, 1975; Williamson, 1975). Chess is of course a game of perfect information, but a complete decision tree is prohibitively complex to develop, hence players must play with substantial uncertainty regarding the future evolvements.

4. Opportunism: Williamson postulates opportunism on the part of all parties involved in an exchange — "a lack of candor or honesty in transactions, to include self-interest seeking with guile" — as a major factor in explaining the choice between alternative contractual relationships. He considers opportunism as an extension of the standard economic assumption of self-interest on the part of agents, "to make allowance for strategic behavior" [Williamson, 1975, p.26].

Williamson argues that these four factors, and especially the interactions among them, explain when economic exchange relationships that were previously coordinated through the market are internalized within a firm. For example, when substantial uncertainty exists regarding future contingencies, bounded rationality of the actors involved makes it very costly or impossible to specify appropriate course of action in all possible contingencies. Thus, long-term contracting costs are increased which may lead to integration, since internal organization relies on administrative processes to orchestrate adaptations to uncertainty by means of an "adaptive, sequential decision-making process" instead of trying to anticipate all possible contingencies in advance. A second example posits the pairing of opportunism and small-numbers bargaining that results in increased short-term contracting costs — Williamson stresses that such a pairing is necessary, for opportunism itself will not result in internal transfer if there are a large number of bidders available because "rivalry among large number of bidders will render opportunistic inclinations ineffectual" [Williamson, 1975, p.27].

In essence, the argument is as follows: firms involved in a market exchange make investments in specialized assets that limit their future choices in terms of alternative partners. This exposes both firms to opportunistic behavior by the other. Therefore, firms negotiate a bilateral contract that specifies each party's obligations in all possible contingencies. Such a specification is, however, made impossible or very costly by the existence of market uncertainty and bounded rationality of the actors involved — more so for long-term contracts that have to balance the higher costs and increased complexity against flexibility (as a rigidly specified contract may lock the parties in a mutually harmful relationship if the market conditions change). An equivalent series of short-term contracts may provide the requisite flexibility by giving an opportunity to the parties to re-specify terms at contract renewal time. However, problems related to small-numbers bargaining and opportunistic behavior due to asset specificity (since "fixed investments made by one party generate a stream of quasi-rents that may be appropriated by the other party" [Blair and Kaserman, 1983]) may make short-term contracting unattractive. Thus, basic predictions of this approach can be summarized as follows: *internal transfers (ie, hierarchies) will replace market exchange whenever the costs of using the market mechanism to coordinate the exchange are high. This will happen in situations where market uncertainty is relatively great and where short-term contracts involve small-numbers bargaining.*

3.2.2. Advantages of Internal transfers

As indicated above, the transactions cost approach attributes certain advantages to coordinating economic activity within a single firm instead of through the market mechanism. Four major properties that favor internal control of related stages of production, as summarized by Blair and Kaserman (1983), are:

a) Flexibility to adapt to changing market conditions: output and capacity changes are easier to coordinate, and convergence of expectations can be realized.

b) Reduced opportunistic tendencies of the parties: "internal divisions do not have preemptive claims on profit streams (but more nearly joint profit maximize instead)"; and "the internal incentive and control machinery is much more extensive and refined than that which obtains in market exchanges" [Williamson, 1975, p. 10].

c) Informational advantages: reduction in incentives to behave opportunistically reduces the threat of falsifying information to gain strategic advantages at the expense of other party ("strategic misrepresentation risk"). Moreover, common experiences within a single firm improve communication that aids the flow of information. Finally, the firm has greater access to relevant performance data of its internal divisions than of other firms.

So what prevents all economic activity from being organized in one giant firm? Williamson, and Coase and Malmgren before him, have based the arguments limiting firm size on *managerial diseconomies of scale* — that is, as firm size increases, the costs of organizing additional transactions within the firm rise, making further integration unattractive.

3.3. Incomplete Contracting and the Theory of Residual Ownership

The transaction-cost based arguments summarized above have been modified and "sharpened" by Grossman and Hart (1986), who stress that the allocation of *residual decision rights* implied by different modes of governance is crucial in enunciating a theory of vertical (or lateral) integration. This framework relies on the argument that most contracts are fairly incomplete owing to the transaction costs associated with foreseeing and writing all contingencies, as well as costs of monitoring and enforcing the contract [Williamson, 1975]. This incompleteness gives rise to opportunities for ex-post bargaining, which, in turn, might lead to inefficiencies in ex-ante investments or ex-post trade [Perry, 1989; Tirole, 1988]. However, in contrast to the transaction cost literature where vertical integration is a way of alleviating opportunism and the associated investment inefficiencies, the focus here is on the residual decision rights, identified with the ownership of assets, that are any rights not explicitly contracted away beforehand in an (incomplete) contract [Perry, 1989; Holmstrom and Tirole, 1989]. Integration is thus viewed as a means of gaining ownership of another firm's assets, which gives the acquiring firm the residual rights of control over production decisions of the other firm and alters the ex-post bargaining positions of the parties involved. Several examples have been provided to illustrate how distribution of residual decision rights (or, authority) affects the division of gains from trade and incentives for ex-ante investments — see Tirole (1988), Holmstrom and Tirole (1989), Hart and Holmstrom (1987). Most of these examples consider ex-ante investments by one (or both) parties that enhance the gains from trade by increasing the value of the exchange to the buyer (for example, a higher quality good), or by decreasing the costs of production for the seller. The investment decisions are assumed to be not contractible. The (realized) value of the improvement (due to a technological innovation or product design change, say) is assumed to be observable to the parties involved, but not verifiable by an outside party (eg, court) — hence a contract contingent on realized value is not feasible. It is then shown that desirability of integration depends on the particular parameter values chosen. In particular, "this mode of analysis offers a reason why selective intervention is not possible and therefore why integration may not be desirable" [Holmstrom and Tirole, 1989].

3.4. Market Imperfections

The literature on integration incentives as a result of market imperfections, especially in the neoclassical tradition, is extensive and scattered. Excellent surveys have been provided by Blair and Kaserman (1983), and Perry (1989). We only mention below some of the major results that are closer to our models in subsequent chapters.

A basic distinction that can be made for various models in this category is that of the assumption regarding degree of substitutability between intermediate inputs. The *fixed input proportions* models assume that one unit of each intermediate product is produced for each unit of the final product. This is a realistic assumption in several industries such as computers and semiconductors, automobiles, and petroleum. More importantly, this assumption also allows analysis of manufacturer-retailer relationships in the recent but growing literature on distribution channel choice (see Chapter 4). In contrast, the variable input proportions models explicitly consider the effect of substitutability among intermediate products that form inputs to the production of a final product. Consideration of substitution among production factors may have important consequences for conclusions regarding market structure and welfare implications.

3.4.1. Fixed Proportions

First of all, under fixed proportions inputs, Blair and Kaserman (1983) demonstrate with a simple example that a manufacturer with some degree of (horizontal) market power has no incentive to integrate into a downstream competitive industry, assuming no transaction costs, nonstochastic demand, and no product-specific services. Under these conditions, the manufacturer extracts all the monopoly profits through price and output decisions — that is, final product price and quantity are equal to those that would result from a vertically integrated monopoly (controlling both manufacturing and distribution stages). Consequently, there is no need for vertical integration by the manufacturer.

These conclusions are modified when successive monopoly is considered. A common example cited in this context is exclusive territories granted to franchisees by a manufacturer, that gives the retailer function market power within his geographical area. Under these conditions, it has been shown [Spengler,1950; Machlup and Taber, 1960] that the manufacturer's profits are reduced, retailer profits are increased, and total industry profits are lower (compared to the previous case of monopoly in manufacturing and competitive distribution). Thus, there is incentive for the manufacturer to integrate forward. Such an incentive may also exist when there are important product-specific services to be provided by the retailer that would shift the demand for manufacturer's products (see Blair and Kaserman, 1983, pp. 36).

Finally, incentives for vertical integration may exist as an instrument for increasing entry barriers in an industry. If all or most of the firms in an industry are vertically integrated, the input markets will not exist (or will be severely constrained, leading to bargaining difficulties and threat of rationing). Secondly, production costs may be lower for vertically integrated firms. For either of these two reasons, a potential entrant may be obliged to enter simultaneously at multiple stages which makes entry more difficult due to: (a) higher capital requirements, and (b) barriers to entry at any one stage get translated into overall entry barriers for the industry in question (see Blair and Kaserman, 1983; Williamson, 1975). We will return to this issue later.

3.4.2. Variable Proportions

Existence of incentives for a monopolist manufacturer to integrate forward, when the downstream industry employs the monopolist's product in variable proportions with other intermediate inputs, is "one of the most extensively discussed incentives for vertical integration" [Perry, 1989]. The basic argument in this stream, popularized by Vernon and Graham (1971), is as follows: monopoly pricing by the upstream manufacturer leads the downstream firms to substitute away from the monopoly input toward other competitively supplied inputs. As this substitution results in efficiency loss in downstream production, manufacturer has an incentive to integrate forward and internalize the profits obtained by restoring the efficient combination of inputs. Schmalensee (1973) established that this incentive persists till the upstream monopolist has successfully monopolized the downstream (final-good) industry as well. Moreover, a number of authors established that the final retail prices rise as a result of integration under a range of demand conditions — making integration even more attractive for the upstream monopolist. However, the welfare effects are a priori indeterminate — hence the importance of this issue for government policy.

Blair and Kaserman (1983) discuss a number of contractual alternatives that would yield outcomes equivalent to vertical integration. Specifically, they show that under assumptions similar to those for the models discussed above, following alternatives are equivalent to vertical integration: (a) an input tying arrangement, whereby the purchase by downstream firms of input x_2 (that is competitively supplied) is tied to the purchase of input x_1 (the monopoly input under question); (b) an output royalty whereby the x_1 monopolist charges a per-unit tax on output of the downstream firms; (c) a sales revenue royalty whereby the x_1 monopolist places an *ad valorem* tax on downstream sales revenue; (d) a lump-sum entry fee charged by the monopolist to the downstream firms for the right to purchase the monopolized input. Consequently, the authors argue that the antitrust treatment of these contractual alternatives should be the same as that of integration.

A substantial literature also exists on integration incentives under conditions of price discrimination, product differentiation, retail service externalities, and uncertainty or private information. We will review these models elsewhere (alongwith the role of product differentiation and flexibility in the theory of the firm). We turn now to a review of some of the works on successive oligopolies which are closer in spirit to our model presented in Chapter 4. Models in this stream are more recent and comparatively fewer.

3.5. Oligopolistic Vertical Integration

Issues of firm and market structure become more interesting, and empirically relevant, when one turns to oligopolies. Recent advances in game theory, and its increasing popularity, have certainly helped bring about more models analyzing markets that are best characterized by oligopolistic interactions. Some of the papers close to our analysis are reviewed below.

Two strands of research on oligopolistic vertical integration with fixed coefficients of technology can be distinguished. The first considers a general successive oligopoly — that is, two vertically related oligopolistic industries (suppliers and manufacturers) with market power assumed to be distributed asymmetrically, suppliers deciding on the price or quantity of the intermediate good, and producers having power in their output markets. The focus, then, is on welfare effects of vertical integration. The second stream of literature focuses on the relationship between a manufacturer and a distributor when both industries are oligopolies. In a game setting – typically taken to be a 2- or 3- stage four-player game with price or quantity competition – the authors analyze equilibrium market structures that would emerge under various degrees of substitutability among the final products. This second approach is much closer to our work, and we will analyze it in somewhat greater detail in Chapter 4. A brief review of the first approach follows.

One of the earlier models is by Greenhut and Ohta (1979). The setting is two vertically related industries, where each industry is an oligopoly engaged in Cournot competition, and there is perfect competition at the final consumer level. Assuming constant returns to scale and linear demand, the authors establish that a vertical merger by a subgroup of firms leads to an increase in total industry output and a reduction in final product price, thus raising consumer welfare. However, the industry profits fall, while the profits of the integrated firms increase at the expense of non-integrated firms. These conclusions are, therefore, in opposition to those obtained under successive monopoly whereby both consumers and producers benefit from integration.

Hamilton and Lee (1986a, b) consider the effect of entry into the upstream (intermediate product) market as well the possibility of market foreclosure in the downstream (final product) industry. That is, industry A supplies an input to industry B. A has a dominant firm and a competitive fringe, while B has two firms competing in quantities. Entry into market B is assumed to be impossible, while the entry rate into the competitive fringe of market A is a function of market price at which A supplies to B — higher price attracts more firms. The authors show that under these conditions, a merger between the dominant firm in A and one of the two firms in B results in a reduction in quantities produced by, and market shares of, the firms at the competitive fringe of market A. Therefore, this foreclosure effect has adverse consequences for welfare. However, integration still produces the welfare-enhancing effect of reduced final product price due to elimination of mark-up over the intermediate product (see comment below). The final effect on welfare depends on the relative strength of these two effects.

Salinger (1988) examines the price path of intermediate as well as the final product in a 2-stage Cournot game setting with n firms. Two opposing effects of vertical integration are identified: the first is due to the elimination-of-markup effect mentioned above, which increases competition in the final product market and lowers the intermediate as well as final good price. The second effect results from an increased concentration in the intermediate goods market for the non-integrated producers, causing an increase in the price of intermediate goods. In other words, as more downstream producers merge with their suppliers, the choice of suppliers for non-integrated producers is reduced, leading to higher input prices. In Salinger's model, the first effect dominates the second, leading to lower input prices as a result of vertical integration.

As a brief review of these models shows, reduction in the price of the intermediate and final products as a result of vertical integration seems to be a fairly robust result. The reason generally offered is elimination of mark-up on the intermediate product that otherwise obtains (ie, when the firms are not vertically integrated), because the input is transferred at the marginal cost of production within a firm, but at a cost greater than the marginal cost if the exchange takes place in an oligopolistic market. Put differently, when a vertically integrated firm decentralizes the downstream function (eg, assembly or retail), it leads to an increase in the price of the final product, by shifting the derived demand curve faced by the upstream producer to the right[2]. The same argument is used by McGuire and Staelin (1983) and others in describing "strategic decentralization" by manufacturers[3] as a way of committing to higher prices and, thus, raising their profitability (see Chapter 4). In this context then, it becomes more relevant to ask what happens to final product prices, consumer welfare and firm profits when there is a possibility of reducing production costs through R&D? We answer this question in the next chapter.

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[2] for price competition, demand substitutes, and strategic complements – see next chapter.

[3] That is, choice of vertical integration vs market transfer is purely strategic – there is no difference in operational efficiency or transaction costs.

4. PROCESS INNOVATION, PRODUCT DIFFERENTIATION, AND CHANNEL STRUCTURE: A MODEL OF STRATEGIC INCENTIVES IN DUOPOLY

4.1. Introduction

One of the major decisions facing any manufacturer is the design of a distribution channel. A number of factors affect a manufacturer's decision whether to distribute his products himself or through an independent intermediary. The usual theoretical explanations for the forward integration incentive of a manufacturer revolve around transaction costs (see Chapter 3), or a trade-off between informational and distribution efficiencies and distribution expenses (eg, see Stern and El-Ansary, 1988). A parallel stream of literature exists that analyzes the integration incentive in an oligopolistic industry and the choice of a distribution channel structure as a function of transfer pricing agreements and end-product substitutability (eg, McGuire and Staelin, 1983; Coughlan, 1985; Moorthy, 1988; Coughlan and Wernerfelt, 1989). This literature, concentrated primarily within marketing, does not consider the effect of a manufacturer's operational parameters such as production costs or the reduction in production costs that the manufacturer may realize as a result of process improvements, on downstream integration incentives. In this chapter, we wish to analyze the joint effects of manufacturing variables (such as production costs and process improvements) as well as marketing decisions (such as pricing) on the channel structure and forward integration incentive, in the context of an oligopolistic market with manufacturers producing differentiated products. That is, we ask: how do internal operational parameters of a manufacturer affect his incentives to choose an integrated or decentralized distribution channel structure; conversely, how does the channel structure affect a manufacturer's incentives to invest in process improvements? We show that the assumption of constant marginal cost of production employed in most of the existing models is not without consequence for the determination of equilibrium structures and the relative profitability of downstream integration. Specifically, while the existing results on the nature of equilibria hold in general, the precise range over which these equilibria obtain depends on other parameters such as the cost of process R&D. More importantly, consideration of the option available to the manufacturer of reducing his production costs through investments in process R&D accentuates the marginalization effect (ie, transfer price greater than marginal cost of production) in a decentralized channel, with the result that the relative manufacturer profits in a decentralized structure at high product substitutability (and that in an integrated structure at low substitutability) are higher than those obtained without R&D. As the cost of R&D rises, the R&D effect diminishes, and in the limit, earlier results on channel structure (eg, those of McGuire and Staelin, 1983) that are dependent only on the marginalization effect, are replicated.

Second, we show that channel equilibria depend on two dimensions: the degree of product differentiation, and the ease of production cost reduction achieved by the manufacturers. This, in our view, is a significant contribution because both cost leadership and product differentiation have long been considered the two most important 'generic strategies' in the management literature (Porter, 1980); however, analytical studies of the effect of these strategies on specific marketing decisions such as the design of distribution channel have been lacking.

Third, we show that the distribution channel structure has an impact on the manufacturers' incentives to invest in process improvements to reduce their own production costs. Decentralization of the downstream function to independent retailers causes the manufacturers to reduce their R&D investments because of an externality created by lower production costs of the manufacturer — the associated increase in retailer's profits is not taken into account by a decentralized manufacturer maximizing his own profits. Thus, while effective marginal cost of production is higher when both manufacturers are decentralized than when both are integrated, the manufacturers make higher profits by non-cooperatively choosing the former structure when their products are close substitutes. In other words, the manufacturers have an incentive to keep their production costs high.

Finally, we provide an analysis of the joint effect of reduction in production costs (as a result of process R&D) and increase in decentralized channel's effective marginal cost (as a result of individual profit maximization by the independent channel members) on retail prices and quantities produced. The significance of our analysis lies in providing a useful extension of the earlier models, as well as providing a synthesis of research streams on production costs and distribution channel management. The intent is to open up the analyses of industry structure and the choice of distribution channels to explicitly include the joint effect of operational parameters such as production costs, along with product differentiation and intrachannel pricing arrangements, in an oligopolistic setting. Consideration of strategic incentives may provide a counterpoint to supposed benefits of coordinated decision making that most studies on supply chains or channel coordination take for granted. The basic model in this chapter is kept simple to highlight the underlying effects; some important extensions will be discussed in subsequent chapters.

We consider an industry with two manufacturers, M_1 and M_2, each producing a single, differentiated product. In any given geographical area, there are two retail outlets, R_1 and R_2, and each retailer (R_i) is restricted to selling the products of only one manufacturer ($M_i, i = 1, 2$). Each R_i could be privately owned (ie, a franchised outlet) or owned by the manufacturer M_i (ie, a company-owned store). Thus, inter-brand competition within one retail outlet is ruled out, and each retailer is assumed to have exclusive distribution rights within a given territory[1].

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[1] Usual explanations for territorial restrictions entail curtailing excessive intrabrand competition among retailers that would lead to failures (eg, see Pashigian, 1961; Blair and Kaserman, 1983). Recent court rulings in the U.S. suggest that franchisees in some industries are having success in ensuring territorial monopolies even when such restrictions are not part of a formal contract. For example, in July 1996, a California federal court ordered Naugles Inc., a Mexican fast-food chain, to pay $2.2 million to a franchisee after it opened a company-owned store nearby; and, recently, Burger King agreed to notify its franchisees whenever it planned to open a new outlet nearby, promising to reimburse the franchisee for the resulting loss in profits [Business Week, 1997].

Examples of industries that meet these criteria include consumer products such as gasoline, fast food chains, and (new) automobiles[2]; and, industrial products such as heavy farm equipment, fork lift trucks and industrial gases [McGuire and Staelin, 1983].

The basic model-structure we use is that of a 4-stage game, where players at each stage make their choices simultaneously, non-cooperatively, and in full knowledge of the actions taken by all the players at previous stages. At the first stage, each manufacturer decides whether to integrate or decentralize the downstream retailer function. Second stage decision variables are investments in cost-reducing R&D by the manufacturers. At the third stage, manufacturers decide on the wholesale price they would charge their retailers; and, finally, retailers compete on prices in the market. Thus, the manufacturers are assumed to act as Stackelberg leaders with respect to the retailers. That is, channel power is assumed to lie with the manufacturers in that retailers are price takers, although privately-owned stores do have pricing autonomy over the final product. In order to focus on the strategic incentive, it is assumed that there is no difference in the distribution efficiency between the private or company-owned stores, no marketing economies of scale or scope, and no value-added (in terms of better customer service, for example) by the retailers. This structure closely follows some of the existing models in the literature, which we briefly discuss in the next section. Section 4.3 presents our model in detail. In section 4.4 we demonstrate the procedure followed for determination of equilibria. Our main results appear in section 4.5. Section 4.6 concludes this chapter.

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[2] Although exclusive dealing in the automobile industry was made illegal in the U.S. in the 1940s [Womack et al., 1990, pp. 170], a vast majority of auto-dealers remain single-manufacturer outlets. However, the single-manufacturer franchise system with territorial restrictions seems to be changing as the number of "megadealers" carrying the product lines of many manufacturers at the same location (eg, Autonation and CarMax) grows rapidly (see Business Week, 1996), in response to a consumer backlash against poor service and higher search costs that they face in gathering relevant information and comparing the expanding product-lines of rival manufacturers. Though state franchise laws prevent the manufacturers from forcing consolidation on their dealers, publicly owned companies like Republic Industries (that owns AutoNation) have already amassed dealerships worth $3 billion in estimated 1997 sales [Business Week, 1997].

4.2. Related Literature

The literature that we draw upon consists primarily of a number of recent papers that have analyzed the incentive for forward integration by a manufacturer in an oligopolistic setting when the final product is differentiated (eg, McGuire and Staelin, 1983, 86; Coughlan, 1985; Bonanno and Vickers, 1988; Lin, 1988; Moorthy, 1988; Coughlan and Wernerfelt, 1989). The basic conclusion is that if the products produced by two different manufacturers are nearly identical, then it is profitable for a manufacturer to delegate the marketing function to an independent intermediary who has pricing autonomy. The intuitive reason for this assertion is that price competition is strongest when products are identical (leading to zero profits under the conditions of a Bertrand equilibrium). By inserting an independent intermediary, the manufacturers can 'shield' themselves from this competition, as it restricts their ability to react to price changes by the competitor (McGuire and Staelin, 1983; Coughlan, 1985). The underlying cause is higher transfer price to the retailer (instead of marginal-cost pricing in an integrated firm) that leads to higher retail prices and higher manufacturer profits (at high substitutability) as a result of decentralization. This effect, known as 'double marginalization' (Spengler, 1950), and the associated social welfare issues, have been analyzed in the economics literature for a long time. In a monopoly situation, the retailer in a decentralized channel always charges a higher price than an integrated manufacturer would charge.[3] Variants of this effect have been studied under different assumptions on the retail sector (see Blair and Kaserman, 1983, for a review), as well as under successive oligopoly (eg, Greenhut and Ohta, 1979). The recent marketing studies mentioned above have isolated this effect in the context of manufacturer-retailer relations and choice of a distribution channel; the unique contribution of this literature is that determination of the market structure is endogenized in the game, and, the equilibrium structure is shown to be dependent on the degree of substitutability between the final products. In particular,

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[3] For a vertically integrated monopoly, the retail price is $p_m = \arg\max\,(p-c)f(p)$, and the monopoly output is $q_m = f(p_m)$. However, in a decentralized channel, the manufacturer charges the retailer a transfer price $w > c$ in order to make a profit, and the retailer, maximizing $(p-w)f(p)$, charges a retail price $p > p_m$, leading to lower industry profits as well as lower consumer welfare (eg, see Rey and Tirole, 1986).

decentralization can be achieved as an equilibrium strategy, in contrast to the traditional result on successive monopolies whereby integration always improves manufacturer profits (as well as consumer welfare). None of these papers, however, consider the effect of manufacturer's internal operational parameters.

The earliest contribution in this stream is by McGuire and Staelin (1983) who consider a two-stage four-player game with retailers facing a linear demand function. The per unit production costs as well as the unit selling costs are assumed constant and equal for both products. The authors analyze a rescaled demand system in order to suppress all other parameters except θ, the degree of substitutability between the two products.[4] In contrast, we work with the most general form of a linear demand system, from which McGuire and Staelin's results can be easily derived. The main conclusions of their seminal paper can be summarized as follows: The attractiveness for the manufacturer of integrating the retailer function depends on the substitutability between the two manufacturers' end-products. When each is a monopolist ($\theta = 0$), it is twice as profitable for the manufacturers to integrate forward than to sell through private retailers. On the other hand, when products are highly substitutable ($\theta \approx 1$), it is three times as profitable for the manufacturers to insert independent retailers than to sell through company owned stores. In the determination of industry structure, the mixed system is never a Nash equilibrium. For $0 \leq \theta \leq 0.931$, the pure vertically integrated structure is the unique Nash; whereas for $\theta \geq 0.931$, both pure integrated and pure decentralized structures are Nash equilibria. For $0.708 \leq \theta \leq 0.931$, a classical Prisoner's dilemma situation arises.

The results obtained by McGuire and Staelin (1983) have been commented on and generalized by a number of authors. Coughlan (1985) replaces the linear demand function with a more general function that is linear with respect to the competitor's price, but can be convex, concave or linear in its own price, and obtains similar results. Moorthy (1988) shows that the

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[4] Although these authors establish that the profit maximizing behavior of the players is the same in both systems, the rescaled demand system makes it more difficult to attach meaningful interpretations to comparisons of different parameter values across equilibria, and change in equilibrium conditions with parameters such as market size and production costs.

results affirming superiority of delegation are dependent on the condition that manufacturers' products be demand substitutes *and* strategic complements, or demand complements and strategic substitutes, at the manufacturer and retailer levels.[5] The nature of strategic interaction is important in that decentralization (for demand substitutes) is beneficial only when it raises the other manufacturer's retail price as well (otherwise the profit impact of an increase in own retail price is negative). For example, Moorthy shows that decentralization can never be Nash equilibrium strategy if one assumes constant elasticity demand functions because of the strategic independence between channels.

Bonanno and Vickers (1988), and, Coughlan and Wernerfelt (1989) modify the above models to allow for two-part tariffs to be charged by the manufacturer to its independent retailer. That is, in addition to the constant per-unit fee (the wholesale price), the manufacturers can now charge a fixed fee as well, as is the case in many franchise systems observed in practice (eg, McDonald's and Burger King). Consideration of a fixed fee allows the manufacturer to extract all profits from the retailer, and therefore, the manufacturer is concerned with maximization of channel profits rather than his own profits. The authors conclude that under these conditions, decentralization is *always* an equilibrium strategy for both manufacturers when products are strategic complements — regardless of the level of product differentiation.

All of these papers consider the unit production costs of the manufacturer to be fixed (or, normalized to zero to focus on transfer pricing). From an operational perspective, investment by a manufacturer in cost reduction is one of the most important decision variables; it has been a long-standing theme in the management literature, gaining further scrutiny as a result of the emphasis on continuous improvement (or kaizen) by the 'lean' manufacturers. The phenomenal success of a large number of Japanese companies, and the ensuing widespread acceptance of

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[5] Two products A and B are ***demand substitutes*** if A's demand function rises with B's price (ie, $\frac{\partial D_A}{\partial p_B} > 0$). However, A and B are ***strategic complements*** if A's marginal profitability with respect to price increases in B's price (ie, $\frac{\partial^2 \pi_A}{\partial p_A \partial p_B} > 0$). That is, when B lowers its price, it is optimal for A to lower its price as well: aggressive behavior begets aggressive response. Demand complements and strategic substitutes are defined analogously (see Bulow et al. (1985)).

continuous improvement practices among manufacturers worldwide, are indicators of the competitive advantages that a strict discipline of cost management and process innovation can confer on an organization. Moreover, there is an increasing realization on the part of organizations and academics alike of the need to take a 'systems approach' and manage costs in the whole supply chain, and to focus on the final delivered price to the customer which affects the profitability of all the channel members (eg, Lee and Billington, 1992). Most of these studies, however, take an efficiency perspective and focus on ways of achieving coordination along the supply chain in production, distribution, and inventory control policies to optimize certain performance measures such as costs and lead times (eg, Cohen and Lee, 1988; Lee and Billington, 1995; Arntzen *et al.*, 1995), or consider the problem of incentives between marketing and manufacturing in a principal-agent framework (eg, Porteus and Whang, 1991). Several models also exist that examine pricing and production planning decisions in a competitive framework with varying assumptions on demand and cost functions (see Gaimon, 1994 for a review). Most of these models are dynamic and are formulated in continuous time, thus requiring a differential games approach; and, most of them focus either on the horizontal or the vertical dimension. Examples of models with horizontal competition include a dynamic game between two manufacturers with asymmetric cost functions (Eliashberg and Steinberg, 1991); and, a dominant and a smaller firm (Dockner and Jorgensen, 1984). Models in a vertical channel setting include a dynamic game between a single manufacturer and a retailer (Jorgensen, 1986); and, a manufacturer and a distributor who has to further process the goods (Eliashberg and Steinberg, 1987). In contrast to these models, Gaimon (1989) analyzes a model where production cost is a decision variable in a differential game between two manufacturers choosing prices and capacity levels, where acquisition of new technology reduces a firm's unit production costs. None of these authors consider the strategic incentives for cost reduction through investments in process improvement by manufacturers producing differentiated products in an oligopolistic market, who sell through competing retailers.

4.3. Model Specification

Consider two manufacturers, each producing a single, differentiated product. Each manufacturer can distribute its product itself or through a single, privately-owned retailer in a particular geographical area. Each retailer is restricted to carrying the product of only one manufacturer, and it is assumed that the ownership decision does not affect the efficiency of distribution. The manufacturers specify the price at which they will sell their output to their own retailer, the retailers make their pricing decisions contingent on the manufacturers' prices, and the manufacturers take the retailers' decision rules into account while setting their wholesale prices.

The demand function for product i is

$$q_i = M - bp_i + b\theta p_j, \quad j = 3 - i,\, i = 1, 2 \tag{4.1}$$

as described in chapter 2.[6] Let c_i represent the unit cost of production for manufacturer i. We consider a situation where each manufacturer can invest in R&D (eg, in process improvement) that would reduce his unit production cost. Specifically, we let $c_i = c - x_i$, where c is the unit cost if no R&D is carried out, assumed equal for both manufacturers $(c < M/b)$[7], and x_i is the

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[6] Thus, our demand system is very similar to the one used by McGuire and Staelin (1983), though ours is more 'convenient' in that an additional parameter (μ) capturing the absolute difference in demand is ignored (which does not affect any results, as shown by them). However, given the nature of our problem, our analysis is carried out in terms of the 'full' demand system, instead of a rescaled one in McGuire and Staelin. Also note that in this specification, own-price rate of change is not affected by changes in θ. The reader is, however, cautioned at the outset against comparing solutions across different values of θ as the industry demand tends to expand with θ in the present formulation. We choose this formulation primarily for two reasons: 1) to provide a comparison of our results with those existing in the literature, and 2) to provide a foundation for future studies where it would be possible to distinguish between two effects of the degree of substitutability between products: demand *expansion* as a result of new product introduction, and increased *competition* between single-product duopolists (see Shaked and Sutton, 1990). Such an analysis would be highly useful in studying product line decisions of a multiproduct firm as compared to competition between single-product firms. This article is limited to analysis of the latter effect only (as are most studies on marketing channels cited above).

[7] ie, for the market to exist, the maximum unit production cost has to be less than the price at which demand

amount of unit cost reduction achieved by manufacturer i as a result of his efforts in process improvement. It is assumed that the R&D results of a manufacturer are fully protected by intellectual property rights so that competitors cannot free-ride on a firm's R&D; that is, no R&D 'spillovers'.[8] We further assume decreasing returns to R&D expenditures: cost of R&D is given by αx_i^2, where α is some positive constant.

Therefore, letting w_i represent the wholesale price that a decentralized manufacturer i charges to its retailer, the profit function for manufacturer i is written as:

$$\pi_i^M = (w_i - c_i)q_i - \alpha(x_i)^2 \tag{4.2}$$

For retailer i, w_i becomes the effective variable unit cost, and thus, his profit function, ignoring any fixed costs, can be written as:

$$\pi_i^R = (p_i - w_i)q_i \tag{4.3}$$

On the other hand, an integrated manufacturer is assumed to make his decisions to maximize the profits accruing from both levels, setting the (internal) transfer price to equal his unit production cost ($w_i = c_i$), and the retail price to maximize total channel profits. Thus, the profit function of an integrated manufacturer is:

$$\pi_i^I = (p_i - c_i)q_i - \alpha(x_i)^2 \tag{4.4}$$

Our four-stage game unravels as follows: at the first stage, manufacturers simultaneously and non-cooperatively decide whether to integrate or decentralize the downstream retailing function. This decision is observed by all the players at the end of the first stage, and then the manufacturers set their R&D levels and transfer prices respectively at the second and third stages

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drops to zero.

[8] The generalization of this model to include the impact of R&D spillovers, and the associated government policy initiatives (such as the National Cooperative Reaearch Act of 1984) that encourage horizontal cooperation (eg, in the form of Research Joint Ventures), is carried out in chapter 7.

of the game. Finally, retail prices are set at the fourth stage. The manufacturers specify the price at which they will sell their output to their own retailer, the retailers make their pricing decisions contingent on the manufacturers' prices, and the manufacturers take the retailers' decision rules into account while setting their wholesale prices. That is, channel power is assumed to lie with the manufacturers in that retailers are price takers, although privately-owned stores do have pricing autonomy over the final product. Moreover, the following two assumptions are utilized in our analysis:

1. Intrachannel decisions are observable to the competitors. We recognize that this assumption somewhat restricts the applicability of our analysis, since Coughlan and Wernerfelt (1989) and Katz (1991) have shown that lack of observability of intrachannel contracts can nullify strategic interaction between channels by making the delegation decision incredible. However, intrachannel contracts are observable in a large number of industries, particularly in geographically dispersed markets where it may be quite difficult to maintain secret transfer pricing mechanisms.[9] For example, franchising terms for automotive dealers and fast food outlets are fairly well-known[10]. Moreover, even with unobservable contracts, the underlying strategic incentives can persist in some situations (e.g., see Corts and Neher, 1997).

2. In the basic model analyzed in the next section, we focus our attention on linear transfer pricing mechanisms. This implies that there is no cooperation in a decentralized channel; manufacturers and retailers make their decisions to maximize their own profits; and, channel coordination through more complex contracts (e.g., two-part tariffs) is not considered. On the other hand, integration is assumed to provide perfect coordination of all decisions in a channel. In the next chapter, we will see some examples of 'intermediate' decision rules where coordination in some, but not necessarily all, decisions is explicitly analyzed. Nevertheless, there is plenty of support for both theoretical and empirical relevance of 'simple' transfer pricing mechanisms

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[9] The Robinson-Patman act, which requires manufacturers to offer similar terms to all retailers, makes it even more difficult for the manufacturers to maintain secret contracts with a large number of retailers. Coughlan and Wernerfelt (1989) also acknowledge this (p. 233).

[10] See Coughlan and Wernerfelt (1989; footnote 2) for McDonald's and Burger King's franchising terms.

(e.g., see Ingene and Perry, 1995; Lee and Staelin, 1997).

4.4. Solution Procedure

We look for subgame perfect equilibria [Selten, 1975] of the four-stage game described above. The equilibrium expressions are obtained by backward induction, conditioning on the equilibrium retail market structures decided by the manufacturers at the first stage of the game. Three possible scenarios are considered: homogenous equilibria where both manufacturers (independently) choose to distribute their products through private retailers (DD) or both integrate forward (II), and the heterogenous equilibrium where one integrates and the other decentralizes (ie, a 'mixed structure'). Closed-form expressions can be obtained for all the variables of interest (ie, prices, quantities, R&D levels, and profits), though these depend in general on five parameters (M, α, b, θ, and c). These expressions, for each of the three cases, are given in Appendix A. The first stage decision of the manufacturers regarding the choice of decentralization is then given by a comparison of manufacturer profits. For illustration, we present below the details only for the case (DD) – the other two cases are solved similarly.

4.4.1. Pure Decentralized Structure (DD)

In this case, both manufacturers use independent retailers. The solution procedure followed is as follows: at the *fourth stage*, retailers set their retail prices, conditioning on the R&D levels and wholesale prices of both the manufacturers, as well as retail price of the competitor. That is, each retailer i sets p_i to maximize π_i^R. First order conditions (ie, $(\partial/\partial p_i)\pi_i^R = 0$ for $i = 1, 2$) yield the following reaction functions:

$$p_i = \frac{M + bw_i + b\theta p_j}{2b}, \quad j = 3 - i, i = 1, 2 \tag{4.5}$$

which can be solved for the fourth stage Nash equilibrium retail prices[11], given wholesale

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[11] $(\partial^2/\partial p_i^2)\pi_i^R = -2b < 0$; $(\partial^2/\partial p_i \partial p_j)\pi_i^R = b\theta > 0$ for $\theta > 0$ (ie, for demand substitutes); and, $\left|\frac{\partial p_i}{\partial p_j}\right| = \theta/2 < 1$

prices w_i :

$$p_i^* = \frac{M(2+\theta) + 2bw_i + b\theta w_j}{b(4-\theta^2)}, \quad j = 3-i, i = 1,2 \tag{4.6}$$

Note that the players' decision variables are strategic complements at the retailer level; and, the equilibrium retail price increases in own as well as rival's wholesale price.

At the *third stage*, manufacturers take the retailers' decision rules into account while setting their wholesale prices; equations (4.6) determine the derived demand functions that manufacturers face as a function of both manufacturers' wholesale prices, given by:

$$q_i^* = \frac{M(2+\theta) - b(2-\theta^2)w_i + b\theta w_j}{(4-\theta^2)}, \quad j = 3-i, i = 1,2 \tag{4.7}$$

Therefore, the manufacturers set their wholesale prices by solving:

$$\max_{w_i} \pi_i^M = (w_i - c_i)[\frac{M(2+\theta) - b(2-\theta^2)w_i + b\theta w_j}{(4-\theta^2)}] - \alpha(x_i)^2, \quad i = 1,2$$

The first-order conditions $((\partial/\partial w_i)\pi_i^M = 0, i = 1,2)$ give the reaction functions:

$$w_i = \frac{M(2+\theta) + b(2-\theta^2)c_i + b\theta w_j}{2b(2-\theta^2)}, \quad j = 3-i, i = 1,2 \tag{4.8}$$

and the equilibrium wholesale prices, conditional on manufacturers' unit production costs, are:

$$w_i^* = \frac{M(2+\theta)(4-2\theta^2+\theta) + 2b(2-\theta^2)^2 c_i + b\theta(2-\theta^2)c_j}{b(4-2\theta^2+\theta)(4-2\theta^2-\theta)}, \quad j = 3-i, i = 1,2 \tag{4.9}$$

Here, note that the wholesale prices are also strategic complements; and a manufacturer's equilibrium wholesale price decreases in his own as well as rival's R&D levels (recall $c_i = c - x_i$).

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as required for stability. Thus, for $b > 0$, and $0 < \theta < 1$, second-order and stability conditions are always satisfied. Similar comments apply to the third-stage equilibrium in wholesale prices below.

