The Dissertation Committee for Sadik Sinan Erzurumlu
certifies that this is the approved version of the following dissertation:

Competition and Collaboration Issues in Technology Development and Deployment

Committee:

Stephen M. Gilbert, Supervisor

Edward Anderson

Uttarayan Bagchi

Vijay Mahajan

Douglas Morrice

Competition and Collaboration Issues in Technology Development and Deployment

by

Sadik Sinan Erzurumlu, B.S., M.S.

DISSERTATION

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

DOCTOR OF PHILOSOPHY

THE UNIVERSITY OF TEXAS AT AUSTIN

August 2007

To my Family: Arikan, Sezen and Omer Erzurumlu,

for their love and support.

Acknowledgments

First of all, I would like to thank my advisor, Prof. Steve Gilbert, for his help, support and guidance during my studies and working on this dissertation. He has been a great example as an academic, a scholar and I have learned from him immensely. Especially, without his insights, patience and support, this work would not have been completed.

I would also like to thank my committee members: Professors Edward Anderson, Uttarayan Bagchi, Vijay Mahajan and Douglas Morrice. Their comments and feedback have helped me lift this work. They also have been great sources of support and inspiration in making this dissertation possible and building my academic career. Thanks are also due to Professor Nitin Joglekar where his support and guidance for my career has been extremely valuable to me.

At McCombs I have also had the opportunity to collaborate with wonderful and smart friends, Karthik Ramachandran, Sreekumar Bhaskaran, and Fehmi Tanrisever. My research experience and friendship with them have made my academic life incredibly fun and interesting. And all my friends that I have made over the years at McCombs and in Austin have enriched my life and made my studies and stay in Austin a memorable one. Their presence turned Austin into a true home that I will cherish all my life.

My family has always proved to be there for me. They have given me the most that parents could provide: No matter what the outcome would be, they always showed their support and love and encouraged me to find out the best in me. Behind all of my accomplishments their presence, guidance and now friendship had provided me the supportive environment I needed in work and life.

Competition and Collaboration Issues in Technology Development and Deployment

Publication No. ____________________

Sadik Sinan Erzurumlu, Ph.D.
The University of Texas at Austin, 2007

Supervisor: Stephen M. Gilbert

In today's marketplace firms have to become specialized in specific technological aspects in product development due to intensifying competition. Further, the increasing complexity of offerings make firms become more dependent on other value-chain contributors such as providers of complementary and component technologies. Therefore, in addition to the inherent market appeal of a product, a successful introduction may depend on the firm's interactions with suppliers and even "competitors". These interactions with other firms in the marketplace present a unique set of challenges to firms. In this dissertation, we explore how a firm's approach to interacting with supply chain partners and/or competitors may depend upon how its product provides value to consumers.

In the first essay, we look into how a firm should design the interdependence between a durable good and a consumable such as a printer and a

cartridge and utilize the benefits of an industry of generic consumable suppliers. In the second essay, we analyze the different approaches that firms adopt while commercializing their technologies to competitors in a networked environment (such as telecommunications). We identify the impact of the competitor's development capabilities on the trade-off between the increased competition and network benefits. In the third essay, we explore situations in which firms collaborate to develop a component innovation that they later market individually; they codevelop and jointly market; and they choose to individually develop and market. We consider how competitive strategies between development partners should consider the influence of supplier formation on the investment incentives of an OEM. In summary, this dissertation examines how the management of interactions with supply chain partners and competitors can play an important role in technology development and deployment. Our results highlight key trade-offs and provide insights for managers who are involved in developing and deploying new products.

Table of Contents

Acknowledgments **v**

Abstract **vii**

List of Tables **xii**

List of Figures **xiii**

Chapter 1. Executive Summary **1**

Chapter 2. Managing Revenue Streams for Durable Products with Contingent Services or Consumable Components **6**

2.1 Introduction 6
2.2 Literature Review 9
2.3 Model 13
2.3.1 Formulation of the Manufacturer's Optimization Problem 16
2.4 Analysis and Results 23
2.4.1 Incompatible Consumables 23
2.4.2 Compatible Competitive Consumables 31
2.4.3 Optimal Design Strategy 39
2.5 Conclusion 44

Chapter 3. Commercializing Component Innovations: The Roles of Firm Capabilities and Network Effects **48**

3.1 Introduction 48
3.2 Literature Review 52
3.3 Model 56
3.3.1 The Market 57
3.3.2 The Innovator and the Licensing Opportunity 58

3.3.3 Strategies for the Innovator 62
3.4 Commercialization in Uncontested Markets 65
3.4.1 Interactions with a Weaker Licensee 65
3.4.2 Interactions with a Stronger Licensee 71
3.5 Licensing Innovations in Contested Markets 77
3.5.1 Interactions with a Weaker Rival 80
3.5.2 Interactions with a Stronger Rival 83
3.6 Conclusions 85

Chapter 4. Collaborating with Competitors in New Product Development 91
4.1 Introduction 91
4.2 Literature Review 96
4.3 Model 100
4.4 Analysis 104
4.4.1 Strategic Supplier Formations 106
4.4.2 Equilibria Analysis for Supplier Formations 109
4.5 Conclusions 114

Chapter 5. Conclusions and Directions for Future Research 118

Appendices 121

Appendix A. Managing Revenue Streams for Durable Products with Contingent Services or Consumable Components 122
A.1 Construction of the Steady State Solution 122

Appendix B. Commercializing Component Innovations: The Roles of Firm Capabilities and Network Effects 125
B.1 Proof of Proposition 3.4.1 ($\alpha < 1$) 125
B.2 Proof of Corollary 3.4.2 ($\alpha < 1$) 126
B.3 Proof of Proposition 3.4.3 ($\alpha > 1$) 126
B.4 Proof of Proposition 3.5.1 127
B.5 Proof of Proposition 3.5.2 128

B.6 Commercializing Persistently Incompatible Innovations 128
B.7 Proof of Proposition 3.5.3 129

Appendix C. Collaborating with Competitors in New Product Development 131

C.0.1 Proof of Proposition 4.4.3 131

Bibliography 132

Vita 142

List of Tables

2.1 The Manufacturer's Profits when no generic consumable is compatible. 27

2.2 The Manufacturer's Profits when generic consumables are compatible. 36

3.1 Threshold Values 89

B.1 Commercialization Strategy in an Uncontested Market with a Strong Rival 126

List of Figures

2.1 Market Segmentation for Consumers with different valuations. 18

2.2 Optimal Strategies for the Incompatible Manufacturer 31

2.3 Optimal Strategies for a Compatible Manufacturer when $s_{d2} = 0.85$, $s_G = 0.5$, $p_G = 0.2$. 39

2.4 Optimal Design Strategies for the Manufacturer when $s_{d2} = 0.85$, $s_G = 0.5$, $p_G = 0.2$ 41

2.5 Optimal Design Strategies for the Manufacturer when $s_{d2} = 0.85$, $s_G = 0.6$, $p_G = 0.1$. 44

3.1 Profit Difference Curves for the Licensor between Licensing to a Weaker Licensee and Captively Using the Innovation in an Uncontested Market, for the values of $\theta = 0.5$ and $\theta = 0.6$. . . 70

3.2 Commercialization Strategy in an Uncontested Market with a Strong rival for various values of α and θ. 76

4.1 Optimal Supplier Formations, $s = 0.8$ and $c = 0.2$. 114

Chapter 1

Executive Summary

In today's marketplace firms have to become specialized in specific technological aspects in product development due to intensifying competition. Further, the increasing complexity of offerings make firms become more dependent on other value-chain contributors such as providers of complementary and component technologies. Therefore, in addition to the inherent market appeal of a product, a successful introduction may depend on the firm's interactions with suppliers and even "competitors". These interactions with other firms in the marketplace present a unique set of challenges to firms.