Substituting for w_i from (4.9) into equations (4.6) and (4.7) gives retail prices and quantities as functions only of the manufacturers' unit cost of production c_i and c_j, as follows:

$$p_i^* = \frac{2M(2+\theta)(3-\theta^2)(4-2\theta^2+\theta)+b(2-\theta^2)(8-3\theta^2)c_i+2b\theta(2-\theta^2)(3-\theta^2)c_j}{b(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}, \quad i=1,2 \tag{4.10}$$

$$q_i^* = \left(\frac{2-\theta^2}{4-\theta^2}\right)\left[\frac{M(2+\theta)(4-2\theta^2+\theta)-b(8-9\theta^2+2\theta^4)c_i+b\theta(2-\theta^2)c_j}{(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\right], \quad i=1,2 \tag{4.11}$$

Thus, the equilibrium retail price decreases in own as well as rival's R&D levels; quantities produced increase in own R&D, but decrease in rival's R&D levels. Similarly, substituting for w_i and q_i into π_i^M gives the second-stage manufacturer profits as functions of c_i, $i = 1,2$:

$$\pi_i^M = \frac{1}{b}\left[\frac{4-\theta^2}{2-\theta^2}\right](q_i^*)^2 - \alpha(x_i)^2 \tag{4.12}$$

At the *second stage*, manufacturers set their R&D levels, conditioning on the competitor's R&D and fully taking into account the effect that a lower unit production cost will have on the wholesale and retail prices and the quantities produced, by means of equations (4.10-4.11). Thus, the R&D levels are determined by maximizing the profit functions (4.12): $\max_{x_i} \pi_i^M$, $i = 1,2$. The first-order conditions are:

$$AB[M-(1-\theta)bc]+(ADb-\alpha)x_i - AEbx_j = 0, \quad j=3-i, i=1,2 \tag{4.13}$$

where constants $A,\ldots,E$ are given by:

$$\begin{aligned} A &= \tfrac{(2-\theta^2)(8-9\theta^2+2\theta^4)}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2} & B &= (2+\theta)(4-2\theta^2+\theta) \\ D &= (8-9\theta^2+2\theta^4) & E &= \theta(2-\theta^2) \end{aligned}$$

Equations (4.13) yield the following reaction functions in the R&D-level space:

$$x_i = \frac{AB[M-(1-\theta)bc]-AEbx_j}{(\alpha-ADb)}, \quad j=3-i, i=1,2 \tag{4.14}$$

Note from above that $A > 0$, $B > 0$, $(D-E) \geq 0$, and $E \geq 0 \; \forall\theta$ (where $(D-E) = (1-\theta)B = 0$ for $\theta = 1$, and $E = 0$ for $\theta = 0$). Moreover, $AD > 0$, $\forall\theta$ which implies $(\alpha - ADb) > 0 \; \forall\theta$ as long as $\alpha > \frac{b}{8}$ (as required by the second-order conditions)[12]. Therefore, (4.14) yields downward sloping reaction curves; that is, manufacturers' R&D level decision variables are strategic substitutes $((\partial^2/\partial x_i \partial x_j)\pi_i^M < 0$ for $\theta > 0)$: an increase in the R&D level of the rival manufacturer reduces the marginal profitability of own R&D. On the other hand, recall that both wholesale and retail prices are strategic complements. Hence, when the products are demand substitutes, the following two opposite effects exist:

(a) Higher equilibrium R&D investment (x_j) by manufacturer j lowers his unit production cost $(c_j = c - x_j)$, which allows him to cut his wholesale price (w_j), translating into lower retail price (p_j) for his product, and higher quantities produced (q_j). For demand substitutes, higher q_j results in reduction in quantity (q_i) demanded for product i, which reduces manufacturer i's incentives to invest in R&D.

(b) On the other hand, strategic complementarity between the wholesale (and retail) prices requires that manufacturer i respond to a price cut by j by lowering his own wholesale price w_i (which will translate into lower retail price p_i as well) — thus increasing i's incentives to invest in R&D.

Solving equations (4.14) gives the equilibrium R&D levels. The solutions for the other two channel structures (pure integrated and mixed) are obtained similarly (see Appendix A for a summary of all equilibrium expressions).[13] To ensure the existence, uniqueness, and stability of R&D-level equilibria under all the structures studied, we assume from now on that $b/\alpha < 3.44$; that is, the cost of R&D is 'large enough'. This assumption is rather innocuous for most industrial environments as can be readily seen from the following simple example.

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[12] Second-order conditions are: $(\partial^2/\partial x_i^2)\pi_i^M = ADb - \alpha < 0$, which hold as long as $b/\alpha < 8$ (AD decreases from 0.125 to 0.037 as θ goes from 0 to 1). Stability requires $\left|\frac{\partial x_i}{\partial x_j}\right| = \frac{AEb}{\alpha - ADb} < 1$, or $\alpha/b > A(D+E)$,which implies $b/\alpha < 7.68$.

[13] Note that ignoring the process-R&D stage and assuming $M = b = 1, c = 0$, will exactly reproduce McGuire and Staelin's (1983) results.

Consider an automobile industry with market size of one million cars annually ($M = 10^6$). The average price of a car is \$20,000, and assume that a manufacturer can increase his sales by 10,000 cars for each \$300 reduction in the unit production cost that he can achieve; thus $b \approx 33$. A reasonable estimate for R&D expenditures needed to achieve this level of cost reduction is \$20 million, implying that $\alpha \approx 222$. Thus, $\alpha/b \approx 6.67$, much larger than required by the above assumption. (Alternatively, note that $\alpha/b = 0.3$ implies $\alpha = 9.9$, which means that a cost reduction of \$300 per car can be achieved via R&D expenditures of less than \$900,000, a very low value indeed.)

4.5. Results and Discussion

Given our assumptions, when will a manufacturer have an incentive to decentralize the retailing function? What effect does the channel structure have on the incentives of a manufacturer to invest in process improvements, as well on prices and output? We examine these issues below.

4.5.1. Characterization of Equilibria

We now determine the equilibrium channel structure as given by the subgame perfect equilibrium of our 4-stage game, assuming that the manufacturers at the first stage decide on the downstream integration based on their own profits. The game faced by the manufacturers at the first stage is shown in Figure 4.1.

		Manufacturer 2	
		I	D
Manufacturer 1	I	π^M_{II}, π^M_{II}	π^M_{ID}, π^M_{DI}
	D	π^M_{DI}, π^M_{ID}	π^M_{DD}, π^M_{DD}

Figure 4.1

(i) Pure integrated structure: (I, I) is a Nash equilibrium if no manufacturer has an incentive to unilaterally decentralize, when the other manufacturer is integrated. That is, $\pi_{II}^{M} > \pi_{DI}^{M}$, which, using expressions in Appendix A, can be written as:

$$\Theta_5(\Theta_1)^2 - (2-\theta^2)\Theta_6(\Theta_2)^2 > 0 \tag{4.15}$$

where $\Theta_1, \Theta_2, \ldots$ are as given below. It is easily shown that (4.15) always holds; therefore, (I, I) is always an equilibrium.

(ii) Pure decentralized structure: Similarly, (D, D) is a Nash equilibrium if no manufacturer has an incentive to unilaterally integrate, when the other manufacturer is decentralized. That is, $\pi_{DD}^{M} > \pi_{ID}^{M}$, which, using Appendix A, can be written as:

$$(2-\theta^2)\Theta_7(\Theta_1)^2 - \Theta_8(\Theta_4)^2 > 0 \tag{4.16}$$

where:

$$\begin{aligned}
\Theta_1 &= [b^2(1-\theta^2)(2-\theta^2)(8-9\theta^2+2\theta^4)] - \\
&\quad 2\alpha b[(2-\theta^2)^3(4-\theta^2)+(8-9\theta^2+2\theta^4)^2] + 8\alpha^2(2-\theta^2)^2(4-\theta^2)^2 \\
\Theta_2 &= [\alpha(2-\theta)(4-\theta^2) - b(1-\theta)(2-\theta^2)] \times \\
&\quad [2\alpha(2+\theta)(2-\theta^2)(4-\theta^2) - b(1+\theta)(8-9\theta^2+2\theta^4)] \\
\Theta_4 &= [\alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2 - b(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)] \times \\
&\quad [2\alpha(2+\theta)(4-2\theta^2+\theta) - b(1+\theta)(2-\theta^2)] \\
\Theta_5 &= \alpha(4-\theta^2)^2 - b(2-\theta^2)^2 \\
\Theta_6 &= 4\alpha(4-\theta^2) - b(2-\theta^2) \\
\Theta_7 &= \alpha(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2 - b(2-\theta^2)(8-9\theta^2+2\theta^4)^2 \\
\Theta_8 &= 4\alpha(2-\theta^2)^2(4-\theta^2)^2 - b(8-9\theta^2+2\theta^4)^2
\end{aligned}$$

(iii) Mixed structure: Heterogenous equilibria involving one manufacturer integrated and the other decentralized will occur when both (4.15) and (4.16) are violated. Since (I, I) is always a Nash equilibrium, a mixed structure is never one.

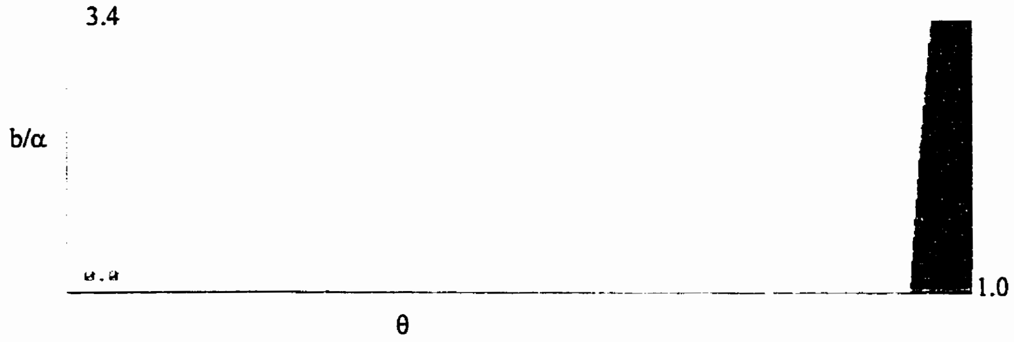
Comparing manufacturer profits under the two channel structures, (D, D) and (I, I), we see that $\pi^M_{DD} > \pi^M_{II}$ iff :

$$(2-\theta^2)\Theta_7(\Theta_9)^2 - \Theta_5(\Theta_{10})^2 > 0 \tag{4.17}$$

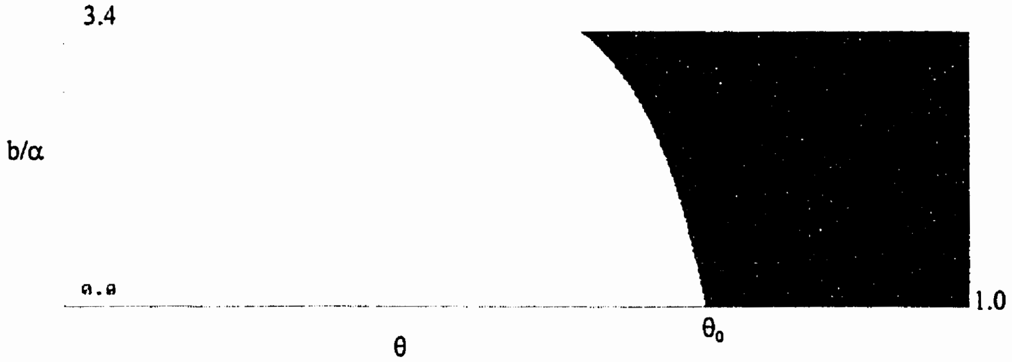
where $\Theta_1 \ldots \Theta_8$ are as given above, and:

$$\begin{aligned}
\Theta_9 &= \alpha(2-\theta)(4-\theta^2) - b(1-\theta)(2-\theta^2) \\
\Theta_{10} &= \alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2 - b(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)
\end{aligned}$$

The equilibrium and profit dominance conditions are depicted graphically in Figure 4.2 (a). ((I, I) always remains an equilibrium and is thus not shown in Figure 4.2.) First, note that channel equilibria depend on two parameters: the degree of product differentiation (represented by θ), and the ease of production cost reduction (represented by b/α). This provides a more general picture of the underlying drivers for channel structure decisions than that discussed so far in the channels literature, which focuses only on the product differentiation dimension following McGuire and Staelin's (1983) pioneering analysis. By adding the process innovation dimension, our analysis points out the need to focus on the interactions between marketing and operations decisions. Second, these two dimensions represent what have repeatedly been stressed in the management literature as the two primary 'generic strategies' that most organizations follow: cost leadership and product differentiation (Porter, 1980). Thus, the general picture provided by our model is an important complement to the marketing channels literature, and at the same time, provides an analytical foundation for numerous studies that exist in the strategic management literature on the role of cost leadership and product differentiation. An important managerial implication here is the strategic and interdisciplinary nature of the channel structure decision. While deciding whether to assume retailing responsibilities for their products themselves or to engage independent retailers, managers will have to consider not only the degree to which the consumers perceive their products to be differentiated from those of the competitors' products, but also their own production processes and technology, their budget for investments in process improvements and the level of cost reduction that they expect to achieve.



(a): Feasible Region for Pure Decentralized Equilibrium



(b): Region where Decentralized Structure Dominates the Integrated

Figure 4.2: Equilibrium and Profit Dominance Conditions with Linear Contracts
(Manufacturer Profits Criterion)

Our first result summarizes the nature of equilibrium channel structure that would be expected in industries where our model assumptions are applicable.

Proposition 1. *(a) Pure Integration is always a subgame perfect equilibrium of the four-stage game.*
(b) Pure Decentralization is an equilibrium only under condition (4.16).
(c) Whenever the pure decentralized structure is an equilibrium, it gives higher profits to the manufacturers than a pure integrated structure (see Figure 4.2).

While integration (i.e., full coordination) is always an equilibrium outcome, the somewhat surprising result is that decentralization (i.e., no coordination in any decisions) can be an equilibrium strategy - and a more profitable one - for the manufacturers under certain conditions. A similar result was established by McGuire and Staelin (1983) and Coughlan and Wernerfelt (1989) who analyze channel equilibria in relation to product differentiation alone. Thus, the inclusion of process R&D decision does not change the general nature of equilibria found in the literature, in particular, the appearance of decentralized, non-coordinated channels as a more profitable equilibrium strategy at high levels of product substitutability. However, consideration of the production cost dimension has the following effect on channel equilibria:

Proposition 2. *The easier it is to reduce production costs (i.e., smaller α), the smaller the range of product substitutability (θ) over which (D, D) is an equilibrium outcome. (See Figure 4.2 (a).)*

To understand this result, it will be useful to recall why decentralization is obtained as an equilibrium strategy in the models that consider channel structure in relation to product differentiation alone. Briefly, the argument is as follows (Coughlan, 1985; Moorthy, 1988): decentralization by a manufacturer raises the retail price of his product, which leads the other channel to raise its price as well (under the conditions of demand substitutes and strategic complements). The effect of own-price increase is negative, but the increase in other channel's price raises your demand curve, which leads to higher profits. When markets are not too much interdependent (i.e., low θ), the first effect dominates and thus, it does not benefit the manufacturer to decentralize. As θ increases, the second effect increases in magnitude and becomes dominant at high θ when manufacturers find it profitable to use independent retailers as a credible commitment to charge high prices and thus dampen the price competition between them even though their products are nearly homogenous.

Our result indicates that the above view *understates* the cost penalty of decentralizing (and consequently, not coordinating any decisions with the retailer) that the manufacturer and the channel as a whole incurs. As we will see below, lack of channel coordination dampens manufacturer's incentives to invest in cost reduction. This effect, when combined with 'double marginalization', makes the effective marginal cost of a decentralized channel much higher than that of an integrated channel. The easier the cost reduction, the larger the cost penalty of not coordinating, and smaller the range of substitutability over which decentralization is an equilibrium strategy. That is, when process innovation is accounted for, the strategic effect (through committing to higher prices and 'raising the demand curve') needs to be larger in magnitude to compensate for the lost savings in lower production cost in order for decentralization to be an equilibrium strategy for the manufacturers. Looked at another way, if both manufacturers are decentralized, no one can benefit by unilaterally integrating to achieve efficiencies of coordinated decision making, in the parameter range indicated in Figure 4.2 (a). Thus, *there is an explicit trade-off between efficiency and strategic incentives in distribution channel design.* It also implies that we will be less likely to observe decentralized channels in industries such as semiconductors, computers, and communication equipment, where adoption of new technologies makes cost reduction easier, than in industries such as earth-moving and heavy farm equipment, fork lift trucks, and industrial gases, with more mature technologies and processes making it harder to reduce production costs.

To provide an easy comparison of our results with those in the literature, we illustrate equilibrium manufacturer profits in Figure 4.3 as a function only of product substitutability (θ). As depicted, (I, I) is always an equilibrium; (D, D) becomes an equilibrium only for $\theta \geq 0.938$. Thus, there are two equilibria for $\theta \geq 0.938$, and (D, D) Pareto-dominates (I, I). For $0.688 \leq$

$\theta \leq 0.938$, the classic prisoner's dilemma game obtains. It is easy to check that as $\alpha \rightarrow \infty$ (i.e., as R&D becomes infeasible), the above results reduce to those obtained by McGuire and Staelin (1983).

4.5.2. Decision Variables

In order to gain better insight into the underlying drivers of our model, we now turn to a comparison of the level of decision variables (i.e., R&D investments, prices, and quantities produced) *assuming a given channel structure.* That is, we ignore the first-stage decision of channel structure choice of our game and focus on the levels of different variables conditional on the channel structure. We have three reasons for doing this. First, in situations where multiple equilibria exist in at least some part of the parameter space (as is the case here), it is of intrinsic interest to know how equilibrium levels of decision variables and profits compare under different equilibria.[14] For example, both managers and policy-makers would want to know the outcomes not only under industry equilibria that presently exist, but also under those that are likely or more desirable. Second, it could be argued that oligopolistic industries where we do observe mixed channels (or, non-equilibrium channel structures) represent industries in transition towards a more stable pure-channels equilibrium condition (for example, see Coughlan's (1985) discussion of channel choice in the international semiconductor industry). The level of these decision variables are therefore of interest to managers in such industries. Third, the results discussed below are robust to the inclusion of channel equilibrium conditions, that is, consideration of the parameter ranges under which single or multiple equilibria hold do not change the nature of these results.[15]

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[14] It should be noted here that the fact that (D,D) is a dominant equilibrium at high substitutability *does not* imply that manufacturers would switch from (I,I) to (D,D) unless some other mechanism not modeled here is considered that would allow the manufacturers to coordinate their channel decision on a mutually more profitable equilibrium.

[15] Also note that the results discussed here only involve comparisons across channels holding θ fixed (see footnote 6).

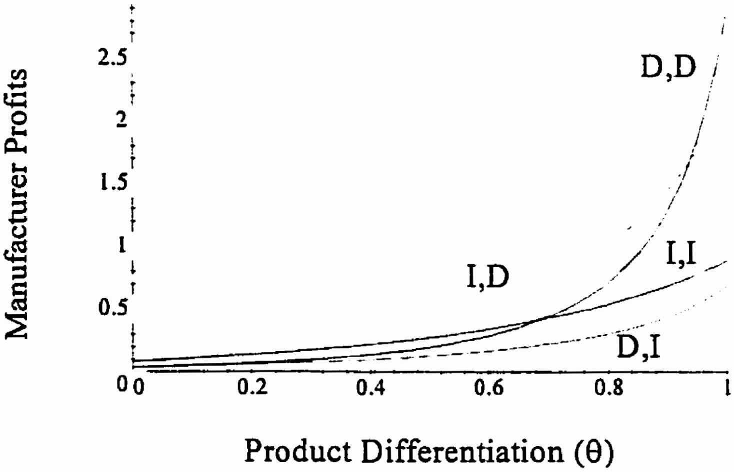

Figure 4.3: Equilibrium Manufacturer Profits as a Function of
Product Differentiation (θ)
($M/b=1$, $b/\alpha=1$, $c=0.5$)

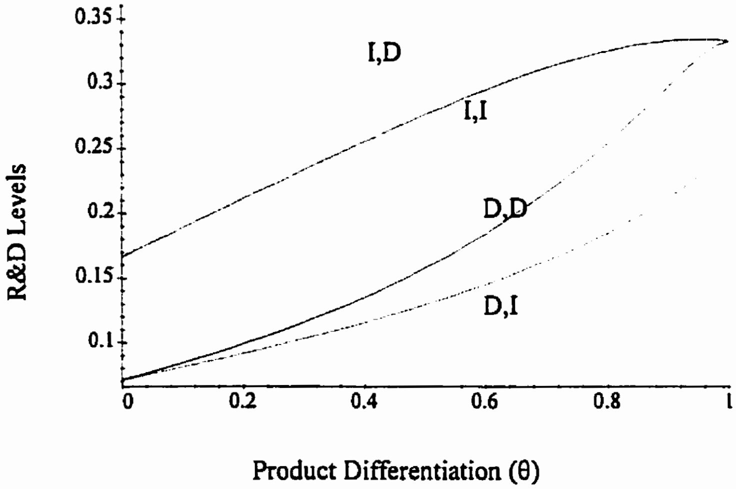

Figure 4.4: Equilibrium R&D Levels as a Function of Product
Differentiation (θ)
($M/b=1$, $b/\alpha=1$, $c=0.5$)

Process Innovation Investments

The first question we address is as follows: Is there a difference in the manufacturer's incentives to invest in cost reduction in a decentralized (non-coordinated) channel as opposed to that in an integrated (coordinated) one? Jeuland and Shugan (1983) examine a similar question in the context of bilateral monopoly. They show that in a non-coordinated channel, the retailer has an incentive to lower his marketing efforts, and the manufacturer to lower the product quality, below the joint maximum level. It is not a-priori clear how this result will be affected when we consider competition from rival channels and varying degrees of substitutability between competing products. An answer to this question is provided by the following result.

Proposition 3. *The equilibrium R&D expenditures by the manufacturers satisfy the following relations:*

(a) $x^*_{DD} \le x^*_{II}$ *and* $x^*_{DI} \le x^*_{ID} \quad \forall \alpha, \theta$ *(equality for* $\theta = 1$*).*

(b) $x^*_{DI} < x^*_{II} \quad \forall \alpha > b/4, \forall \theta.$

(c) $x^*_{ID} <, =, \text{or} > x^*_{DD}$ *as* $\Theta <, =, \text{or} > \Lambda$*, where*

$$\Theta = 128(8\alpha - b) + 2\theta^4(1412\alpha - 229b) + 2\theta^8(144\alpha - 31b) \quad \text{and}$$
$$\Lambda = \theta^2[16(176\alpha - 25b) + \theta^4(1314\alpha - 245b) + 6\theta^8(4\alpha - b) + b\theta(4 - \theta^2 + \theta^4)]$$

(d) $x_{ID} = x_{II}$ *at* $\theta = 0$*. If* $\theta \neq 0$*, then* $x^*_{ID} <, =, \text{or} > x^*_{II}$ *as* $\Phi <, =, \text{or} > \Psi$*, where*

$$\Phi = 2[32\alpha + 2\theta^3(6\alpha - 5b) + \theta^4(17\alpha + 13b)] \quad \text{and}$$
$$\Psi = \theta[16(2\alpha - b) + 8\theta(11\alpha + 2b) + 4\theta^4(\alpha - 2b) + \theta^5(4\alpha + 13b) + b\theta^6(1 - 2\theta)]$$

Proof: See Appendix B.

The above proposition states that each manufacturer spends more on R&D when both manufacturers are integrated than when both manufacturers are decentralized. In a mixed structure, the integrated manufacturer spends more than the decentralized one. Moreover, unilateral decentralization by a manufacturer always reduces his R&D investments, when the other manufacturer is integrated. However, when the other manufacturer is decentralized, decentralization by a manufacturer reduces his R&D investments only if θ is below a certain threshold value. These relationships are illustrated in Figure 4.4 (for $M/b = 1, \alpha/b = 1, c = 0.5$).

Clearly, there is a 'vertical externality' generated by manufacturers' investments in cost-reducing R&D. A lower unit production cost also benefits the retailer by lowering his cost of procurement[16], which a decentralized manufacturer maximizing his own profits ignores. In other words, the manufacturer recovers only part of the profits generated by lower production costs, the other part is retained by the retailer. In absence of any contractual or other means of channel coordination, this externality lowers the manufacturer's incentives to invest in cost reduction. However, as stated by Result 1, decentralization is an equilibrium strategy (and a more profitable one than integration) at high substitutability. This suggests that manufacturers can, in fact, use independent intermediaries as a credible commitment to invest less in cost-reducing R&D. Thus, our analysis not only generalizes the notion of vertical externality in manufacturing efforts to duopolistic markets, but also provides a basis for understanding why we still observe decentralized, non-coordinated channels in a number of industries (Lee and Staelin, 1997), despite the fact that the consequences of decentralization for prices as well as manufacturer and retailer effort incentives are "well-known". Also note from Appendix A that, regardless of the channel structure, equilibrium R&D investments by the manufacturers increase as the final market size (M) increases, decrease as the cost of carrying out R&D (α) increases, and decrease as the existing level of variable production cost (c) increases.

Prices and Quantities

Secondly, we ask how the retail prices and output levels compare between decentralized and integrated channels. It is well-known that, if marginal costs of manufacturing and retailing are constant, a decentralized channel charges a higher price than an integrated one does because

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[16] Note from Appendix A that retailer i's profits rise in proportion to the square of the output of product i, and quantities produced increase as production cost goes down.

of successive mark-ups imposed by independent profit-maximizers, irrespective of whether the situation considered is that of a bilateral monopoly (as in Jeuland and Shugan, 1983; also see Machlup and Taber, 1960) or successive oligopoly (as in McGuire and Staelin, 1983, 1986). However, it is not clear what the effect on final prices will be when marginal production costs are not constant — in particular, when the manufacturer has the option of reducing his production costs through investments in process R&D. We provide an answer below.

Proposition 4. *(a) A decentralized channel charges higher retail prices and produces lower quantities than the integrated one, regardless of the degree of substitutability between their products, in pure as well as mixed structures.*
(b) The easier it is to reduce costs, the higher the difference between the retail price charged by a pure decentralized channel over that of a pure integrated channel's retail price.

The above result generalizes the long-standing result in the economics and marketing channels literature that prices increase and output levels fall as a result of non-coordinated decision making at successive stages in an isolated production-distribution system[17]. Introduction of competition and manufacturer's investments in cost reducing process innovation do not change this result. In fact, over the last few years, a renewed realization of this fact on the part of both academics and practitioners alike has helped spawn a multi-billion dollar industry focused on ways of achieving coordination in various production, inventory, and pricing decisions along a supply chain.[18] The major concern in these studies is cost reduction, but competitive reactions are typically ignored. Whereas part (a) of the above result gives credence to the notion of channel coordination to reduce prices even when competitive reactions are accounted for, part (b)

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[17] For a vertically integrated monopoly, the retail price is $p_m = \arg\max\,(p-c)f(p)$, and the monopoly output is $q_m = f(p_m)$. However, in a decentralized channel, the manufacturer charges the retailer a transfer price $w > c$ in order to make a profit, and the retailer, maximizing $(p-w)f(p)$, charges a retail price $p > p_m$, leading to lower industry profits as well as lower consumer welfare (e.g., see Rey and Tirole, 1986).

[18] Witness, for example, the rise in the number of companies such as i2 Technologies, selling software packages (and management consulting companies offering customized solutions) that help other firms reduce their costs through coordinated decision making along their supply chains.

indicates that the 'benefits' of coordinated decision making that an integrated channel enjoys (in terms of lower prices) become even greater the easier it is to reduce production costs[19]. The reason behind this latter assertion is as follows: proposition 3 tells us that a decentralized manufacturer invests less in process R&D, and therefore has a higher marginal cost of production, than an integrated manufacturer does. This difference gets bigger the lower the investment required in process innovation to achieve a given level of cost reduction, with the result that the retail price increase in a decentralized channel (over that of an integrated channel's price) is also higher the easier the cost reduction. Moreover, since the vertical externality of lower R&D investments in a decentralized channel operates in conjunction with the successive mark-ups due to individual profit-maximization, the increase (decrease) in retail prices (quantities) in a decentralized channel is higher in our model than is the case when marginal production cost is treated as constant (which corresponds to $b/\alpha = 0$), as in most of the studies cited above. This result is illustrated in Figure 4.5.

Industry Profits and Consumer Welfare

What is the effect on manufacturer and channel profits, and consumer welfare? It is an old result that in a successive monopoly, integration will always improve industry profits as well as consumer welfare. However, consideration of process innovation incentive makes this improvement larger in value than that obtained due to marginalization alone (as illustrated in Figure 4.7)[20]. When competition is introduced into the picture, the result on consumer welfare still holds (as is obvious from proposition 4 above). The effect on manufacturer profits, on the other hand, is not that clear. It is well-known that, if marginal production costs are treated as constant, manufacturers in competitive markets may be better off *not* coordinating their decisions with

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[19] although whether lower prices lead to higher profits is not guaranteed; see next section.

[20] Assuming a demand function of the form $q = A - Bp$, and an integrated monopolist's profit function as $\pi_I^M = (p - c')q - \alpha x^2$, where $c' = c - x$ is the unit production cost after process R&D, it is easy to show that the ratio of total industry profits in a decentralized channel to that in an integrated one, $\frac{\pi_D^{CH}}{\pi_I^{CH}} = 3/4$ with no R&D, and $< 3/4$ with R&D investments; in the latter case, $\frac{\pi_D^{CH}}{\pi_I^{CH}} \rightarrow 3/4$ as $B/\alpha \rightarrow 0$.

retailers when competitors' products are very similar, because then the price competition is the strongest (see McGuire and Staelin, 1983, 1986; Coughlan, 1985; Coughlan and Wernerfelt, 1989). The effect of the inclusion of process innovation dimension on manufacturer profits is summarized below:

Proposition 5. *(a) The manufacturers make higher profits under a pure decentralized structure than in a pure integrated one for $\theta > \theta_0$, and θ_0 decreases with α (see Figure 4.2 (b))*[21].

(b) The easier it is to achieve production cost reduction, the larger the difference between manufacturer profits in decentralized and integrated channels.

To understand part (b) of this result, let us look at Figure 4.6, where we plot the ratio of equilibrium manufacturer profits ($\pi^{M*}_{DD}/\pi^{M*}_{II}$) as a function of product substitutability (θ) at different levels of the investment cost of process innovation. When the relative cost of R&D is low (i.e., high b/α), (D, D) is more than three times as profitable as (I, I) at θ close to unity, and (I, I) is more than twice as profitable as (D, D) at $\theta = 0$. However, as the cost of R&D increases, the effect of the vertical R&D externality diminishes, and the ratio approaches that obtained by McGuire and Staelin (1983). An intuitive explanation is as follows: lower cost of R&D makes higher cost reduction feasible, which leads to a larger difference in the level of marginal production costs in decentralized and integrated channels due to the vertical externality (see proposition 3). It also leads the decentralized channel to sell its products at a much higher price than those of an integrated channel (see proposition 4). Thus, decentralization can be viewed as a non-cooperative way for the manufacturers to do less R&D, commit to higher prices, and thus reduce the intensity of competition between themselves. This strategic commitment is larger in value the higher the substitutability between products, and, beyond a cut-off level of θ, dominates the advantages of having lower costs by integrating downstream. Since the higher profits in a decentralized channel are a result of strategic commitment only[22], lower R&D costs

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[21] Please see page 49 for the exact condition under which this result holds.

[22] That is, a channel cannot benefit from deentralization in absence of strategic interaction with the other channel.

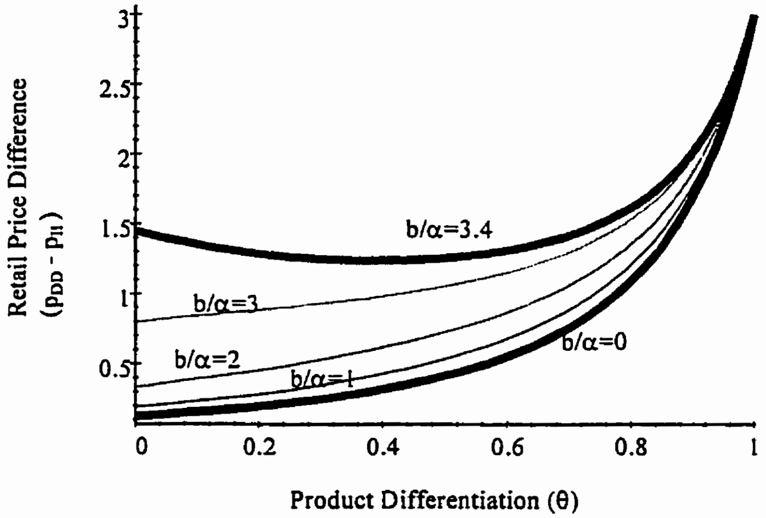


Figure 4.5: Variation in Retail Price Difference (p_{DD} - p_{II})
with b/α and θ
(M/b=1, b/α=1, c=0.5)

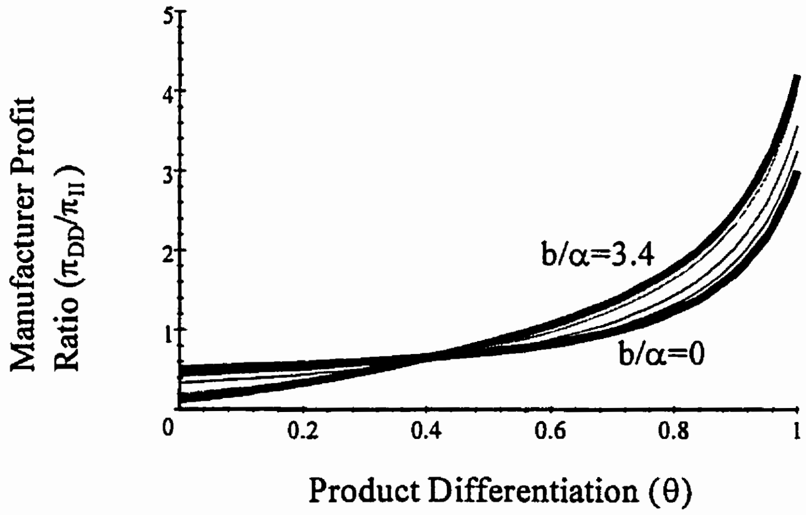
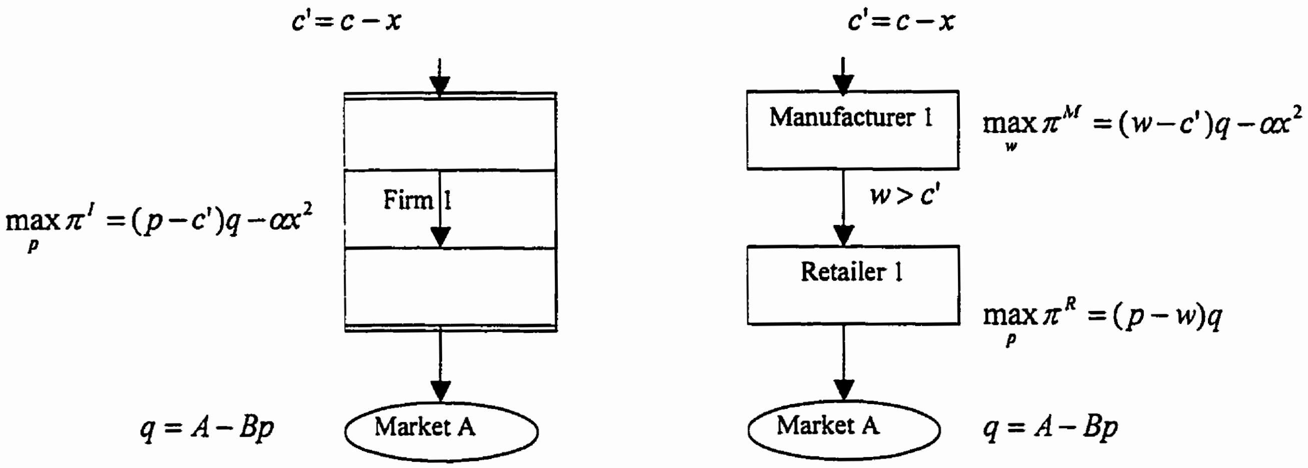


Figure 4.6: Variation in Manufacturer Profit Ratio (π_{DD}/π_{II})
with b/α and θ



$\dfrac{\pi_D^M}{\pi^I}$ $= \frac{1}{2}$ with no R & D
$< \frac{1}{2}$ with R & D investment

$\dfrac{\pi_D^{CH}}{\pi^I}$ $= \frac{3}{4}$ with no R & D
$< \frac{3}{4}$ with R & D investment

Figure 4.7: Comparison of Manufacturer and Channel Profits in Integrated and Decentralized Structures in Absence of Competition

make this profit increase (over manufacturer profit level in an integrated channel) larger in value in the upper region of θ. Similarly, below the cut-off level of substitutability, the strategic interaction effect between channels is dominated by lower costs of an integrated channel. Thus, in this region, lower R&D costs result in a larger increase in profits that the manufacturer makes by integrating downstream. *Process innovation accentuates the profit difference between integrated and decentralized channels.*

By the same argument, lower R&D costs, by increasing the value of strategic commitment, make decentralization more profitable than integration for a wider range of substitutability (see Figure 4.2 (b)), though decentralization is an equilibrium strategy over a *smaller* range of substitutability (see proposition 2). Thus, *process innovation makes the Prisoner's Dilemma situation worse in the choice of distribution channel structure.*

'Buffering'

Finally, we analyze the 'buffering' argument for decentralization that has often been advanced in the literature (e.g., McGuire and Staelin, 1983; Coughlan, 1985). It is argued that by inserting independent intermediaries between themselves and the consumers, the manufacturers can reduce the intensity of their rivalry by restricting their competitive reactions to price movements. Since our model allows us to investigate the effect of a second category of strategic commitment by means of investments in production cost reduction, we ask the following question: does decentralization provide any advantages to the manufacturers in terms of responding to rivals' commitment to invest in production cost reduction? The following result provides the answer:

Proposition 6. *An integrated manufacturer increases (respectively, decreases) his output more rapidly than a decentralized manufacturer does for a small positive change in his own (respectively, the rival manufacturer's) investments in cost reduction.* [23]

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[23] More precisely, the result is as follows:

(a) $\Delta_1(I,I) \geq \Delta_1(I,D) \geq \Delta_1(D,I) \geq \Delta_1(D,D) \geq 0$ and

(b) $\Delta_2(I,I) \leq \Delta_2(I,D) = \Delta_2(D,I) \leq \Delta_2(D,D) \leq 0$

Note that investments in cost-reducing R&D can be viewed as commitment by a manufacturer to be more aggressive, because lower production cost allows him to lower his price (or, equivalently, produce higher quantities of his product). The above result indicates that the strength of rivalry between manufacturers is dependent on their downstream integration level. By inserting independent profit-maximizing retailers, the manufacturers dampen the competitive reactions to opponents' aggressive moves to capture market share by increasing investments in cost reduction. Thus, this result provides additional support for the hypothesis of a strategic incentive for decentralization.

4.6. Managerial Implications and Conclusion

Jeuland and Shugan (1983) suggest that a retail experiment that ignores competitive reactions from other retailers will recommend lower prices than is optimal, while those ignoring vertical channel coordination will suggest prices that are above the optimal level (and non-price variables that are below the channel-optimal levels). Our analysis establishes what one would intuitively expect: 'optimal' levels of prices, as well as the promotional and manufacturer effort variables, depend on both the vertical channel structure and the (horizontal) competitive environment. Empirical studies that ignore either of these two aspects do not provide a complete picture of the underlying incentives (Lee and Staelin, 1997, also make a similar point).

Second, our analysis highlights the importance of considering the implications that marketing decisions such as product positioning, pricing, and distribution channel structure will have on manufacturing decisions such as the level of investments in process improvements, and vice versa. Managers who pay attention to this broader picture – including the interactions between horizontal and vertical dimensions, and cross-functional integration – are in a better position to increase firm profitability.

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where $\Delta_1(i,j)$ and $\Delta_2(i,j)$ represent, respectively, the rate of change in a manufacturer's equilibrium output level with respect to his own and rival's R&D levels, when his own vertical structure is characterized by i and the rival's as j; $i,j = D$ or I.

An old theme in most economic analyses is that in an oligopolistic market, the competitive environment has a tremendous effect on a firm's behavior and its decision variables such as prices and output levels. However, a second major effect on prices and production output is derived from the vertical structure of the supply chain and the specific operational capabilities of the firms. The recent surge of interest in 'supply chain management' has brought forth the realization that the cost of producing a unit of product in a channel is heavily dependent on how efficiently the flow of production is managed from the suppliers to the manufacturer to retailers, the production control and inventory policies of the various members in the chain, and, the level of coordination achieved in various decisions along the supply chain. While the two streams have tended to develop in virtual isolation of each other, there are obvious gains in considering both the horizontal and vertical dimensions. For example, while an efficiency perspective is assumed in most managerial studies of supply chains, an oligopolistic context implies that firms may have a strategic incentive as well to reduce, or *increase*, the effective costs of production and distribution in their channels, as shown in this chapter. This is especially true when intrachannel arrangements can be used as a signalling mechanism to induce competitors to behave cooperatively. Similarly, strategic interaction with competitors, alongwith ownership and incentive structures, may affect the desirability of engaging in various degrees of supply chain coordination, and vice versa. The attractiveness of following cost leadership or differentiation strategies may be different depending on both the channel and the industry structure. And finally, specific firm decisions intended to increase short term profitability may have consequences for the industry structure at various levels of the supply chain. All these issues need further examination in order to better understand inter-organizational relations and emergence of market structures. Our analysis in this chapter is an important first step in understanding channel structure decisions in relation to interactions between two dimensions: product differentiation and production costs. Whereas the marketing literature has generally tended to focus only on the demand side and the operations literature on the cost side, we argue that a better understanding of the underlying incentives for organizational decision making can be achieved only when cross-functional interactions are explicitly analyzed.

Thus, there are a large number of extensions possible of the simple framework presented in this chapter. In subsequent chapters, we analyze two extensions to this model. In Chapter 5, we consider the possibility that ownership is distinct from coordination in individual decisions, and analyze various games based on decision rules that incorporate different possibilities of coordinated decision making with or without ownership. A second extension is to relax the assumption of perfect intellectual property rights enforcement of the present model, and consider the possibility of R&D spillovers — that is, rival firms may be able to benefit from the process improvements carried out by one manufacturer, at no cost to them (see Chapter 6). Finally, we will merge the two to consider the impact of various horizontal cooperative arrangements in presence of R&D spillovers, on vertical channel structures as well as on R&D levels, prices and output in Chapter 7. Preliminary results indicate that upstream horizontal arrangements have a tremendous impact on the vertical supply chain relations as well as on the downstream industry structures, and conversely.

5. INSTITUTIONAL ARRANGEMENTS AND CHANNEL COOPERATION

It has been argued that a focus on the two extremes of anonymous, spot transactions in the market and internal hierarchy within a firm — explicit in the transaction cost approach and implicit in much of the rest — does not do justice to the complexity and variety of institutions one finds in reality. "The continuum from market to hierarchy is less like a ruler than a football, with a vanishing small pure type at each end, and a swollen middle that mixes the two. ... The "society of organizations" is a dense and ever-changing network of reciprocating competition and cooperation; very little of organizational life remains at the two ends of the football" [Perrow, 1986, pp. 255].

Indeed, the whole notion of efficiency as the guiding principle in firm size and industry structures has been challenged, with compelling empirical evidence attesting to the fact that growth of large firms in a number of industries had nothing to do with efficiency. Instead, profit and power motives — such as control over markets, labor and government; possibilities of collusive behavior; driving out smaller competitors; limiting entry into an industry — often play an important role.[1] In this chapter, we will examine how strategic interactions among

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[1] Perrow (1986) gives numerous examples of such behavior. In addition, following accounts are mentioned: Scherer (1980); Bridges' (1903) description of Carnegie's acquisitions at the end of 19th century as being purely profit-motivated; Yago's (1984) account of how DuPont and General Motors interests destroyed much of urban mass transit in the U.S.; Jones' (1982) critique of Williamson's evidence and interpretations of the early history of capitalism (arguing that hierarchies proved to be more efficient than cooperatives and inside contracting); Du Boff and Herman's (1980) evidence, as a critique of Chandler's (1969, 1977) work, that the emergence of several of the hierarchies that Chandler had described had much more to do with market power than with coordinating

competitors may influence their incentives to coordinate their decisions with, or obtain ownership of, different members in the supply chain. The intent is to demonstrate that both efficiency and strategic incentives have a bearing on the form of institutional arrangements we observe in any economy.

5.1. Channel Coordination

It has long been recognized that firms in a channel can improve their joint profits if they coordinate their production and pricing decisions. Moreover, integration itself does not result in improved coordination in individual decisions, and by the same token, coordination can be achieved among separate firms. Thus, two dimensions to integration can be identified: the degree of ownership integration, and the degree of coordination integration. Langlois and Robertson (1995) characterize various types of organizational 'networks' on these two dimensions: a 'holding company' being high on the first and low on the second dimension, whereas the 'third Italian district' is just the opposite[2]. Similarly, Mattsson's (1969) conceptualizes integration along three different dimensions: (a) institutional, (b) decision and (c) execution. In his terminology, institutional integration is concerned with the formal-legal power, such as ownership, of an organization over another. Decision integration is defined as "... the degree of centralization of a decision process and who controls what in the relationship". Execution integration refers to "... the way activities are executed and the characteristics of the flow" in terms of the content as well as the frequency and amount of resources exchanged [Hertz, 1992; Mattsson, 1969]. This framework thus captures the essential aspects of changes in inter-organizational relationships that various forms of cooperation or integration would bring, and is useful in teasing apart

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efficiencies.

[2] A number of studies have analyzed the pattern of organizational arrangements in what is known as 'Third Italy'. This region is dominated by a large number of small firms with high degrees of horizontal and vertical specialization, and competition based on product differentiation and distinctive competencies developed by the firms in a limited shere of activities (eg,design). A high degree of cooperative coordination among these firms ensures them access to capital and world markets despite their size [Langlois and Robertson, 1995].

the effects of different levels of integration that are otherwise lumped together in a "market versus hierarchy" perspective or are ignored in the interests of desirable cooperative behavior in a supply chain (or channel). In the light of this framework, our model in the previous chapter can be described as being focused on the first dimension (ie, institutional integration). In this chapter, we will first discuss various mechanisms for coordination that can be described as being concerned with decision integration. We will then extend our model presented in chapter 4 to consider coordination in various decisions and the implications for organizational form. Finally, we will provide a brief summary of some of the models in operations management that focus on devising means of lowering production and distribution costs by better coordinating short-term production schedules and inventory placements along the supply chain. These models fit within the 'execution integration' dimension of the above framework, although they typically do not consider the related issues of incentives and organizational structure. The interplay among these dimensions can be best illustrated through a discussion of mass- and lean-production systems.

5.1.1. Mechanisms of Channel Coordination

In a widely cited article on the need to coordinate individual decisions among channel members, Jeuland and Shugan (1983) note that "... without joint ownership and its associated coordination, the manufacturer has the power and profit-maximizing incentive to raise his margin above the level at which total channel profits are maximized. He also has the incentive to lower the product quality below the joint maximum level and lower all other promotional decision variables at his disposal. The lack of coordination leads to self-satisfying behavior, which increases the product's price while lowering its quality." Researchers have looked at various mechanisms for overcoming this deficiency and ensuring decision-coordination among individual decision-makers, with or without formal-legal integration, that would maximize the joint profits to both. Obviously, the problem of bargaining over how to split the gains from cooperation surfaces, and a lot of economic research has focused on this. We will ignore the bargaining problem for now and look only at means of coordination.

Contracts

Jeuland and Shugan (1983) state that, under perfect information, a legal contract specifying each channel member's decision variables (eg, fixing their respective margins) can lead to joint profit maximization. Blair and Kaserman (1983) have listed and analyzed a number of contractual alternatives —such as output royalties, price fixing, exclusive dealing, customer and territorial allocations — that, under certain circumstances, produce economically equivalent results to ownership integration. However, the relative benefits to each party are very clear, and the fact that these arrangements are not equally treated by legal authorities leaves open the possibility that firms might use these arrangements to circumvent any legal restrictions that might exist on integration, without actually realizing the gains from coordinated decision-making.

Implicit Understandings

Shugan (1985) proposes that 'implicit understandings' among the channel members may obviate the need to have formal mechanisms of coordination, that is, channel members may learn through repeated interactions or farsighted behavior how their own decisions influence the decisions of other members and hence their joint profits. The author shows that when channel members modify their behavior in response to such learning, some coordination (though not perfect) can be achieved.

Quantity Discounts

Another popular way of achieving channel coordination is by means of quantity discounts. That is, the per unit price paid by the retailer to the manufacturer is lower, the larger the quantity ordered. The basic idea is to determine a payment schedule consisting of a fixed fee and a per-unit transfer price that fixes the retailer's (and hence the manufacturer's) profits to some fixed linear function of the total channel profits. Thus, a quantity discount schedule is essentially a profit-sharing mechanism that ensures incentive compatibility between channel members' decisions and total channel profit maximization. This can be illustrated with an example from Jeuland

and Shugan (1983):

For a channel consisting of a manufacturer and a retailer, let $p(D)$ be the inverse demand function facing the retailer; ; C and c represent the per unit variable costs of the manufacturer and the retailer respectively; G and g are the per unit margins, and Π, π the profit functions of the manufacturer and the retailer respectively. Then, a quantity discount schedule takes the form:

$$t = k_1 p(D) + (1 - k_1)C - k_1 c + \frac{k_2}{D}$$

where k_1, k_2 are some constants, $0 < k_1 < 1$. It can be easily shown that with this schedule, the retailer makes his pricing decisions to maximize total channel profits. Quantity discounts have spawned a large amount of literature (eg, Lal and Staelin, 1984; Lee and Rosenblatt, 1986; McGuire and Staelin, 1986; Weng, 1995) as researchers have sought to integrate the coordination function provided by quantity discounts as well as the implications on production, inventory and ordering policies.

Franchising

Franchising is one of the most widely implemented means of ensuring channel coordination through an institutional arrangement that has similarities to both the purely integrated and purely decentralized systems, accounting for nearly $1 trillion in annual sales in North America (Business Week, 1997). An extensive literature on franchising lists many advantages of this practice whereby a manufacturer grants the rights to distribute his product to independent, usually small, entrepreneurial firms under various kinds of arrangements, typically consisting of an annual fixed fee and a per-unit transfer price, alongwith certain territorial privileges. In the auto industry, for example, a manufacturer typically allocates exclusive territories to franchisees, usually justified on the basis that "cost structure of the franchisee's business indicates that excessive intrabrand competition among distributors would lead to failures... The classic example of this involves the distribution of automobiles" [Blair and Kaserman, 1983, pp. 31; also see Pashigian, 1961]. In addition, interbrand competition is curtailed through exclusive dealing clauses that prevent a distributor from carrying the product lines of another manufacturer.[3] Thus, auto manufacturers, who could "in principle.... also own all of their dealerships" [Blair and Kaserman, 1983, pp.38] achieve a similar result to vertical integration with much lower capital requirements. We digress a little to build on the example of franchising practice in the automobile industry, to demonstrate that even though such an arrangement might have benefited the industry, consumer preferences and other environmental changes may make such practices outmoded. Moreover, this example also serves to underline our argument that manufacturers may prefer certain types of institutional arrangements for strategic reasons.

Recent evidence indicates that the automobile distribution structure is changing in North America in response to a widespread dissatisfaction with the existing system, which most buyers perceive as "the most anxiety-provoking and least satisfying of any retail experience" [Business Week, 1996b] for the second most expensive purchase that most buyers would ever make.[4] Besides having to cope with the hard sell tactics of the salespersons, consumers also face higher search costs in gathering relevant information and comparing different manufacturers' products because of single-manufacturer dealers who are reluctant to give any product-specific information anyway. Moreover, increasing proliferation of product varieties has also substantially increased the capital requirements for the dealers. One of the results is emergence of capital-rich megadealers (eg, AutoNation, CarMax, PriceCostCo, Sam's Club) who carry a wide range of models from a number of different manufacturers and guarantee low, "haggle-free" prices: "... the whole process took two hours... and the whole time we were treated like human beings who were able to decide what we liked", exclaims one satisfied customer [Business Week, 1996a, pp. 34]. At this point, auto manufacturers are reluctant to deal with such huge distributors, as it predictably puts the manufacturers at a bargaining disadvantage.[5] Nevertheless, signs of

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[3] Exclusive dealing was made illegal in the U.S. in 1940s [Womack et al., 1990, pp.170]. Nevertheless, a vast majority of car dealers remain single-manufacturer outlets.

[4] Consumers would "rather have a root canal" than go to a showroom to buy a new car, says Chrysler Chairman Robert Eaton [Business Week, 1996a, pp.35].

[5] Consequently, most of these megadealers' efforts are still concentrated on the $ 275 billion used-car market (compared to an estimated $ 295 billion new-car business - see Business Week, 1996a, p.35) — a very attractive

consolidation are clear in the North American new-car dealerships: their number having fallen from 47,500 in 1951 to 22,400 in 1995, and only the largest dealerships seem to be gaining in sales [Business Week, 1996b]. For example, Carl Spielvogel's United Auto Group, formed four years ago on the premise that it can "revolutionize cars the way Walmart and Home Depot did to retail", has bought 41 dealerships, sells 22 brands ("from Jeeps to BMWs"), and focuses on efficiency and customer service (with stores open from 8.00 am till midnight "in an industry that has tended to keep bankers' hours") [Business Week, 1996b, p. 72]. The emergence of such chains has brought the widespread consumer discontent with the existing dealership structure more sharply in focus. Many contend that the primary reason this "creaky, antiquated, and inefficient" [ibid] dealership system has survived is because it has been "protected by some of the most anticonsumer and anticompetitive laws in the nation" [Thomas Kinnear, quoted in Business Week, 1996b]. Dealer franchise laws (exclusive territories, for example) make it very difficult for newcomers to enter the new-car business; and, single-brand dealership system adds huge costs to the distribution system: "Imagine what it would cost to buy a TV if Circuit City had to have 15 different stores to sell 15 brands of television" says W. Ligon, Senior Vice President of Circuit City who oversees CarMax, the used-car chain that had sales of $ 288 million at just four stores in 1995 [Business Week, 1996b].

Perhaps more importantly, we note that the rise of such multibrand mega-retailers substantially lowers the entry barriers to the auto assembler's industry. Indeed, as numerous studies have shown, access to distribution channels has very successfully been used by auto manufacturers all over the world for decades to ward off entry of foreign (or domestic) competitors. A potential entrant faces huge setup costs in trying to build up its own nationwide distribution structure. Partial evidence for this assertion can be gleaned from international comparisons: in

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segment itself because of the proliferation of late-model low mileage cars made available by a flood of leasing arrangements. Analysts reckon the profit margins on used cars to be around 4 percent compared to 1.3 percent on new cars. Used car sales now account for 47.8 percent of the total profits of a car dealer (1995 data) compared to a meager 7 percent a decade ago; the share of new car sales having fallen in the same period from 78.5 percent to 6.3 percent (rest comes from service and parts — see Business Week, 1996b, p. 72). So much for Akerlof's market for lemons (see Akerlof, 1970).

United Kingdom, where no exclusive dealing or equivalent agreements bind the retailers, the drop in number of dealerships and the rise of megadealers (eg, Lex Group) has been much faster than in Continental Europe or North America. In the U.S., end of exclusive dealing in 1940s was at least partially responsible for giving new competitors, such as Volkswagen and Renault, a foothold in the market in 1950s (see Womack et al., 1990, pp.171).

Thus, in summary, there seem to be compelling reasons other than efficiency of why upstream manufacturers in an industry may want to keep the downstream market fragmented and dependent, and that changes in market structures may emerge for a variety of reasons. Similar arguments could be made for changes in the upstream (ie, supplier) structures.

5.1.2. Quasi-Vertical Integration

Another form of hybrid arrangement that is often mentioned is "quasi-vertical integration" (Blois, 1972; Monteverde and Teece, 1982). Monteverde and Teece (1982), referring to the auto industry, describe quasi-vertical integration as "a common organizational form in industrial economies ..., the ownership by a downstream firm of the specialized tools, dies, jigs, and patterns used in the fabrication of components for larger systems ... Quasi-vertical integration differs from full vertical integration in that the downstream firm still contracts with a supplier for the actual manufacture of the component, whereas with full vertical integration the production process itself is internalized." Such a practice is sometimes asserted to increase the flexibility of the downstream firm as the assembler has the option of moving its equipment from one supplier to another in case of problems; moreover, it reduces the probability of entry into upstream parts production (eg, see Crandall, 1968). Monteverde and Teece (1982), on the other hand, provide an efficiency explanation for this phenomenon: quasi-integration is a response to the supplier fears of post-contractual opportunistic behavior by the assembler (ie, buyer). The possibility of such behavior arises because of the "appropriable short-term quasi-rents" generated by supplier's investments in specialized tools and equipment (that are more valuable when employed in production of inputs required by a specific buyer, but may not be costlessly adaptable to produce products for another buyer). Thus, from supplier's point of view, payment by the buyer for those specialized assets alleviates the danger of buyer opportunistic behavior [Monteverde and Teece, 1982, pp.326, footnote 13]. However, as the authors themselves recognize, it is not very plausible that the assembler would make these investments just to allay supplier's fears of appropriation – ownership rights to those assets have to be associated with buyer's investments, implying also the "... the right, at minimum, to transfer tooling when the original production agreement cannot be met (the prominent example being when the supplier is struck by its union)" [ibid]. Therefore, it seems that the aforementioned 'flexibility and market power' explanation of Crandall is subsumed in Monteverde and Teece's arguments as well. The following objections can be raised against this line of reasoning:

(a) In the Grossman-Hart framework, the primary incentive for a firm to integrate is to gain ownership and thus residual rights of control over another firm's assets (see section 3.3). In particular, no distinction is made between "employees" and "outside contractors" as long as the ownership of the assets used is not changed. Thus, ownership of specialized tools and equipment upstream by the assembler is not *quasi-integration* but *integration*. That is, assemblers owning such assets in the supplier industries should be considered vertically integrated, even though the actual production decisions are contracted away.

(b) Empirically, it seems to be rare that the option of moving its equipment from an existing supplier to a new one is exercised by the downstream firm.[6] Partly, the reason might be that the tools and equipment themselves do not fully determine how productive the relationship is between the supplier and the buyer. Managerial capabilities and operational practices, that are firm-specific to a large extent, have a tremendous effect on how that equipment is utilized in production. Moreover, investment in upstream production equipment raises the capital expenses of the downstream firm. And, it is precisely in production or assembly of "complex" products such as automobiles, aircrafts or computers, which require thousands of different components,

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[6] Very few of the incidents that have been reported include Ford's removal of a one-and-a-half ton die from Sage and Company after Sage's workforce had been on strike for 5 days — reported in Financial Times, 1970, discussed in Blois, 1972.

that the option of owning upstream production equipment becomes infeasible.

(c) A second instance of when such specific investments by the manufacturers become infeasible is when the technology development and replacement cycles become shorter and shorter, as it would be virtually impossible for the manufacturer to keep abreast of and invest in new technologies every few years in production of a large number of components. Under such conditions, it is much more likely that the downstream manufacturer relies on independent, specialized producers who invest in and utilize new technological developments to improve the quality of their products and reduce production costs. In turn, these specialized producers of components seek a larger output — that is, a broader customer base and a larger number of units of the final product — to amortize their technology investments over a shorter life span, and to generate sufficient funds for investments in continued research and development. Larger output volumes and broader customer base also contribute to building of expertise and faster learning. This chain of events thus leads to higher quality products at lower costs, and contributes to improved consumer welfare. However, the price paid is in the form of higher concentration and higher market power of these upstream producers — a few, large producers now supply components to the downstream manufacturers through an intermediate market, instead of a large number of small, captive suppliers related to a downstream manufacturer through contracts. This transition has been most evident in the computer industry, where former small "suppliers" such as Microsoft and Intel have evolved into dominant firms supplying components to downstream computer assemblers largely through intermediate open market. We note, in this context, Perry's example of vertical quasi-integration as IBM's "... substantial equity interest in Intel, a leading manufacturer of semiconductors used in IBM products" [Perry, 1989, p. 186]. The reality today is more like IBM being in a highly competitive, almost commodity-like market for personal computers, which it once used to dominate and now shares along with an increasing number of competitors. Intel and Microsoft seem to dictate the new generation of products that these manufacturers will make; and the open market availability of inputs (both hardware and software) seem to have facilitated entry in the personal computer market by even small producers "working in their garages".

From this perspective then, it would seem that in the automobile industry, the strategic decisions made by the auto manufacturers to produce a relatively high percentage of their parts and components in-house, to rely on small captive suppliers for most of their sourced components, and to further limit their discretion through partial ownership of production equipment have, at least to some degree, been responsible for limiting the technological innovation in the upstream industries – which would have ultimately benefited the consumers. Moreover, these practices have also contributed to forestalling horizontal integration in the upstream industries, keeping the suppliers small and dependent on the auto manufacturer. This not only improves the bargaining position of the manufacturer vis a vis the suppliers in the short term, but also wards off possibility of entry into the manufacturer's industry over a longer time horizon. In this regard, bilateral relations work as effectively as vertical integration as a means of creating entry barriers by eliminating the input markets.

To summarize, we have discussed in this section the need to coordinate individual decisions among different members of a channel, and outlined several mechanisms that the firms can use to achieve such coordination. We have also shown that while an efficiency perspective is implicitly assumed in most of these mechanisms, firms may have other incentives to choose certain forms of arrangements or coordinate certain decisions. In the next section, we consider such incentives in the context of our duopoly model discussed in chapter 4.

5.2. Process Innovation and Channel Cooperation: The Duopoly Model Revisited

Recall that in the previous chapter we analyzed the manufacturer's incentive to decentralize the downstream function when each member of a channel retains complete autonomy over all his decision variables – manufacturers set their R&D levels and wholesale prices to maximize their own profits, and retailers set the retail prices to maximize their own profits. This option was compared with vertical integration that gives ownership and control over all decision variables to one, integrated, entity. As we have discussed above, organizations in reality employ a variety of arrangements in between these two extremes of "market" or "hierarchy" to transfer goods between the two stages of production and retailing. A better understanding of the underlying incentives for vertical integration thus requires an explicit consideration of alternative arrangements within a channel. Our focus here is on the strategic incentives for cooperative decision making or integration when there are more than one sequential decisions to make — choice of a distribution channel, investments in process R&D, transfer prices and final price to the consumer. That is, we address the following questions:

In a competitive environment, is there any strategic value to observable coordination in individual decisions? Is there any value in publicly announcing that even after the manufacturer has acquired (ie, has obtained ownership of) the retailer, the two firms are autonomous in their own operations and retain their separate decision-making powers? Or, is there any strategic value in having different profit centers or autonomous divisions within a firm: eg, R&D, manufacturing and retailing as separate divisions maximizing their own profits?

Thus, along the lines of the arguments in section 5.1, we consider ownership to be distinct from coordination in individual decisions. That is, institutional integration between a manufacturer and a retailer is seen as one where the manufacturer gets the ownership rights over both stages of the supply chain, but each stage retains the autonomy to set its 'crucial' decision variables (ie, R&D levels and transfer prices for the manufacturer, retail prices for the retailer). Ownership also gives residual decision rights to the owner, that is control over those rights not explicitly contracted away [Grossman and Hart, 1986], though residual ownership matters less in a world of certainty assumed in our model.

On the other hand, we consider decision integration as the extent to which the individual decisions are coordinated between the two entities. For example, two firms may have an incentive to coordinate their R&D, pricing or production decisions without common ownership, as has been made obvious by the recent emphasis on management of product flows throughout the supply chain (the benefits of supply chain coordination being, for example, lower inventory levels, lower lead times, faster market response), as well as by the numerous studies of the new product development process that underscore the importance of coordinated decision making among all the players involved (a necessity for successful innovation). The subsequent bargaining over how to split the benefits resulting from inter-firm coordination can pose some problems, specifically in the presence of uncertainty and asset specificities, which has been focused on by the substantial literature on transaction costs. Organizations employ a variety of institutional arrangements in between the two extremes of market transactions or ownership to ensure the necessary incentives. In the context of our model, we abstract from such difficulties and focus on the coordination incentive in individual decisions, and whether ownership (in as much as it gives title to profits) is more beneficial with or without such coordination.

Table 5.1 lists the possible decision rules for the three decision variables focused on in our model, in addition to the first stage decision of channel structure choice. Below we present results for only the first two of these rules which correspond, respectively, to 'divisional integrated system' and 'franchising'. Other decision rules could be worked out similarly.

	R&D Level (x_i)	Wholesale Price (w_i)	Retail Price (p_i)
DR1	max π_i^M	max π_i^M	max π_i^R
DR2	max π_i^M	max π_i^{CH}	max π_i^R
DR3	max π_i^{CH}	max π_i^M	max π_i^R
DR4	max π_i^{CH}	max π_i^{CH}	max π_i^R

Table 5.1

5.2.1. Divisional Integrated System

The first instance of coordinated decision making in a channel is a formal-legal ownership of the retailing function by the manufacturer with no decision-integration — that is, manufacturers and retailers set their respective R&D and pricing levels as before (ie, to maximize their own profits), but ownership gives the manufacturer the title to retailer-level profits (DR1). Thus, the manufacturers, at the first stage of our game, choose between an independent retailer or a company-owned store based on the expected profits to the channel as a whole. This situation corresponds to the "total channel profitability" criterion analyzed by McGuire and Staelin (1983) (or, a "divisional integrated system", cf. McGuire and Staelin, 1986).

Proceeding as in the previous chapter, it can be shown that:

1) (I,I) is an equilibrium if:

$$\Theta_5(\Theta_1)^2 - (2-\theta^2)\Theta_{11}(\Theta_2)^2 > 0 \tag{5.1}$$

2) (D, D) is an equilibrium if:

$$(2-\theta^2)\Theta_{12}(\Theta_1)^2 - \Theta_8(\Theta_4)^2 > 0 \tag{5.2}$$

3) $\pi_{DD}^{CH^*} > \pi_{II}^{CH^*}$ if

$$(2-\theta^2)\Theta_{12}(\Theta_9)^2 - \Theta_5(\Theta_{10})^2 > 0 \tag{5.3}$$

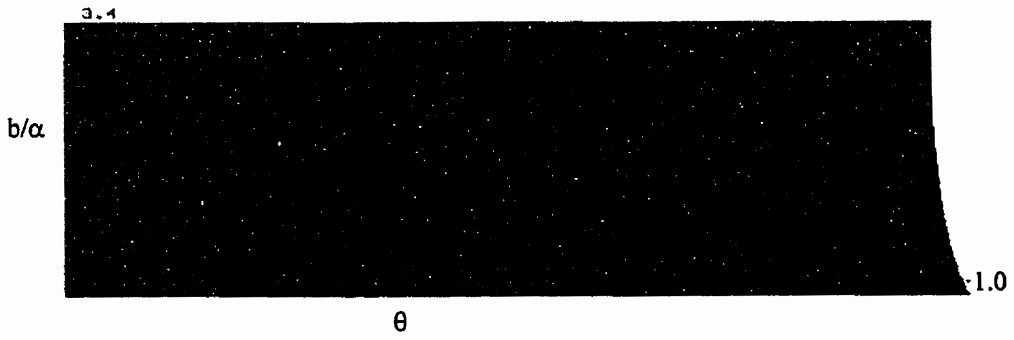
where: $\Theta_1, \ldots \Theta_{10}$ are as given on page 48, and

$$\begin{aligned}\Theta_{11} &= 8\alpha(3-\theta^2) - b(2-\theta^2)\\ \Theta_{12} &= 2\alpha(3-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2 - b(2-\theta^2)(8-9\theta^2+2\theta^4)^2\end{aligned}$$

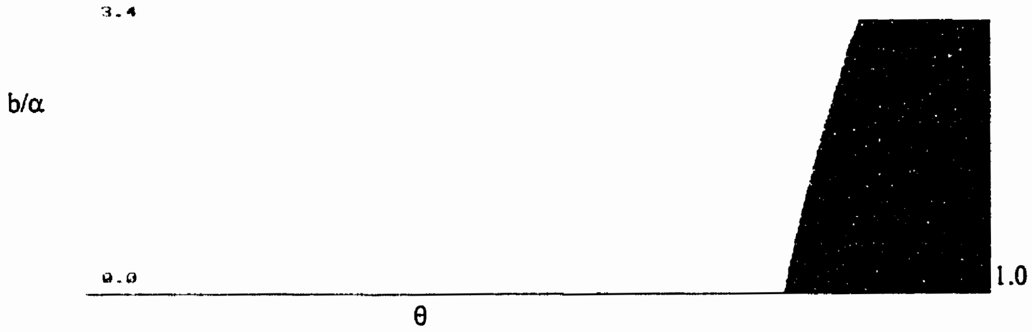
Our main results for this case are summarized below:

Proposition 7. *(I, I) is always an equilibrium except at very high degrees of product substitutability; (D, D) becomes an equilibrium at high substitutability; and, the region where (D, D) gives higher channel profits than (I, I) is larger than the region over which (D, D) is an equilibrium.*

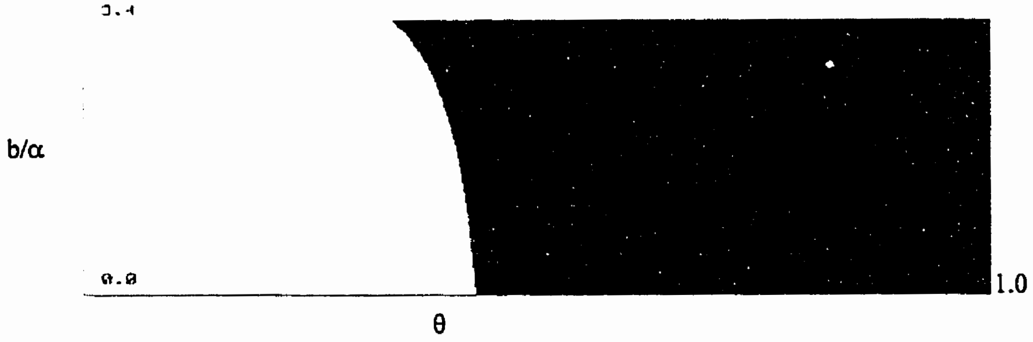
The equilibrium and profit dominance conditions are plotted in Figure 5.2. First, observe that when the manufacturer has the title to retailer-level profits, he would prefer decentralization over a wider range of parameter values than that in section 4.5.1, as would be expected since the manufacturer-level profits in a decentralized channel are a fraction of the total channel



(a): Feasible Region for Pure Integrated Equilibrium



(b): Feasible Region for Pure Decentralized Equilibrium



(c): Region where Decentralized Structure Dominates the Integrated

Figure 5.2: Equilibrium and Profit Dominance Conditions with Linear Contracts
(Channel Profits Criterion)

profits, and the manufacturer benefits from decentralization only if the channel as a whole does (Moorthy, 1988). Second, pure decentralization is obtained as a *unique* equilibrium for higher values of θ (i.e., for nearly homogenous products), in contrast to McGuire and Staelin's (1983) results where pure integrated structure always remains an equilibrium even with the criterion of total channel profitability. The reason for this difference is simple: decentralization in our model has the added 'advantage' of reducing manufacturer's R&D investments, thereby committing him to a higher price and inducing a higher increase in other channel's retail price than is the case in McGuire and Staelin's model (see page 55). Since channel profits are increasing in other channel's retail price, decentralization leads to a higher increase in manufacturer and channel profits (beyond a cut-off level of θ) in our model (see page 57). When θ is high enough, the manufacturer can increase his total channel profits even by *unilateral* decentralization (i.e., even if the other manufacturer does not follow suit and remains integrated), thus disrupting the (I, I) equilibrium. The easier the cost reduction, the stronger this indirect effect is, and thus smaller the value of θ beyond which (I, I) ceases to be an equilibrium on channel profits criterion. This can never happen in McGuire and Staelin's model because with the assumption of constant marginal production costs, the indirect effect on channel profits (by committing to a higher price through decentralization) is never strong enough to make unilateral decentralization profitable; it becomes profitable only when combined with the direct effect of the other channel decentralizing.

Finally, varying the cost of R&D has the following effect on channel equilibria:

Proposition 8. *The easier it is to reduce production costs (i.e., smaller α), the smaller the range of product substitutability (θ) over which (D, D) or (I, I) is an equilibrium outcome. (See Figure 5.2, a and b.)*[7]

This result is similar to proposition 2 obtained for the model in Chapter 4 (see page 50

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[7] As is clear from Figure 7, the ranges for (I, I) and (D, D) equilibria overlap even at the smallest value of α permitted in our model, indicating that there is a region where multiple equilibria exist but under no set of parameters can the game fail to have an equilibrium.

and the discussion there).

Channel profits are illustrated in Figure 5.3 with parameter values: $M/b = 1, b/\alpha = 1, c = 0.5$. For this example, (I, I) is an equilibrium for $\theta < 0.972$; (D, D) becomes an equilibrium for $\theta > 0.79$; and (D, D) gives higher channel profits than (I, I) for $\theta > 0.423$. Thus, there are two equilibria for $0.79 \leq \theta \leq 0.972$; (D, D) is the unique equilibrium for $\theta > 0.972$; and a Prisoner's Dilemma is obtained for $0.423 \leq \theta \leq 0.79$.

5.2.2. Franchising

The above example assumed that even if the manufacturer has the title to retailer-level profits, he sets his transfer price to maximize only his own profits. Since this raises a channel's effective marginal cost, a manufacturer may be able to increase his profits if he takes the total channel profits into account while setting his transfer price (DR2). This situation is similar to a franchise arrangement whereby the manufacturer charges both a fixed fee and a per-unit transfer price to the retailer for the right to sell his product, and where competition at the retailer-level drives the fixed fee up till the point where the manufacturer extracts all the retailer profits (McGuire and Staelin, 1986; Coughlan and Wernerfelt, 1989). Therefore, the manufacturer at the first stage chooses the distribution channel structure to maximize total channel profits. The analytical channels literature argues that under these conditions, franchising provides a means of achieving channel coordination (Bonanno and Vickers, 1988; Coughlan and Wernerfelt, 1989): decentralization is always obtained as a unique subgame perfect equilibrium irrespective of the degree of product differentiation, and decentralization is shown to be always more profitable to the manufacturer than integration. Although this result rests on the assumption of constant marginal cost of production, it has very much become part of the folklore in marketing channels literature. Does this result hold when marginal production cost is not constant, and in particular, when the manufacturer can invest in process innovation to reduce his production costs?

In order to answer this question, we solve for various equilibria following a similar procedure to that in section 4.3. Equilibrium and profit-dominance conditions are summarized

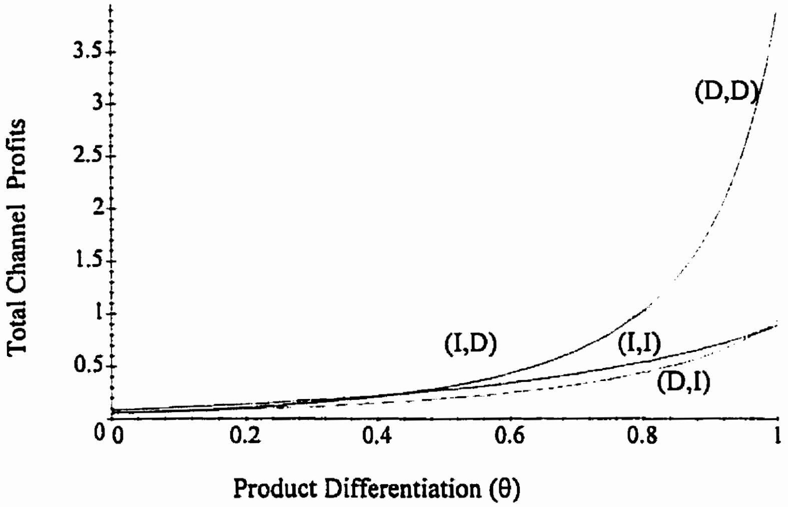

Figure 5.3: Equilibrium Total Channel Profits as a Function of Product Differentiation (θ)
(M/b=1, b/α=1, c=0.5)

below[8], and plotted in Figure 5.4.