In this dissertation, we explore how a firm's approach to interacting with supply chain partners and/or competitors may depend upon how its product or innovation provides value to consumers. Specifically, we focus on three strategic collaborative and competitive issues related to product design, product development, technology development and deployment: the interdependence between a durable good and a contingent consumable; the commercialization of a component innovation in an environment that has network externalities; and the formation of strategic development alliances among competitors that supply a critical component to an original equipment manufacturer (OEM).

The manner in which the product provides value to the consumers can change the strategy that the firm would consider against its competitors. In chapter 2, we explore this issue further in the context of a durable good and a contingent service or consumable. Many durable products provide value only when used together with contingent services or consumables, such as printers and ink, electronic products and batteries, automobiles and maintenance and repair services. The interdependence between the durable good and the consumable creates a stream of revenues for the durable good manufacturer from the consumable sales over the lifetime of the durable good. In fact, many manufacturers of such durable products have come to rely primarily upon the revenues generated from the contingent services or consumables as the primary source of profitability. Therefore, the manufacturer's decision to make a durable good compatible with generic consumables becomes not only a design decision, but an important aspect of the manufacturer's market strategy, particularly when the potential entrants also compete with the manufacturer in the consumable market. However, observation from practice suggests that some manufacturers allow the use of generic components with their durable goods, while some do not.

Therefore, to better understand the impact of the interdependence between a durable good and its contingent consumable on the manufacturer's product design, we examine the conditions under which it is beneficial for the manufacturer to exploit the availability of generic substitutes for the consumable by designing its product to be compatible with them. We identify situations in which the manufacturer should design its product to be incompatible with generic consumables and other situations in which it would benefit from designing its durable so that consumers could substitute other manufacturers' consumables. We find that consumers' willingness to pay increases by their rational expectations of the future value of their durable good and the availability of more affordable consumables. Our results suggest that the provision of a consumable by a third party may affect consumer expectations of future prices of new and used durables and the manufacturer can benefit from the presence of this third party competition.

Commercialization of a component innovation is also significantly determined by the inter-firm relationships. When a firm develops an innovation with respect to one particular component, other firms that posses different capabilities in other components may be more or less able to exploit the innovation than the innovator. In chapter 3, we specifically examine not only the benefits of the increased network effects, but also the rival's ability to integrate the component technology with its own product. We focus our analysis on industries that are characterized by modular product architectures, vertically differentiated products and network effects. e.g. cellular phones, interactive software, media players, etc. First, we analyze the different approaches that firms adopt while commercializing their technologies to competitors in a networked environment. Next we identify the impact of the competitor's development capabilities on the trade-off between the increased competition and network benefits. Our results suggest that the innovator is generally more willing to share (license or sell-out) her component technology with competitors whose capability to develop other components for the product and integrate it with the component technology are significantly different from her own abilities. This interaction between component innovators and competitors offers a potential explanation for why many technological firms engage in innovation transfer despite the potential of dominating the market with their technology.

Firms seek ways of interacting with external partners and/or competitors to best utilize their know-how and expertise. In particular, the strategic alliances and joint ventures could improve a firm's ability to influence the decisions of other participants and non-participants in the collaboration and hence, its profits. Without understanding the impact of the alliance formation on the nature of the supply chain, firms may face profound consequences in maximizing their profits. Therefore, in chapter 4 we explore how the structure of one level of the supply chain affects other dimensions of channel operations and the nature of the supply chain.

Specifically, we consider the formation of strategic development alliances among competitors that supply a critical component to an original equipment manufacturer (OEM). We first consider a situation in which suppliers would form a joint venture to develop and market the component. We next consider how the outcome for the OEM and suppliers in a development alliance would change if they codevelop the component, but compete in marketing and sales to the OEM. And finally, we look into the situation where the suppliers may choose not to form any alliance, and compete to develop and market the component individually. In all of these situations we study the tradeoff between the reduced profits due to competition and the demand increase due to investment decisions of the OEM. The selection of supplier formation gives rise to some important questions: How does the attractiveness of an alliance play a role in affecting the OEM's decision to invest in the demand stimulating activities? Under what conditions is it more valuable for the suppliers to compete rather than collaborate? To answer these questions, we consider the strategic consequences of collaboration and competition that the alliance between two upstream suppliers can impose upon the cost reducing investments of a downstream manufacturer. Based on our analysis we identify the conditions under which it is beneficial for the suppliers to codevelop and compete in sales. Our results explain the counter-intuitive behavior of innovators with radical breakthroughs, who willingly create competition.

In subsequent chapters, we conceptualize and model these strategic issues related to product design, product development and technology development and deployment, and examine how competitive and collaborative forces in a supply chain influence these decisions. Finally, we conclude with a discussion of our results and managerial implications, and point to directions for future research.

Chapter 2

Managing Revenue Streams for Durable Products with Contingent Services or Consumable Components

2.1. Introduction

Many products are sold in a bundle that includes a durable good and a contingent consumable, such as printers and ink, electronic products and batteries, automobiles and warranty services. However, in order for a consumer to continue to derive value from the durable, he must continue to buy the contingent[1] consumable. This interdependence between the durable good and the consumable creates a stream of revenues for the durable good manufacturer over the life of the product. Over the entire life cycle of a durable, the stream of revenues and profits from the consumables can often far exceed that from the initial sale of the durable.

The printer and ink supply industry provides a good example. In 2004 Hewlett-Packard (HP) derived 73% of its profits from its printer division, but more than 50% of the profits in the printer division came from the sales of

[1]As described in Peterson and Mahajan (1978), a contingency between two products is a special case of complementarity that occurs when neither product can be used in the absence of the other.

ink and toner supplies (Business Week, 2005b). Naturally, the profitability of the ink supply business has not gone unnoticed, and it has attracted many fast-growing startups, such as Cartridge World.

However, not all manufacturers of printers responded to the entry of generic ink suppliers in the same way. Lexmark initially made its printer cartridge incompatible with any generic ink cartridges by installing a special electronic chip that prevented consumers from using cartridges that were not obtained directly from Lexmark. In contrast, although HP did not take any initiative to interfere with consumers ability to use generic ink cartridges in its printers, it instead focused on maintaining a perceived gap in quality between its ink and that of other manufacturers, both through its marketing and through legal channels. For example, HP has threatened to litigate Cartridge World for infringing on its patented ink formulations (Business Week, 2005a).

Consider another example from the electronic products industry. When Apple first introduced its iPod, some consumers were horrified to discover that the product was not designed to be opened up in order to replace the battery. Once the original lithium-ion battery died, replacement required a fairly high level of technical sophistication and ingenuity on the part of the consumer. For most consumers, the life of their iPod was thereby limited to the life of its battery. Subsequently, in response to environmental issues as well as the entry of third-party firms offering iPod battery replacements, Apple set up its own battery replacement program. However, Apple has not interfered with the compatibility between the iPod and alternative battery kits, and even promotes these alternatives on its website.

In other durable goods industries, e.g. heavy equipment, automobiles, etc., the maintenance and repair services that are required to keep a durable product in good working order represent contingent consumables. In some industries, the market for these is four or five times larger than the product market (Bundschuh and Dezvane, 2003). Some manufacturers attempt to prevent third-party service providers from gaining access to their consumers by withholding technical specifications or specialized replacement parts, or by requiring large investments in expensive diagnostic equipment as is common in the automobile industry.

Motivated by these examples, we develop a model of monopolist manufacturer of a durable product that requires a contingent consumable for continued use. The model includes the costs of producing the durable and the consumable and the rate at which the performance of the durable deteriorates. We assume that there exists a competitive industry that supplies a generic consumable that is a possible alternative to the *branded* one provided by the durable goods manufacturer, and further assume that this generic substitute is of lower quality. By analyzing this model we identify conditions under which the manufacturer should attempt to avoid competition with the generic consumables, perhaps by making her product incompatible with them, as well as conditions under which she should seek to exploit the availability of generic substitutes for her own branded consumable.

The remainder of the chapter is organized as follows: In Section 2.2 we review the literature. Section 2.3 details our model. In Section 2.4 we first analyze the optimal strategies for the incompatible consumable market and a consumable market with generic consumables. We then compare the profits that the manufacturer makes under both market structures. The final section concludes the chapter. Throughout the chapter, we adopt the convention of using masculine pronouns to refer to the manufacturer.

2.2. Literature Review

There are several distinct literatures to which our work relates. There exists a large literature that addresses the conditions under which a firm can benefit from compatibility with a rival. As discussed in Katz and Shapiro (1994), compatibility can be an important issue either in settings in which there are direct network effects, that allow consumers to benefit from being able to interact with other consumers of compatible products, or in settings in which products consist of sets of *compatible components,* e.g. video gaming hardware and software, and increasing compatibility increases the choices available to consumers. Although it has long been recognized that compatibility can be advantageous in settings in which there are direct network effects, our work is more closely related to compatibility among components of product systems. Matutes and Regibeau (1988) consider a setting in which two firms offer products that are *systems* of two component types, and each firm offers exactly one flavor of each of the component types. They demonstrate that compatibility among the two firms' components can be beneficial by allowing differentiated consumers to better match their preferences. Economides (1989) extended this work by allowing for n firms and allowing for a more general demand function. In a later work, Matutes and Regibeau (1992) allow for firms to make their components compatible but to offer discounts to consumers who purchase all of the components from one firm. They demonstrate that although firms will offer these discounts in equilibrium, they would be better off if they could commit to not doing so. Although we also focus on a product that requires two compatible components, we include a time dimension in which one of the components is durable, i.e. lasts for more than one period, while the other is not.

Church and Gandal (2000) study a product system composed of a hardware good and complementary software and the value of the system depends on the availability of software. They show that the merger of a hardware firm with a software firm can be an effective strategy to monopolize the hardware market when the integrated firm makes its software incompatible with a rival technology. Our paper demonstrates that a firm can benefit from low end competition even in the absence of the network externalities. The generic consumable industry extends the availability of the consumables to the consumers with low valuations for the product bundle and increases the price the consumers are willing to pay.

The problem that we study is closely related to the one considered in the literature on remanufacturing. Implicitly, a remanufacturable product involves a durable *core* as well as one or more consumable components that wear out sooner than the durable core and are critical to the operation of the product. In this respect, remanufacturing has some similarity to the setting that we study. Although much of the work in remanufacturing has focused on logistical issues, there are several papers that address the competition between the original manufacturer and remanufacturers, which is similar to the competition between the firms to provide the service or consumable component in our setting. Majumder and Groenevelt (2001) show how a rival remanufacturer can erode the profits of a monopolist manufacturer and discuss how the manufacturer can deter the remanufacturer from entering. This work was extended by Ferrer and Swaminathan (2006), who focus on the effect of remanufacturability on the pricing strategies of a monopolist original manufacturer with and without competition from a remanufacturer, and by Ferguson and Toktay (2006), who focus on strategies for deterring the entry of a remanufacturer. Debo et al. (2005) endogenizes the manufacturer's remanufacturability decision and shows how the joint pricing-remanufacturability decision is affected by a rival remanufacturer. This work was extended in the context of a diffusion of technology model, but ignoring the possibility of competition, in Debo et al. (2006). In all of these papers, it is assumed that the durable cores are disposed of by consumers who consume them with either new or remanufactured units, and it is up to either the original manufacturer or a remanufacturer to collect the cores and convert them into marketable products. Relatively little attention has been paid to the potential for these durable cores to have value to consumers, either for their market resale value or their ability to provide additional usefulness. Two notable exceptions are Guide et al. (2003), who analyze the optimal prices that a remanufacturer should pay for acquiring cores of varying levels of quality, and Ray et al. (2005) who consider various trade-in allowances that a monopolist can offer when it sells to both new consumers and those wanting to replace a unit that they currently own. However, neither of these papers allows for consumers' willingness to pay to be influenced by their rational expectations of the future value of their durable *core*.

In addition to the literatures on component commonality and remanufacturing, there are several papers that have addressed the provision of service after the sale of a durable product. The work of Cohen and Whang (1997) has perhaps the most similarity to our own. They also study the effect of competition to provide the contingent consumable[2] for a durable product and examine how it affects the level of quality and the pricing decisions for the manufacturer. More recent papers, e.g. Kim et al. (2007a), Bhattacharya et al. (2006) and Kim et al. (2007b), consider methods of contracting for these after sales services. However, none of these papers consider how the provision of service by a third party may affect consumer expectations of future prices of new and used durables nor whether the manufacturer can benefit from the presence of this third party competition.

[2]They specifically refer to the contingent consumable as *service*.

2.3. Model

We consider a situation in which a manufacturer produces a durable good that provides value to the consumer only when used together with a contingent non-durable consumable. A new product in our setting is the bundle of a durable good and a branded consumable, and we assume that a brand new durable good is not sold separately. However, the durable good lasts for two periods with some depreciation in its value, so there are available used durable goods that could be obtained separately. Each period in our model corresponds to a period of use of the consumable by a consumer, after which a new consumable has to be purchased. To receive some positive utility from a used durable good in any period, consumers must own a consumable, which is used in combination with the durable good. Alternatively, they may buy a new product or not use it at all.

Therefore, there are two potential parts in the revenue stream of the manufacturer: sale of new product bundles and sale of consumables. The manufacturer could be the sole supplier of the consumables by keeping his durable good incompatible with industry standard consumable brands. Alternatively, he could design his durable good compatible with identical generic consumables, provided by a competitive consumable industry.[3] Therefore, the variety

[3]There could be practical issues associated with compatibility such as sacrifice of quality to design the durable good compatible. In our model, we exclude such practical issues and assume that the manufacturer's design decision does not reduce the quality of its durable good or consumable. For example, HP does not necessarily change the design of its cartridge to be compatible with generic ink, but an HP cartridge accommodates generic ink as well as HP branded ink, as it is now.

of available consumables depend on the compatibility decision of the manufacturer. For example, the battery of the first generation iPod nano is soldered to the main board and in the design of fifth generation iPods the battery is attached to a metal plate. The battery is not designed to be replaced by the user. On the other hand, Apple's design does not limit the battery replacement exclusive to Apple's battery replacement program. The iPod design also allows third-party companies to offer cheaper battery replacement kits with higher capacity batteries. The assumption of the competitive consumable industry is critical to our model since the price competition generates positive value for a bundle of a used durable good and a consumable.