1. (I, I) is a Nash equilibrium if

$$\Gamma_1(\Gamma_5)^2 - (2-\theta^2)\Gamma_6(\Gamma_7)^2 > 0 \tag{5.4}$$

2. (D, D) is a Nash equilibrium if:

$$(2-\theta^2)\Gamma_3(\Gamma_5)^2 - \Gamma_4(\Gamma_2)^2 > 0 \tag{5.5}$$

3. $\pi_{DD}^{CH} > \pi_{II}^{CH}$ if:

$$(2-\theta^2)\Gamma_3(\Gamma_8)^2 - \Gamma_1(\Gamma_9)^2 > 0 \tag{5.6}$$

where:

$$\begin{aligned}
\Gamma_1 &= \alpha(4-\theta^2)^2 - b(2-\theta^2)^2 \\
\Gamma_2 &= [\alpha(4+2\theta-\theta^2)(4-2\theta-\theta^2)^2 - b\theta^2(1-\theta)(2-\theta^2)(4-3\theta^2)] \times \\
&\quad [4\alpha(4+2\theta-\theta^2) - b\theta^2(1+\theta)(2-\theta^2)] \\
\Gamma_3 &= [2\alpha(4+2\theta-\theta^2)^2(4-2\theta-\theta^2)^2 - b\theta^4(2-\theta^2))(4-3\theta^2)^2] \\
\Gamma_4 &= 16\alpha(2-\theta^2)^2 - b(4-3\theta^2)^2 \\
\Gamma_5 &= b^2\theta^2(1-\theta^2)(2-\theta^2)(4-3\theta^2) + 64\alpha^2(2-\theta^2)^2 - 4\alpha b[(4-3\theta^2)^2 + \theta^2(2-\theta^2)^3 \\
\Gamma_6 &= 32\alpha - b\theta^4(2-\theta^2) \\
\Gamma_7 &= [\alpha(2-\theta)(4-\theta^2) - b(1-\theta)(2-\theta^2)][4\alpha(2+\theta)(2-\theta^2) - b(1+\theta)(4-3\theta^2)] \\
\Gamma_8 &= \alpha(2-\theta)(4-\theta^2) - b(1-\theta)(2-\theta^2) \\
\Gamma_9 &= \alpha(4+2\theta-\theta^2)(4-2\theta-\theta^2)^2 - b\theta^2(1-\theta)(2-\theta^2)(4-3\theta^2)
\end{aligned}$$

Our main results for this case appear below:

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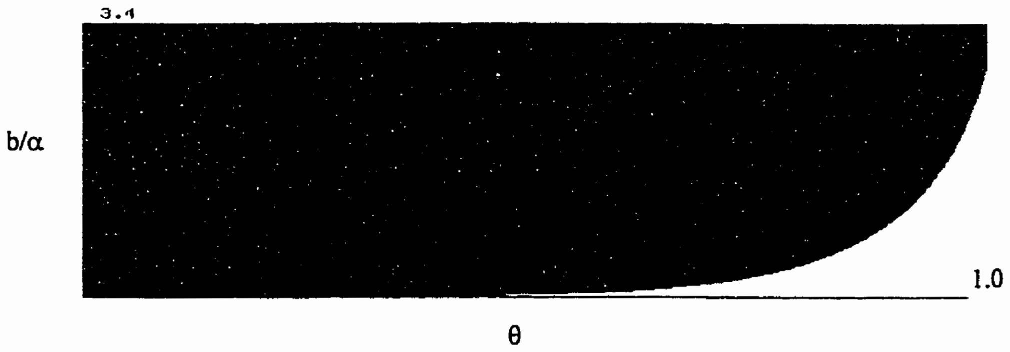
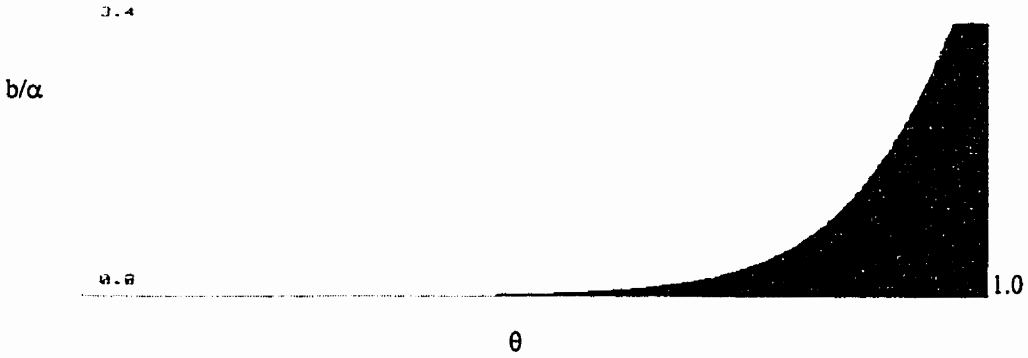
[8] Note that Coughlan and Wernerfelt's (1989) results are obtained as a special case of this decision rule, assuming $c_i = c_j = 0$ and considering the solutions to the subgame starting at the third stage; fixed costs of manufacturing and retailing do not affect any of the marginal decisions or channel profits comparisons.



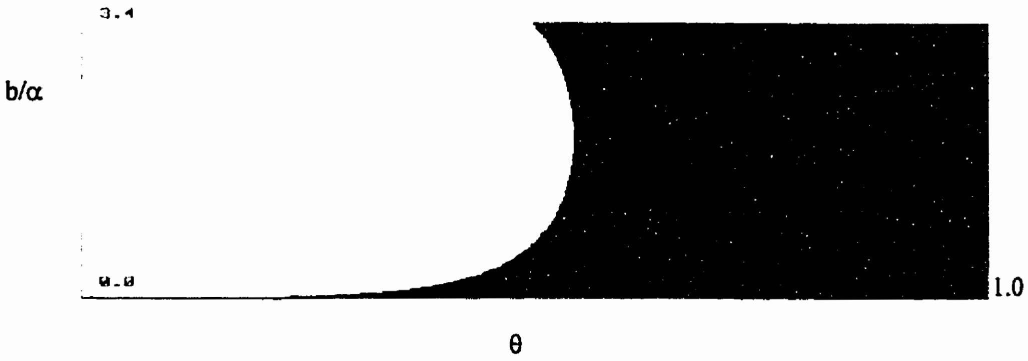
(a): Feasible Region for Pure Integrated Equilibrium

(Note: The region is empty at b/α =0.)



(b): Feasible Region for Pure Decentralized Equilibrium

(Note: The region contains the whole range of θ at b/α =0.)



(c): Region where Decentralized Structure Dominates the Integrated

(Note: The region contains the whole range of θ at b/α =0.)

Figure 5.4: Equilibrium and Profit Dominance Conditions with Franchising
(Channel Profits Criterion)

Proposition 9. *Decentralization is not always a unique perfect equilibrium, and it is not always more profitable than integration.*

This is a rather surprising result as it goes against the general wisdom. Thus, we see that the strong result in favor of decentralization stressed in the literature is not robust to variations in production costs, a crucial operational parameter. Using expressions in Table 2, we find that for θ close to 0, (I, I) is the unique equilibrium. On the other hand, when products are close substitutes (θ close to 1), (D, D) is always an equilibrium, but (I, I) is also one if:

$$1152\alpha^3 - 452\alpha^2 b - 4b^2\alpha + 7b^3 < 0 \tag{5.7}$$

which holds only in a very small range of permissible values of b/α (i.e., $2.86 \leq b/\alpha \leq 3.4$). Moreover, (D, D) yields higher channel profits than (I, I) only in the range indicated in Figure 5.4(c). It is easy to check that as $\alpha \to \infty$ (i.e., as process R&D becomes infeasible), (D, D) becomes the unique equilibrium, and it gives higher profits than (I, I), in agreement with the existing literature. However, for positive R&D expenditures, the range over which (I, I) is an equilibrium is much larger than that for (D, D) (see Figure 5.4).

The intuitive reason behind this result is easy to understand in the context of our model. A two-part tariff does not eliminate the vertical externality in manufacturer's investments in a decentralized channel[9]. On the other hand, the strategic commitment effect of decentralization whereby manufacturers commit to higher prices still obtains (note from Table 3 that the transfer price in a decentralized channel is higher than marginal cost of production, and consequently, retail price is also higher than that in an integrated channel). Thus, the trade-off between cost efficiency and strategic commitment effects holds even in this case (see page 57). Accordingly, decentralization is beneficial only when the second effect dominates, which happens when product substitutability is high *or* when the cost of R&D is high. Models with constant marginal cost of production ignore this trade-off and therefore conclude that decentralization is a unique

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[9] A quantity discount schedule, on the other hand, can be modified to incorporate a cost sharing mechanism between the manufacturer and the retailer, as in Jeuland and Shugan (1983).

(and mutually more profitable) equilibrium strategy for the manufacturers.

5.2.3. Quantity Discounts

It is easy to show that if we take into account the manufacturers' investments in process innovation, the quantity discount schedule that would induce channel optimal decisions (as discussed in the previous section) has to be modified as follows (also see Jeuland and Shugan, 1983):

$$w_i = k_1 p_i + (1 - k_1)c_i + \frac{k_2}{q_i} + (1 - k_1)\frac{\alpha(x_i)^2}{q_i}$$

where w_i represents the per-unit price paid by the retailer to the manufacturer, and the total payment to the manufacturer for q_i units is $w_i q_i$. Thus, $(1-k_1)\alpha(x_i)^2$ is the retailer's share in manufacturer's total investments in cost-reducing process R&D. Making the retailer pay for part of the cost reduction efforts of the manufacturer ensures that both the manufacturer and the retailer make channel optimal decisions while setting R&D levels and prices.

Note that here we have focused only on the coordination function of quantity discounts and have not considered their effect on manufacturer's operating costs. In the operations management literature, a large number of models exist that examine the impact of quantity discounts on manufacturer's lot-sizing and inventory related costs (eg, Monahan, 1984; Lee and Rosenblatt, 1986; Dada and Srikanth, 1987; Joglekar, 1988). In these models, demand is usually considered to be fixed. Other authors have examined the role of quantity discounts in coordinating a single buyer-supplier channel when demand is a decreasing function of price but operating costs are assumed to be fixed (eg, Jeuland and Shugan, 1983; McGuire and Staelin, 1986). Models that integrate these two streams (eg, Weng, 1995a, b) typically conclude that coordination benefits due to quantity discounts are greater when demand is a function of price than in the case where only reduction in operating costs is considered. Specifically, "... the joint profit is increased because both demand is increased and the unit operating cost is reduced as a result of joint coordination" [Weng, 1995b, p. 1520]. We argue that this result is true only under monopoly conditions. When competition from rival channels is taken into account, benefits to quantity discounts will be far less pronounced. The reason is that the demand-enhancing effect of quantity discounts (essentially a reduction in price) may not occur when both channels have the opportunity to do so. In such cases, strategic incentives on the part of the manufacturers, of the type studied in this and previous chapter, may lead the manufacturers to offer no discounts in order to maximize their profits. The equilibrium conditions on what kind of quantity discounts we would expect to see in oligopolistic markets will depend on the intensity of competition between rival channels and the observability of intrachannel contracts. This can be shown through a game-theoretic model very similar to the ones discussed here; we omit the details.

5.3. Coordinating Production and Inventory

As mentioned before, a large number of models exist in the operations management literature that attempt to coordinate the detailed production schedules at different levels of a supply chain. Most of this literature (focused in the past on 'multi-echelon inventory' and re-fashioned now with increasing popularity as 'supply chain management') takes an efficiency perspective whereby the benefits of coordinated plans are taken for granted, and issues of incentives and institutional arrangements are neglected. However, there is potentially value in considering such coordination also along with the other two dimensions studied above, especially given the increasing proliferation of industrial practices such as just-time-systems and other forms of supply chain coordination that change the content as well as intensity of inter-organizational relationships at the level of individual activities — for example, suppliers' involvement in product design, increased dependency between production schedules of the supplier and the manufacturer that just in time system brings, increased intensity of interlinkages between the inventory control systems of the manufacturer and the retailer due to point-of-sale systems, EDI, and other information technologies being employed to increase the efficiency of the supply chain. These practices are thus various forms of execution integration, and their effects, especially in relation to institutional and decision integration, have not been well understood. We take the example of automobile industry to demonstrate how execution-level coordination can mandate, and is facilitated by, development of institutions that guarantee proper incentives.

5.3.1. Supply Chain Relations in the Automobile Industry: Mass Production vs. Lean Production

Management literature has repeatedly emphasized the requirement imposed on most firms of a coordinated effort along their supply chains in order to increase the quality of their products, as well as reduce product costs and manufacturing lead times, in the face of intensified competition (similar emphasis emerges from the growing literature on new product development). A large number of studies have traced the causes of poor international competitiveness of North American firms to lack of such coordination (eg, Dertouzos et al., 1990; Womack et al., 1990). This led to (or was prompted by) a comparison of the "mass production systems" of North American manufacturers (particularly in automobiles) with the "lean production systems" perfected by Japanese firms. This focus on comparative practices is due to the age-old problem of coordinating the production flow of more than 10,000 different parts that go into making a typical car. North American companies approached this problem as a choice between "visible hand" in an integrated firm, or "arm's length, market-based, short-term interactions" with independent suppliers. Various manufacturers integrated to different degrees — depending on the company history and size (in 1980s, GM was making almost 70 percent of its parts in house, while Saab made only 25 percent of its parts itself). Most manufacturers did most of the design and engineering development work on parts and components themselves, and put out the finished designs for competitive bidding by suppliers, playing off suppliers against one another to drive down prices. There is no information sharing between the manufacturer and the supplier except the bid price; part costs rise over time; quality lags; and, new product development suffers [Womack et al. (1990); Clark and Fujimoto (1995)].

In contrast, the approach taken by lean producers (eg, Toyota) concentrated on the 'real question' of "... how the assembler and the supplier could work smoothly together to reduce costs and improve quality, *whatever formal, legal relationship they might have*" [Womack et al.

(1990), pp. 58, emphasis added]. A typical lean producer deals with a small number of 'first-tier' suppliers who work with the assembler as an integral part of the product development team, and are responsible for detailed design and engineering of a particular part or subassembly (braking or electrical system, say). These first-tier suppliers then engage their own second-tier suppliers to fabricate individual parts needed for that subassembly. This system, coupled with just-in-time system for control of production flow, has worked remarkably well in reducing costs while producing high-quality products in a much wider variety. There are substantial asset specificities – both in terms of human capital (because of early and continued involvement in product development effort) and interdependence of production schedules (because of just-in-time small lot production and frequent deliveries, without an inventory buffer). Yet it does not lead to vertical integration. Most of Toyota's suppliers are independent companies "with completely separate books" [Womack et al., 1990, pp.61], though with varying degrees of cross-equity holdings. For example, Nippondenso, Toyota's supplier for electrical and electronic systems, does more than 40 percent of its business with other car assemblers; it is also the world's largest manufacturer of such systems (worth more than $7 billion). Toyota's equity stake in Nippondenso is less than 22 percent [ibid].

A similar discussion applies to the downstream, that is, manufacturer- retailer relationships. A typical mass-producer (Ford, say) inserted independent, small retailers to isolate itself from the customer and the market fluctuations. Dealers were rationed for the popular models, and were forced to accept some slower-moving models as a tie-in condition. An average of 60 days worth of inventory is the norm, and in most cases, dealers are required to pay ahead of sales. The "bazaar tradition of car selling" is still in place, where the customer and the dealer haggle over prices, and the dealer has no incentive to give any information to the customer more than is necessary to close the deal, "... same principle on which the relationship between dealers and manufacturers is based" [ibid, pp.174]. This contrasts sharply with the dealer relationships of a lean manufacturer, organized into nationwide channels focusing on different market segments. As with suppliers, each channel is tied into the product development process, and has had long and close relationship with the manufacturer, "... best described as part of an extended family" [ibid, pp.181]. Dealer relations with the final customer also rely on extended, life-time commitment — dealers zealously prevent losing any single customer (which fits very well with the JIT production system's intolerance for volume fluctuations). Finally, dealer outlets typically carry only a small number of demonstration vehicles — most cars sold in Japan are custom-ordered, while this option is being eliminated in the U.S.[10]

A final, related point here concerns modularity of product designs and standardization of inputs (parts and components). An increase in the number of different types of products that a manufacturer makes leads him to invest in changing product designs so as to increase the commonality of parts used across different products (eg, different car models based on same "platform"). The practice is not new, and has been practiced by companies like GM for decades.[11] However, this trend becomes important when it takes place in those parts that the manufacturers had previously outsourced, for then, opportunities arise for the suppliers of those parts to standardize their components to the point where these are used in products of most of the downstream manufacturers. Economies of scale, high profits, and accelerated research and development – as mentioned above – may then make these suppliers dominant. Moreover, standardized designs make intermediate markets more feasible, and thus final assembly and customization easier — facilitating entry into the downstream market.

To summarize, we have argued in this chapter that a focus on efficiency as the sole determinant of coordination incentives among firms along a supply chain or channel ignores many other important dimensions that influence inter-organizational relations and the incentives to cooperate.

In the subsequent chapters, we will take a look at another instance of the interplay between incentives for cooperation and emergence of alternative structures, in the context of research

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[10] Most North American manufacturers started, in the 1980s, eliminating the practice of allowing a customer to go to a dealer and specify a car with a particular set of options [Womack et al., 1990]. Manufacturers found they could not cope with the schedule disruptions and cost disadvantages of handling custom orders.

[11] for example, in late 1960s, GM was offering four different models from different divisions in which "everything tucked out of sight was exactly the same" [Womack et al., 1990, p.106].

joint ventures as a response to imperfectly appropriable research and development. The topic has gained tremendous attention over the last few years, and is an important one for both the government policy implications that it entails, as well as for our line of argument that coordination incentives can arise for a variety of reasons, that institutional arrangements develop to properly align such incentives, and that market structures, government policies as well as actions of firms in one industry affect market structures in related upstream and downstream industries.

6. HORIZONTAL R&D COOPERATION: RESEARCH JOINT VENTURES

Over the last couple of decades, there has been a surge of agreements among rival firms across various industries in the United States to jointly conduct research and development. While the Sherman Antitrust Act of 1890 made it illegal for rival business firms to collaborate to pursue their collective interests, cooperation in research activities has continued to exist in various forms. Predominant among such cooperative industry efforts were various kinds of trade associations (eg, Portland Cement Association) that conducted noncompetitive technical activities with modest budgets [Fusfeld and Haklisch, 1985]; research institutes in the regulated sectors, such as gas, electric power, and telecommunications (eg, Electric Power Research Institute) that were formed to deal with regulatory threats and facilitate technology transfer among members [Evan and Olk, 1990]; and, research centers formed as a result of collaboration between universities and industry, that tended to focus more on development of basic research. However, at the heart of debate today is the involvement of direct product-market competitors in cooperative research and development efforts that are aimed towards the applied end of the R&D spectrum, and that serve a more strategic role in enhancing the international competitiveness of member organizations. It is this shift in emphasis from noncompetitive, basic research to "precompetitive", applied research that underlies the heated debates on antitrust implications of such R&D consortia, and the role of government in shaping an appropriate industrial policy, especially in the wake of supposed threats to US technological dominance from an increasingly intense foreign competition. Semiconductor Research Corp. (SRC), and the Microelectronics and Computer Technology Corp. (MCC) were among the first of such consortia that came up in the early 1980s. The passage of National Cooperative Research Act (NCRA) in 1984 that limits the antitrust exposure of firms involved, resulted in a large number of firms participating in research joint ventures; by 1992, over 250 such consortia had registered with the U.S government under the Act[1]. The number of such consortia is increasing in Europe as well, and Japan has long had a history of successful RJVs[2] — often led by Ministry of International Trade and Industry (MITI). All this activity has led many researchers to examine the phenomenon more closely, and a wealth of opinions and models has been built up addressing a range of questions regarding the underlying reasons for the proliferation of RJVs, as well as their benefits and costs. Though empirical analyses have been lacking, a small number of case studies on a few successful (and not-so-successful) RJVs fairly complements the analytical treatment and opens up further questions.

We begin in the next section with a brief characterization of RJVs, and follow it up in the subsequent section with a discussion of various arguments that have been put forth in favor of RJVs. In section 6.3, we present one class of models analyzing the effects of R&D cooperation, and summarize the underlying assumptions as well as the insights gained from these models. We close by discussing some of the policy implications of this debate.

6.1. The Nature of Research Joint Ventures

The term "Research Joint Venture" refers to an interorganizational arrangement whereby individual firms — generally, direct competitors in an industry — coordinate their research efforts with a view to strengthen their technological base, and speed up the process of new product or

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[1] U.S. government is also encouraging cooperative R&D agreements between government laboratories and industry. In 1986, the Federal Technology Transfer Act was passed; this act encourages technology transfer by granting intellectual property rights in advance to private sector collaborators, through Cooperative Research and Development Agreements (CRADAs). Before this act, there was no exclusive licensing of any patent belonging to the Federal Government [Maital, 1991]. Now, more than 500 CRADAs exist between federal labs and the industry.

[2] We will use the terms Research Joint Ventures (RJVs), R&D Consortia, and Cooperative R&D Ventures interchangeably.

process innovations that would increase the product market competitiveness of all the participating firms. It involves pooling of resources in the form of capital, people, technology and other assets by the member firms; however, in contrast to joint ventures, it does not involve an equity ownership. Moreover, RJVs generally involve a large number of participants whereas most joint ventures are limited to two or three firms. The operating budget of an RJV is usually smaller, its potential output more uncertain, and its goals less focussed than a joint venture.

RJVs also differ from Industry/University Cooperative Research Centers (IUCRCs), developed on the initiative of National Science Foundation. IUCRCs generally receive federal funding to leverage industry contributions, and are typically initiated by universities who retain substantial input into center's operations. Typically, their primary goal is to "... expand general-knowledge research than to develop patentable or commercialized products" [Evan and Olk, 1990]. Most RJVs on the other hand do not receive federal funding[3], and the member firms retain substantial control over the research.

There is a wide variety of RJVs in terms of the organizational arrangements, level of funding and the use of facilities. Two broad types of RJVs by structure include: research corporations as a freestanding body with their own facilities (eg, MCC); and, an administrative body that coordinates research conducted either at the member firms' own facilities or at a university (eg, Semiconductor Research Corp, Plastics Recycling Foundation) [Evan and Olk, 1990]. RJVs also vary widely in terms of number of members, from as small as 2 to 92 (eg, National Center for Manufacturing Sciences); and, the level of funding ranges from an annual budget of $160,000 (Management of Advanced Automation Technology Center at WPI, 1983 figures) to $878 million (Bellcore, 1983 figures) [Fusfeld and Haklisch, 1985]. RJVs employ a

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[3] However, there are certain exceptions such as SEMATECH, whose 200 million-a-year operating cost is shared equally by the 11 member firms (who together account for more than 75 percent of the US semiconductor manufacturing capacity) and the US Department of Defence. However, the main focus of SEMATECH has shifted from horizontal collaboration among member firms to jointly develop and improve their process technology, to the improvement of vertical relationships between semiconductor manufacturers and equipment suppliers [Spencer and Grindley, 1993]. The issue of federal subsidies for industrial cooperative research is currently a debatable one (eg, see Cohen, 1994), and is outside the scope of this paper.

range of agreements in terms of member firms' contributions (eg, initiation fee and/or annual contribution); level of involvement in various research projects (across-the-board or on a select project basis); access to RJV's R&D output (unrestricted access or based on contribution level); division of revenues from licensing; inputs in managerial decision making and setting the research agenda; hiring personnel from member firms or outside; and, dealing with membership turnover.

6.2. The Need for Cooperation

Various authors have argued for the increased need and inevitability of allowing cooperative research agreements among firms in many industries, especially the high-tech industries.[4] We divide the various justifications put forth along the following four major categories[5]:

1. Gap between private and social returns from R&D
2. RJVs as a new institutional form
3. Threat of foreign competition and declining national competitiveness
4. Cost and risk sharing

A brief discussion of each category follows.

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[4] The notion of "high-tech" seems to be widely prevalent, though a precise definition is hardly ever agreed to. There does, however, seem to be a broad consensus that the following industries are considered high-tech: computers, semiconductors, telecommunications, and bio-technology [Patrick, 1986]. An essential feature of a high-tech industry, that sets it apart from a "smokestack" industry is the potential for technological change [Okimoto, 1989, p.58]; or in other words, "...its great reliance on the application of new science-based technologies to products or production processes" [Patrick, 1986]. For our purposes, useful quantitative indicators of a high-tech industry include a high ratio of R&D expenditures to sales, and a high proportion of new products in total sales.

[5] These categories do not entail distinct and mutually exclusive arguments; rather, the arguments are somewhat related, and proponents of horizontal cooperation generally put forth a combination of these arguments. Such a classification, however, serves to highlight the underlying reasoning behind these arguments.

6.2.1. The Incentive Gap

In the US, traditionally, competition policy has relied on market forces to generate enough incentives for the firms to conduct R&D to devise new products, or to improve the production process that would allow the firm to produce the existing products at a lower cost. A large body of literature has addressed the question whether the resulting investment in R&D is optimal from a social point of view, as an individual firm engaged in R&D ignores the externalities conferred on other firms and on the consumers. While it is possible to construct examples where the firms may collectively invest too much in R&D (e.g., Dasgupta and Stiglitz, 1980[6]), empirical studies from various industries have found that the societal benefits from R&D may be far greater than the private incentives to the firms (e.g., Mansfield et al., 1977; Bernstein and Nadiri, 1988). Some possible reasons for the divergence between social and private incentives for R&D are discussed below:

A) *Technological spillovers*: One of the primary reasons for the incentives gap that is most widely recognized is the issue of involuntary spillovers. Rival firms may be able to benefit from the R&D efforts of the innovating firm without purchasing the right to use the R&D output of the firm.[7]. To the extent that such spillovers strengthen the competitors, a firm's incentive to conduct R&D are lowered the stronger the spillovers [Katz, 1986; Katz and Ordover, 1990; Spence, 1984]. However, in an empirical investigation, Levin (1988) finds that in certain situations, spillovers may actually encourage more R&D investment, to the extent that such spillovers complement a firm's own investment in R&D.[8]

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[6] In their analysis, though each firm invests less than the socially optimal level, market equilibrium sustains a large number of firms, leading to excessive duplication.

[7] Some of the methods through which these spillovers may occur include patent disclosures, publications or technical meetings, conversations with employees of the innovating firm, hiring employees of the innovating firm, and reverse engineering of the product [Levin, 1988].

[8] Levin finds high degree of technological intensity in industries such as computers, communication equipment and electronic components, that ranked the highest in terms of intra-industry spillovers. A possible explanation offered by Levin is based on distinction between industries characterized by "discrete" vs "cumulative" technological advance — in the latter case, current innovations generally form the "building blocks" for future innovations,

B) *Appropriability*: A firm that innovates successfully may want to generate revenues by licensing its R&D results to other firms, given the low cost of dissemination of knowledge as opposed to its generation [Katz, 1986].[9] However, in absence of strong intellectual property rights, a firm may not be able to appropriate all the surplus generated by the use of its R&D results; and, a high level of technological spillovers may limit the bargaining power of the innovating firm in selling or licensing its results. Moreover, the innovator's inability to price discriminate perfectly, as well as the problems of opportunism and asymmetric information may lead to insufficient appropriability of surplus to the innovator, even when strong property rights are enforced [Katz, 1986; Katz and Ordover, 1990]. Thus, lack of full appropriability of R&D results may lower the incentives of a firm to invest in R&D.

Comment: Cockburn and Griliches (1988) empirically demonstrate that markets also recognize the effects of insufficient appropriability; market valuations of similar R&D moves may have different payoffs in different appropriability environments. The lack of full appropriability of R&D as a result of spillovers takes a central role in the "new" endogenous growth theories as well. These theories try to postulate the relation between economic growth and endogenous technological change, when there are externalities associated with development of technical knowledge. It is usually assumed that the benefits of an innovation can be partly appropriated by the innovator (which provides an incentive to innovate), but another part takes the form of spillovers that can be used by the competitors. The conclusions regarding equilibrium vs optimal growth rates of an economy then depend on the way endogenization of technical change is accomplished in models. In one class of models (eg, Aghion and Howitt, 1992; also see OECD, 1991), a distinct research sector is envisaged that produces two types of goods: blueprints

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and, therefore, R&D spillovers from other firms may raise the marginal product of a firm's own R&D.

[9] If the innovating firm is unable to exploit the results of its own R&D, the incentives to license to other firms are clear. However, if the innovator also has the production capability to exploit the results of its R&D, licensing to its rivals may lead to tough competition and lower industry profits [Tirole, 1988]. Nevertheless, Tirole argues that motivations to license may come from "soft product-market competition" (due to product differentiation, capacity constraints, nonoverlapping geographical markets etc.) and other product-market incentives (eg, when cross-licensing may guarantee ex-post the quality of the licensor's products).

for production of new goods (completely appropriable), and a general technological knowledge (that directly flows to other producers). The equilibrium rate of investment in innovation is then determined from a trade-off between a positive externality (due to the effect that an innovation lowers production costs beyond the current period), and a negative externality (due to Schumpeterian "creative destruction") .

C) *Complementary products or services*: To the extent that the production and/or use of new or cheaper products depends on access to certain complementary products or services (e.g., development of software applications for a new operating system), the benefits of a firm's successful R&D accrue in part to the owners of such complementary resources, which do not figure in a firm's private incentives [Katz and Ordover, 1990].

All these factors combine to create a divergence between private and social incentives to conduct R&D. Several mechanisms have been considered to correct these market failures; the most important ones among them are the following:[10],[11]

a) *Subsidies*: A large body of literature exists on the effects of subsidies to private firms in order to restore incentives to conduct R&D. While some have argued that subsidies can be an effective public policy in markets where spillovers are high [Spence, 1984][12], others have listed serious shortcomings of this approach [Katz, 1986], such as monitoring problems and problems associated with raising the necessary subsidy revenues. We will eschew this debate in this thesis.

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[10] It should be noted that while discussing the effectiveness of these mechanisms in restoring incentives, other concerns, such as efficiency of the R&D process and dissemination of R&D results, inevitably come up in the analysis. Consequently, policy recommendations and conclusions of the authors can differ depending on where they place more emphasis.

[11] A detailed discussion of the first two mechanisms is beyond the scope of this paper, as their relative merits and pitfalls in correcting the market failures have been the subjects of long-standing debates. We mention them here for the sake of completeness.

[12] Spence's basic argument is that the output of the R&D process has the character of a public good, and therefore, should be priced at its marginal cost, ie, zero. As such, private firms have inadequate incentives to supply it, and making other firms pay more than the marginal cost of R&D output is inefficient. Therefore, the best solution is to subsidize the private supplier, thus restoring incentives while ensuring wide dissemination through spillovers at near-zero prices.

b) *Strengthening Intellectual Property Rights*: The effects of providing strong property rights and enforcing patent protection on incentives, efficiency and costs of R&D have also been extensively examined. Stronger patent protection can reduce spillovers and restore appropriability, thus restoring ex-ante incentives of a firm to invest in R&D by strengthening the ex-post bargaining position of the innovator (other firms cannot then rely on spillovers alone to gain access to new technology) and making licensing more profitable.[13] However, it could also lead to monopoly power, insufficient dissemination of R&D [Arrow, 1962], wasteful duplication and excessive levels of R&D, and high industrial costs of achieving a given level of R&D results [Spence, 1984]. Moreover, stronger property rights may reduce incentives for other firms to invest in the development of successive or complementary products or services [Katz and Ordover, 1990; Scotchmer, 1991]. Thus, there is a trade-off involved in restoring private incentives through stronger patent protection, and the resulting effects on efficiency and dissemination of R&D.

c) *Ex-ante Cooperation*: The third mechanism to correct market failures is ex-ante cooperation in the form of research joint ventures. It has been argued that such a mechanism can serve to internalize the externalities created by technological spillovers, by having the participants in the cooperative venture commit to payments before R&D is conducted. Moreover, by involving a large number of participants in the R&D process, ex-ante cooperation facilitates wider dissemination of R&D results; and it increases the efficiency of R&D efforts by reducing the cost of investment for each firm and eliminating wasteful duplication of research [Katz, 1986; Katz and Ordover, 1990]. We will examine the validity of such claims, as well as the potential pitfalls from such ex-ante cooperation, in detail in the following pages.

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[13] Thus, on one hand, a firm's incentives to license a new technology to its rivals may increase due to higher expected profitability. On the other hand, however, concerns about strengthening the competition (as mentioned before) may be heightened as well, for it is precisely in highly-appropriable environments where a firm can expect to gain a substantial market share away from its rivals due to a new technology.

6.2.2. RJVs as a new Institutional Form

Many authors have carried the basic arguments concerning the underlying reasons for divergence between social and private incentives to conduct R&D (presented in the previous section) a step forward, by arguing for an explicit acceptance of the intrinsic "leaky property" nature of R&D output, and devising appropriate institutional arrangements for creation of such a property to properly match the incentives. Arrow had argued a long time ago that "... no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information" [Arrow, 1962]. He attributed the inevitability of leakages in technological knowledge to the mobility of personnel among firms as well to the embodiment of knowledge in products.[14] Recognition of this aspect of technological knowledge is very important in understanding the effects of stricter enforcement of intellectual property rights, as well as the policy implications on designing alternative institutional frameworks that would naturally be suitable for generation of, and as claimants of ownership rights to, this "leaky property". Ouchi and Bolton (1988) distinguish between three types of intellectual property — private, leaky, and public — based on the difference in appropriability, and argue that the institutional form best suited to create each type of property is that whose incentives match the pattern of incentives necessary to create that particular type of property. Thus, private firms can be relied on to undertake socially desirable levels of R&D if the property generated is private (i.e., fully appropriable). Likewise, generation of public knowledge is best entrusted to universities or government laboratories. However, entrusting the creation of leaky property solely to private firms would lead to a mismatch of incentives since such property, by definition, cannot be fully appropriated. Many authors have argued that prohibition of intra-industry groups — including research joint ventures, strategic alliances, and other forms of horizontal cooperation — has been one of the fundamental reasons that U.S. has lagged behind Japan and Europe in creation and commercialization of new technology [Dertouzos, Lester and Solow, 1989; Jorde and Teece, 1990; Ouchi

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[14] In a survey by Levin (1988), "hiring employees of the innovating firm" and "reverse engineering of product" were rated as highly effective means of acquiring technical knowledge of process and product innovations developed by a competitor.

and Bolton, 1988]. It has been argued that Antitrust regulations in the US have traditionally restricted the development of such horizontal linkages which may be a precondition to a number of successful innovation programs, particularly in the high technology sector where increasing complexity and costs of research programs makes it extremely difficult for even the biggest firms to undertake R&D alone[15]. This effect is more pronounced the more fragmented an industry is. Thus, the lack of resources together with inadequate incentives make the individual firms less likely to undertake socially optimal levels of R&D. This is the basis for arguments in favor of allowing intra-industry horizontal linkages in research and development; that is, consideration of such linkages as the most appropriate institutional form for development of leaky property, and for ownership rights to the same.

Moreover, horizontal linkages also provide a more effective governance alternative than the price mechanisms of the market or the administrative processes (ie, hierarchy) within the firm. Various forms of market imperfections (e.g., because of ignorance of the firms "... with respect to their competitors' future actions, preferences, states of technological information") make the pricing system much less effective in providing adequate levels of coordination needed for successful innovations [Koopmans, 1957, quoted in Jorde and Teece, 1990]. On the other hand, problems of excessive bureaucracy, inertia, and rising management costs of coordination and control limit the effectiveness of administrative processes within a firm. Private agreements between firms in an industry can achieve the "... benefits of less hierarchical structures ... without incurring the disadvantages of insufficient scale and scope" [Jorde and Teece, 1990]. However, a detailed investigation of coordination and monitoring mechanisms employed by such linkages has been lacking.

6.2.3. Threat of Foreign Competition

The most forceful (and, one might add, rhetorical) arguments for allowing broad horizontal co-operation among firms come from those raising the spectre of "... all these foreign governments...

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[15] we will discuss these arguments in detail in the next two sections; the government policy issues and antitrust implications are discussed in section 6.6.

doing these terrible things, and American firms cannot possibly compete because the antitrust laws hold them back" [c.f. Fisher's comments on Katz and Ordover, 1990]. The widespread concern over declining competitiveness of American firms in the international markets, especially the increasing dominance of high-tech sectors by Japanese firms, has led to an unprecedented search for potential causes — the answers have ranged from macroeconomic factors such as low cost of capital, to better expertise in managing production operations, to active government involvement in shaping and supporting the industries.[16] We will focus here on the last of these arguments. The Japanese Ministry of International Trade and Industry (MITI) has been widely credited for earmarking the important R&D projects, bringing together competitors, and guiding these joint efforts in research with a view to dominate the international high-tech markets. These joint ventures often involve government subsidies and de facto exemption from antitrust concerns. The virtual exclusion of the implications of Japanese antitrust laws – a legacy of the American occupation[17] – is often justified by nationalistic appeals to the necessity of having "... rapidly growing and internationally competitive high-tech industries, even at the cost of courting anticompetitive behavior" [Yamamura, 1986]. The high rate of success of these ventures, and the resulting fierce competitiveness of Japanese firms in the international markets, has led many US observers to argue for similar joint industry efforts in the US also. Additional justification

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[16] "Partly, it [The loss of US leadership in science and technology] has resulted from a targeting strategy where foreign nations have mounted subsidized government/industry collaboration efforts to capture share in the global marketplace" [D. Bruce Merrifield, Department of Commerce, quoted in Radtke and Ponikvar, 1986].

[17] Scherer (1994) notes that in pre-World War II Japan, unfettered competition was viewed as unstable, and government intervention was welcome to mitigate the effects of excessive competition; leading, in many instances, to the creation of "zaibatsu" (large family groupings; literally, money cliques). After the War victory, the US sought to transplant its own competition policy to Japan, through enactment of the 1947 Antimonopoly law and a program to dissolve the zaibatsu. The law was weakened after the end of US occupation, and carried the stigma of being foreign-imposed, "... to suppress the economy of Japan so that it could not recover and grow" [Scherer, 1994]. Yamamura (1986) discusses a few recent MITI-led joint research projects, as well as the relevant parts of the Antimonopoly act (including the 1977 amendments that supposedly strengthened the act). He notes that insurmountable hurdles exist in the way of Fair Trade Commission (the enforcing agency) if it wants to pursue an antitrust investigation against any MITI-led project.

for these arguments comes from a relatively high number of such ventures in Europe as well. "It is always useful to wave the Rising Sun... "! [Fisher, comments on Katz and Ordover, 1990].

6.2.4. Cost and Risk Sharing

The final argument used in justification of joint R&D, as alluded to before, is the increasing complexity, risk and capital intensiveness of the R&D process that makes it outside the scope of any individual firm's resources to carry out R&D alone. The issues of risk and complexity are related to the knowledge intensive nature of high-tech markets where successful R&D requires coordinating actions of a variety of stakeholders (including those having access to inputs; complementary processes and technologies; as well as distributors, retailers and other downstream firms that are closer to the customer). That R&D process also tends to be highly capital intensive in these sectors is a widely accepted theme (though clear empirical demonstrations are not easily available) — some indirect evidence for this claim comes from the high R&D-to-sales ratio of firms in high-tech sectors compared to conventional industries (eg, see Link and Tassey, 1987), and high level of spending by governments and consortia on such R&D projects (for example, total funding for only the software projects in Japan between 1966 and 1991 was in excess of 175 billion yen – see Sinha and Cusumano, 1991).

6.3. Models: Spillovers and Research Joint Ventures

A large number of models have been proposed to explore the various effects of RJVs as discussed in the previous section. The questions that are primarily addressed through these models can be listed as follows:

(1) Do RJVs restore the divergence between social and private incentives to conduct R&D? (Or, equivalently, do RJVs provide a natural institutional arrangement for the creation of knowledge, ie, natural claimants of ownership rights to a leaky property)?

(2) How do RJVs affect the efficiency of the R&D process?

(3) Do RJVs aid or restrict the dissemination of R&D results?

(4) Issues for government policy:

a) Should antitrust regulations be relaxed for RJVs?

b) Should government subsidize RJVs?

Below we will present one class of models that can be used to answer some of these questions. In these models, it is assumed that:

1. There can be only one RJV in an industry. Moreover, if an RJV forms, it includes all the firms in that industry.
2. All firms in the industry are single-product firms (producing either homogenous or differentiated products).
3. Firms engage in R&D that leads to reduction in cost of production.

The effect of RJV formation in an industry on the incentives of each firm to invest in R&D is captured through the change in the (expected) profit levels of individual firms. The R&D effort levels of firms are represented by R&D expenditures.[18] The basic question then is how do individual firm-profits as well as investments in R&D change when firms in an industry are allowed to cooperate in R&D. The dissemination effect is captured through the extent of cost reductions achieved in the industry, and related welfare effects provide guidance for government policy.

We consider a two-stage game, where n firms in an industry commit in the first stage to a certain level of R&D expenditure, and compete in the product market in the second stage.[19] Let $N = \{1, 2, \ldots, n\}$ be the set of n firms, each producing a single, differentiated good; $\tilde{q} = (q_1, q_2,, \ldots, q_n)$ and $\tilde{x} = (x_1, x_2,, \ldots, x_n)$ denote respectively the vector of output levels and R&D effort levels of the firms; $p_i \equiv p_i(\tilde{q})$ be the inverse demand func-

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[18] Cockburn and Griliches (1988) find that R&D expenditures may be a better measure of the R&D input of a firm than the patent counts are of the R&D output.