In our model, to capture the depreciation of the durable good, we assume that the brand new durable good has quality $s_d = 1$ and the used durable good has quality $s_{d2} \leq s_d$ in the following period. It is plausible to expect that the manufacturer's consumable would have higher perceived quality because of superior integration of the branded consumable with his own durable good, his brand reputation, etc. Thus, we assume that the branded consumable made by the manufacturer has quality $s_B = 1$, whereas the generic consumable produced by a consumable industry has quality s_G, which is lower than s_B, $s_G < s_B = 1$. And due to the interdependence between the durable good and the contingent consumable, the marginal benefit of increasing the quality of the consumable s_j is increasing in the quality of the durable good s_i and vice versa, so we assume that the overall quality of the product is $s_i s_j$. There is no value in having only a durable good or a consumable alone. If one component is missing, the overall quality is simply zero.

We assume that the marginal cost of production for the durable good c_d and the branded consumable c_B are constant. In addition, the competition in the generic consumable industry drives the retail price, p_G, down to the marginal production cost. Besides the compatibility decision, the production costs would dictate whether a consumable manufacturer could enter the consumable market or not. In order to enter, the generic industry has to be more efficient at producing consumables, i.e. it needs to have a higher quality-to-cost relative to the manufacturer ($p_G < c_B s_G$). Further, we assume that the used durable goods can be bought and sold among consumers in a second-hand market with no transaction costs.

In each period, each consumer either uses one durable and one consumable or uses no product. They differ in their valuation for product quality, which consists of the quality of the durable good and the consumable. Their valuation v for product quality is uniformly distributed on the interval $[0, 1]$. We refer to a consumer with valuation v as a consumer of type v. A product of quality s provides an intrinsic value of vs for a customer of type v. Therefore, the utility for a product bundle of a durable good of quality s_i and a consumable of quality s_j is given by $U(v, s_i, s_j) = vs_i s_j$. A consumer of valuation v has a total valuation of $vs_d s_B = v$ from having a new product bundle. In the following period, the consumer has valuation $vs_{d2} s_B = vs_{d2}$ if he has a used durable good with a branded consumable; and valuation $vs_{d2} s_G$ if he owns a used durable good with a generic consumable. This model of valuation with the assumption of zero transaction costs insures that a consumer of any given valuation v who has a new durable good has higher utility for the branded consumable than he would if he had the used durable good and also, a consumer with a branded consumable has higher utility than he would with a generic consumable ($s_d s_B \geq s_{d2} s_B \geq s_{d2} s_G$).

2.3.1 Formulation of the Manufacturer's Optimization Problem

Since the technological life of the durable good is long relative to the physical durability of the consumable, we develop a discrete-time, infinite-horizon optimization problem for the manufacturer. We use superscript t to label periods.

In this game the manufacturer decides on the quantities of new product bundles and the consumables at the beginning of each period. The manufacturer's quantity vector in each period is stated as $q^t = (q_n^{t-1},\, q_n^t,\, q_B^t)$, where he would produce a quantity q_n^t of new product bundles and a quantity q_B^t of the branded consumables at period t. If the durable good is compatible, the generic consumable industry would produce a quantity q_G^t of the generic consumables. Let N, B, G and O represent consumer actions corresponding to purchasing a new product, a branded consumable, a generic consumable, and not buying anything, respectively. Each consumer chooses an action strategically, depending on the consumer's action in the past period, the current action and the manufacturer's current quantity vector. We represent the action of a consumer of type v at time t, $a^t(v)$. We repeat this game forever and model the decision making process of the manufacturer as a steady state profit maximization problem. We require equilibrium of our model to be perfect in every period. However, we focus on any perfect equilibrium which depends only on the payoff relevant history. Therefore, we take the standard Markov perfect equilibrium approach to solve the optimization problem similar to Maskin and Tirole (1988) and Huang et al. (2001).

Before we describe the dynamic game and the steady state optimization in detail, we characterize the consumer behaviors. When different types of consumables are available, each consumer purchases the product mix that maximizes his or her payoff and the market is segmented according to the consumer valuations. Here we construct the model for the case when both types of consumables would be available and consumers with a separate consumable need to purchase a used durable good. It is straightforward to apply this model to other situations in which only one type of consumable or no consumable is available.

Based on the model of consumer valuation, let v_n represent the valuation of the marginal consumer who is indifferent between buying a new product and a consumable, and let v_b denote the valuation of the marginal consumer who is indifferent between buying a branded and a generic consumable. Further, v_c represents the valuation of the marginal consumer who is indifferent between buying a generic consumable and nothing. All consumers with valuations in $[v_b, v_n)$ and $[v_c, v_b)$ purchase a branded consumable and a generic consumable, respectively, while consumers with valuations in $[v_n, 1]$ purchase a new durable good from the manufacturer. Consumers with valuations in $[0,\, v_c)$ purchase nothing. This market segmentation is seen in Figure 2.1.

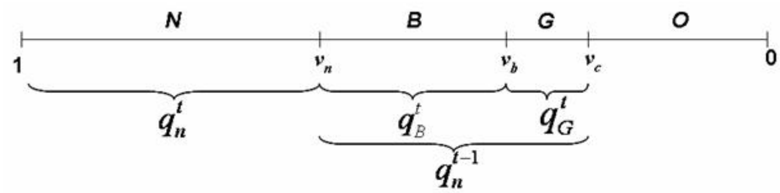


Figure 2.1: Market Segmentation for Consumers with different valuations.

The marginal consumers with valuations at v_n, v_b and v_c can obtain the same payoff from either purchasing choices that they are indifferent and would have the following incentive compatibility constraints, respectively,

$$v_n - p_n^t + \delta E\left[p_u^{t+1}\right] = v_n s_{d2} - p_B^t - p_u^t \quad (2.1)$$

$$v_b s_{d2} - p_B^t - p_u^t = v_b s_{d2} s_G - p_G - p_u^t \quad (2.2)$$

$$v_c s_{d2} s_G - p_G - p_u^t = 0 \quad (2.3)$$

where p_n^t, p_B^t and p_u^t denote the prices of new product bundles, consumables and used durable goods at period t, respectively. The new product owners anticipate a sales price for their durable goods in the subsequent period, denoted by $E\left[p_u^{t+1}\right]$ with a discount factor of δ. Recall that $s_d = s_B = 1$.

As Figure 2.1 shows, since at period t the manufacturer produces a quantity q_n^t of new product bundles, the marginal consumer of type v_n, who is indifferent between buying a new product and a consumable, will have a valuation of $1 - q_n^t$, i.e. $v_n = 1 - q_n^t$. Similarly, we can express the marginal consumer valuations in terms of quantities as $v_b = 1 - q_n^t - q_B^t$ and $v_c = 1 - q_n^t - q_n^{t-1}$. Writing the valuations in (2.1)-(2.3) in terms of quantities and solving them simultaneously, we can find the price functions of quantities as

$$p_n^t\left(q^t\right) = 1 - q_n^t - s_{d2}q_B^t + s_{d2}s_G\left(q_B^t - q_n^{t-1}\right) + \delta E\left[p_u^{t+1}\left(q^t\right)\right] \quad (2.4)$$

$$p_B^t\left(q^t\right) = p_G + \left(1 - q_B^t - q_n^t\right)\left(1 - s_G\right)s_{d2} \quad (2.5)$$

$$p_u^t\left(q^t\right) = Max\left\{0,\, \left(1 - q_n^t - q_n^{t-1}\right)s_{d2}s_G - p_G\right\} \quad (2.6)$$

Since the generic consumable industry produces at its marginal cost, the manufacturer has the market power to control the prices, which are determined by the manufacturer's decisions on the production quantities.

Now we can characterize the payoff function for a consumer of type v. The payoff at period t depends on the consumer's action in the past period, the current action and the current quantity vector, i.e. $g_v^t\left(a^{t-1}(v),\, a^t(v),\, q^t\right)$. If the consumer has no used durable goods, i.e. $a^{t-1}(v) \in \overline{N} = \{B, G, O\}$, the payoff function becomes,

$$g_v^t\left(\overline{N},\, a^t(v),\, q^t\right) = \begin{cases} v - p_n^t\left(q^t\right) + \delta E\left[p_u^{t+1}\left(q^t\right)\right] & if\ a^t(v) = N \\ vs_{d2} - p_B^t\left(q^t\right) - p_u^t\left(q^t\right) & if\ a^t(v) = B \\ vs_{d2}s_G - p_G - p_u^t\left(q^t\right) & if\ a^t(v) = G \\ 0 & if\ a^t(v) = O \end{cases}$$

where δ represents the discount factor. When the consumer has a used durable good, the price functions in (2.4)-(2.6) will not change and the payoff function for any consumer of type v becomes $g_v^t\left(N,\, a^t(v),\, q^t\right) = g_v^t\left(\overline{N},\, a^t(v),\, q^t\right) + p_u^t\left(q^t\right)$. Hence, the ownership of a used durable good improves the consumer payoffs with the same amount under each action.

To understand the steady-state behaviors of the manufacturer and the consumers, we construct the Bellman equations for a consumer of type v and the manufacturer. We first establish the consumer's Bellman equation with the value function $D_v^t\left(a^{t-1}(v), q^t\right)$ as

$$D_v^t\left(a^{t-1}(v), q^t\right) = \max_{a^t(v)}\left\{g_v\left(a^{t-1}(v), a^t(v), q^t\right) + \delta D_v^{t+1}\left(a^t(v), q^{t+1}\right)\right\} \tag{2.7}$$

with a discount factor of δ. Given his previous action $a^{t-1}(v)$, the optimal action vector of (2.7), $a^t(v)^*$, determines the reaction function of the consumer of type v to the quantity vector q^t,

$$R_v^t\left[a^{t-1}(v), q^t\right] = a^t(v)^* \tag{2.8}$$

Note that the relative preference among actions N, B, G and O is independent of whether the consumer owns a durable good from the previous period. Therefore, the reaction function would depend only upon q^t and consumers would make the same preferences as long as q^t is constant. As a result, at each period of the steady state a consumer chooses the same consumption strategy, i.e. $a^t(v)^*$ is constant. Therefore, $R_v^t\left[q^t\right] = a^t(v)^*$.

Now we can formulate the Bellman equation for the manufacturer with the value function $M^t\left(q^t\right)$, the reward function $\pi^t\left(q^t\right) = q_n^t\left(p_n^t - c_d - c_B\right) + q_B^t\left(p_B^t - c_B\right)$ and a discount factor of δ,

$$\begin{aligned} M^t\left(q^t\right) &= \max_{q_n^t, q_B^t}\left\{\pi^t\left(q^t\right) + \delta M^{t+1}\left(q^{t+1}\right)\right\} \\ \textit{subject to} \quad & q_B^t \le q_n^{t-1} \\ & q_n^t,\, q_n^{t-1},\, q_B^t \ge 0 \end{aligned} \tag{2.9}$$

Since there is no second-hand market for the consumables and no hidden information, there will never be excess consumable production at the steady state. The consumable demand in any given period t, however, is constrained by a supply constraint, the number of available used products that are generated by the sales of new product bundles at the previous period $t-1$, i.e. $q_B^t \leq q_n^{t-1}$. Solving the manufacturer's Bellman equation, we compute the optimal quantities q_n^{t*} and q_B^{t*}.

In the steady limit, the manufacturer's decisions and consumer strategies are constant in time, so we eliminate the time dependence from all of the equations. Hence, the optimization problem for the manufacturer becomes static. The profit maximization problem of the manufacturer is reduced to a generic period problem. In a generic period the manufacturer would produce a quantity q_n of new product bundles and a quantity q_B of the branded consumables to maximize his total profit π,

$$\pi(q_n, q_B) = q_n(p_n - c_d - c_B) + q_B(p_B - c_B) \tag{2.10}$$

$$\textit{subject to} \quad q_B \leq q_n \tag{2.11}$$

$$q_n, q_B \geq 0$$

where p_n and p_B denote the prices of new product bundles and consumables, as shown in (2.4) and (2.5), respectively.

Next we determine the conditions on the equilibrium path and characterize how the manufacturer's decisions lead to the steady state quantities. The initial conditions at $t = 0$ are that $q_B^0 = q_G^0 = 0$ since there are no initial used durable goods. Using backward induction, it is possible to show that the game converges to a focal point of (q_n^{t*}, q_B^{t*}) for all values of t in the strategy space beginning from an initial state in a finite horizon game (Maskin and Tirole, 1988; Huang et al., 2001). We can show that the manufacturer uses the same production strategy in every period after Period 1. Period 2, without loss of generality, is the first of an infinite stream of identical periods. In general, if the equilibrium is to depend only on the payoff relevant history, the production quantity vector at time $t-1$, $q^{(t-1)*}$, will be equal to q^{t*} at the steady state. The optimal quantities for new product bundles and consumables also form the outcomes of reaction functions R_n and R_B of the manufacturer , i.e. $q_n^{t*} = R_n\left(q_n^{(t-1)*}\right)$ and $q_B^{t*} = R_B\left(q_B^{(t-1)*}\right)$. The manufacturer would always produce his optimal quantity (q_n^{t*}, q_B^{t*}) at the steady state. This method is illustrated in Appendix.

It is straightforward to apply this approach to other two possible situations with different preferences. When the consumable market is proprietary to the manufacturer's product, the market is segmented according to consumer preferences N, B and O. And when the consumables are supplied only by the generic industry, the consumers prefer to choose among N, G and O. The discussion for the steady state holds similarly for each case. In Section 4.4, we analyze each of these possible cases at the steady state. In order to keep our expositions clear in discussing the presence of the generic consumables, we present our results with the additional assumption that $\delta = 1$ in the rest of the chapter. This assumption has limited bearing on our results for the steady state and no significant insights are lost.