[19] This type of model was pioneered by d'Aspremont and Jacquemin (1988), and has been considerably extended since then. The presentation of the model here is based on Kamien et al. (1992), and Suzumara (1992).

tion facing firm i. The unit cost of production of firm i is represented by $c(x_i;\tilde{x}_{-i})$, where $\tilde{x}_{-i} \equiv [x_1, x_2, \ldots, x_{i-1}, x_{i+1}, \ldots, x_n]$.

Following assumptions are needed for what follows [Friedman, 1983; Okuguchi and Szidarovszky, 1990; Suzumura, 1992]:

Assumption 6.3.0.1. *For all $\tilde{q} \geq 0$ such that $p(\tilde{q}) > 0$,*
(i) $p_i(\tilde{q})$ is twice continuously differentiable with respect to q_i, as well as with respect to (q_i, q_j) for any $j \neq i$ such that $q_j > 0$.
(ii) $p_i^j < 0 \quad \forall j \in N$[20]

Assumption 6.3.0.2. *The average variable cost function $c(x_i;\tilde{x}_{-i})$ is twice continuously differentiable. Moreover, for any $\tilde{x} = (x_1, x_2,, \ldots, x_n) \geq \tilde{0}$:*
(i) $c(x_i;\tilde{x}_{-i}) > 0$; $(\partial/\partial x_i)c(x_i;\tilde{x}_{-i}) < 0$; and, $(\partial/\partial x_j)c(x_i;\tilde{x}_{-i}) \leq 0$.
(ii) $(\partial/\partial x_i)c(x_i;\tilde{x}_{-i}) \leq (\partial/\partial x_j)c(x_i;\tilde{x}_{-i})$ for any symmetric $\tilde{x}$.

Assumption 6.3.0.3. *The inverse demand function $p_i(\tilde{q})$ is concave in q_i, for all $i \in N$.*

Below we will consider four different models, depending on various alternative structures possible for organizing the R&D activity.

6.3.1. Model I:

In this model it is assumed that firms act noncooperatively in both stages of the game. That is, each firm in the industry independently and simultaneously decides on a level of R&D at the first stage, and subsequently, on level of output in the second stage. A subgame perfect equilibrium can be found by solving the game backwards. That is, we first solve for the Cournot-Nash equilibrium in outputs in the second stage, given an R&D profile $\tilde{x}$. The second stage profits of firm i, corresponding to an output vector $\tilde{q} = (q_1, q_2,, \ldots, q_n)$, can be written as:

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[20] p_i^j denotes the derivative of $p_i(\tilde{q})$ with respect to q_j.

$$\pi_i(\tilde{q}; x_i, \tilde{x}_{-i}) = p_i(\tilde{q})q_i - c(x_i, \tilde{x}_{-i})q_i - x_i \tag{6.1}$$

The equilibrium is determined by simultaneously solving

$$\max_{q_i} \ \pi_i(\tilde{q}; x_i, \tilde{x}_{-i}) \quad \forall i \in N$$

The first-order necessary conditions can be written as $(\partial/\partial q_i)\pi_i(\tilde{q}; x_i, \tilde{x}_{-i}) = 0, \forall i \in N$, or

$$\frac{\partial}{\partial q_i} p_i(\tilde{q}^N(\tilde{x}))q_i^N(\tilde{x}) + p_i(\tilde{q}^N(\tilde{x})) - c(x_i, \tilde{x}_{-i}) = 0 \tag{6.2}$$

Assuming interior optimum and second-order conditions, equation 6.2 characterizes the equilibrium output levels for a specified first-stage R&D level profile $\tilde{x}$, where $\tilde{q}^N(\tilde{x}) = (\tilde{q}_1^N(\tilde{x}), \ldots, \tilde{q}_n^N(\tilde{x}))$ denotes this equilibrium output vector. We consider only symmetric equilibria, that is, $q_i^N(\tilde{x}) = q_j^N(\tilde{x})$ if $x_i = x_j$, for all $i, j \in N$.[21]

Now, given the equilibrium output levels of the second stage, the profit function of firm i in the first stage can be written as $\pi_i^*(\tilde{x}) \equiv \pi_i(\tilde{q}^N(\tilde{x}); x_i, \tilde{x}_{-i})$. Assuming interior optimum and second-order conditions again, a symmetric Nash equilibrium of the first stage game can be characterized, by means of the first-order necessary conditions $(\partial/\partial x_i)(\pi_i^*(\tilde{x}))$, as follows:

$$\frac{\partial}{\partial x_i}\pi_i(\tilde{q}^N(\tilde{x}^N); x_i^N, \tilde{x}_{-i}^N) + \sum_{j=1}^{n} \frac{\partial}{\partial q_j}\pi_i(\tilde{q}^N(\tilde{x}^N); x_i^N, \tilde{x}_{-i}^N) \cdot \frac{\partial}{\partial x_i} q_j^N(\tilde{x}^N) = 0, \quad \forall i \in N \tag{6.3}$$

where $\tilde{x}^N = (\tilde{x}_1^N, \ldots, \tilde{x}_n^N)$ denotes the first-stage equilibrium R&D levels. Then, $\{\tilde{x}^N, \tilde{q}^N(\tilde{x}^N)\}$ is the subgame perfect Nash equilibrium of the two-stage game, because given $\tilde{x}^N$, $\tilde{q}^N(\tilde{x}^N)$ is the Cournot-Nash equilibrium of the second-stage game.

Special Cases

Below we derive three models analyzed in the literature as special cases of the model presented above. We will use these models later to derive some specific results on the effects of R&D

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[21] We assume that all firms produce actively in equilibrium (ie, $q_i^N > 0 \, \forall i \in N$).

spillovers and cooperation.

Case I: In the case of n firms producing a homogenous product, we can replace $p_i(\bar{q})$ above by $p(Q)$, $Q = \sum_{j=1}^{n} q_j$. Then, $(\partial/\partial q_i)p_i(\bar{q}) = (\partial/\partial q_j)p_i(\bar{q}) = p'(Q)$; the resulting model is exactly the one analyzed by Suzumura (1992).

Case II: We can also derive the model presented by Kamien et al. (1992), assuming a linear inverse demand function of the form $p_i(\bar{q}) = a - q_i - \gamma \sum_{j \neq i} q_j$, where $a > 0$ is the demand intercept, $0 \leq \gamma \leq 1$ is a *substitutability parameter* (ie, $\gamma = 0$ implies each firm is a monopoly in its respective market, and $\gamma = 1$ implies that goods are perfect substitutes). We can explicitly incorporate an R&D spillover parameter in the model as follows: assume that, prior to carrying out cost-reducing R&D, each firm has the same constant unit cost of production, c. The cost reduction realized by a firm i, as a result of R&D investments by all firms in the industry in the first stage, is represented by an R&D production function $f(X_i)$; X_i being the *effective* R&D investment of firm i, written as:

$$X_i = x_i + \beta \sum_{j \neq i} x_j$$

where β is a *spillover parameter* $(0 \leq \beta \leq 1)$, which represents a part of the R&D expenditures of firm j that benefits all firms $i \neq j$. That is, the second stage unit production cost of firm i is written as $c(x_i, \bar{x}_{-i}) = c_i = c - f(X_i)$ for all $i \in N$. Substituting these price and cost functions in our model above, we can write the FONC for the second-stage equilibrium (ie, condition (6.2)) as:

$$a - q_i - \gamma \sum_{j \neq i} q_j - c_i - q_i = 0 \tag{6.4}$$

which, after substituting for c_i and some algebraic manipulation, can be written as

$$q_i = \frac{a - c + f(X_i) - \frac{\gamma}{2-\gamma} \sum_{j \neq i} [f(X_j) - f(X_i)]}{2 + \gamma(n-1)} \tag{6.5}$$

as found by Kamien et al. (1992). The second stage equilibrium profits of firm i are:

$$\pi_i = (a - q_i - \gamma \sum_{j \neq i} q_j - c_i)q_i - x_i$$

which, using (6.4) can be written compactly as $\pi_i = q_i^2 - x_i$.

Similarly, the FONC for the first-stage equilibrium (ie, condition (6.3)) reduces to:

$$\frac{2q_i}{[2 + \gamma(n-1)][2-\gamma]}[(2 - 2\gamma + \gamma n)f'(X_i) - \beta\gamma \sum_{j \neq i} f'(X_j)] = 1$$

For symmetric equilibrium, we can write $X_i = X^N$. Then, substituting for q_i from (6.5) and simplifying, we get:

$$\frac{2[a - c + f(X^N)]f'(X^N)}{[2 + \gamma(n-1)]^2[2-\gamma]}[2 - \gamma + \gamma(n-1)(1-\beta)] = 1 \tag{6.6}$$

which is the equation determining the equilibrium effective R&D investment X^N, in agreement with the results obtained by Kamien et al. (1992). Existence and uniqueness of a solution to equation (6.6) are proved in Kamien et al. (1992).

Case III : Finally, we derive as a special case the original model proposed by d'Aspremont and Jacquemin (1988), that formed the basis of this class of models of R&D with spillovers and product market competition. Consider $n = 2$, both firms producing a single product; linear inverse demand function facing the industry, $p = a - bQ$ (where $Q = q_i + q_j$); and, linear cost function, $c_i = c - x_i - \beta x_j$ (q_i, x_i, and β as defined above). Diminishing returns to R&D expenditures can be incorporated by assuming a quadratic cost-of-R&D function: $\delta x_i^2/2$. Then, the second-stage profits of firm i can be written as

$$\pi_i = (a - bQ)q_i - [c - x_i - \beta x_j]q_i - \delta x_i^2/2$$

Therefore, in this case, condition 6.2 reduces to:

$$(a - c) - 2b(q_i) - b(q_j) + x_i + \beta x_j = 0, \quad i \neq j, i = 1, 2 \tag{6.7}$$

which can be solved to yield the Cournot-Nash equilibrium output levels:

$$q_i = \frac{(a-c) + x_i(2-\beta) + x_j(2\beta - 1)}{3b} \tag{6.8}$$

Substituting for the equilibrium output levels, the first-stage profits of firm i are obtained:

$$\pi_i^* = \frac{1}{9b}[(a-c) + x_i(2-\beta) + x_j(2\beta-1)]^2 - \delta\frac{x_i^2}{2}$$

And, the first order condition (equation 6.3) for the first-stage equilibrium in R&D levels reduces to:

$$\frac{2(2-\beta)}{9b}[(a-c) + x_i(2-\beta) + x_j(2\beta-1)] = \delta x_i \tag{6.9}$$

which, under the assumption of symmetric equilibrium, can be solved easily to give:

$$x^N = \frac{(a-c)(2-\beta)}{4.5b\delta - (2-\beta)(1+\beta)}, \quad i = 1,2 \tag{6.10}$$

in agreement with d'Aspremont and Jacquemin's (1988) results.[22]

Analysis

We will now investigate the effect of a change in first stage R&D efforts of a firm i on the equilibrium output level in the second stage of firm i as well as that of firm $j, j \neq i$, when firms act noncooperatively in both stages. Following Suzumura (1992), we define the following: $\zeta_i(\tilde{q}, \tilde{x}) = (\partial^2/\partial q_i^2)\pi_i(\tilde{q}; x_i, \tilde{x}_{-i}), i \in N$; $\eta_{ij}(\tilde{q}, \tilde{x}) = (\partial^2/\partial q_i \partial q_j)\pi_i(\tilde{q}; x_i, \tilde{x}_{-i}), i \neq j;\ i,j \in N$. Also, $\omega(\tilde{x}) = (\partial/\partial x_i)q_i^N(\tilde{x})$ and $\theta(\tilde{x}) = (\partial/\partial x_i)q_j^N(\tilde{x})$, for any symmetric R&D profile $\tilde{x} = (x_1, x_2, \ldots, x_n)$.[23]

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[22] Note that these results could also be obtained from Kamien et al's (1992) model discussed above, with $n = 2$, $\gamma = 1$, $f(X_i) = X_i = x_i + \beta x_j$.

[23] Note that for symmetric $\tilde{q}$ and $\tilde{x}$, $\omega(\tilde{x})$ and $\theta(\tilde{x})$, as well as $\zeta_i(\tilde{q}, \tilde{x})$ and $\eta_{ij}(\tilde{q}, \tilde{x})$ become independent of the firm indices i and j. For brevity, we write $\zeta(\tilde{x}) \equiv \zeta(\tilde{q}^N(\tilde{x}), \tilde{x})$; and $\eta(\tilde{x}) \equiv \eta(\tilde{q}^N(\tilde{x}), \tilde{x})$ corresponding to the second stage equilibrium output profile $\tilde{q}^N(\tilde{x}) = (q_1^N(\tilde{x}), \ldots, q_n^N(\tilde{x}))$.

Now, differentiating equation 6.2 (ie, the first-order condition characterizing the equilibrium output profile $\tilde{q}^N(\bar{x})$), with respect to x_i and collecting terms, we can write (recall that we look only at symmetric solutions):

$$\zeta(\bar{x})\omega(\bar{x}) + (n-1)\eta(\bar{x})\theta(\bar{x}) = \frac{\partial}{\partial x_i} c(x_i, \bar{x}_{-i}) \tag{6.11}$$

Similarly, differentiating (6.2) wrt $x_j, j \neq i$ and simplifying (using above notation and symmetry), we get:

$$\eta(\bar{x})\omega(\bar{x}) + [\zeta(\bar{x}) + (n-2)\eta(\bar{x})]\theta(\bar{x}) = \frac{\partial}{\partial x_j} c(x_i, \bar{x}_{-i}) \tag{6.12}$$

Solving equations 6.11 and 6.12, we get the following expressions:

$$\omega(\bar{x}) = \frac{1}{\Delta(\bar{x})}\{[\zeta(\bar{x}) - \eta(\bar{x})]\frac{\partial}{\partial x_i} c(x_i, \bar{x}_{-i}) + (n-1)\eta(\bar{x})[\frac{\partial}{\partial x_i} c(x_i, \bar{x}_{-i}) - \frac{\partial}{\partial x_j} c(x_i, \bar{x}_{-i})]\}, \tag{6.13}$$

$$\theta(\bar{x}) = \frac{1}{\Delta(\bar{x})}\{\zeta(\bar{x})[\frac{\partial}{\partial x_j} c(x_i, \bar{x}_{-i}) - \frac{\partial}{\partial x_i} c(x_i, \bar{x}_{-i})] + [\zeta(\bar{x}) - \eta(\bar{x})]\frac{\partial}{\partial x_i} c(x_i, \bar{x}_{-i})\} \tag{6.14}$$

where, $\Delta(\bar{x}) = [\zeta(\bar{x}) - \eta(\bar{x})][\zeta(\bar{x}) + (n-1)\eta(\bar{x})]$. These two equations characterize the influence of firm i's R&D level on the second-stage equilibrium output of firm i and firm $j, j \neq i$. That is, the sign of equation 6.13 (respectively, equation 6.14) indicates whether a change in first-stage R&D expenditure by a firm i raises or lowers the output of firm i (respectively, firm j) in the second-stage. To get some unambiguous results, we discuss these effects in the three special cases outlined before.

Case I: For the case of a homogenous product [Suzumura, 1992], we can write the inverse market demand function as $p(Q)$ (see page 101). Then, $\zeta(\bar{x}) - \eta(\bar{x}) = p'(Q^N(\bar{x}))$ which is < 0 by assumption. Also, since $\zeta(\bar{x}) < 0$, $\eta(\bar{x}) < 0$ (implied by assumptions 6.3.0.1 and 6.3.0.3), we have $\Delta(\bar{x}) > 0$. This, alongwith the assumptions (6.3.0.1) - (6.3.0.3), implies the following:

(a) From equation 6.13, $\omega(\tilde{x}) > 0$. That is, an increase in R&D level of a firm in the first stage increases the equilibrium output of that firm in the second stage.

(b) The sign of $\theta(\tilde{x})$ is more ambiguous. From equation 6.14, we see that the effect of an increase in firm i's R&D on firm j's output depends on the relative strength of two countervailing influences:

(i) spillover effect: a reduction in firm j's cost of production due to spillover of R&D benefits from firm i (that tends to raise firm j's output); and,

(ii) competitive effect: a reduction in firm i's cost of production due to its own R&D that makes it more competitive in the second-stage product market and, therefore, tends to decrease firm j's output (recall that firms engage in a Cournot competition in the second stage of the game).

If the spillovers are "small", then the second effect dominates; the cost reduction realized by firms $j \neq i$ due to R&D spillovers from firm i are not sufficient to counteract a decrease in their outputs and market share. On the other hand, if spillovers are "large", equilibrium outputs of all firms increase as the aggregate industry output increases due to cost reducing R&D by a firm i[24] and market shares of firms $j \neq i$ do not fall significantly. A threshold value for the spillovers can be determined from equation 6.14; spillovers are "large" if $\theta(\tilde{x}) > 0$ holds. At $\theta(\tilde{x}) = 0$, the two opposing effects just balance each other and the externality vanishes. Finally, note that in presence of no R&D spillovers (ie, $(\partial/\partial x_j)c(x_i, \tilde{x}_{-i}) = 0,\ i \neq j$), $\theta(\tilde{x}) < 0$; only the competitive effect exists.[25]

Case II: For the case of linear inverse demand and a concave R&D production function (see page 101), we can calculate $\Delta(\tilde{x}) = (2-\gamma)[2+\gamma(n-1)] > 0$ (because $\gamma < 1$)[26]. Therefore, from

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[24] Let $Q^N(\tilde{x}) = \sum_{j=1}^{n} q_j^N(\tilde{x})$ denote the equilibrium aggregate industry output. Then, $(\partial/\partial x_i)Q^N(\tilde{x}) = \omega(\tilde{x}) + (n-1)\theta(\tilde{x}), \forall i \in N$. Then, using above results, it is easy to see that $(\partial/\partial x_i)Q^N(\tilde{x}) > 0$ as long as $\theta(\tilde{x}) > 0$.

[25] All these results apply to our general case as well if we assume the following stability condition $(\partial^2/\partial q_i^2)\pi_i(\tilde{q}; x_i, \tilde{x}_{-i}) < (\partial^2/\partial q_i \partial q_j)\pi_i(\tilde{q}; x_i, \tilde{x}_{-i})$, or $\zeta(\tilde{x}) - \eta(\tilde{x}) < 0$.

[26] Note that here we get $(\partial/\partial x_i)c(x_i, \tilde{x}_{-i}) = -f'(X_i) < 0$ (because $f'(X) > 0$ by assumption); and, $(\partial/\partial x_j)c(x_i, \tilde{x}_{-i}) = -\beta.f'(X_i) < 0$. Also, since $0 \leq \beta \leq 1$, $(\partial/\partial x_i)c(x_i, \tilde{x}_{-i}) \leq (\partial/\partial x_j)c(x_i, \tilde{x}_{-i})$ as required by assumption 6.3.0.2

equations 6.13 and 6.14 respectively[27], we get

$$\omega(\tilde{x}) = \frac{(2-\gamma) + \gamma(n-1)(1-\beta)}{(2-\gamma)[2+\gamma(n-1)]} f'(X) \tag{6.15}$$

$$\theta(\tilde{x}) = \frac{2\beta - \gamma}{(2-\gamma)[2+\gamma(n-1)]} f'(X) \tag{6.16}$$

(6.15) implies $\omega(\tilde{x}) > 0$; that is, an increase in firm i's R&D level raises that firm's equilibrium output, as in case I. (6.16) implies that $\theta(\tilde{x}) > 0$ iff $\beta > \gamma/2$: firm i's R&D raises firm j's output if and only if spillovers are large enough in this sense (recall that γ is the substitutability parameter)[28]. For $\gamma = 0$, the above condition is trivially satisfied as long as $\beta > 0$; that is, as long as there are some R&D spillovers that reduce the unit production costs of all the firms, the equilibrium output of each firm increases as the negative externality of intensified competition in the second stage disappears (individual firms, being monopolists in their respective product markets, do not compete). For $\gamma = 1$ (perfect substitutes), the condition is most stringent ($\beta > 1/2$) as the product market competition is then most intense; a large enough spillover is needed to counteract the decline in market share of the higher cost firms.[29]

Case III: Finally, we derive d'Aspremont and Jacquemin's (1988) results from our analysis above (see page 102 for the model). With $n = 2$, equation 6.13 in this case becomes: $\omega(\tilde{x}) = \frac{2-\beta}{3b} > 0$.[30] Similarly, equation 6.14 yields $\theta(\tilde{x}) = \frac{2\beta-1}{3b}$. Hence, $\theta(\tilde{x}) > 0$ iff $\beta > 1/2$ (as also obtained in Case II above for homogenous products).

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[27] Since in this special case, we have closed form expressions available for the second stage equilibrium output levels, we can get equations 6.15 and 6.16 directly by differentiating equation 6.5 wrt x_i and $x_j, j \neq i$ respectively.

[28] This is essentially the same condition as obtained by Kamien et al. (1992) by a more direct method.

[29] One may take issue here with the implicit assumption (as is the case in Kamien et al's (1992) analysis as well) that R&D spillovers remain the same whether the products are perfect substitutes or not. Since technological spillovers are at the process level, degree of substitutability between products should not have much bearing on the level of spillovers; examples abound where R&D carried out in one industry is costlessly exploited by firms in a closely related industry. Nevertheless, it may be worthwhile to extend the analysis to incorporate the possibility of a β dependent on γ. Also see Chapter 7 on this issue.

[30] Note that $(\partial/\partial x_i)c(.) = -1$, $(\partial/\partial x_j)c(.) = -\beta > -1$; $\zeta(\tilde{x}) = -2b$, and $\eta(\tilde{x}) = -b$.

This completes the presentation of our first model where firms compete in both stages of the game. Next, we assume that firms form an RJV to conduct research at the first stage of the game; in the second stage, firms compete in the product market as before. There are two possible implications of RJV formation: "cost sharing" vs. "information sharing". We discuss three models, depending on whether the formation of RJV is assumed to result in sharing of the costs of R&D and/or results.

6.3.2. Model II.A: Cost Sharing

First, we assume that formation of RJV implies only that firms coordinate their R&D expenditures; however, the spillover rate is not affected ("R&D cartelization" in Kamien et al's (1992) terms). That is, firms decide on their R&D levels taking into account the effect on all other firms, but do not disclose the results of their R&D to other firms. Thus, each firm $i \in N$ determines its R&D level by solving

$$\max_{x_i} \sum_{j \in N} \pi_j^*(\tilde{x})$$

The first-stage equilibrium R&D profile $\tilde{x}^C = (\tilde{x}_1^C, \ldots, \tilde{x}_n^C)$ is determined by simultaneously solving $(\partial/\partial x_i) \sum_{j \in N} \pi_j^*(\tilde{x}^C) = 0 \ \ \forall i \in N$, or:

$$\frac{\partial}{\partial x_i}\pi_i^*(\tilde{x}^C) + \sum_{j \neq i} \frac{\partial}{\partial x_i}\pi_j^*(\tilde{x}^C) = 0, \quad \forall i \in N \tag{6.17}$$

Using first-order conditions for the second-stage equilibrium output profile (ie, $(\partial/\partial q_i)(\pi_i^*(.)) = 0$) and the assumption of symmetric equilibria, we can write this condition as:

$$\begin{aligned}
\tfrac{\partial}{\partial x_i} \textstyle\sum_{j \in N} \pi_j^*(\tilde{x}^C) &= [-q_i^N(\tilde{x}^C)\tfrac{\partial}{\partial x_i} c(x_i^C, \tilde{x}_{-i}^C) - 1] \\
&\quad +(n-1)[-q_j^N(\tilde{x}^C)\tfrac{\partial}{\partial x_j} c(x_i^C, \tilde{x}_{-i}^C)] \\
&\quad +(n-1)[q_i^N(\tilde{x}^C)\tfrac{\partial}{\partial q_j} p_i(\tilde{q}^N(\tilde{x}^C))\,\theta(\tilde{x}^C)] \\
&\quad +(n-1)[q_j^N(\tilde{x}^C)\tfrac{\partial}{\partial q_j} p_i(\tilde{q}^N(\tilde{x}^C))\,\left\{\omega(\tilde{x}^C) + (n-2)\theta(\tilde{x}^C)\right\}] \\
&= 0
\end{aligned}$$

where $\omega(\tilde{x}^C)$ and $\theta(\tilde{x}^C)$ are as defined before. Using $\psi(\tilde{x}^C) = \omega(\tilde{x}^C) + (n-1)\theta(\tilde{x}^C)$, and $q_i^N(\tilde{x}^C) = q_j^N(\tilde{x}^C)$ for a symmetric $\tilde{x}^C$, we get the following condition characterizing the equilibrium R&D investments in the first stage:

$$q_i^N(\tilde{x}^C)\{(n-1)\frac{\partial}{\partial q_j}p_i(\tilde{q}^N(\tilde{x}^C))\,\psi(\tilde{x}^C) - [\frac{\partial}{\partial x_i}c(x_i^C, \tilde{x}_{-i}^C) + (n-1)\frac{\partial}{\partial x_j}c(x_i^C, \tilde{x}_{-i}^C)]\} - 1 = 0 \quad (6.18)$$

Then, the subgame perfect Nash equilibrium of the two stage game in this case is given by $(\tilde{x}^C, \tilde{q}^N(\tilde{x}^C))$. We again analyze the three special cases below:

Case I: The homogenous products case is directly obtained from above by replacing $(\partial/\partial q_j)p_i(.)$ in equation 6.18 by $p'(.)$ (see Suzumura, 1992).

Case II: In this case we have, as before, $(\partial/\partial q_j)p_i(.) = -\gamma$, $(\partial/\partial x_i)c(.) = -f'(X)$, and $(\partial/\partial x_j)c(.) = -\beta f'(X)$. Also, using equations 6.15 and 6.16, we get $\psi(\tilde{x}^C) = \omega(\tilde{x}^C) + (n-1)\theta(\tilde{x}^C) = \frac{(2-\gamma)[1+(n-1)\beta]}{(2-\gamma)[2+\gamma(n-1)]}f'(X)$. Substituting for all these quantities, as well as for $q_i^N(\tilde{x}^C)$ for a symmetric $\tilde{x}^C$ from equation 6.5, into equation 6.18 we get:

$$\frac{2[a-c+f(X^C)]f'(X^C)}{[2+\gamma(n-1)]^2[2-\gamma]}\{(2-\gamma)[1+(n-1)\beta)]\} = 1 \quad (6.19)$$

which is precisely the equation determining the symmetric equilibrium R&D profile obtained by Kamien et al. (1992) for the case of "R&D Cartelization".

Case III: In this case, recall that we had $n = 2$, $(\partial/\partial x_i)c(.) = -1$, $(\partial/\partial x_j)c(.) = -\beta$, $(\partial/\partial q_j)p_i(.) = -b$, $\omega(\tilde{x}^C) = (2-\beta)/3b$, $\theta(\tilde{x}^C) = (2\beta-1)/3b$. Therefore, $\psi(\tilde{x}^C) = \omega(\tilde{x}^C) + (n-1)\theta(\tilde{x}^C) = 1/(3b)[(2-\beta)+(n-1)(2\beta-1)]$. Also, for a symmetric $\tilde{x}^C$ (ie, $x_i^C = x_j^C = x^C$), we get from equation 6.8: $q_i^C = [(a-A)+(\beta+1)x^C]/3b$. Substituting all these quantities in equation 6.18 and accounting for a quadratic R&D cost function[31], we get the following condition:

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[31] R&D expenditure δx^2 is netted out of the profit function, instead of x; partial derivatives wrt x are adjusted accordingly.

$$\frac{[(a-A)+(\beta+1)x^C]}{9b}2(\beta+1)=\delta x^C \tag{6.20}$$

which determines the equilibrium R&D levels of the firms. Equation 6.20 can be easily solved to yield:

$$x^C=\frac{[(a-A)(\beta+1)]}{4.5\beta\delta-(\beta+1)^2} \tag{6.21}$$

in accordance with d'Aspremont and Jacquemin's (1988) results.

Since the firms act non-cooperatively in the second-stage of the game, the equilibrium output profile in model (II. A) is determined as in model I. Also, since the spillover rate is assumed not to be affected by the formation of RJV, the effect of change in first-stage R&D level of firm i on the equilibrium output levels of firm i and firm j, $j \neq i$, (ie, sign of $\omega(\tilde{x})$ and $\theta(\tilde{x})$) remains the same as in model I.

6.3.3. Model II.B: Information Sharing

In this case it is assumed that firms do not coordinate their R&D expenditures, but the results of R&D are equally shared by all firms (one could think of a situation where firms carry out their R&D independently, but fully disclose the results to all members of the RJV — "RJV competition"). Therefore, each firm determines its R&D levels as in model I; the equilibrium R&D profile $\tilde{x}^{NJ}=(x_1^{NJ},\ldots,x_n^{NJ})$ being characterized by the first order condition given in (6.3), with the additional assumption that $(\partial/\partial x_i)c(x_i^{NJ},\tilde{x}_{-i}^{NJ})=(\partial/\partial x_j)c(x_i^{NJ},\tilde{x}_{-i}^{NJ})$.

Case I is similar to above. For cases II and III, we set $\beta=1$. The corresponding first-order conditions are then obtained from equation 6.6 and 6.9 respectively (setting $\beta=1$).

Now, substituting $(\partial/\partial x_i)c(.)=(\partial/\partial x_j)c(.)=c'(.)$ in equations 6.13 and 6.14, we get:

$$\omega(\tilde{x}^{NJ})=\theta(\tilde{x}^{NJ})=\frac{[\zeta(\tilde{x}^{NJ})-\eta(\tilde{x}^{NJ})]c'(\tilde{x}^{NJ})}{\Delta(\tilde{x}^{NJ})}=\frac{c'(\tilde{x}^{NJ})}{\zeta(\tilde{x}^{NJ})+(n-1)\eta(\tilde{x}^{NJ})}$$

For the case of homogenous products, we have $\zeta(\tilde{x}^{NJ})<0$, and $\eta(\tilde{x}^{NJ})<0$. Since $c'(.)<0$, we have $\omega(\tilde{x}^{NJ}) = \theta(\tilde{x}^{NJ}) > 0$. That is, in this case, an increase in firm i's R&D expenditure always leads to an increase in firm j's second stage equilibrium output, for all $j \in N$. Similar results are easily obtained for case II by setting $\beta = 1$ in equations 6.15 and 6.16. Same holds for case III.

6.3.4. Model III: Cost and Information Sharing

Finally, it is assumed that formation of an RJV by the firms leads to coordination of R&D expenditures as well as sharing of information ("RJV cartelization"). Therefore, the first stage equilibrium is determined by solving $\max_{x_i} \sum_{j \in N} \pi_j^*(\tilde{x})\ \forall i \in N$, as in model (II.A), with the additional assumption $(\partial/\partial x_i)c(x_i^{CJ}, \tilde{x}_{-i}^{CJ}) = (\partial/\partial x_j)c(x_i^{CJ}, \tilde{x}_{-i}^{CJ})$. Therefore, equation 6.18 yields:

$$q_i^N(\tilde{x}^{CJ})\{(n-1)\frac{\partial}{\partial q_j}p_i(\tilde{q}^N(\tilde{x}^{CJ}))\,\psi(\tilde{x}^{CJ}) - n\frac{\partial}{\partial x_i}c(x_i^{CJ}, \tilde{x}_{-i}^{CJ})\} - 1 = 0 \tag{6.22}$$

Derivation of special cases is also as before. Case I is similar to above. Put $\beta = 1$ in equation 6.19 for case II, and in equation 6.21 for case III. Sign of $\omega(\tilde{x})$ and $\theta(\tilde{x})$ is as obtained in model (II. B).

6.4. Comparison of Models

We now wish to compare various alternative arrangements as represented by the models in the previous section in terms of equilibrium R&D levels, prices and individual firm profits. We start with the following result for our Special Case II (page 101).

Proposition 10 (Kamien et al., 1992). *The equilibrium effective R&D investments,* X^l, $l = N, C, NJ, CJ$, *satisfy the following for all* β: $X^{CJ} \geq X^C \geq X^{NJ}$; *and,* $X^{CJ} \geq X^N \geq X^{NJ}$. *Moreover,* $X^C \geq X^N$ *holds iff* $\beta \geq \gamma/2$. *(see Kamien et al. (1992) for proof.)*

The above result can be partially extended in the context of our general model[32] as follows:

Proposition 11. *The equilibrium R&D levels satisfy the following relations for all levels of R&D spillovers:* $x^{CJ} \geq x^{C}$*; and,* $x^{N} \geq x^{NJ}$*. Moreover,* $x^{C} \geq x^{N}$ *if and only if the following condition holds:*

$$\frac{\partial}{\partial q_j} p_i(\tilde{q}^N(\tilde{x}^N))\,[\omega(\tilde{x}^N) + (n-2)\theta(\tilde{x}^N)] - \frac{\partial}{\partial x_j} c(x_i^N, \tilde{x}_{-i}^N) \geq 0 \tag{6.23}$$

Proof: *(see Appendix A)*

Note that condition 6.23 reduces to $(\beta \geq \gamma/2)$ in the special case II[33] (page 101) in accordance with Kamien et al's results; and to $(\beta \geq 1/2)$ in the special case III[34] (page 102) in accordance with d'Aspremont and Jacquemin's results.

An interpretation of (6.23) is that spillovers should be large enough so that cost reduction achieved by firm i as a result of firm j's R&D is larger in absolute value than the reduction in price faced by firm i as a result of a net increase in quantities produced by all the other firms, including firm j (see discussion on page 105). Of course, in presence of no spillovers (ie, $(\partial/\partial x_j)c(x_i^N, \tilde{x}_{-i}^N) = 0$), condition (6.23) reduces to (using 6.13 and 6.14):

$$\frac{\partial}{\partial q_j} p_i(\tilde{q}^N(\tilde{x}^N))\,\frac{1}{\Delta(\tilde{x}^N)}\zeta(\tilde{x}^N)\,\frac{\partial}{\partial x_i} c(x_i^N, \tilde{x}_{-i}^N) \geq 0$$

which is never satisfied as the left hand side of the above equation is always negative.

Therefore, proposition 11 implies that if spillovers are "large" in the sense that condition 6.23 holds, we get the following relation:

$$x^{CJ} \geq x^{C} \geq x^{N} \geq x^{NJ}$$

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[32] For all the results in this section, we impose the following assumption that guarantees stability of equilibria: $\zeta(\tilde{x}^N) - \eta(\tilde{x}^N) < 0$.

[33] Here, $(\partial/\partial q_j)p_i(.) = -\gamma$, $(\partial/\partial x_j)c(.) = -\beta f'(X)$; and, $\omega(\tilde{x}^N) + (n-2)\theta(\tilde{x}^N) = \frac{2(1-\beta)+\beta(n-1)(2-\gamma)}{(2-\gamma)[2+\gamma(n-1)]} f'(X)$.

[34] Here, we have $n = 2$; $(\partial/\partial x_j)c(.) = -\beta$, $(\partial/\partial q_j)p_i(.) = -b$, $\omega(\tilde{x}^N) = (2-\beta)/3b$, $\theta(\tilde{x}^N) = (2\beta - 1)/3b$.

Thus, R&D investments are largest in the case of RJV cartel (model III) and smallest in the case of RJV competition (model II.B). Intuitively, the perfect information sharing among all the firms without letting them coordinate their R&D expenditures (as is the case in model II.B) exposes the firms to a "free-rider" effect: when a firm expects to obtain a large cost reduction due to spillovers generated by other firms' R&D efforts, there is a tendency to cut down its own R&D investment levels. A joint determination of R&D levels along with full information sharing (as in model III) eliminates this effect and leads to highest levels of R&D investments. The superiority of R&D levels (x^C) in case of R&D cartelization (model II.A) over those in model I (x^N) is also explained by similar arguments – due to internalization of externalities created by large R&D spillovers (the free-rider effect in model I is smaller than in model II.B, as in the latter case, the rate of spillovers is internally set at the maximal level — hence the relation $x^N \geq x^{NJ}$). These remarks are in agreement with those by Suzumura (1992); Kamien et al. (1992); and, d'Aspremont and Jacquemin (1988).

Proposition 11 and assumption 6.3.0.2 imply the following (let Z^l represent the equilibrium *cost reduction* achieved under case l, $l = N, C, NJ, CJ$.)

Corollary 12. *The equilibrium cost reduction achieved by a firm satisfies the following relations for all levels of R&D spillovers:* $Z^{CJ} \geq Z^C$*; and,* $Z^N \geq Z^{NJ}$*. Moreover,* $Z^C \geq Z^N$ *iff condition (6.23) holds.*

Now, recall that in all the models above, the equilibrium quantities produced by each firm in the second stage of the game are determined from equation (6.2), for the corresponding specified R&D profile (ie, x^N, x^{NJ}, x^C, or x^{CJ}). Moreover, we had $\omega(\tilde{x}) = (\partial/\partial x_i)q_i^N(\tilde{x}) > 0$. Therefore, we have the following results:

Corollary 13. *The equilibrium output produced by each firm satisfies:* $q^N(\tilde{x}^{CJ}) \geq q^N(\tilde{x}^C)$*; and;* $q^N(\tilde{x}^N) \geq q^N(\tilde{x}^{NJ})$*. Moreover,* $q^N(\tilde{x}^C) \geq q^N(\tilde{x}^N)$ *iff condition (6.23) holds.*

The above corollary and assumption 6.3.0.1 imply the following (here, we represent the equilibrium prices as $P^l \equiv p_i(\tilde{q}^N(\tilde{x}^l))$; $l = N, C, NJ, CJ$):

Corollary 14. *The equilibrium prices satisfy:* $P^{CJ} \leq P^{C}$*; and,* $P^{N} \leq P^{NJ}$*. Moreover,* $P^{C} \leq P^{N}$ *iff condition (6.23) holds.*

Therefore, under condition (6.23), equilibrium prices obtained are the lowest under RJV cartelization (CJ) and the highest under RJV competition (NJ).

Now, to compare individual firm's profits under different scenarios, recall that profits of firm i under equilibrium conditions l (where $l = N, C, NJ, CJ$) are written as:

$$\pi_i(\tilde{q}^N(x^l); x_i^l, \tilde{x}_{-i}^l) = [p_i(\tilde{q}^N(x^l)) - c(x_i^l, \tilde{x}_{-i}^l)]q_i^N(x^l) - x_i^l \tag{6.24}$$

where $\tilde{q}^N(x^l)$ is determined from equation 6.2. Substituting equation 6.2 into equation 6.24, we can write the equilibrium firm profits as:

$$\pi_i(\tilde{q}^N(x^l); x_i^l, \tilde{x}_{-i}^l) = [-\frac{\partial}{\partial q_i}p_i(\tilde{q}^N(x^l))]\,[q_i^N(x^l)]^2 - x_i^l \tag{6.25}$$

Since we consider only symmetric solutions, let us denote equilibrium firm profits under different scenarios as Π^l, $l = N, C, NJ, CJ$. Then, we have the following result:

Proposition 15. *The equilibrium firm profits satisfy:* $\Pi^{CJ} \geq \Pi^{l}$*, for* $l = N, C, NJ$*. Moreover,* $\Pi^{C} \geq \Pi^{N}$.

These results are partial extensions of those obtained by Kamien et al. (1992) for a linear demand function, and are also generally in agreement with those obtained by Suzumura (1992) who employs a first-best as well as a second-best welfare criterion under homogenous products (Suzumura only considers the first two models). The results of d'Aspremont and Jacquemin (1988) can be obtained as a special case of any of these models.