2.4. Analysis and Results

In this section, we examine under what conditions the generic consumable industry influences the manufacturer's design decision on the compatibility of his durable good with other generic consumables. We solve the manufacturer's optimization problem at the steady state and we will not have any time dependence in our analysis. We are particularly interested in the industry structure depending on the costs of production of the durable and the contingent consumable, the rate of deterioration of the durable good and the quality of his own branded consumable relative to that of the generic substitutes. In Section 2.4.1, we examine a situation where the manufacturer designs the durable good compatible only with his proprietary consumable. Later in Section 2.4.2, we study another situation when the durable good is compatible with generic consumables produced by a competitive industry with a higher quality-to-cost ratio. In Section 2.4.3, we compare our findings and derive the optimal design strategies for the original manufacturer.

2.4.1 Incompatible Consumables

As a benchmark, we first consider a situation where the manufacturer focuses on incompatibility by not making his durable good compatible with any generic consumables. Let v_n represent the marginal consumer who is indifferent between buying a new product and a branded consumable to use with a used durable good. Similarly, let v_b represent the marginal consumer who is indifferent between purchasing a branded consumable and nothing. Thus, all consumers with valuations in $[v_b,\, v_n)$ purchase a used durable good and a consumable while consumers with valuations in $[v_n,\, 1]$ buy a product bundle of a new durable good and a consumable from the manufacturer. Consumers with valuations in $[0,\, v_b)$ purchase nothing. In addition, the valuations of the marginal consumers in terms of manufacturer's quantities are $v_n = 1 - q_n$ and $v_b = 1 - q_B - q_n$, respectively. Furthermore, the limited supply for the used durable goods could generate a positive value of p_u when all used durable goods are purchased with a consumable. We do not explicitly compute the value of p_u since the manufacturer controls both markets and can get this additional value by charging a higher price for the new product bundles p_n or the consumables p_B.

In order to find the price functions, we first solve the incentive compatibility constraint of the marginal consumer with valuation v_b,

$$(1 - q_B - q_n)\, s_{d2} - p_B = 0$$

we can easily find the price for the branded consumable as

$$p_B\,(q_n,\, q_B) = (1 - q_n - q_B)\, s_{d2} \tag{2.12}$$

Then, the incentive compatibility of the marginal consumer who is indifferent between buying a product and a branded consumable is given as

$$(1 - q_n) - p_n = (1 - q_n)\, s_{d2} - (1 - q_n - q_B)\, s_{d2}$$

and we can find the retail price for the durable product,

$$p_n\left(q_n,\, q_B\right) \;=\; 1 - q_n - q_B s_{d2} \tag{2.13}$$

The manufacturer's optimization function in (2.10) can be solved inserting p_B in (2.12) and p_n in (2.13) subject to a specific constraint in (2.11) that defines the manufacturer's optimal strategy. In Proposition 2.4.1 below, we summarize optimal design strategies when the manufacturer keeps the durable good of his product compatible only with his own consumable.

Proposition 2.4.1. Incompatible consumables market

When the manufacturer does not make his durable good compatible with any generic brand consumable, the manufacturer's optimal production strategy in the steady limit can be characterized according to three thresholds, $c_{d1} = \frac{c_B(1-s_{d2})}{s_{d2}} \leq c_{d2} = \frac{(c_B+s_{d2})(1-s_{d2})}{2s_{d2}} \leq c_{d0} = 1 - 2c_B + s_{d2}$. *At each period,*

a) If $c_{d1} < c_d \leq c_{d2}$*, the manufacturer produces more new product bundles than consumables.*

b) If $c_d \leq c_{d1}$*, the manufacturer only produces new product bundles.*

c) If $c_{d2} < c_d \leq c_{d0}$*, the manufacturer produces as many new product bundles as consumables.*

d) If $c_d > c_{d0}$*, the manufacturer does not produce anything.*

Proof. When the manufacturer produces a higher quantity of new product bundles than the quantity of the consumables in each period, there would be no positive value for the used durable good, i.e. $p_u = 0$ at the steady state.

In such case when the constraint (2.11) becomes $q_n > q_B > 0$, solving for the first-order conditions of the profit function in (2.10), we obtain the equilibrium quantities as

$$\begin{aligned} q_n^* &= \tfrac{1-c_d-s_{d2}}{2(1-s_{d2})} \\ q_B^* &= \tfrac{(c_B+c_d)s_{d2}-c_B}{2(1-s_{d2})s_{d2}} \end{aligned} \tag{2.14}$$

If $c_{d1} < c_d \leq c_{d2}$, $q_n^* > q_B^* > 0$ and the equilibrium quantities are the optimal quantities.

When the production cost is low ($c_d \leq c_{d1}$), the manufacturer would only produce all new product bundles. The marginal consumer of type v_{n0} who is indifferent between purchasing a new product and nothing would have the valuation of $v_{n0} = 1 - q_n$. The consumers with valuations $[v_{n0}, 1]$ purchase a new product bundle. Maximizing the manufacturer's profit function in (2.10) subject to constraint (2.11) as $q_n > q_B = 0$, we find the first order quantity as $q_n^{***} = \frac{1-c_B-c_d}{2}$, which is optimal if $c_d \leq c_{d1}$.

On the other hand, if $c_d > c_{d2}$, by substituting $q_n = q_B$ in (2.11) and solving the first order conditions of (2.10), the manufacturer's first order quantities in this case are obtained

$$q_n^{**} = q_B^{**} = \frac{1 - 2c_B - c_d + s_{d2}}{2\,(1 + 3s_{d2})} \tag{2.15}$$

And the manufacturer produces as many new product bundles as consumables. Alternatively, the manufacturer would produce nothing when $c_d > c_{d0}$.

The optimal profits of the incompatible consumable market under different strategies are listed in Table 2.1. Further, we can easily justify that

$\pi\left(q_n^*,\, q_B^*\right) \;=\; max\left\{\pi\left(q_n^*,\, q_B^*\right),\, \pi\left(q_n^{**},\, q_B^{**}\right),\, \pi\left(q_n^{***},\, 0\right)\right\}$ for $c_{d1} \;<\; c_d \;\leq\; c_{d2}$;

$\pi\left(q_n^{**},\, q_B^{**}\right) \;=\; max\left\{\pi\left(q_n^*,\, q_B^*\right),\, \pi\left(q_n^{**},\, q_B^{**}\right),\, \pi\left(q_n^{***},\, 0\right)\right\}$ for $c_{d2} \;<\; c_d \;\leq\; c_{d0}$;

and $\pi\left(q_n^{**},\, q_B^{**}\right) \leq \pi\left(q_n^{***},\, 0\right) < 0$, when $c_d > c_{d0}$.

Market Structure	*The Manufacturer's Profits*
$q_n > q_B > 0$	$\pi\left(q_n^*,\, q_B^*\right) = \frac{1}{4}\left(1 - 2c_B - c_d\left(2 - \frac{c_d}{1-s_{d2}}\right) + \frac{c_B^2}{s_{d2}}\right)$
$q_n = q_B > 0$	$\pi\left(q_n^{**},\, q_B^{**}\right) = \frac{\left(1-2c_B-c_d+s_{d2}\right)^2}{4\left(1+3s_{d2}\right)}$
$q_n > q_B = 0$	$\pi\left(q_n^{***},\, 0\right) = \frac{1}{4}\left(1 - c_B - c_d\right)^2$

Table 2.1: The Manufacturer's Profits when no generic consumable is compatible.

□

Proposition 2.4.1 shows that the manufacturer finds it optimal to offer only new product bundles at each period and does not produce any consumables separately when he produces the durable good at a relatively low cost ($c_d \leq c_{d1}$) or with a high deterioration rate. When the quality of the deteriorated units, s_{d2}, is equal to the ratio of the consumable costs to overall costs, $\frac{c_B}{c_B+c_d}$, the manufacturer is indifferent between having a consumable and not having one. Otherwise, he is strictly better off having one ($\pi\left(q_n^*,\, q_B^*\right) > \pi\left(q_n^{***},\, 0\right)$) when $s_{d2} > \frac{c_B}{c_B+c_d}$, i.e. $c_d > c_{d1}$. Since a product is a bundle of a durable good and a contingent consumable, a high production cost of the consumable increases the overall cost of the product and for high c_B, the sales margin on the consumables is less than on the new product bundles. Further, the manufacturer's production of consumables offers an alternative to the consumers and reduces the demand for its new product bundle. Therefore, he offers all new product bundles and generates higher sales profit. However, he is less inclined to follow this strategy as the production cost of the consumables goes down ($c_B \downarrow$) and thereby, the sales margin on the consumables increases. As a result, the manufacturer starts producing separate consumables. This is displayed as an increasing threshold of the cost of the durable goods, c_{d1}, with c_B.

As it gets costlier to make the durable goods ($c_d \uparrow$), the sales margin on the new product bundles drops whereas the sales margin on the consumables does not change. The manufacturer's production quantity of the consumables increases with c_d while he produces fewer new product bundles. Because the demand for consumables is constrained by the availability of the durable goods, he could offer as many consumables as there are available used durable goods above a certain production cost of the durable good, c_{d2}. Nevertheless, when it is too costly to produce a durable good ($c_d > c_{d0}$), then the manufacturer would not find it profitable to enter the product market.

Further, the quality of the used durable good influences the incompatible manufacturer's optimal production strategy.

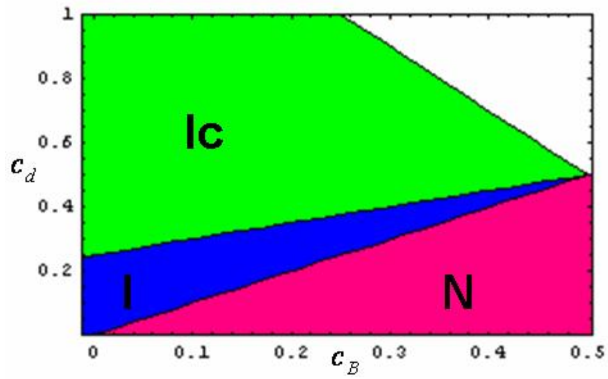
Corollary 2.4.2. Quality of the Used Durable Good

i) c_{d0} *increases;* c_{d2} *and* c_{d1} *decreases with* s_{d2}. *That is, an increase in the quality of the used durable good increases the motivation of the manufacturer to offer as many new product bundles as consumables at each period.*

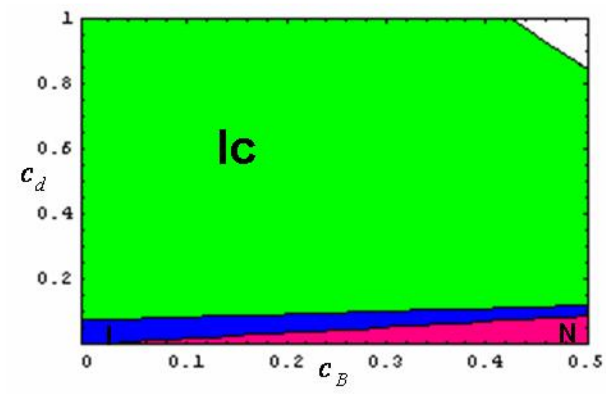
ii) If the used durable good does not deteriorate ($s_{d2} = 1$), *the manufacturer* *would only produce the same amount of new product bundles and consumables at each period.*

The proof to Corollary 2.4.2 is straightforward from the first derivatives of the thresholds with respect to s_{d2}. When the durable good deteriorates significantly, the branded consumable serves to differentiate the market as the consumers with low valuations prefer the more affordable consumable than the new product bundle. If the manufacturer could produce a durable good which deteriorates less over time, an increase in s_{d2} would generate a reduction in the quality gap between a bundle of used durable good and consumable and a new product bundle. This increase in the quality of the used durable good creates some positive value and therefore, consumers are willing to pay a higher price for a higher quality durable good. The manufacturer could obtain this positive value of the used durable good by increasing its product price. Further, the branded consumable production reduces the manufacturer's cost of delivering the product to the market. Therefore, an increase in the quality of the used durable good influences the manufacturer to limit the quantity of the new product bundles to the quantity of consumables and expand the region bounded by $c_{d2} < c_d \leq c_{d0}$. When the quality gap between a used and a new durable good diminishes, the manufacturer would only consider offering the same quantity of consumables and new product bundles because the differentiation between a used and a new durable good vanishes and it is cheaper to produce the consumables.

To further understand the conditions that determine the optimal strategy, we consider a numerical example. Suppose the manufacturer's product deteriorates with $s_{d2} = 0.5$. Figure 2.2.a shows the cost parameters (c_B, c_d) for which incompatible consumable market (I), constrained incompatible consumable market (Ic) and no consumable market (N) with sales of all new product bundles are optimal strategies for the manufacturer if he does not permit any entry in the consumable market. In Corollary 2.4.2 above, we have shown that a higher quality used durable good creates a shift in the manufacturer's decision to consider selling as many new product bundles as consumables for a wider range of cost parameters. This result is illustrated in Figure 2.2.b, e.g. $s_{d2} = 0.85$. The region "Ic" gets larger whereas the regions "I" and "N" shrink as the deterioration rate drops.



(a)



(b)

Figure 2.2: Optimal Strategies for the Incompatible Manufacturer
(a) $s_{d2} = 0.5$, (b) $s_{d2} = 0.85$

2.4.2 Compatible Competitive Consumables

In this section, we consider what happens when the manufacturer makes his product compatible with a competitive consumable industry which produces identical generic consumables and explore the conditions under which the presence of a generic consumable industry could be beneficial for the manufacturer. We first study the consumable market where the manufacturer produces branded consumables, which compete with the generic consumables. Later we analyze a market where only generic consumables would be available. We do not consider the manufacturer profits of an incompatible consumable market derived in the previous section. We leave this comparative discussion to § 2.4.3.

Let q_G denote the quantity of the generic consumables in the steady state. If the manufacturer decides on the product quantity q_n such that there would be no abundant number of used durable goods in the steady state ($q_n = q_B + q_G$ or $q_n = q_G$), the market price for the used durable good would be positive, i.e. $p_u > 0$. Therefore, p_u is dependent on q_n.

First consider the situation where both types of consumables would be available. Let v_n represent the valuation of the marginal consumer who is indifferent between buying a new product and a consumable, and let v_b denote the valuation of the marginal consumer who is indifferent between buying a branded and a generic consumable. Further, v_c represents the valuation of the marginal consumer who is indifferent between buying a generic consumable and nothing. All consumers with valuations in $[v_b, v_n)$ and $[v_c, v_b)$ purchase a branded consumable and a generic consumable, respectively, while consumers with valuations in $[v_n, 1]$ purchase a new product bundle from the manufacturer. Consumers with valuations in $[0, v_c)$ purchase nothing.