6.5. Discussion

We see that, in general, this class of models supports the coordination of R&D expenditures by competitors in an industry if spillovers are large, as long as competition in downstream product markets is ensured. As seen from the results above, RJV cartelization (model III) yields the highest R&D levels, highest equilibrium per-firm profits and lowest equilibrium prices (thus highest consumer-plus-producer surplus). On the other hand, RJV competition (model II.B) fares the worst in terms of equilibrium prices and R&D levels. One may intuitively expect that wide sharing of information among firms regarding their R&D results will ensure wide dissemination of technical advances (that should lead to lower product prices), while competition in R&D expenditures will ensure industry R&D levels close to (or higher than) the social optimum. However, analyses such as above seem to point towards the importance of letting firms coordinate their R&D expenditures in presence of large R&D spillovers. The underlying reason for this apparently counter-intuitive result is, as seen above, the firms' tendency to free-ride on each other that drives R&D expenditures lower and outweighs the effect of wide dissemination of R&D results — the free-rider effect being stronger the larger the spillovers. Moreover, the analysis also bears out the importance of spillovers being large — in presence of no spillovers, cooperation tends to lower R&D levels.

Thus, formation of an RJV that allows firms to conduct R&D jointly and fully share the results overcomes both the problems of insufficient R&D levels and insufficient dissemination of R&D results.[35] However, these conclusions need to be qualified by the somewhat restrictive nature of assumptions imposed in the analysis. We now discuss a few of these assumptions:

1. *A Single Industry-wide RJV:* This is one of the most troublesome assumptions of most of the models of RJVs. Empirically, it seems rarely to be the case that an R&D joint venture would include all the firms in that industry (though the assumption of *one* RJV per industry seems to be less restrictive). Although many authors have commented on the need to address this issue, models of RJVs that include only a subset of the firms in an industry (or multiple rjvs in the same industry) have been lacking. Besides added realism, another important reason why such models are needed is that, in absence of spillovers, it seems to be a robust conclusion that research joint ventures (involving a subset of an industry's firms) tend to restrict the dissemination of

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[35] **Jacquemin (1988) makes a similar argument in that cooperative R&D alleviates the trade-off between incentives and dissemination (identified by Spence (1984) – see footnote 12).**

an innovation, and incentives to develop an innovation are weaker the larger is the joint venture [Reinganum, 1989]. How these conclusions are modified in the presence of involuntary spillovers remains to be seen.

2. *Single Product Firms:* Almost all the models of R&D cooperation developed so far assume firms producing only a single product, either homogenous or differentiated. However, it is an empirical fact that firms differentiate their own products by offering a diverse product line — the wide variety of breakfast cereals and toiletries produced by a handful of firms, dozens of different models offered by automobile as well as computer manufacturers are just a few examples. Indeed, a large part of the R&D expenditures of most firms is devoted to new product development – to match varied tastes of the consumers with the technological capabilities of the firm. Consumers may be willing to pay more for products that closely match their preferences. However, an increase in the product variety offered by a firm may also lead to an increase in production costs to the extent that economies of scale are present in production. In an operational sense, cost-reducing R&D efforts of a firm can be characterized as investments in setup cost reduction (ie, reduction in costs associated with changing over from producing one kind of product to another), that allows the firm to produce a wider variety of products. Then, one way of extending the above analysis is by means of a three stage game, where firms invest in R&D in the first stage, choose the number of different varieties of products to produce in the second stage, and compete in product markets in the third stage. Analysis of multiproduct firms in a Cournot oligopoly will also be useful in addressing the first limitation mentioned above of single industry-wide RJV.[36]

A related assumption employed in all the models above is the cost-reducing nature of R&D. Models have been proposed where firms carry out R&D to improve the quality of their products (vertical differentiation) instead of cost reduction — for example, Motta (1992) presents one such model and achieves results similar to those of d'Aspremont and Jacquemin (1988).

3. *Lack of Resource Complementarity:* Models discussed above assume that there are no syner-

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[36] The reason for this latter assertion is that "group equilibrium problem" where firms form disjoint coalitions – the objective of each firm being to maximize the profits of the coalition to which it belongs – can be reduced to the problem of determining the equilibrium of a multiproduct oligopoly game [Okuguchi and Szidarovszky, 1990].

gistic effects among firms cooperating in R&D. In reality, firms may differ in their R&D abilities, technical knowledge and experience, and research personnel. Indeed, it would seem that firms wish to cooperate in R&D when they can pool their diverse resources and abilities in solving problems of process and product innovations. One model addressing this issue has been proposed by Sinha and Cusumano (1991). Within the context of a homogenous goods industry and cost-reducing R&D, they assume an R&D project that requires a given (stochastic) investment, and at most one RJV in the industry. The results of R&D are stochastic (see below), and the probability of success of the RJV depends on the complementarity of resources among the RJV partners. The authors then analyze the managerial problem of deciding when would a firm choose to participate in the RJV, and conclude that, indeed, a firm will prefer to participate in the RJV if the complementarity of resources and skills of partners is high. Moreover, high complementarity also makes it preferable for the firms to cooperate in areas where technology is more appropriable — contrary to the results obtained by Katz (1986) (who considers only symmetric firms), and a widespread general perception that underlies the U.S. government policy encouraging cooperation only in basic research.

4. *Static Conditions and Certainty of R&D outcomes:* The models discussed above are in the form of a one-shot game where there is no uncertainty regarding the cost reductions achieved from R&D. Models that address the uncertain nature of technical advance as well as the timing of innovation have long existed (eg, see Reinganum, 1981, 1989). However, these models do not recognize the imperfect appropriability of R&D results. One model along the lines discussed in this chapter and that addresses the uncertainty issue is by Choi (1993) (also see Sinha and Cususmano, 1992 – discussed above). Choi assumes two firms in an industry, each of which can succeed or fail in obtaining a cost-reducing innovation. The probability of success of a firm depends on the amount spent on R&D. Moreover, it is assumed that the spillover rate increases with cooperation in R&D (as in our model III), and the total industry profit declines as the spillover rate increases due to intensified competition in the downstream product market. Under these conditions, Choi obtains results similar to those presented above — that is, firms have an incentive to cooperate if the spillover rate is above a certain threshold value. However, analysis

of dynamic conditions in presence of involuntary spillovers still seems to be lacking.

Some of the other factors that should be addressed in a comprehensive analysis of R&D cooperation include complementary products and cumulative R&D efforts [Scotchmer, 1991]; and, inter-industry spillovers (eg, benefits accruing to suppliers; Suzumura, 1992).

Dangers of R&D Cooperation:

We will now briefly mention some of the disadvantages and dangers that stem from allowing competing firms in an industry to cooperate on R&D. Foremost among them is the danger of extended collusion among R&D partners that could lead to market sharing and price fixing in the downstream product markets. This could happen for a variety of reasons. First, a cooperative venture provides an opportunity for firms to discuss their strategies and markets, thus making discussions on price fixing and market sharing more likely and harder to detect. Besides, it also provides a ready mechanism for side payments to redistribute revenues among the member firms [Jacquemin, 1988]. Second, a large body of literature addressing the process of innovation has stressed the need for extended cooperation among different departments of a firm (R&D, marketing, manufacturing etc) as well as along the supply chain (from suppliers to the manufacturer to retailer), in order to successfully manage a product or process innovation. Employing a similar argument, Jorde and Teece (1990) stress that conception of a "simultaneous" model of innovation (as opposed to a "serial" model, implicitly assumed in the separation of R&D and product-market stages in the models above) implies that firms cooperating in R&D should also be allowed to collaborate in commercialization of R&D. Thus, prohibition of horizontal collaboration in downstream activities such as manufacturing and marketing is asserted to lead to important losses in efficiency of the innovation process, difficulties in commercialization of new technology, and loss of valuable feedback from manufacturing activities and customers that is instrumental in developing successive generations of products and technology. Moreover, it is also argued that in the absence of an opportunity to jointly exploit downstream benefits of their cooperative R&D, the firms may expect such benefits to be quickly dissipated through intense product market competition, and therefore, will be tempted to use their cooperation to unduly limit their R&D, or to avoid R&D cooperation altogether [Jacquemin, 1988].[37] The challenge for any government in shaping an antitrust policy then is to demarcate the extent of such useful horizontal collaboration that will not stifle the innovation process itself, and at the same time, will ensure against cartelization of the industry and associated losses in consumer welfare. We briefly review the policy implications in the next section — however, a detailed discussion of this issue is beyond the scope of this thesis.

6.6. Policy Implications and Antitrust

We have seen the various arguments above that lead to policy recommendations for or against encouraging R&D cooperation. To recap, there seems to be enough evidence for the belief that strong antitrust policies pursued by the government, such as the Sherman Antitrust Act of 1890 in the US, that are aimed at preserving the market efficiency "... by making some kinds of cooperation criminal" [Telser, 1985] can sometimes distort the private returns to R&D investments [Katz and Ordover, 1990]. Many have argued that such is indeed the case in global high-technology markets that are characterized by high R&D costs, high risks and uncertainty. These factors make undertaking effective R&D for technological leadership in such sectors as semiconductors and telecommunications beyond the resources of any individual firm. Moreover, the prevalence of ineffective patent protection, ease of imitation and "inventing around" in such high-tech sectors makes private incentives to conduct R&D even more inadequate. Proponents of horizontal cooperation have also pointed to the aggressive government support of multi-firm consortia by Japan and some European countries as an important factor in gaining market share and technological leadership. While Japanese reliance on MITI's guiding hand seems to be too extreme to many, American belief in the efficiency of the markets is seen to be detrimental as well. In this vein, some observers perceive the European antitrust policies to be some sort of

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[37] Other potential dangers from R&D cooperation include a reduction in variety of R&D programs in the industry; possibility that a dominant firm could avoid competition by co-opting very innovative rivals, and controlling and slowing down the innovation race [Jacquemin, 1988; Reinganum, 1989]; creation of entry-barriers and market foreclosure for non-members (eg, by creating a technological standard for future products and processes), etc.

ideal middle-ground. For example, Jacquemin (1988) states that while Article 85 of the Treaty of Rome contains a broad prohibition of explicit and tacit collusion among firms that could distort competition, it explicitly recognizes some fundamental trade-offs in welfare economics. Thus, the law provides a more favorable treatment of cooperative R&D ventures as well of the "exploitation of results" (ie, manufacture of the joint venture product). However, it also contains guidelines to prevent agreements that might result in elimination of competition.

It is clear that the analytical results on the various effects of horizontal cooperation on social welfare, consumer prices, quantity of output produced, and amount of research undertaken are far less than conclusive. That is partly the reason for widely varying opinions on policy formulation on this issue — for example, Jorde and Teece (1988) argue, on one extreme, for the extension of rule-of-reason consideration and exemption from treble damages applicable under the antitrust laws to downstream cooperative ventures (such as production and marketing) under a procedure of registration and certification (National Cooperative Research Act of 1984 provides these benefits to research joint ventures). On the other extreme, authors such as Franklin Fisher (see Fisher's comments on Katz and Ordover, 1990) argue for a per se sceptical treatment of cooperative agreements unless conclusive evidence is presented: Fisher argues that there is no evidence at this stage for the supposed economies of scale or benefits of risk sharing associated with cooperative agreements; the fear of foreign competition is overhyped; and, while cooperation may lead to Pareto efficient outcomes for the firms, the society at large may suffer because of increased prices and/or reduced R&D. We have tried here to underscore the importance of this debate in today's knowledge intensive global markets, and discussed the basic issues involved in assessing the likely implications of horizontal cooperation. It is hoped that future work — not only theoretical analyses, but empirical work and case studies as well of the cooperative agreements in place across various industries — will serve to identify the appropriate industry conditions under which R&D and downstream cooperation could be beneficial to the society, and that should form the basis of any suitable government policy.

In light of our discussion in earlier chapters, it is somewhat surprising that numerous analyses of cooperative R&D that have come up in the last few years have ignored the implications of vertical relations among firms along the supply chain on horizontal cooperation incentives and vice versa. Government policies on the two aspects have also tended to focus on each in isolation: legislation granting exemptions from antitrust implications to manufacturers cooperating in R&D typically does not consider vertical relations, except by some authors (as discussed above) who argue for an extension of such exemptions to downstream functions such as production and marketing based on the arguments of the importance of feedback from such functions in the process of innovation itself. Our interest is instead to explicitly consider the incentives of manufacturers to engage in various horizontal and vertical arrangements when their process innovation efforts could potentially benefit their competitors, and when they have a choice between downstream integration, decentralization or other instruments of channel cooperation (discussed in chapter 5). We tackle this task in the next chapter.

7. RESEARCH JOINT VENTURES AND CHANNEL STRUCTURE: HORIZONTAL AND VERTICAL COORDINATION IN OLIGOPOLISTIC MARKETS

In the previous chapters, we examined the integration or coordination incentives of manufacturers along their supply chains for a given horizontal (competitive) context (chapters 4 and 5), as well as horizontal coordination incentives in presence of externalities such as R&D spillovers ignoring the vertical channel relations (chapter 6). In this chapter, we merge the two. As a first step towards investigating the effect of operational parameters (such as production costs) as well as the horizontal institutional arrangements in the upstream industry on the downstream channel structure, we outline a model incorporating both research joint ventures and forward integration. The basic model-structure we use is the same as that in chapter 4: a four-stage game, where players at each stage make their choices simultaneously and in full knowledge of the actions taken by all the players at previous stages. To recap, at the first stage, manufacturers decide whether to integrate or decentralize the downstream retailer function. Second stage decision variables are investments in cost-reducing R&D by the manufacturers; where the R&D decision is made independently or jointly by the manufacturers depending on the particular institutional arrangement that is assumed to exist in the industry (eg, 'R&D Competition' or 'RJV Cartel'; see below). At the third stage, manufacturers decide on the wholesale price they would charge their retailers; and, finally, retailers compete on prices in the market. However, we relax the assumption of perfect property rights enforcement of chapter 4. As discussed at length in the previous chapter, a lot of attention has recently been focused on measuring the extent of such involuntary spillovers of R&D benefits that exist across a range of industries, particularly the "high-tech" ones. A large number of models now exist that demonstrate the superiority of certain types of cooperative ventures for conducting R&D in presence of "leakages" over other institutional arrangements (in terms of industry R&D levels and product prices). Such results are almost always conditional on the level of spillovers being greater than a certain threshold value — in the absence of ex-ante cooperation in setting R&D levels, a high level of R&D spillovers exposes the firms to a free-rider effect thus lowering their incentives for investments in R&D. However, these models have generally ignored the possibility that R&D spillovers may induce different incentives for integrated and decentralized firms — that is, how much a manufacturer spends on R&D and what kind of institutional arrangement he finds profitable may be different depending on whether the manufacturer is integrated forward or not. Conversely, involuntary spillovers of the benefits of R&D conducted by one firm on the competitors, and allowing cooperation in R&D among manufacturers, may have important consequences for downstream channel structure, vertical coordination incentives and contractual practices, as well as consumer and social welfare. Given the prevalence of marketing middlemen (most manufacturers do indeed distribute their final products through one or more independent retailers), the lack of analyses addressing this issue is surprising, particularly so when government policy initiatives rely on such analyses. Our model here is a first attempt at filling that gap, and it brings together these two research streams. We outline the model and some preliminary results below.

7.1. Model Specification & Solution Procedure

The demand system and profit functions are as described in chapter 4, except that the unit production cost of manufacturer i is now taken to be

$$c_i = c - x_i - \gamma x_j, \quad j = 3 - i, i = 1, 2 \tag{7.1}$$

where γ is a spillover parameter, $0 \leq \gamma \leq 1$: $\gamma = 0$ implies no spillovers and $\gamma = 1$ implies that the results of R&D conducted by one manufacturer can be perfectly exploited by the rival manufacturer at no cost. As a result of this externality, manufacturers may have an incentive to coordinate their R&D efforts among themselves through formal or informal agreements such as the formation of a research joint venture. As discussed at length in Chapter 6, we can consider four types of institutional arrangements, depending upon whether the two manufacturers share the cost of R&D, the results of R&D, both, or none.

We will focus our discussion below on the effect of R&D spillovers when competing manufacturers act independently (ie, 'R&D Competition') and on the formation of a research joint venture that allows competitors to cooperate in setting their R&D levels (ie, 'R&D Cartel) – other arrangements are obtained as special cases of these (ie, assuming maximal spillovers). Please see Chapter 6 for a detailed discussion of these arrangements.

Two assumptions implicit in the above formulation require comments. First, we have kept the decision on whether or not to cooperate on setting R&D levels exogenous to the model, whereas all other decisions (including channel structure are endogenized). We have several reasons for doing so. First, our focus here is on comparing the effect of different horizontal coordination mechanisms on the vertical channel structure, prices, output levels, and R&D investments. We are not analyzing an individual manufacturer's decision whether to participate in a research joint venture or not. Although that itself is an interesting question to analyze, it requires a different model structure and assumptions[1], and is beyond the scope of our thesis. Second, exogenous R&D arrangements are entirely in agreement with our models in Chapter 6 and the bulk of the R&D literature discussed there. Third, formation of an RJV is usually not only a decision agreed upon by firms in an industry; external factors such as legal constraints and government subsidies substantially influence the formation as well as the organizational form the RJV takes (see Chapter 6). Fourth, with the possible exception of our assumption that

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[1] For example, while choosing which form of institutional arrangement to adopt for R&D cooperation, the manufacturers would have to simultaneously and non-cooperatively choose the same form for there to be a joint venture in the industry. Moreover, for an oligopoly with more than two manufacturers in the industry, we would also have to abandon the assumption that the RJV, if forms, includes all the firms in the industry – this assumption is utilized in this chapter as well as in Chapter 6.

there is a single, industry-wide RJV (also see Chapter 6), there is little loss in generality due to keeping the RJV decision exogenous. Thus, for the purpose at hand, we think the present formulation is the best possible alternative – it allows us to capture the effect of horizontal and vertical externalities on channel structure, and identify the interactions between these two dimensions of inter-organizational relations.

Second assumption implicit in our formulation is that the level of spillovers is not affected by the degree of substitutability between the competitors' products, as was the case also for models in Chapter 6 (see footnote 29). To reiterate our earlier argument, process knowledge and technical know-how can be transferred to manufacturing different products, not necessarily to immediate substitutes only. As numerous studies in benchmarking and 'best practices' indicate, firms routinely visit and imitate processes from other firms outside of their own industries. Examples include Xerox's and Chrysler's lessons from L.L. Bean's logistics and distribution system (Business Week, 1992), or more dramatically, attempts by a number of firms to learn from pit-stop teams at Formula 1 racing circuits to speed up the setup and changeover times in their factories. Second, low θ simply means that products do not directly compete in the same geographical market, even though they may be very similar. Nevertheless, we recognize that a more general model may explicitly analyze the dependence of spillovers on the degree of product substitutability.

7.1.1. Case I: R&D Competition

In this case, both firms simultaneously and non-cooperatively set their own R&D levels in the second stage game, maximizing their individual profits while taking into account the fourth stage decision rules of the retailers and third stage wholesale prices that the manufacturers will charge their own retailer. Thus, there is no formal R&D cooperation between the manufacturers, though there are some involuntary spillovers, the extent of which will be different in different industries. The first stage of the game involves manufacturers non-cooperatively deciding on the vertical channel structure to maximize their own profits. Due to simultaneous choice and symmetry of the model, there are three possible vertical structures as in Chapter 4. We solve for subsequent stages conditioning on a given channel structure. The subgame perfect equilibrium of the four-stage game is then determined as shown in Figure 4.1 (see page 47).

The solution procedure followed is similar to the one described in Chapter 4. The differences in the determination of second-stage equilibria in R&D levels are summarized below.

Pure Decentralized Structure

At second stage the first-order conditions are: $\frac{\partial \pi_i^M}{\partial x_i} = 0$, $i = 1, 2$, where π_i^M is given by equation 4.12, and c_i by equation 7.1, thus yielding[2]:

$$A'B[M-(1-\theta)bc] + [A'(D-\gamma E)b - \alpha]x_i + A'(\gamma D - E)bx_j = 0, \quad j = 3-i, i = 1,2 \qquad (7.2)$$

where A', B... etc are given in Table 7.1 below.

From 7.2 we get the reaction functions in R&D-level space as follows:

$$x_i = \frac{A'B[M-(1-\theta)bc] + A'b(\gamma D - E)x_j]}{[\alpha - bA'(D-\gamma E)]} \qquad (7.3)$$

Here we note that $A' \geq 0$ and $(D-\gamma E) \geq 0 \ \forall\theta$ and $\forall\gamma$; $\alpha - bA'(D-\gamma E) > 0$ as long as $b/\alpha < 8$ (as required by second order conditions). Moreover, the coefficient of x_j is negative as long as $\gamma < E/D$. Thus, under the condition:

$$\gamma < \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)} \qquad (7.4)$$

we have downward sloping reaction functions — that is, R&D-level decision variables are strategic substitutes as long as spillovers are not large in the sense that condition (7.4) is satisfied. Note that this condition is never satisfied when manufacturers are monopolists (ie, $\theta = 0$), and holds for all levels of spillovers when the manufacturers' products are almost perfect substitutes

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[2] Second-order conditions require: $\alpha/b > A'(D-\gamma E)$, which implies $b/\alpha < 8$.

(ie, $\theta \approx 1$). Equations 7.2 can be solved for equilibrium R&D levels: see Appendix E for all equilibrium expressions.[3]

Pure Integrated Structure

At the second stage, second-order conditions for manufacturers' profit maximization require $\alpha/b > JM$, or $b/\alpha < 4$; and reaction functions are given by:

$$x_i = \frac{JK[M-(1-\theta)bc] + bJNx_j}{\alpha - bJM} \tag{7.5}$$

where $J, K...$ etc are given in Table 7.1.

Thus, we have downward sloping reaction functions under the following conditions:

$$\gamma < \frac{\theta}{(2-\theta^2)} \tag{7.6}$$

Solutions to 7.5 are summarized in Appendix E.[4]

Mixed Structure

The procedure followed is the same as above, and the differences are noted below for the second stage equilibrium in R&D levels.

First, for (I,D) second-order conditions require $\alpha > A''(D-\gamma E)$, or $b/\alpha < 4$; and the reaction function is given by:

$$x_i = \frac{A''B[M-(1-\theta)bc] + A''b(\gamma D - E)x_j]}{[\alpha - bA''(D-\gamma E)]} \tag{7.7}$$

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[3] Stability conditions depend on the level of spillovers (γ). For small γ (condition 7.4), stability requires $\alpha/b > (1-\gamma)A'(D+E)$, or $b/\alpha < 8$. For large γ, stability requires $\alpha/b > (1+\gamma)A'(D-E)$, or $b/\alpha < 4$. See Appendix F.

[4] For small γ (condition 7.6), stability requires $\alpha/b > (1-\gamma)J(2-\theta^2+\theta)$, or $b/\alpha < 3.8$. For large γ, stability requires $\alpha/b > (1+\gamma)J(2-\theta^2-\theta)$, or $b/\alpha < 2$. See Appendix F.

which is downward sloping[5] for

$$\gamma < \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)} \tag{7.8}$$

Second, for (D,I), second-order conditions for manufacturers' profit maximization require $\alpha/b > J'M$, or $b/\alpha < 8$; and the reaction functions is given by:

$$x_i = \frac{J'K[M-(1-\theta)bc] + bJ'Nx_j}{\alpha - bJ'M} \tag{7.9}$$

(7.9) is downward sloping[6] under the condition:

$$\gamma < \frac{\theta}{(2-\theta^2)} \tag{7.10}$$

Thus, we have downward sloping reaction functions (ie, strategic substitutability between the R&D level decision variables) under condition (7.8). Solutions for this case are summarized in Appendix E.

In order to ensure the existence and stability of equilibria under all the vertical channel structures in this case, we assume that $b/\alpha < 2$ (see Appendix F). Please see Chapter 4 for a discussion of why this assumption is reasonable in many instances.

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[5] Stability conditions depend on the level of spillovers (γ). For small γ (condition 7.8), stability requires $\alpha/b > (1-\gamma)A''(D+E)$, or $b/\alpha < 3.8$ (approx.). For large γ, stability requires $\alpha/b > (1+\gamma)A''(D-E)$, or $b/\alpha < 2$. See Appendix F.

[6] For small γ (condition 7.10), stability requires $\alpha/b > (1-\gamma)J'(2-\theta^2+\theta)$, or $b/\alpha < 5.8$ (approx.). For large γ, stability requires $\alpha/b > (1+\gamma)J'(2-\theta^2-\theta)$, or $b/\alpha < 4$. See Appendix F.

A'	$=$	$\frac{(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2}$	A''	$=$	$\frac{(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{4(2-\theta^2)^2(4-\theta^2)^2}$
B	$=$	$(2+\theta)(4-2\theta^2+\theta)$			
D	$=$	$(8-9\theta^2+2\theta^4)$	E	$=$	$\theta(2-\theta^2)$
F	$=$	$\frac{(2-\theta^2)(\gamma(8-9\theta^2+2\theta^4)-\theta(2-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2}$	F'	$=$	$\frac{\gamma(8-9\theta^2+2\theta^4)-\theta(2-\theta^2))}{4(2-\theta^2)^2(4-\theta^2)^2}$
G	$=$	$\frac{\gamma(2-\theta^2)-\theta}{(4-\theta^2)^2}$	G'	$=$	$\frac{\gamma(2-\theta^2)-\theta}{4(2-\theta^2)(4-\theta^2)}$
J	$=$	$\frac{(2-\gamma\theta-\theta^2)}{(4-\theta^2)^2}$	J'	$=$	$\frac{(2-\gamma\theta-\theta^2)}{4(2-\theta^2)(4-\theta^2)}$
K	$=$	$(2+\theta)$	L	$=$	$(2+\theta)(1-\theta)$
M	$=$	$(2-\gamma\theta-\theta^2)$	N	$=$	$\gamma(2-\theta^2)-\theta$

Table 7.1

7.1.2. Case II: R&D Cartel

In this case, firms coordinate their R&D expenditures at the second stage — that is, they maximize joint profits while setting the R&D levels. However, they do not share the R&D results — that is, the spillover parameter remains as in Case I . This distinction between cost and information sharing between firms was first advanced by Kamien et al (1992); see Chapter 6 for details. Vonortas (1994) refers to this kind of RJV as a "Secretariat RJV", implying that the organizational setup of the RJV dictates that the firms carry out research separately at their own facilities, even though the firms take into account the effect of their R&D on the profits of all the firms (ie, maximize joint profits). Thus, spillover level is not affected as the firms do not share their private information and experiences on R&D projects. Another justification is the empirical observation that in many cases, a firm's participation in an RJV does not guarantee access to results of R&D, which could be sold or licensed to individual members for a fee. In any case, the situation where formation of an RJV also provides results of R&D to all members at no extra cost, thereby diffusing information among all members ("RJV Cartel" or "Operating entity RJV[7]"), is simply a special case of the scenario analyzed here – assuming $\gamma = 1$.

Let $T = \pi_1^M + \pi_2^M$. Then, solving the first-order conditions $(\partial T/\partial x_i) = 0, i = 1,2$ gives

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[7] The RJV in this case is organized as an independent research facility that "... undertakes the generic research activity of the whole industry and distributes the results to all members" (Vonortas, 1994, p. 423).

the equilibrium R&D levels. Again, the major differences in determination of the second-stage equilibrium in R&D levels in this case are summarized below.

Pure Decentralized Structure

At second stage the first-order conditions are: $\frac{\partial \pi_i^M}{\partial x_i} = 0$, $i = 1, 2$, where π_i^M is given by equation 4.12, and c_i by equation 7.1, thus yielding[8]:

$$(A'+F)B[M-(1-\theta)bc]+[A'(D-\gamma E)b+F(\gamma D-E)b-\alpha]x_i+[A'(\gamma D-E)+F(D-\gamma E)]bx_j = 0 \tag{7.11}$$

(see Table 7.1 for A', B... etc).

Second-order conditions require $\alpha/b > A'(D-\gamma E)+F(\gamma D-E)$, or $b/\alpha < 4$. From 7.11 we get the reaction functions in R&D-level space as follows:

$$x_i = \frac{(A'+F)B[M-(1-\theta)bc]+[A'(\gamma D-E)+F(D-\gamma E)]bx_j]}{\alpha - b[A'(D-\gamma E)+F(\gamma D-E)]} \tag{7.12}$$

Here, the denominator is always positive under the second-order conditions, and it is easy to check that the sign of the coefficient of x_j depends on the sign of the term $(\gamma D - E)$. Thus, under the condition:

$$\gamma < \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)} \tag{7.13}$$

we have downward sloping reaction functions, as in Case I. Solutions to equations 7.11 are summarized in Appendix E.[9]

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[8] Second-order conditions require: $\alpha > A'(D-\gamma E)$, which implies $\alpha > 1/8$.

[9] For small γ (condition 7.13), stability requires $\alpha/b > (1-\gamma)^2 Z(D+E)^2$, or $b/\alpha < 6.7$ (approx.). For large γ, stability requires $\alpha/b > (1+\gamma)^2 Z(D-E)^2$, or $b/\alpha < 2$, where $Z = \frac{(2-\theta^2)}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2}$.

Pure Integrated Structure

At the second stage, second-order conditions for manufacturers' profit maximization require $\alpha/b > JM + GN$, or $b/\alpha < 2$; and reaction functions are given by:

$$x_i = \frac{(J+G)K[M-(1-\theta)bc] + (JN+GM)bx_j}{\alpha - b(JM+GN)} \tag{7.14}$$

It is easy to check that, as in Case I, we have downward sloping reaction functions under the following conditions:

$$\gamma < \frac{\theta}{(2-\theta^2)} \tag{7.15}$$

Solutions to 7.14 are summarized in Appendix E.[10]

Mixed Structure

First, for (I,D) second-order conditions require $\alpha > (A''(D-\gamma E)+G'N)$, or $b/\alpha < 2.7$ (approx.); and reaction function is given by:

$$x_i = \frac{(A''B+G'K)[M-(1-\theta)bc] + (A''(\gamma D-E)+G'M)bx_j}{\alpha - b[A''(D-\gamma E)+G'N]} \tag{7.16}$$

Second, for (D,I), second-order conditions for manufacturers' profit maximization require $\alpha/b > (F'(\gamma D - E) + J'M)$, or $b/\alpha < 2.7$ (approx.); and reaction functions are given by:

$$x_i = \frac{(F'B+J'K)[M-(1-\theta)bc] + (F'(D-\gamma E)+J'N)bx_j}{\alpha - b[F'(\gamma D-E)+J'M]} \tag{7.17}$$

Solutions for this case are summarized in Appendix E.[11]

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[10] For small γ (condition 7.15), stability requires $\alpha/b > (\frac{(1-\gamma)(1+\theta)}{(2+\theta)})^2$, or $b/\alpha < 2.2$ (approx.). For large γ, stability requires $\alpha/b > (\frac{(1+\gamma)(1-\theta)}{(2-\theta)})^2$, or $b/\alpha < 1$.

[11] Stability conditions for (ID) and (DI) depend on the sign of $(\gamma D - E)$ and N. To simplify, we assume that γ is large enough so that both of these are positive. In that case, stability condition for (ID) requires $\alpha/b > (1+\gamma)(1-\theta)(A''B+G'K)$, or $b/\alpha < 1.3$ (approx.). For (DI), stability requires $\alpha/b > (1+\gamma)(1-\theta)(F'B+J'K)$,or

In order to ensure the existence and stability of equilibria under all the vertical channel structures in this case, we assume that $b/\alpha < 1$ (see Appendix F). Please see Chapter 4 for a discussion of why this assumption is reasonable in many instances.

The last two examples of institutional arrangements for research joint ventures involve 'RJV competition' and 'RJV cartel' (see Chapter 6 for details). In RJV competition, firms form a research joint venture to share all results of their R&D but do not coordinate their R&D expenditures — that is, γ is internally set to 1. Thus, this is a special case of Case I above — the equilibrium R&D levels are obtained by setting $\gamma = 1$ in the first-order-conditions.

In RJV cartel, firms form an RJV to share output of R&D and also coordinate their R&D expenditures. The problem solved is similar to Case II with $\gamma = 1$.

7.2. Results and Discussion

7.2.1. Case I: R&D Competition

First of all, we need to determine the subgame perfect equilibrium of our 4-stage game. The equilibrium market structure chosen by the manufacturers at the first stage is determined by comparing manufacturer profits, assuming a particular horizontal arrangement at the second stage for conducting R&D. The equilibrium conditions when the horizontal R&D arrangement is 'R&D competition' are summarized below[12]:

(i) Pure integrated structure: (I, I) is a Nash equilibrium if no manufacturer has an incentive to unilaterally decentralize, when the other manufacturer is integrated. That is, $\pi^M_{II} > \pi^M_{DI}$, which, using expressions in Appendix C, can be written as:

$$\Delta_5(\Delta_1)^2 - \Delta_6(\Delta_{21})^2(\Delta_{22})^2 > 0 \tag{7.18}$$

$b/\alpha < 1.3$ (approx.).

[12] In order to ensure the existence and stability of equilibria in all the vertical structures studied, the relevant parameter range in this case is $b/\alpha < 2$.

where $\Delta_1, \Delta_2, \ldots$ are as given below.

(ii) Pure decentralized structure: Similarly, (D, D) is a Nash equilibrium if no manufacturer has an incentive to unilaterally integrate, when the other manufacturer is decentralized. That is, $\pi^M_{DD} > \pi^M_{ID}$, which can be written as:

$$\left(2-\theta^2\right)\Delta_7(\Delta_1)^2 - \Delta_8(\Delta_{41})^2(\Delta_{42})^2 > 0 \tag{7.19}$$

where:

$$\begin{aligned}
\Delta_1 &= b^2(1-\gamma^2)(1-\theta^2)(2-\gamma\theta-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)) \\
&\quad -2b\alpha((2-\theta^2)(4-\theta^2)(2-\gamma\theta-\theta^2)^2+(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2)+8\alpha^2(2-\theta^2)^2(4-\theta^2)^2 \\
\Delta_{21} &= \alpha(2-\theta)(4-\theta^2)-b(1+\gamma)(1-\theta)(2-\gamma\theta-\theta^2) \\
\Delta_{22} &= 2\alpha(2+\theta)(2-\theta^2)(4-\theta^2)-b(1-\gamma)(1+\theta)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)) \\
\Delta_{41} &= \alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2-b(1+\gamma)(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)) \\
\Delta_{42} &= 2\alpha(2+\theta)(4-2\theta^2+\theta)-b(1-\gamma)(1+\theta)(2-\gamma\theta-\theta^2) \\
\Delta_5 &= \alpha(4-\theta^2)^2-b(2-\gamma\theta-\theta^2)^2 \\
\Delta_6 &= 4\alpha(2-\theta^2)(4-\theta^2)-b(2-\gamma\theta-\theta^2)^2 \\
\Delta_7 &= \alpha(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2-b(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2 \\
\Delta_8 &= 4\alpha(2-\theta^2)^2(4-\theta^2)^2-b(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2
\end{aligned}$$

Thus, conditions (7.18) and (7.19) determine the equilibrium regions. Manufacturer's profit dominance condition is summarized as follows: $\pi^M_{DD} > \pi^M_{II}$ if

$$\left(2-\theta^2\right)\Delta_7(\Delta_{21})^2 - \Delta_5(\Delta_{41})^2 > 0 \tag{7.20}$$

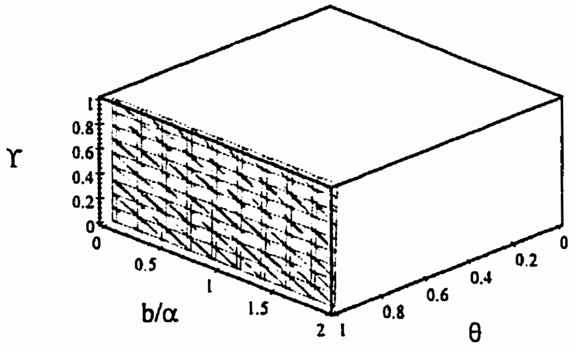
For $\gamma = 0$ (ie, no spillovers), these conditions reduce to (4.15) and (4.16) respectively, as obtained in model I. In general, the equilibrium and profit dominance conditions depend on three parameters: the degree of product differentiation (θ), the ease of production cost reduction (b/α), and the level of spillovers (γ). These conditions are graphically illustrated in Figure 7.1. It is found that in the relevant parameter range, (I,I) always remains an equilibrium. Therefore, the plot of condition 7.18 is not shown in Figure 7.1. Thus, our model integrates the triple influence of demand and cost side parameters along with externalities created by involuntary R&D spillovers. Major results for this case are summarized in the following proposition:

Proposition 16. *(a) (I,I) always remains an equilibrium of the four-stage game. (b) (D,D) becomes an equilibrium at high product substitutability. (c) Whenever (D,D) is an equilibrium, it gives higher profits to the manufacturers than (I,I) (see Figure 7.1).*

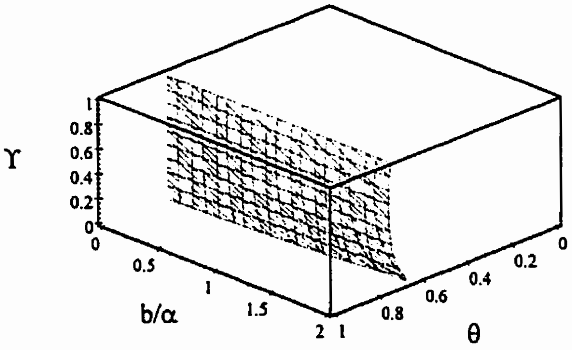
Comparing this result to Proposition 1 in Chapter 4, we see that consideration of spillovers in R&D does not change the nature of equilibria, although the parameter ranges over which these results hold vary. This implies that the underlying effects in channel choice decisions discussed in Chapter 4 are fairly robust. However, spillovers do have the following effect:

Proposition 17. *When spillovers are large (in the sense that condition 7.10 is violated), the range of product substitutability (θ) over which (D,D) is an equilibrium outcome is* larger *the easier it is to reduce production costs (ie, smaller α).*

The result is graphically shown in Figure 7.1 (a clearer illustration is provided in Figure 7.2, where the equilibrium and profit dominance conditions are plotted at maximal spillover level, ie, $\gamma = 1$). Comparing this result to Proposition 2 in Chapter 4, we see that the direction of the change in equilibrium region with α is reversed when spillovers are large. This implies that the trade-off between efficiency and strategic incentives that we established in Chapter 4 (see page 51) does not hold when spillovers are large. This is a consequence of the change in the nature of strategic interaction between competitors' R&D levels caused by large spillovers. When γ is small, R&D levels are strategic substitutes (ie, have downward-sloping reaction curves), but are strategic complements at large γ (ie, have upward-sloping reaction curves). That is, large spillovers create a situation where a manufacturer would find it optimal to increase his investments in process R&D if a competitor increases his R&D levels ("aggressive behavior begets aggressive response"). Thus the nature of R&D competition under large spillovers is the same



(a): Equilibrium Region for (D,D)

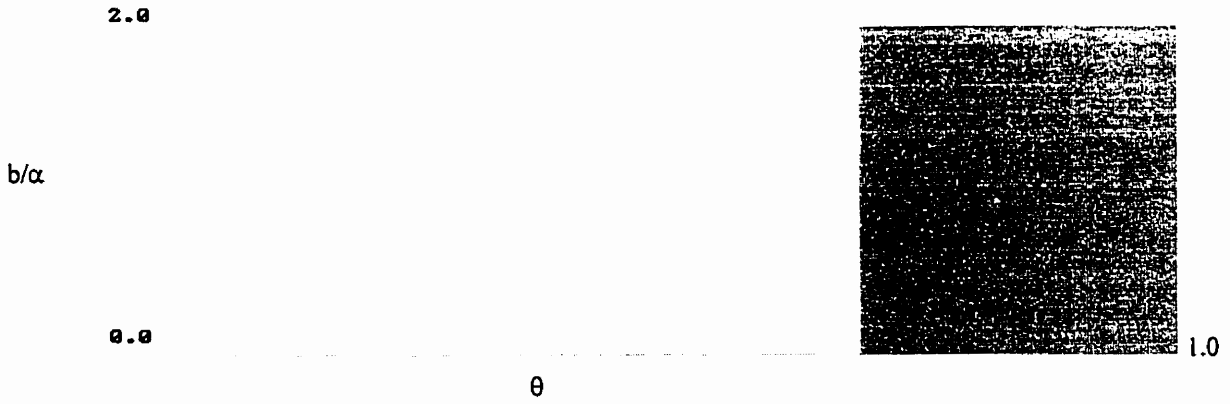


(b): Region where (D,D) gives higher profits to manufacturers than (I,I)

Figure 7.1: Equilibrium and Profit Dominance Conditions under R&D Competition (ie, no cooperation)

(Note: The relevant region in these figures is to the left of the shaded surface.)

(a): Equilibrium region for (D,D)



(b): Region where (DD) gives higher profits to manufacturers than (II)

Figure 7.2: Equilibrium and Profit Dominance Conditions under R&D Competition with maximal spillovers ($\Upsilon=1$)

as price competition. When products are nearly homogenous, manufacturers in oligopolistic markets have an incentive to limit the intensity of price competition by inserting independent, profit-maximizing retailers to provide a "buffering" (see Chapter 4). Similarly, when spillovers are large, manufacturers have an incentive to avoid too much investment in cost reduction by decentralizing because lack of coordinated decision making in a decentralized channel leads to a reduction in R&D investments by the manufacturer (due to the 'vertical R&D externality' that we discussed in Chapter 4). This latter incentive becomes stronger the easier (ie, cheaper) it is to reduce production costs. Hence, in the presence of large spillovers, the range over which (D,D) is an equilibrium is larger the lower the value of α.

The above comparisons have some important implications on the vertical channel structure and the desirability of channel coordination for manufacturers in oligopolistic markets. First, we see that the (horizontal) externalities in upstream R&D investments do influence the (vertical) channel structure. Analyses of channel structure decisions that focus only on the contractual relations between the manufacturer and the retailer as well as the extent of differentiation between competitors' products (eg, those discussed in Chapter 4) do not provide a complete picture of the underlying effects that shape channel equilibria. In particular, interactions among operational and marketing variables, and across horizontal and vertical dimensions of inter-organizational relations, are important determinants of firm and market structure.

7.2.2. Case II: R&D Cartel

The equilibrium and profit dominance conditions for this case are summarized below[13]:

1. (I,I) is an equilibrium if:

$$(\Omega_3)^2 - (2+\theta)\Omega_1\Omega_8 > 0$$

2. (D,D) is an equilibrium if:

---

[13] In order to ensure the existence and stability of equilibria in all the vertical structures studied, the relevant parameter range in this case is $b/\alpha < 1$ (see Appendix F).

$$(2-\theta^2)(\Omega_3)^2-(2+\theta)\Omega_2\Omega_9>0$$

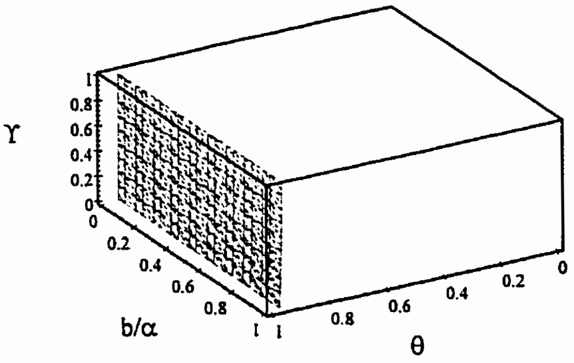
3. $\pi^M_{DD}(C)>\pi^M_{II}(C)$ if:

$$(2+\theta)(2-\theta^2)\Omega_1-\Omega_2>0$$

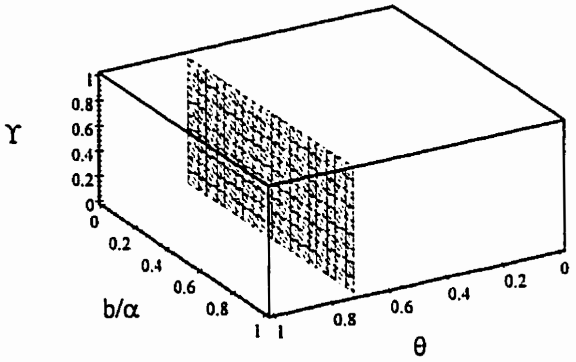
where:

$$\begin{aligned}
\Omega_1 &= \alpha(2-\theta)^2-b(1+\gamma)^2(1-\theta)^2\\
\Omega_2 &= \alpha(2-\theta)(4-2\theta^2-\theta)^2-b(1+\gamma)^2(1-\theta)^2(2+\theta)(2-\theta^2)\\
\Omega_3 &= b^2(1-\gamma^2)^2(1-\theta^2)^2(2-\theta^2)(4-\theta^2)-b\alpha((1+\gamma^2)\\
&\quad (3-\theta^2)\left(32-52\theta^2+29\theta^4-5\theta^6\right)-4\gamma\theta\left(2-\theta^2\right)\left(16-15\theta^2+3\theta^4\right))+4\alpha^2(2-\theta^2)^2(4-\theta^2)^2\\
\Omega_4 &= 2\alpha\left(2+\theta\right)\left(4-2\theta^2+\theta\right)-b\left(1-\gamma\right)^2\left(1+\theta\right)^2\left(2-\theta\right)\\
\Omega_5 &= 2\alpha\left(2+\theta\right)^2\left(2-\theta^2\right)-b\left(1-\gamma\right)^2\left(1+\theta\right)^2\left(4-2\theta^2-\theta\right)\\
\Omega_6 &= \alpha\left(\gamma\left(2-\theta^2\right)\left(8+4\theta-3\theta^2-\theta^3\right)+\left(32+32\theta-20\theta^2-23\theta^3+3\theta^4+4\theta^5\right)\right)\\
&\quad -b(1+\gamma)(1-\gamma)^2(1+\theta)^2(2-\theta)(2-\theta^2)\\
\Omega_7 &= \alpha\left(\left(2-\theta^2\right)\left(8+4\theta-3\theta^2-\theta^3\right)+\gamma\left(32+32\theta-20\theta^2-23\theta^3+3\theta^4+4\theta^5\right)\right)\\
&\quad -b(1+\gamma)(1-\gamma)^2(1+\theta)^2(2-\theta)(2-\theta^2)\\
\Omega_8 &= \alpha(2-\theta)^3(2-\theta^2)(\Omega_5)^2-b(1-\theta)^2(2+\theta)(\Omega_7)^2\\
\Omega_9 &= \alpha(2-\theta)^2(2-\theta^2)^2(\Omega_4)^2-b(1-\theta)^2(\Omega_6)^2
\end{aligned}$$

These conditions are shown in Figure 7.3. The results for this case are very similar to those in the previous case. These figures are plotted for $\gamma=0$ in Figure 7.4 and for $\gamma=1$ in Figure 7.5. In absence of R&D spillovers (Figure 7.4), the nature of equilibria is similar to those obtained in Chapter 4, though the fact that manufacturers now cooperate in the second stage (in setting their R&D levels) affects the range over which (D,D) is an equilibrium (Figure 7.3a), and, in particular, the profit dominance region. Here, cheaper R&D (ie, lower α) does *not* increase the range over which (D,D) gives higher profits to the manufacturers than (I,I) (Figure 7.3b), as was the case in our first model in Chapter 4 (see page 57). Intuitively, since in the



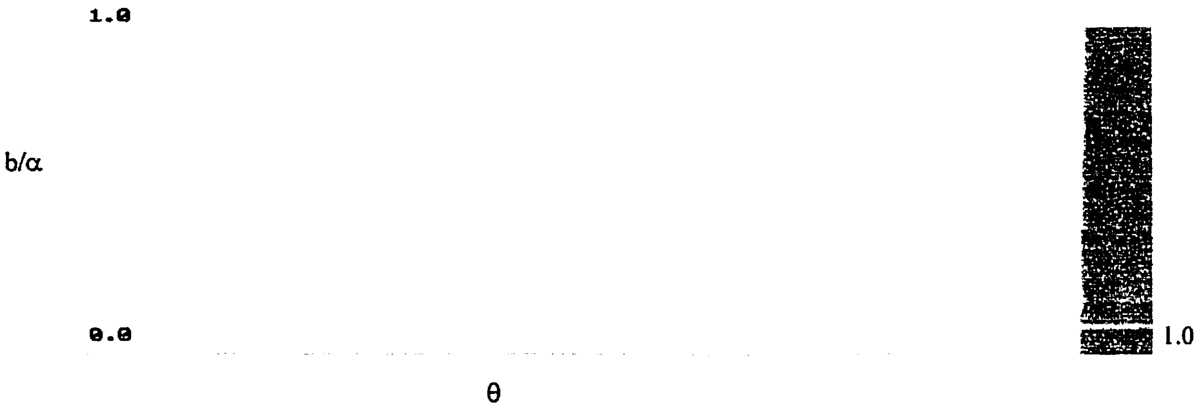
(a): Equilibrium Region for (D,D)



(b): Region where (D,D) gives higher profits to manufacturers than (I,I)

Figure 7.3: Equilibrium and Profit Dominance Conditions under R&D Cartel (ie, cooperation in R&D)

(Note: The relevant region in these figures is to the left of the shaded surface.)

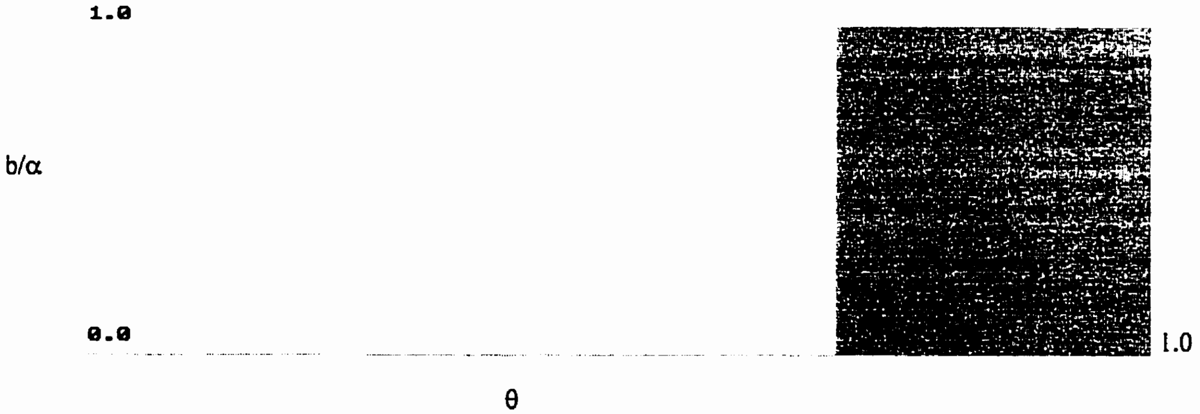


(a): Equilibrium region for (D,D)

(b): Region where (DD) gives higher profits to manufacturers than (II)

Figure 7.4: Equilibrium and Profit Dominance Conditions
under R&D Cartel with no spillovers
$(\Upsilon=0)$

(a): Equilibrium region for (D,D)



(b): Region where (DD) gives higher profits to manufacturers than (II)

Figure 7.5: Equilibrium and Profit Dominance Conditions
under R&D Cartel with maximal spillovers
($\Upsilon=1$)

case of R&D cartel, manufacturers cooperate in setting their R&D levels, subsequent effects of lower production costs on prices and profits are fully internalized. A change in the cost of R&D has no effect on the range of substitutability over which (D,D) gives higher profits than (I,I). In other words, *cooperation in R&D by the manufacturers mitigates the Prisoner's Dilemma situation in the choice of distribution channel structure*, as would be expected. It would also be expected that such cooperation reduces manufacturers' incentives to invest in R&D as long as spillovers are low (ie, reaction functions are downward sloping), irrespective of the vertical channel structure. This conjecture can be easily verified (see next section).

For maximal spillovers ($\gamma = 1$), we find, similar to the previous case, that the range of product substitutability (θ) over which (D,D) is an equilibrium becomes *larger* as production cost reduction becomes easier, ie, lower α (Figure 7.5(a)). Thus, the reversal in the nature of strategic interaction caused by large spillovers creates a similar effect on the equilibrium region in this case as in Case I.

7.2.3. R&D Investments: Comparisons

We now compare the equilibrium R&D levels under various horizontal arrangements, for a given vertical structure.

Proposition 18. *(a) Assuming the vertical industry structure to be (DD), the equilibrium R&D levels satisfy the following relations:* $x^*(CJ) \geq x^*(l)\,\forall\theta$, *where* $l = N, C,$ *or* NJ. *Moreover,* $x^*(N) \geq x^*(C)$ *if condition (7.4) holds, and* $x^*(N) \geq x^*(NJ)$ *if:*

$$b/\alpha \leq \frac{\theta(2-\theta)(4-2\theta^2-\theta)^2}{(1-\theta)^2(2+\theta)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))} \tag{7.21}$$

(b) Assuming the vertical industry structure to be (II), the equilibrium R&D levels satisfy the following relations: $x^*(CJ) \geq x^*(l)\,\forall\theta$, *where* $l = N, C,$ *or* NJ. *Moreover,* $x^*(N) \geq x^*(C)$ *if condition (7.6) holds, and* $x^*(N) \geq x^*(NJ)$ *if:*

$$b/\alpha \leq \frac{\theta(2-\theta)^2}{(1-\theta)^2(2-\gamma\theta-\theta^2)} \tag{7.22}$$

The above result states that the equilibrium R&D levels are always higher under RJV cartel (ie, CJ) than under any other arrangement. Moreover, we have:

$$x^*(CJ) \geq x^*(C) \geq x^*(N) \geq x^*(NJ)$$

under conditions (7.21) and ($\gamma > \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}$) when the vertical structure is (DD), and under conditions (7.22) and ($\gamma > \frac{\theta}{2-\theta^2}$) when the vertical structure is (II).

We can also compare R&D levels under different vertical structures (DD and II) for a given horizontal arrangement. Simple comparisons give the following results:

$x^*_{DD}(CJ) \geq x^*_{II}(CJ)$, $x^*_{DD}(C) \geq x^*_{II}(C)$, and $x^*_{DD}(NJ) \geq x^*_{II}(NJ)$, if:

$$(2-\theta^2)(4-\theta^2) - (4-2\theta^2-\theta)^2 > 0 \tag{7.23}$$

which holds only for $\theta > 0.7$. Thus, if product substitutability is low, manufacturers' investments in cost-reducing R&D are lower in a pure decentralized vertical structure than in a pure integrated structure, irrespective of the level of spillovers — for three of the four horizontal arrangements considered here (ie, R&D cartel, RJV competition, and RJV cartel). The condition for R&D competition does depend on the spillover parameter, and is given by:

$x^*_{DD}(N) > x^*_{II}(N)$, if:

$$F_1 - F_2 > 0 \tag{7.24}$$

where

$$\begin{aligned} F_1 &= (2-\theta^2)(4-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)) \\ F_2 &= (2-\gamma\theta-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2 \end{aligned}$$

Note that for $\gamma = 1$, (7.24) reduces to (7.23); and for $\gamma = 0$ (ie, no spillovers), (7.24) is never satisfied, implying that $x^*_{DD}(N) < x^*_{II}(N) \, \forall\theta \; (\theta \neq 1)$ – in agreement with results from model I (see section 4.5).

Proposition 18 states that R&D Competition (ie, N) generates higher levels of R&D investments than R&D Cartel (ie, C) for both equilibrium structures ((DD) and (II)), as long as conditions (7.4) and (7.6), respectively, are satisfied. Now, recall that (7.4) and (7.6) define the upper limit on R&D spillovers for which the manufacturers' R&D levels are strategic substitutes, under the structures (DD) and (II) respectively. This result is in agreement with the existing literature on the desirability of cooperative research ventures being conditional on the level of spillover parameter. For example, in d'Aspremont and Jacquemin's (1988) model, R&D levels are higher for a cooperative setup than a non-cooperative one if the spillover parameter (γ)is > 0.5, the condition required to make the R&D-level variables strategic complements (see section 6). Similarly, Vonortas (1994) proves that a "secretariat RJV"[14] yields higher R&D levels over R&D competition only when the R&D level decision variables become strategic complements.[15]

Moreover, since $\frac{\theta(2-\theta^2)}{8-9\theta^2+2\theta^4} < \frac{\theta}{2-\theta^2} \forall\theta$, we can say that at any given level of product substitutability, a relatively larger level of spillovers are required to induce strategic complementarity between the R&D levels if both manufacturers are integrated than if both are decentralized. Looked at another way, recall that investments in cost-reducing R&D can be viewed as an indication of aggressive behavior by a manufacturer (as lower production cost allows him to

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[14] R&D Cartel in the terminology used here.

[15] This result can be explained as follows: large spillovers induce strategic complementarity between R&D levels. Thus a firm trying to increase its R&D investments to gain a cost advantage can expect an equally aggressive reaction from its rival, reducing the profitability of both firms. Hence, large spillovers reduce the incentives of a firm to unilaterally increase R&D investments. Under these conditions, formation of a research joint venture improves welfare. On the other hand, low spillovers imply strategic substitutability, which increases incentives for a firm to invest in R&D as it reduces the profitability of R&D for the other firm. Thus R&D competition provides sufficient incentives, whereas an RJV under these conditions would provide the firms a chance to collude to limit the R&D investments (see Vonortas, 1994).

lower his price). When technological spillovers are small or absent, an increase in the R&D level of the rival manufacturer reduces the profitability of own R&D at the margin (ie, strategic substitutes).[16] A large amount of spillovers, however, reverses this relationship – that is, manufacturers' R&D expenditures become strategic complements whereby a higher R&D level of the rival induces a manufacturer to itself invest more aggressively in R&D. The above discussion thus points out that such strategic complementarity is achieved at a lower level of R&D spillovers if both manufacturers are decentralized. That is, the threshold value for determining the nature of strategic interaction between the R&D level decision variables is dependent on the vertical structure of the industry. Hence our argument that previous results on research joint ventures should be suitably modified to take into account the downstream integration level of the firms involved, and government policy initiatives encouraging such cooperative arrangements should consider not only the horizontal structure but also the vertical structure of the firms in the industry concerned.

In summary, the model presented in this section attempts to integrate the influences of R&D spillovers and product substitutability on downstream market structure. We have shown that desirability of horizontal and vertical coordination depends on interactions between two kinds of externalities in process innovation investments: a 'horizontal' externality created by involuntary spillovers of the benefits of one manufacturer's investments on the competitors, and a 'vertical' externality due to the fact that a manufacturer distributing his products through an independent retailer cannot capture all the benefits of reducing his production costs (with linear intrachannel contracts). These two effects have been treated separately in the literature, and thus, existing results can only be seen as special cases of our more general model. In a broader sense, our model also implies that development of a more comprehensive theory of firm and market structure should be based on explicitly modeling and analyzing the interactions between horizontal and vertical dimensions of interorganizational relations.

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[16] Recall from model I (section 4.3) that R&D level variables are *always* strategic substitutes when there are no spillovers.

8. CONCLUDING REMARKS: CONTRIBUTIONS, LIMITATIONS, AND FUTURE RESEARCH

We have argued in this thesis that a joint consideration of operational efficiency and strategic incentives, as well as channel coordination and lateral cooperation practices, can yield important insights into the nature and variety of organizational forms, pattern of organizational linkages within and across industries, and the evolution of market structure. With a limited selection out of the vast literature available on the subject, we tried to show the inadequacies of prevalent economic explanations such as transaction-cost economizing, as well as the limitations of a large number of studies of supply chain/channel coordination practices within operations management and marketing. We stressed the need to consider such coordination decisions explicitly in a competitive context. To that end, we developed a series of game-theoretic models in which firms recognize their interdependence and act to maximize their profits. In the first model, we analyzed the interactions between firms' investments in process innovation and their choice of channel structure (integrated or decentralized). We then extended this model to consider various means of channel coordination, such as franchising or two-part tariffs and quantity discounts, alongwith the process innovation decision. Third, we pointed to a need for considering various institutional arrangements available to firms in coordinating their productive activities and how such arrangements affect the market structures in related upstream and downstream industries. As an example, we considered cooperative arrangements in conducting pre-competitive research when technology and industry conditions generate the externality of spillovers of the benefits of R&D conducted by one firm to its competitors. We then presented two more models in an attempt to see the effects of R&D investments and lateral cooperative arrangements by the manufacturers on prices and output levels, as well as on the downstream industry structure. The first of these models showed that under certain conditions on the extent of R&D spillovers (and ignoring vertical relations), horizontal cooperation among competitors in an industry may be desirable to ensure high levels of R&D activity and lower retail prices. In the second model, both horizontal cooperative agreements in presence of R&D spillovers and (vertical) channel coordination practices were analyzed, and it was shown that upstream institutional arrangements do affect the downstream channel structure, and vice versa. Thus, there is at least some merit in considering such cross-industry effects, a point that has not been stressed enough so far in the literature.

8.1. Contributions

The specific contributions of this thesis are summarized below:

1. We have developed a model (chapter 4) to analyze the joint effects of manufacturing variables (such as production costs and investments in process innovation) as well as marketing decisions (such as intermediate and final product pricing) on channel structure and forward integration incentive of manufacturers producing differentiated products in an oligopolistic market. The results and insights gained from this model include the following:

(a) Most studies of a single supply chain or channel take the benefits of coordinated decision making and cost reduction for granted. Consideration of intrachannel decisions in a competitive context points out certain strategic incentives as well: limiting cost reduction efforts, inserting independent, profit-maximizing intermediaries, or other signalling mechanisms to indicate high costs and commitment to high prices in order to induce cooperative behavior in competitors. In particular, we have shown that there is an explicit trade-off between efficiency and strategic incentives for channel coordination. The identification of a strategic incentive to limit process innovation efforts is somewhat counter-intuitive. We have shown that manufacturers may benefit by decoupling successive decisions in a supply chain, contrary to the theme of increased integration in decision making in most of the management literature.

(b) The model allows an analysis of cost leadership incentive of manufacturers at different levels of product differentiation. We showed that the interactions between the two generic strategies of cost leadership and product differentiation (Porter, 1985) have a significant influence on the downstream channel structure. This, we believe is the first attempt at a systematic analysis of the impact of these two strategic choices on firm structure, particularly in relation to the downstream integration level, despite the wide popularity of Porter's framework.

(c) Our model extends many existing models on the equilibrium channel structure as being dependent on the level of product differentiation (eg, McGuire and Staelin, 1983; Moorthy, 1988; Coughlan and Wernerfelt, 1989). In particular, we have shown that the channel structure decision is dependent not only on the product differentiation parameter but also on the level of production costs. Treatment of production cost as a decision variable (by means of investments in process R&D to reduce costs) necessitates modification of existing results that take unit production costs as given.

(d) We have generalized the existence of a vertical R&D externality in a channel, in that a decentralized manufacturer invests less in process improvement than an integrated one, to competitive markets. Moreover, we have shown that this externality has strategic value in that it allows manufacturers to increase their profits when substitutability between their products is high.

2. An extension of our basic model allows us to analyze the impact of process innovation investments on various channel coordination practices, and vice versa, in a competitive framework (chapter 5). This helps bridge the gap between studies of supply chain management/channel coordination in operations management and marketing literature: while the former typically ignores the competitive context, the latter does not consider manufacturing variables. The following results indicate the advantages of merging the two streams:

(a) An existing result in the literature states that under two-part tariffs (or franchising), manufacturers would always prefer to decentralize the downstream retailing function (eg, Bonanno and Vickers, 1988; Coughlan and Wernerfelt, 1989). Our analysis shows that this result is dependent on the marginal cost of production being constant. That is, this result does not hold when manufacturers can make investments in process innovation to reduce their production costs.

(b) The existing results on quantity discounts as a means of channel coordination also need to be modified if we take process innovation investments into account. In particular, the retailer has to pay the manufacturer an additional charge equal to a fraction of the manufacturer's total investments in process innovation in order to ensure channel-optimal decisions. More generally, competitive interactions mitigate the profit motives that a channel has in offering quantity discounts, because the increase in demand does not materialize if both channels offer similar discounts.

(3) Our third model (chapter 6) allows us to analyze the impact of R&D spillovers on retail prices, output levels, firm profits, and social welfare, ignoring vertical relations. While many such models exist in the literature, our model extends a number of those models (specifically, those of d'Aspremont and Jacquemin, 1988; Kamien et al. 1992; Suzumura, 1992). We extend the results from these models to a setting with n firms, differentiated products, and more general demand and cost functions. This chapter also provides a comprehensive review of various arguments as to why cooperation in R&D activities should be allowed among competitors in an industry.

(4) A second extension of our basic model from chapter 4 allows us to consider the impact of R&D spillovers and horizontal cooperative agreements among manufacturers on vertical channel structure, and vice versa (chapter 7). Neither the extensive literature on channel structure nor that on R&D spillovers makes this kind of analysis. In particular, we have shown that:

(a) Equilibrium channel structure depends not only on the level of unit production costs (as shown by our basic model) but also on the level of R&D spillovers and the upstream institutional arrangements among manufacturers that allow them to cooperate in R&D. Thus, the likelihood of observing decentralized or integrated channels will be different in different industries, depending on the level of involuntary spillovers that exists in that industry.

(b) The desirability of various horizontal cooperative arrangements among manufacturers in an industry is dependent on the vertical channel structure. Thus, government policies that encourage such cooperation among manufacturers in R&D should also take into account the vertical channel relationships of the manufacturers.

8.2. Limitations

A few limitations of our models are worthy of further examination. First, we have considered only single-product firms. Second, we do not consider any uncertainties in demand or in the output of process innovation, the latter of which is especially an interesting and more realistic scenario to analyze. Third, our models do not capture the dynamic aspects of intrachannel relations and the production and pricing policies of the manufacturers and retailers (eg, Eliashberg and Steinberg, 1987, 1991), or the time-dependent nature of continuous process improvement. Fourth, we do not consider transaction costs, which may alter the forward integration incentive of the manufacturers, especially given the exclusive nature of the manufacturer-retailer relationship and the channel-specific investments by the manufacturer in process innovation that may expose him to opportunistic behavior by the retailer (Williamson, 1985). Fifth, we have not modeled the details of production and inventory related decisions of a manufacturer, or retail assortment and shelf-space as well as advertising and promotion related decisions of a retailer. Sixth, our model structure is limited to those situations where a retailer sells the products of only one manufacturer – more general buyer-supplier relations and inter-organizational networks may be an important direction in which to extend our present work. In sofar as our models succeed in highlighting the nature of strategic incentives that influence horizontal and vertical relations in competitive markets, we hope that further studies will help develop a better understanding of these issues.

8.3. Future Research

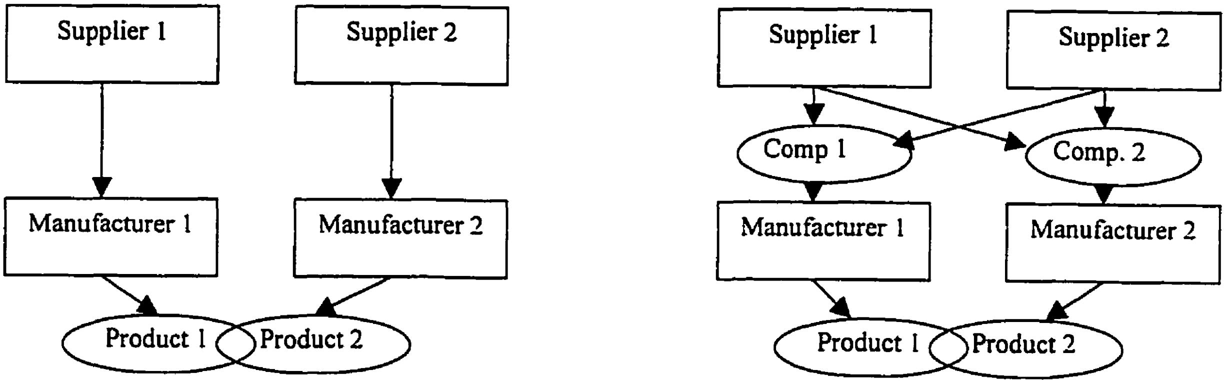
For future research, we have chosen to extend the basic framework presented in this thesis to consider multi-product firms. Most firms differentiate their own products, generally as a result of marketing-led strategies of increasing segmentation. This opens up another decision problem for the firm from an operational perspective – the choice of technologies flexible enough to manufacture the requisite variety without a significant increase in production costs. For a single firm, determination of optimum product diversity, choice of flexible technology to minimize costs of producing a given range of products, joint consideration of the product-line width and technology choice – have all been adequately investigated in the operations management literature. Recently, many authors have also considered the technology choice issue in a competitive context, and looked at the effect such technologies have on firm size and market structure *within an industry*. We intend to develop this line of reasoning further to consider the effects of decisions regarding product diversity and technology choice in one industry on firm size and market structures in related upstream (ie, suppliers) and downstream (ie, retailers) industries. To this end, we propose the following two projects as an extension to our present study. For the first of these projects, a model has already been developed and major results have been obtained; for the second, development of a theoretical framework and data collection is under way. However, for reasons of brevity and focus, we have chosen to exclude these projects from our thesis work. We briefly summarize them below for the sake of completeness and to indicate the potential usefulness of our line of research in understanding organizational form and market structure.

8.3.1. Investments in Flexible Technologies and Buyer-Supplier Relations

We focus first on incentives for the suppliers or the manufacturers to invest in flexible technologies that would allow them to produce a wider range of products, and the impact of such investments on the relations between suppliers and the manufacturers, and vice versa. In the first model, we consider two suppliers and two manufacturers; each manufacturer produces a single differentiated product; and, each unit of the final product (i) requires one unit of input (x_i) that can be sourced from one or both suppliers depending on the technological capabilities of the suppliers and the intermediate market structure. We further assume that there are only two types of technologies available to the suppliers: a dedicated technology, DT, (that restricts the supplier to producing only one of the two intermediate inputs) and a flexible technology, FMS, (that enables a supplier to produce both inputs for the two downstream manufacturers producing differentiated products). We use a simple 3-stage game where players at each stage make their decisions simultaneously, non-cooperatively and in prefect knowledge of all the decisions made at the previous stages. At the first stage, suppliers decide on what type of technology to adopt. Then, given the technology decisions and vertical arrangements, the intermediate product prices are set. The final stage of the game involves Cournot competition among the two downstream producers of differentiated products. Consumer preferences are modeled using a non-address approach.

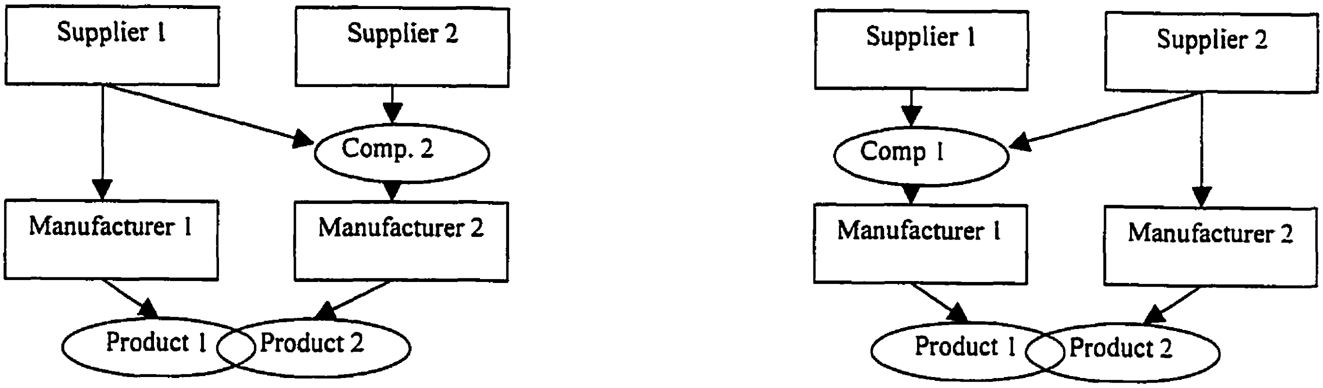
There are many different types of vertical arrangements that could be considered for the transfer of components from the suppliers to the manufacturers. However, we restrict our attention to the following two types: if both suppliers choose DT, the arrangement is characterized as an (exclusive) supply contract. That is, since each supplier can make only one type of component, the manufacturers have no choice but to engage in "single sourcing". On the other hand, if both suppliers choose to invest in FMS, the supply contracts are replaced by intermediate markets for both components. The situation where one supplier chooses FMS and the other DT is characterized as a "mixed" arrangement: choice of FMS by supplier S_i (and DT by supplier S_j) creates an intermediate market for component j while the exclusive supply contract for component i is maintained (see Figure 8.1). Note that a comparison between vertical integration and supply contracts captures the effect of marginalization (ie, intermediate input price being greater than marginal cost of production in a decentralized supply chain); and, a comparison between supply contracts and intermediate markets captures the effect of market elimination. These two effects are often mixed in models that consider only the two extremes of intermediate markets and vertical integration.

First of all, we characterize the equilibrium regions delineated by conditions on market size, fixed cost premium of FMS adoption, and the degree of product substitutability between the final products. The results are rather intuitive: a larger cost differential discourages investment in FMS; a larger final market makes it more attractive for a supplier to participate in the



(a): (DT,DT)

(b): (FMS,FMS)



(c): (FMS,DT)

(d): (DT,FMS)

Figure 8.1: Vertical Arrangements and Market Structure under Different Technology States

intermediate market for both products. Similarly, a high degree of product differentiation (i.e., low θ) encourages suppliers to produce for both manufacturers as they would otherwise forego a large part of the market. For the same cost differential, the market size will have to be almost twice as large when the final products are homogenous than when the downstream manufacturers are monopolists in their respective markets, in order to induce both suppliers to invest in flexible technologies. In other words, a supplier has a bigger incentive to supply to two non-competing manufacturers than to two highly competitive ones.

Secondly, we show that manufacturers always benefit and the suppliers always lose by simultaneous adoption of flexible technologies (irrespective of whether FMS adoption by both suppliers is an equilibrium outcome or not). Thus, there is a conflict of interest among the suppliers and manufacturers as to the adoption of flexible technologies. This is a consequence of the change in vertical relations brought about by flexible technologies — dedicated technologies ensure captive customers for the suppliers. Manufacturers are dependent on a single source of supply, and suppliers specify the price at which they will produce the intermediate product. Adoption of FMS by a supplier enables him to enter the second intermediate market as well, but since the other supplier has the same incentive, the result is competition in both intermediate markets. The manufacturers are not dependent on one supplier, and the exclusive contractual relations are replaced by intermediate markets. Thus, manufacturers benefit as the cost of input is lowered for them, but suppliers lose as the price of their output goes down. However, for "large" markets and high product differentiation, the channel as a whole benefits by FMS adoption.

The above discussion points out that the manufacturers might have an incentive to either vertically integrate backwards or to engage in a profit-sharing contract with their own supplier to encourage him to invest in flexible technologies and supply components to the rival manufacturer as well (thereby establishing multiple sources for their inputs, increase competition in the intermediate input markets, and drive down input prices). We analyze both these possibilities, provide conditions for various equilibria, and find that, indeed, a profit-sharing contract enables a unique FMS equilibrium that provides higher channel profits than adoption of DT. Moreover, we provide conditions on a manufacturer's incentive to integrate backwards, taking into account the alternative arrangements available (ie, through a contract or intermediate market). We see that in absence of any acquisition costs, large markets will provide enough incentive to the manufacturer (in the form of reduced cost of procurement) to integrate backwards. However, taking acquisition costs (equal to the independent supplier's profits) into consideration may reverse this incentive, as alternative arrangements, in the form of a profit-sharing agreement coupled with adoption of flexible technologies upstream (that serve to establish an intermediate market for the manufacturers' inputs), become more profitable. For a given market size, integration incentive declines as product substitutability increases. Based on these results, we propose hypotheses for the probability of upstream investments in FMS as well as the probability of backward integration by the manufacturers. We hope to test these hypotheses empirically in future work.

A second, related, part of the above model is whereby the manufacturers face a choice between dedicated and flexible technologies. A model similar to the one above is employed, and the vertical arrangements are again characterized as supply contracts, intermediate market or vertical integration. Thus, it is assumed that the differentiated products produced by the manufacturers utilize the same input component. There are many extensions possible along these lines — for example, consideration of technology adoption at both the supplier and the manufacturer levels, uncertainty in demand, impact of asset specificities and bargaining in intrachannel relations.

The idea of parts commonality mentioned above is an important trend observed in a number of industries — for example, automobiles and computers — whereby the manufacturers attempt to control their production and inventory costs by increasing the percentage of parts and components that are same across different products as customization and increasing market segmentation expands the product variety. In the next project, we take up the impact of wider product variety, and the manufacturers' responses to deal with it, on the industry structure at different levels of a supply chain as well as on the entry barriers to the manufacturers' industry.

8.3.2. The Impact of Product Variety on Upstream and Downstream Industry Structure

The basic argument underlying this project is that market structure in an industry is affected to a large extent by the degree of product variety and technology choices made by individual firms in the upstream and/or downstream industries. That is, considering a simple three echelon supply chain consisting of suppliers, manufacturers and distributors, we argue that the product variety offered by the manufacturers, as well as the flexibility of technologies employed, affects the market structure in both the suppliers' industries as well as distribution channels. In particular, more product variety in the manufacturer's industry is associated with: a) more concentration in the upstream industries, in presence of delayed customization in the manufacturing process (ie, technologies exploiting high degrees of parts commonality in sourced parts); and b) more concentration in downstream industries, in presence of manufacturing technologies with lead time increasing in product variety. Specifically, our reasoning is as follows:

Downstream Effect:

The product variety offered by one firm in an oligopolistic industry is often rapidly matched or exceeded by other firms — as a result, the increase in product variety in the industry is exponential. This explosion in number of varieties has significant impact on downstream distribution channels. Specifically, the channel structure is pushed towards one of the two extreme forms: (a) Direct marketing by the manufacturer, or b) Independent "Mega-retailers". This is a result of the following intermediate effects of increased product variety: a) increased inventory carrying costs, b) increased difficulty of product mix forecasts, c) increased search costs of the consumers.

Both of these issues (ie, the extent of product variety and the distribution channel structure) affect, and are in turn affected by, the individual firms' technology choices. First, the strategic necessity of a firm to increase its product variety makes flexible technologies more attractive. Conversely, having invested in flexibility, a firm finds it more profitable to increase the product variety offered. Second, the degree of technological flexibility of a firm determines its capability to react to changes in volume and product mix. Therefore, the effect of product variety on downstream distribution channel is reflected on the manufacturer in the form of demand variability. For example, the demand variability faced by a forward-integrated manufacturer is higher than that faced by a manufacturer who uses an independent distributor. However, the forward integration decision is mediated by the manufacturer's technology choice. There are two operational aspects of technology flexibility that are important in this context: production cost and lead time.

(i) In terms of cost alone, we have the following: Given an a priori inflexible technology, a manufacturer would want to insert an independent intermediary, (ie a distributor) to shield itself from the increased demand variability in the product market. On the other hand, given flexible technology, forward integration becomes more likely.

(ii) This effect is diluted when lead time (from the specification of customer order to delivery) is also taken into consideration: longer lead time makes forward integration less likely, even in presence of cost advantages due to flexible technology. In particular, in presence of increasing product diversity, flexible technologies with long lead times increase the likelihood of mega-retailers.

Upstream Effect:

The effect of technology choice on the upstream market structure is mediated through the operational parameter of *parts commonality* — that is, tendency of the firms in an industry to use similar parts (not only in different products produced by one multiproduct firm, but also in products manufactured by different firms), especially in parts sourced from outside. This effect may be quite pronounced in some industries such as autos and computers where increasing product variety, demand for higher quality and rapid obsolescence of older technologies and products tends to push costs higher — therefore, firms wish to exploit economies of scale in sourced parts, and pushing customization to the later stages of product manufacture. In computers, for example, by making the design modular, a vast number of combinations is possible. The inventory-related savings of such product design changes are fairly well recognized. However, another significant effect of such design changes seems to be that it leads to higher concentration in the upstream industries supplying those inputs and increasing fragmentation in the final product industry. As end-product manufacturers utilize more and more standardized components in their widening range of products, the suppliers (formerly, small, fragmented, and limited to only one manufacturer) find it advantageous to merge their operations to exploit economies of scale. Larger markets make it feasible for the suppliers to invest in flexible technologies, thereby enabling them to produce variants of similar components for different manufacturers and/or different final products thus realizing economies of scope as well. Moreover, this standardization and higher upstream concentration results in breakdown of bilateral relations between these suppliers and manufacturers for the following two reasons: (i) Since the parts being manufactured by the upstream suppliers are standardized and form an input to a number of buyers, the asset specificity and danger of opportunistic behavior either by the buyer or the supplier is mitigated. Thus, it is economical for both parties to rely on a market mechanism instead of a contract . (ii) The suppliers' production schedules become less dependent on one manufacturer. Therefore, it becomes increasingly difficult (and less attractive) for the suppliers to adhere to just-in-time norms dictated by the manufacturer. Hence, a market for the intermediate products is created. The final effect of this breakdown of formerly bilateral relations between powerful buyers and small suppliers, and the creation of an open market for standardized components, is that entry of new players into the manufacturing of end-product is made much easier, making the fragmentation of that industry more likely.

Another closely related factor in transformation of supplier-manufacturer relations is the deliberate choices made by the manufacturers during the earlier stages of the product life cycle, especially those related to subcontracting or outsourcing. Technological changes, alongwith the design changes discussed above, can make certain outsourced components central during the later stages of the product cycle, when there are a large number of varieties and increasing commoditization of the end-product. Obvious examples here include Intel and Microsoft. For such suppliers, their ability to innovate and high levels of R&D expenditures are supported by their high profitability (due to high margins on high volumes of basically standardized products). On the extreme, new generations of the end-product are determined by new product innovations of these central suppliers. A similar trend in the automobile industry can be explained by the same arguments.

The above discussion points out certain important directions that we intend to expand upon. First, the cross-industry effects in evolution of market structures have not been stressed enough in the literature, and this, it seems, can be a promising avenue to pursue. Second, certain organizational decisions that may be logical in the short run might have unintended consequences in the long run. For example, increasing market segmentation and expanding the product variety, increasing part commonality and outsourcing, may all lead to increased short-run profits. But in the long run, these actions may be very harmful to the manufacturers as increasing concentration makes both suppliers and the retailers dominant, substantially reducing the bargaining power of the manufacturers as well as the entry barriers to their industry. Third, the conventional wisdom based on the product-process matrix stipulates that, as products mature, the appropriate manufacturing process changes from high flexibility, job-shop type operation to much more dedicated, assembly-line type operation in order to take advantage of higher volumes, high standardization, and lower product varieties. The basis of competition accordingly shifts from unique design capabilities and new product introductions to cost. However, evidence from a number of industries seems to indicate that such a progression no longer adequately describes reality. Alongwith the rapidly shortening product life cycles, it seems frequently to be the case that maturity in an industry is associated with higher, not lower, number of product varieties; and, basis of competition is not cost alone, but cost as well as increasing market segmentation – thus increasing product differentiation. Thus, the product-process matrix should be suitably modified to take account of the changed reality.

A. Appendix A:: Model I: Process Innovation and Channel Structure, Linear Contracts

Case I: Pure Decentralized Structure:

(a) R&D levels:

$$x_i^* = \left[\frac{(2-\theta^2)(8-9\theta^2+2\theta^4)}{\alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2 - b(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)}\right][M-(1-\theta)bc]$$

(b) Unit production cost:

$$c_i^* = c - x_i^* \quad i = 1,2$$

(c) Manufacturer profits:

$$\pi_i^{M^*} = \frac{1}{b}\left[\frac{4-\theta^2}{2-\theta^2}\right](q_i^*)^2 - \alpha(x_i^*)^2$$

(d) Retailer Profits:

$$\pi_i^{R^*} = \frac{1}{b}(q_i^*)^2$$

(e) Wholesale Prices:

$$w_i^* = \frac{M(2+\theta)(4-2\theta^2+\theta) + 2b(2-\theta^2)^2 c_i^* + b\theta(2-\theta^2)c_j^*}{b(4-2\theta^2+\theta)(4-2\theta^2-\theta)}$$

(f). Retail Prices:

$$p_i^* = \frac{2M(2+\theta)(3-\theta^2)(4-2\theta^2+\theta) + b(2-\theta^2)(8-3\theta^2)c_i^* + 2b\theta(2-\theta^2)(3-\theta^2)c_j^*}{b(4-\theta^2)(4-2\theta^2+\theta)(4-2\theta^2-\theta)}$$

(g) Quantities Produced:

$$\begin{aligned} q_i^* &= \frac{(2-\theta^2)}{(4-\theta^2)}\left[\frac{M(2+\theta)(4-2\theta^2+\theta) - b(8-9\theta^2+2\theta^4)c_i^* + b\theta(2-\theta^2)c_j^*}{(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\right] \\ &= \left[\frac{\alpha(4-2\theta^2+\theta)(4-2\theta^2-\theta)}{(8-9\theta^2+2\theta^4)}\right] x_i^* \end{aligned}$$

Case II: Pure Integrated Structure

(a) R&D Levels:

$$x_i^* = \left[\frac{(2-\theta^2)}{\alpha(2-\theta)(4-\theta^2) - b(1-\theta)(2-\theta^2)}\right][M - (1-\theta)bc]$$

(b) Unit production cost:

$$c_i^* = c - x_i^* \quad i = 1, 2$$

(c) Manufacturer Profits:

$$\pi_i^{M^*} = \frac{1}{b}(q_i^*)^2 - \alpha(x_i^*)^2$$

(d) Retail Prices:

$$p_i^* = \frac{M(2+\theta) + 2bc_i^* + b\theta c_j^*}{b(4-\theta^2)}$$

(e) Quantities Produced:

$$q_i^* = \frac{M(2+\theta) - b(2-\theta^2)c_i^* + b\theta c_j^*}{(4-\theta^2)} = \left[\frac{\alpha(4-\theta^2)}{(2-\theta^2)}\right] x_i^*$$

Case III: Mixed Structure

(Note: x^*_{ID} indicates equilibrium R&D level of the integrated manufacturer when the other manufacturer is decentralized, etc.)

(a) R&D Levels:

$$\begin{aligned}
x^*_{ID} &= \frac{(8-9\theta^2+2\theta^4)[2\alpha(2+\theta)(4-2\theta^2+\theta)-b(1+\theta)(2-\theta^2)]}{b^2(1-\theta^2)(2-\theta^2)(8-9\theta^2+2\theta^4)-2\alpha b[(2-\theta^2)^3(4-\theta^2)+(8-9\theta^2+2\theta^4)^2]+8\alpha^2(2-\theta^2)^2(4-\theta^2)^2}[M-(1-\theta)bc)] \\
x^*_{DI} &= \frac{(2-\theta^2)[2\alpha(2+\theta)(2-\theta^2)(4-\theta^2)-b(1+\theta)(8-9\theta^2+2\theta^4)]}{b^2(1-\theta^2)(2-\theta^2)(8-9\theta^2+2\theta^4)-2\alpha b[(2-\theta^2)^3(4-\theta^2)+(8-9\theta^2+2\theta^4)^2]+8\alpha^2(2-\theta^2)^2(4-\theta^2)^2}[M-(1-\theta)bc)]
\end{aligned}$$

(b) Unit production cost:

$$c^*_{ID} = c - x^*_{ID}\,; \;\; c^*_{DI} = c - x^*_{DI}$$

(c) Manufacturer Profits:

$$\begin{aligned}
\pi^{M*}_{ID} &= \left[\frac{M(2+\theta)(4-2\theta^2+\theta)-b(8-9\theta^2+2\theta^4)c^*_{ID}+b\theta(2-\theta^2)c^*_{DI}}{2(2-\theta^2)(4-\theta^2)}\right]^2 - \alpha(x^*_{ID})^2 \\
&= \frac{1}{b}(q^*_{ID})^2 - \alpha(x^*_{ID})^2
\end{aligned}$$

$$\begin{aligned}
\pi^{M*}_{DI} &= \frac{1}{b}\frac{[M(2+\theta)+b\theta c^*_{ID}-b(2-\theta^2)c^*_{DI}]^2}{[4(2-\theta^2)(4-\theta^2)]} - \alpha(x^*_{DI})^2 \\
&= \frac{1}{b}\left[\frac{4-\theta^2}{2-\theta^2}\right](q^*_{DI})^2 - \alpha(x^*_{DI})^2
\end{aligned}$$

(d) Wholesale Prices:

$$w^*_{DI} = \frac{M(2+\theta)+b\theta c^*_{ID}+b(2-\theta^2)c^*_{DI}}{2b(2-\theta^2)}$$

(e) Retail Prices:

$$p^*_{ID} = \frac{M(2+\theta)(4-2\theta^2+\theta)+b(8-3\theta^2)c^*_{ID}+b\theta(2-\theta^2)c^*_{DI}}{2b(2-\theta^2)(4-\theta^2)}$$

$$p^*_{DI} = \frac{M(2+\theta)(3-\theta^2) + b\theta(3-\theta^2)c^*_{ID} + b(2-\theta^2)c^*_{DI}}{b(2-\theta^2)(4-\theta^2)}$$

(f) Quantities Produced:

$$\begin{aligned} q^*_{ID} &= \frac{M(2+\theta)(4-2\theta^2+\theta) - b(8-9\theta^2+2\theta^4)c^*_{ID} + b\theta(2-\theta^2)c^*_{DI}}{2(2-\theta^2)(4-\theta^2)} \\ &= \left[\frac{2\alpha(2-\theta^2)(4-\theta^2)}{(8-9\theta^2+2\theta^4)}\right] x^*_{ID} \\ q^*_{DI} &= \frac{M(2+\theta) + b\theta c^*_{ID} - b(2-\theta^2)c^*_{DI}}{2(4-\theta^2)} \\ &= [2\alpha]x^*_{DI} \end{aligned}$$

(g) Retailer Profits:

$$\begin{aligned} \pi^{R*}_{DI} &= \frac{1}{b}\left[\frac{M(2+\theta) + b\theta c^*_{ID} - b(2-\theta^2)c^*_{DI}}{2(4-\theta^2)}\right]^2 \\ &= \frac{(q^*_{DI})^2}{b} \end{aligned}$$

A. APPENDIX B:: MODEL I: PROOFS

Proof of Proposition 1:

(a) (i) x^{DD} and x^{II}: Using the equilibrium expressions given in Appendix A, we write:

$$\frac{x_{DD}}{x_{II}} = \frac{\alpha(2-\theta)(4-\theta^2)(8-9\theta^2+2\theta^4) - b(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)}{\alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2 - b(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)} \tag{A.1}$$

which is ≤ 1 if the numerator $\leq$ denominator. Therefore, $x_{DD} \leq x_{II}$ if:

$$\alpha(2-\theta)(4-\theta^2)(8-9\theta^2+2\theta^4) \leq \alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2$$

which simplifies to:

$$32 - 16\theta - 56\theta^2 + 17\theta^3 + 33\theta^4 - 4\theta^5 - 6\theta^6 \geq 0 \tag{A.2}$$

Condition (A.2) holds for all $\theta \in [0,1]$. As $\theta \to 1$, numerator and denominator become equal, and thus $x_{DD} \to x_{II}$.

(ii) x^{ID} and x^{DI}: Again, from Appendix A, we write:

$$\frac{x_{ID}}{x_{DI}} = \frac{2\alpha(2+\theta)(4-2\theta^2+\theta)(8-9\theta^2+2\theta^4) - b(1+\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)}{2\alpha(2+\theta)(2-\theta^2)^2(4-\theta^2) - b(1+\theta)(2-\theta^2)(8-9\theta^2+2\theta^4)} \tag{A.3}$$

Therefore, $x_{ID} \geq x_{DI}$ if

$$2\alpha(2+\theta)(4-2\theta^2+\theta)(8-9\theta^2+2\theta^4) \geq 2\alpha(2+\theta)(2-\theta^2)^2(4-\theta^2)$$

or,

$$16 + 8\theta - 32\theta^2 - 9\theta^3 + 18\theta^4 + 2\theta^5 - 3\theta^6 \geq 0 \tag{A.4}$$

which holds for all θ (equality at $\theta = 1$).

(b) (i) $\underline{x^{DI} \text{ and } x^{II}}$: In this case, we have $\frac{x_{DI}}{x_{II}} =$

$$\frac{[2\alpha(2+\theta)(2-\theta^2)(4-\theta^2) - b(1+\theta)(8-9\theta^2+2\theta^4)][\alpha(2-\theta)(4-\theta^2) - b(1-\theta)(2-\theta^2)]}{b^2(1-\theta^2)(2-\theta^2)(8-9\theta^2+2\theta^4) - 2\alpha[(2-\theta^2)^2(4-\theta^2)\{b(2-\theta^2) - 4\alpha(4-\theta^2)\} + b(8-9\theta^2+2\theta^4)^2]}$$

Therefore, $x_{DI} < x_{II}$ if numerator < denominator in the above equation, or if:

$$\alpha > b\left[\frac{2\theta(2-\theta^2)^2(4-\theta^2) + (8-9\theta^2+2\theta^4)(8-4\theta-12\theta^2+\theta^3+3\theta^4}{2(2-\theta^2)(4-\theta^2)^2(4-3\theta^2)}\right] \tag{A.5}$$

Now note that the right hand side of (A.5) is $\leq b/4$ for all θ, and recall from section 6.3 that second-order conditions for manufacturers' profit maximization require $\alpha > b/4$. Hence, $x_{DI} < x_{II}\, \forall \theta$.

(c) (i) $\underline{x^{ID} \text{ and } x^{DD}}$: Following the same procedure as above and using expressions from Appendix A, we find the required conditions.

Proof of Proposition 4:

(a) We first prove the relations between retail prices. Note from Appendix A that the equilibrium retail price (p_i) under any structure increases monotonically in the unit production cost (c_i).

(i) $\underline{p^{DD} \text{ and } p^{II}}$:

Now, from proposition 3, we have $x^*_{DD} \leq x^*_{II}$ which implies $c^*_{DD} \geq c^*_{II}$. Let p^*_l represent p_l evaluated at c^*_l, $l = DD, II$, and p^* represent p_{DD} evaluated at c^*_{II}. Then, $p^*_{DD} \geq p^*$. In order to show that $p^*_{DD} \geq p^*_{II}$, it thus suffices to show that $p^* \geq p^*_{II}$. From Appendix A, we can write:

$$p^* = \frac{2M(3-\theta^2) + bc^*_{II}(2-\theta^2)}{b(2-\theta)(4-2\theta^2-\theta)}$$

Therefore, we get:

$$p^* - p^*_{II} = \frac{(2+\theta)[M - b(1-\theta)c^*_{II}]}{b(2-\theta)(4-2\theta^2-\theta)}$$

which is ≥ 0 for all θ. Hence the result.

(ii) p^{ID} and p^{DI}: Here, we write using expressions in Appendix A:

$$p^*_{DI} - p^*_{ID} = \frac{M(2+\theta)(2-\theta) - b(8-6\theta-3\theta^2+2\theta^3)c^*_{ID} + b(4-2\theta-2\theta^2+\theta^3)c^*_{DI}}{2b(2-\theta^2)(4-\theta^2)} \tag{A.6}$$

which can be written as:

$$p^*_{DI} - p^*_{ID} = A - vc^*_{ID} + wc^*_{DI} \tag{A.7}$$

where $v = \frac{(8-6\theta-3\theta^2+2\theta^3)}{2(2-\theta^2)(4-\theta^2)}$ implies that $0 < v < 1 \forall\theta$; and, $w = \frac{(4-2\theta-2\theta^2+\theta^3)}{2(2-\theta^2)(4-\theta^2)}$ implies that $0 < w < 1 \forall\theta$. Now, from proposition 3 we have: $x^*_{ID} \geq x^*_{DI}, \forall\theta$, which implies $c^*_{ID} \leq c^*_{DI}, \forall\theta$, or $vc^*_{ID} \leq vc^*_{DI}$. From (A.7), $p^*_{DI} \geq p^*_{ID}$ if $A + wc^*_{DI} \geq vc^*_{ID}$. It thus suffices to prove that $A + wc^*_{DI} \geq vc^*_{DI}$. Now,

$$\begin{aligned} A + wc^*_{DI} - vc^*_{DI} &= A - (v-w)c^*_{DI} \\ &= \tfrac{1}{2b(2-\theta^2)}[M - b(1-\theta)c^*_{DI}] \\ &\geq 0 \ \forall\theta \end{aligned}$$

(b) Note here that (q_i) under any structure decreases in the unit production cost (c_i). The proof is similar to the one given above. (Alternatively, we get the result directly by using expressions in Appendix A and proposition 3.)

Proof of Proposition 6:

(a) Differentiating the appropriate expressions for quantities produced (q_i) under various structures (from Appendix A) with respect to R&D level (x_i), we get:

$$\begin{aligned} \tfrac{\partial}{\partial x_i}(q^*_i)_{DD} &= \left[\tfrac{2-\theta^2}{4-\theta^2}\right]\left[\tfrac{b(8-9\theta^2+2\theta^4)}{(4-2\theta^2+\theta)(4-2\theta^2-\theta)}\right] & \tfrac{\partial}{\partial x_i}(q^*_i)_{II} &= \tfrac{b(2-\theta^2)}{4-\theta^2} \\ \tfrac{\partial}{\partial x_i}(q^*_i)_{ID} &= \tfrac{b(8-9\theta^2+2\theta^4)}{2(2-\theta^2)(4-\theta^2)} & \tfrac{\partial}{\partial x_i}(q^*_i)_{DI} &= \tfrac{b(2-\theta^2)}{2(4-\theta^2)} \end{aligned}$$

The result follows from direct comparison of the above. Similarly, differentiating q_i with respect to x_j and comparing proves part (b).

A. Appendix C:: Model II: Process Innovation and Channel Coordination, Franchising Contracts

Case I: Pure Decentralized

$$x_i^* = \frac{\theta^2\left(2-\theta^2\right)\left(4-3\theta^2\right)}{\alpha\left(4+2\theta-\theta^2\right)\left(4-2\theta-\theta^2\right)^2 - b\theta^2\left(1-\theta\right)\left(2-\theta^2\right)\left(4-3\theta^2\right)}\left[M-(1-\theta)bc\right]$$

$$w_i = \frac{M\theta^2\left(4+2\theta-\theta^2\right)+4b\left(2-\theta^2\right)^2 c_i+\theta^3(2-\theta^2)bc_j}{b\left(4+2\theta-\theta^2\right)\left(4-2\theta-\theta^2\right)}$$

$$p_i = \frac{2M\left(4+2\theta-\theta^2\right)+b\left(2-\theta^2\right)\left(4-\theta^2\right)c_i+2b\theta(2-\theta^2)c_j}{b\left(4+2\theta-\theta^2\right)\left(4-2\theta-\theta^2\right)}$$

$$q_i^* = \left(2-\theta^2\right)\left[\frac{M\left(4+2\theta-\theta^2\right)-b\left(4-3\theta^2\right)c_i+\theta b\left(2-\theta^2\right)c_j}{\left(4+2\theta-\theta^2\right)\left(4-2\theta-\theta^2\right)}\right]$$

$$\pi_i^M = \left(\frac{\theta^2}{b(2-\theta^2)}\right)\left[q_i^*\right]^2-\alpha(x_i^*)^2$$

$$\pi_i^S = \frac{1}{b}(q_i^*)^2$$

$$\pi_i^{CH} = \frac{2(q_i^*)^2}{b(2-\theta^2)}-\alpha(x_i^*)^2$$

Case II: Pure Integrated:

(same as in Appendix A)

Case III: Mixed Structure

$$x_{ID} = \frac{(4-3\theta^2)\,[4\alpha\,(4+2\theta-\theta^2) - b\theta^2\,(1+\theta)\,(2-\theta^2)][M-(1-\theta)bc]}{b^2\theta^2\,(1-\theta^2)\,(2-\theta^2)\,(4-3\theta^2) + 64\,(2-\theta^2)^2\,\alpha^2 - 4\alpha b((4-3\theta^2)^2 + \theta^2\,(2-\theta^2)^3)}$$

$$x_{DI} = \frac{\theta^2(2-\theta^2)[4\alpha\,(2+\theta)\,(2-\theta^2) - b\,(1+\theta)\,(4-3\theta^2)][M-(1-\theta)bc]}{b^2\theta^2\,(1-\theta)\,(1+\theta)\,(2-\theta^2)\,(4-3\theta^2) + 64\,(2-\theta^2)^2\,\alpha^2 - 4\alpha b((4-3\theta^2)^2 + \theta^2\,(2-\theta^2)^3)}$$

$$w_{DI} = \frac{M\theta^2\,(2+\theta) + \theta^3 bc_1 + b\,(2-\theta^2)\,(4-\theta^2)\,c_2}{4b\,(2-\theta^2)}$$

$$p_{ID} = \frac{M\,(4+2\theta-\theta^2) + b(4-\theta^2)c_1 + b\theta(2-\theta^2)c_2}{4b\,(2-\theta^2)}$$

$$p_{DI} = \frac{M\,(2+\theta) + \theta bc_1 + b(2-\theta^2)c_2}{2b\,(2-\theta^2)}$$

$$q_{ID} = \frac{M\,(4+2\theta-\theta^2) - b(4-3\theta^2)c_1 + b\theta(2-\theta^2)c_2}{4\,(2-\theta^2)}$$

$$q_{DI} = \frac{M(2+\theta) + b\theta c_1 - b(2-\theta^2)c_2}{4}$$

$$\pi^M_{ID} = \frac{1}{b}\,[q^*_{ID}]^2 - \alpha(x_{ID})^2$$

$$\pi^M_{DI} = \left[\frac{\theta^2}{b(2-\theta^2)}\right][q^*_{DI}]^2 - \alpha(x_{DI})^2$$

$$\pi^R_{DI} = \frac{1}{b}\,[q^*_{DI}]^2$$

$$\pi^{CH}_{DI} = \left[\frac{2}{b(2-\theta^2)}\right][q^*_{DI}]^2 - \alpha(x_{DI})^2$$

A. APPENDIX D:: MODEL III: RESEARCH JOINT VENTURES, PROOFS

Proof of Proposition 11:

(i) x^C and x^{CJ}: Recall that x^C is determined from equation 6.18 and x^{CJ} from equation 6.22. Therefore, evaluating left hand side of equation 6.22 at x^C and substituting from equation 6.18 yields:

$$q_i^N(\bar{x}^C)(n-1)[\frac{\partial}{\partial x_j}c(x_i^C, \bar{x}_{-i}^C) - \frac{\partial}{\partial x_i}c(x_i^C, \bar{x}_{-i}^C)]$$

Since $(\partial/\partial x_j)c(.) \geq (\partial/\partial x_i)c(.)$ by assumption 6.3.0.2, we have that $x^{CJ} \geq x^C$; equality only if $(\partial/\partial x_j)c(.) = (\partial/\partial x_i)c(.)$.

(For the special case of Kamien et al., $(\partial/\partial x_i)c(.) = -f'(X)$, $(\partial/\partial x_j)c(.) = -\beta f'(X)$, and therefore, from above, $X^{CJ} \geq X^C$; equality if $\beta = 1$.)

(ii) x^N and x^{NJ}: Recall that x^N is determined from equation 6.3 which, using (6.1) and symmetry, can be rewritten as:

$$[-q_i^N(\bar{x}^N)\frac{\partial}{\partial x_i}c(x_i^N, \bar{x}_{-i}^N) - 1] + (n-1)q_i^N(\bar{x}^N)\frac{\partial}{\partial q_j}p_i(\bar{q}^N(\bar{x}^N))\,\theta(\bar{x}^N) = 0 \qquad (A.1)$$

Now, substituting for $\theta(\bar{x}^N)$ above from equation 6.14, we get the following as the equation determining x^N:

$$\begin{aligned}&[-q_i^N(\bar{x}^N)\tfrac{\partial}{\partial x_i}c(x_i^N, \bar{x}_{-i}^N) - 1] + (n-1)q_i^N(\bar{x}^N)\tfrac{\partial}{\partial q_j}p_i(\bar{q}^N(\bar{x}^N))\\ &\tfrac{1}{\Delta(\bar{x}^N)}\left\{\zeta(\bar{x}^N)[\tfrac{\partial}{\partial x_j}c(x_i^N, \bar{x}_{-i}^N) - \tfrac{\partial}{\partial x_i}c(x_i^N, \bar{x}_{-i}^N)] + [\zeta(\bar{x}^N) - \eta(\bar{x}^N)]\tfrac{\partial}{\partial x_i}c(x_i^N, \bar{x}_{-i}^N)\right\} \;=\; 0 \qquad (A1)\end{aligned}$$

Similarly, the equation determining x^{NJ} (model II.B) can be written as:

$$\begin{aligned}&[-q_i^N(\tilde{x}^N)\tfrac{\partial}{\partial x_i}c(x_i^N,\tilde{x}_{-i}^N)-1]+(n-1)q_i^N(\tilde{x}^N)\tfrac{\partial}{\partial q_j}p_i(\tilde{q}^N(\tilde{x}^N))\\ &\tfrac{1}{\Delta(\tilde{x}^N)}[\zeta(\tilde{x}^N)-\eta(\tilde{x}^N)]\tfrac{\partial}{\partial x_i}c(x_i^N,\tilde{x}_{-i}^N) \qquad = \quad 0 \qquad (A2)\end{aligned}$$

A simple comparison of the two equations shows that $x^N \geq x^{NJ}$ (since $(\partial/\partial q_j)p_i(.) < 0$; $\zeta(.) < 0$; $\Delta(.) > 0$; and $\frac{\partial}{\partial x_j}c(.) - \frac{\partial}{\partial x_i}c(.) \geq 0$.

(iii) <u>x^N and x^C</u>: Equation 6.18 determines x^C. Evaluating the left hand side of that equation at x^N and substituting from equation A.1, we are left with the following:

$$(n-1)q_i^N(\tilde{x}^N)\{\frac{\partial}{\partial q_j}p_i(\tilde{q}^N(\tilde{x}^N))[\omega(\tilde{x}^N)+(n-2)\theta(\tilde{x}^N)]-\frac{\partial}{\partial x_j}c(x_i^N,\tilde{x}_{-i}^N)$$

Hence, $x^C \geq x^N$ iff condition (6.23) holds.

A. Appendix E:: Model IV: Research Joint Ventures and Vertical Channel Structure

The equilibrium expressions for R&D and output levels under each vertical structure, for each of the four institutional arrangements, are given below. All other expressions (profits, prices etc) are obtained by substituting the relevant x_i^* from the following, alongwith $c_i^* = c - x_i^* - \gamma x_j^*$ into the corresponding equations in Appendix A.

Case I: Pure Decentralized

(a): R&D Competition

$$\begin{aligned} x^*_{DD}(N) &= \frac{(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))[M-(1-\theta)bc]}{\alpha(2-\theta)(4-2\theta^2+\theta)(4-2\theta^2-\theta)^2-b(1+\gamma)(1-\theta)(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))} \\ q^*_{DD}(N) &= \frac{\alpha(4-2\theta^2+\theta)(4-2\theta^2-\theta)}{(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))} x^*_{DD}(N) \end{aligned}$$

(b): R&D Cartel

$$\begin{aligned} x^*_{DD}(C) &= \frac{(1+\gamma)(1-\theta)(2+\theta)(2-\theta^2)[M-(1-\theta)bc]}{\alpha(2-\theta)(4-2\theta^2-\theta)^2-b(1+\gamma)^2(1-\theta)^2(2+\theta)(2-\theta^2)} \\ q^*_{DD}(C) &= \frac{\alpha\,(4-2\theta^2-\theta)}{(1+\gamma)\,(1-\theta)\,(2+\theta)} x^*_{DD}(C) \end{aligned}$$

(c): RJV Competition

$$x^*_{DD}(NJ) = \frac{(1-\theta)(2+\theta)(2-\theta^2)}{\alpha(2-\theta)(4-2\theta^2-\theta)^2-2b(1-\theta)^2(2+\theta)(2-\theta^2)}[M-(1-\theta)bc]$$

(d): RJV Cartel

$$x^*_{DD}(CJ) = \frac{2(1-\theta)(2+\theta)(2-\theta^2)}{\alpha(2-\theta)(4-2\theta^2-\theta)^2-4b(1-\theta)^2(2+\theta)(2-\theta^2)}[M-(1-\theta)bc]$$

Case II: Pure Integrated

(a): R&D Competition

$$\begin{aligned} x^*_{II}(N) &= \frac{(2-\gamma\theta-\theta^2)}{\alpha(2+\theta)(2-\theta)^2-b(1+\gamma)(1-\theta)(2-\gamma\theta-\theta^2)}[M-(1-\theta)bc] \\ q^*_{II}(N) &= \frac{\alpha(4-\theta^2)}{(2-\gamma\theta-\theta^2)}x^*_{II}(N) \end{aligned}$$

(b): R&D Cartel

$$\begin{aligned} x^*_{II}(C) &= \frac{(1+\gamma)(1-\theta)}{\alpha(2-\theta)^2-b(1+\gamma)^2(1-\theta)^2}[M-(1-\theta)bc] \\ q^*_{II}(C) &= \frac{\alpha\,(2-\theta)}{(1+\gamma)\,(1-\theta)}x^*_{II}(C) \end{aligned}$$

(c): RJV Competition

$$x^*_{II}(NJ) = \frac{(1-\theta)}{\alpha(2-\theta)^2-2b(1-\theta)^2}[M-(1-\theta)bc]$$

(d): RJV Cartel

$$x^*_{II}(CJ) = \frac{2(1-\theta)}{\alpha(2-\theta)^2-4b(1-\theta)^2}[M-(1-\theta)bc]$$

Case III: Mixed Structure

(Note: x^*_{ID} indicates equilibrium R&D level of the integrated manufacturer when the other manufacturer is decentralized, etc.)

(a): R&D Competition

$$x^*_{ID}(N) = \frac{num_1}{den_1}[M-(1-\theta)bc] \text{ and } x^*_{DI}(N) = \frac{num_2}{den_2}[M-(1-\theta)bc]$$

where

$$\begin{aligned}
num_1 &= (8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))(2\alpha(2+\theta)(4-2\theta^2+\theta)-b(1-\gamma)(1+\theta)(2-\gamma\theta-\theta^2)) \\
num_2 &= (2-\gamma\theta-\theta^2)(2\alpha(2+\theta)(2-\theta^2)(4-\theta^2)-b(1-\gamma)(1+\theta)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2) \\
den_1 &= den_2 \\
&= b^2(1-\gamma^2)(1-\theta^2)(2-\gamma\theta-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2)) \\
&\quad -2b\alpha((2-\theta^2)(4-\theta^2)(2-\gamma\theta-\theta^2)^2 \\
&\quad +(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))^2)+8\alpha^2(2-\theta^2)^2(4-\theta^2)^2
\end{aligned}$$

and

$$\begin{aligned}
q^*_{ID}(N) &= \frac{2\alpha\,(2-\theta^2)\,(4-\theta^2)}{(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}x^*_{ID}(N) \\
q^*_{DI}(N) &= \frac{2\alpha\,(2-\theta^2)}{(2-\gamma\theta-\theta^2)}x^*_{DI}(N)
\end{aligned}$$

(b): R&D Cartel

$$x^*_{ID}(C)=\frac{num_3}{den_3}[M-(1-\theta)bc] \text{ and } x^*_{DI}(N)=\frac{num_4}{den_4}[M-(1-\theta)bc]$$

where

$$\begin{aligned}
num_3 &= (1-\theta)\,(2+\theta)[\alpha(\gamma\,(2-\theta^2)\,(8+4\theta-3\theta^2-\theta^3) \\
&\quad +(4\theta^5+3\theta^4-23\theta^3-20\theta^2+32\theta+32))-b(1-\gamma)(1-\gamma^2)(1+\theta)^2(2-\theta)(2-\theta^2)] \\
num_4 &= (1-\theta)\,(2+\theta)[\alpha((2-\theta^2)\,(8+4\theta-3\theta^2-\theta^3) \\
&\quad +\gamma\,(4\theta^5+3\theta^4-23\theta^3-20\theta^2+32\theta+32))-b(1-\gamma)(1-\gamma^2)(1+\theta)^2(2-\theta)(2-\theta^2)] \\
den_3 &= den_4 \\
&= b^2(1-\gamma^2)^2(1-\theta^2)^2(2-\theta^2)(4-\theta^2)-b\alpha((1+\gamma^2)\,(3-\theta^2)\,(32-52\theta^2+29\theta^4-5\theta^6) \\
&\quad -4\gamma\theta\,(2-\theta^2)\,(16-15\theta^2+3\theta^4))+4\alpha^2(2-\theta^2)^2(4-\theta^2)^2
\end{aligned}$$

and

$$\begin{aligned}
q^*_{ID}(C) &= \frac{\alpha\,(2-\theta^2)\,(4-\theta^2)\,(2\alpha\,(2+\theta)\,(4-2\theta^2+\theta)-b\,(1-\gamma)^2\,(1+\theta)^2\,(2-\theta))}{num_3}x^*_{ID}(C) \\
q^*_{DI}(C) &= \frac{\alpha\,(2-\theta)\,(2-\theta^2)\,(2\alpha\,(2+\theta)^2\,(2-\theta^2)-b\,(1-\gamma)^2\,(1+\theta)^2\,(4-2\theta^2-\theta))}{num_4}x^*_{DI}(C)
\end{aligned}$$

(c): RJV Competition

$$
\begin{aligned}
x^*_{ID}(NJ) &= \frac{(1-\theta)(4-2\theta^2+\theta)^2}{4\alpha(2-\theta)^2(2-\theta^2)^2-b(1-\theta)^2(24-21\theta^2+5\theta^4+8\theta-4\theta^3)}[M-(1-\theta)bc] \\
x^*_{DI}(NJ) &= \frac{(1-\theta)(2-\theta^2)(4-\theta^2)}{4\alpha(2-\theta)^2(2-\theta^2)^2-b(1-\theta)^2(24-21\theta^2+5\theta^4+8\theta-4\theta^3)}[M-(1-\theta)bc]
\end{aligned}
$$

(d): RJV Cartel

$$
\begin{aligned}
x^*_{ID}(CJ) &= x^*_{DI}(CJ) \\
&= \frac{(1-\theta)(24-21\theta^2+5\theta^4+8\theta-4\theta^3)}{4\alpha(2-\theta)^2(2-\theta^2)^2-2b(1-\theta)^2(24-21\theta^2+5\theta^4+8\theta-4\theta^3)}[M-(1-\theta)bc]
\end{aligned}
$$

A. APPENDIX F:: MODEL IV: SUMMARY OF SECOND-ORDER AND STABILITY CONDITIONS

I. R&D Competition

1. (DD):

stability condition depends on value of gamma:

a) for $\gamma < \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}$, the condition is:

$\frac{\alpha}{b} > (1-\gamma)\frac{(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2}(8-9\theta^2+2\theta^4+\theta(2-\theta^2))$

so $\frac{\alpha}{b} > 0.125$ is OK

b) for $\gamma > \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}$, the condition is:

$\frac{\alpha}{b} > (1+\gamma)\frac{(2-\theta^2)(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{(4-\theta^2)(4-2\theta^2+\theta)^2(4-2\theta^2-\theta)^2}(8-9\theta^2+2\theta^4-\theta(2-\theta^2))$

so $\frac{\alpha}{b} > 0.25$ or $\frac{b}{\alpha} < 4$ is good for both cases

2. (II)

a) for $\gamma < \frac{\theta}{2-\theta^2}$, the stability condition is:

$\frac{\alpha}{b} > (1-\gamma)\frac{(2-\gamma\theta-\theta^2)}{(4-\theta^2)^2}(2+\theta-\theta^2)$

so $\frac{\alpha}{b} > 0.27$ (approx.)

b) for $\gamma > \frac{\theta}{2-\theta^2}$, the stability condition is:

$\frac{\alpha}{b} > \frac{(2-\gamma\theta-\theta^2)}{(4-\theta^2)^2}(2+\theta)(1-\theta)(1+\gamma)$

so $\frac{\alpha}{b} > 0.5$ or $\frac{b}{\alpha} < 2$ is good for both

3. (ID)

a) for $\gamma > \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}$, the stability condition is:

$(1+\gamma)\frac{(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{4(2-\theta^2)^2(4-\theta^2)^2}(\theta-1)(\theta+2)(2\theta^2-\theta-4)$

b) for $\gamma < \frac{\theta(2-\theta^2)}{(8-9\theta^2+2\theta^4)}$, the condition is:

$(1-\gamma)\frac{(8-9\theta^2+2\theta^4-\gamma\theta(2-\theta^2))}{4(2-\theta^2)^2(4-\theta^2)^2}(8-9\theta^2+2\theta^4+\theta(2-\theta^2))$

So $\frac{\alpha}{b} > 0.5$ or $\frac{b}{\alpha} < 2$ is good for both.

4. (DI):

a) for $\gamma > \frac{\theta}{2-\theta^2}$, the stability condition is:

$(1+\gamma)\frac{(2-\gamma\theta-\theta^2)}{4(2-\theta^2)(4-\theta^2)}(2-\theta-\theta^2)$

b) for $\gamma < \frac{\theta}{2-\theta^2}$, the stability condition is:

$(1-\gamma)\frac{(2-\gamma\theta-\theta^2)}{4(2-\theta^2)(4-\theta^2)}(2-\theta^2+\theta)$

so $\frac{\alpha}{b} > 0.25$ or $\frac{b}{\alpha} < 4$ is good for both.

Hence, the relevant parameter range in case of R&D Competition is $\frac{b}{\alpha} < 2$ to ensure stability of equilibria under all the vertical structures analyzed. Other cases (R&D Cartel etc) are worked out similarly.

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