Setting the incentive compatibility constraints of the marginal consumers with valuations $v_n = 1 - q_n$, $v_b = 1 - q_n - q_B$ and $v_c = 1 - 2q_n$, respectively,

$$
\begin{aligned}
(1-q_n)-p_n+p_u &= (1-q_n)\,s_{d2}-p_B-p_u && (2.16)\\
(1-q_n-q_B)\,s_{d2}-p_B-p_u &= (1-q_n-q_B)\,s_{d2}s_G-p_G-p_u && (2.17)\\
(1-2q_n)\,s_{d2}s_G-p_G-p_u &= 0 && (2.18)
\end{aligned}
$$

and solving the set of equations in (2.16)-(2.18) simultaneously, we can find the prices as

$$
\begin{aligned}
p_n\,(q_n,\,q_B) &= 1-q_n-s_{d2}q_B+s_{d2}s_G\,(1+q_B-3q_n) && (2.19)\\
p_B\,(q_n,\,q_B) &= p_G+(1-q_B-q_n)\,(1-s_G)\,s_{d2} && (2.20)\\
p_u\,(q_n,\,q_B) &= (1-2q_n)\,s_{d2}s_G-p_G && (2.21)
\end{aligned}
$$

Alternatively, we look into a situation where the consumable market is solely served by the generic consumable industry. All consumers with valuations in $[v_c,\,v_n)$ either keep their durable good or purchase a used one besides a generic consumable while consumers with valuations in $[v_n,\,1]$ purchase a brand new durable good from the manufacturer. Consumers with valuations in $[0,\,v_c)$ purchase nothing. Similar to the analysis above, the incentive compatibility constraints for the marginal consumers at v_n and v_c are

$$
\begin{aligned}
1-q_n-p_n+p_u &= (1-q_n)\,s_{d2}s_G-p_G-p_u && (2.22)\\
(1-2q_n)\,s_{d2}s_G-p_G-p_u &= 0 && (2.23)
\end{aligned}
$$

From the set of equations in (2.22) and (2.23), we find the price for the new product bundle as

$$p_n = 1 - q_n - s_{d2}q_B + s_{d2}s_G\left(1 + q_B - 3q_n\right) - p_G \tag{2.24}$$

$$p_u = \left(1 - 2q_n\right)s_{d2}s_G - p_G \tag{2.25}$$

The manufacturer's optimal strategy can be found solving the optimization function in (2.10) with respect to the corresponding set of price functions and quantity constraint (2.11). In Proposition 2.4.3, we summarize the optimal market strategies for the manufacturer when he allows the entry of generic consumable manufacturers. The subscripts G and $B0$ denote the thresholds where a consumable market with generic substitutes and with no branded consumables become available, respectively.

Proposition 2.4.3. Compatible consumables market

When the manufacturer makes his durable good compatible with a generic brand, the manufacturer's market strategies can be characterized according to the thresholds $c_{dB0} = -4c_B + 2p_G - 2s_{d2}s_G + \frac{(c_B - p_G)(1+3s_{d2})}{s_{d2}(1-s_G)}$ and $c_{dG} = \frac{c_B(1-s_{d2}-4s_{d2}s_G) - p_G(1+3s_{d2}s_G) + s_{d2}(1-s_{d2}-s_G+s_{d2}s_G)}{2s_{d2}(1-s_G)}$.

a) If $c_{dB0} < c_d < c_{dG}$*, the manufacturer stays in the market while there is a generic consumables industry as an alternative consumable supplier.*

b) If $0 < c_d \leq min\left\{c_{dB0,} 1 - 2p_G - s_{d2}\left(1 - 2s_G\right)\right\}$ *, the manufacturer produces only new product bundles and leaves the consumable market.*

c) Further, if $c_d \geq 1 - 2p_G - s_{d2}\left(1 - 2s_G\right)$*, the manufacturer does not produce any new product bundles.*

Proof. Using p_n in (2.19) and p_B in (2.20), and evaluating the first order conditions of (2.10) subject to $q_n > q_B$ in (2.11), the quantities that satisfy the first order conditions, q_n^{FOC} and q_B^{FOC}, can be found as

$$q_n^{FOC} = \frac{1 - c_d - 2p_G - s_{d2}\left(1 - 2s_G\right)}{2\left(1 - s_{d2}\left(1 - 4s_G\right)\right)} \tag{2.26}$$

$$q_B^{FOC} = \frac{1}{4}\left(1 - \frac{2\left(c_B - p_G\right)}{s_{d2}\left(1 - s_G\right)} - \frac{1 - 2c_d - 4p_G - s_{d2}}{1 - s_{d2}\left(1 - 4s_G\right)}\right) \tag{2.27}$$

where the superscript FOC denotes the first order condition for the case where $q_n = q_B + q_G$. We can have a positive production of consumables $\left(q_B^{FOC} > 0\right)$, when $c_d > c_{dB0}$. And the manufacturer would shut out the generic consumable industry when $q_n^{FOC} = q_B^{FOC}$, which means that $c_d > c_{dG}$. Therefore, for $c_{dB0} < c_d < c_{dG}$, q_n^{FOC} and q_B^{FOC} are the optimal quantities when $q_n = q_B + q_G$.

Similar to the previous case, when $q_n = q_G$, we can compute the equilibrium product quantity q_n^{FOC2} of (2.10) with price functions in (2.24) and (2.25) as

$$q_n^{FOC2} = \frac{1 - \left(c_B + c_d + p_G\right) + s_{d2}s_G}{2\left(1 + 3s_{d2}s_G\right)} \tag{2.28}$$

where the superscript $FOC2$ represents the first order condition. When $c_d \geq 1 - 2p_G - s_{d2}\left(1 - 2s_G\right)$, q_n^{FOC2} is the optimal quantity for the manufacturer.

Lastly, we can find that for $c_d \geq 1 - 2p_G - s_{d2}\left(1 - 2s_G\right)$, the manufacturer does not enter any markets. Further, we can easily show that $\frac{\partial c_{dB0}}{\partial c_B} > \frac{\partial c_{dG}}{\partial c_B} > 0$. The profits are summarized in Table 2.2.

Market Structure	*The Manufacturer's Profits*
$q_n = q_B + q_G$	$\pi\left(q_n^{FOC},\, q_B^{FOC}\right) = \frac{3-8c_B-4c_d+s_{d2}+\frac{4(c_B-p_G)^2}{s_{d2}(1-s_G)}+\frac{(1-2c_d-4p_G-s_{d2})^2}{1-s_{d2}(1-4s_G)}}{16}$
$q_n = q_G > q_B = 0$	$\pi\left(q_n^{FOC2},\, 0\right) = \frac{(1-(c_B+c_d+p_G)+s_{d2}s_G)^2}{4(1+3s_{d2}s_G)}$

Table 2.2: The Manufacturer's Profits when generic consumables are compatible.

□

Whether the manufacturer allows a generic consumable industry and stays in the consumable market depends on the differentiation of the products and competition. When the products are sufficiently differentiated and the production costs are not very high ($c_{dB0} < c_d < c_{dG}$), he serves the high-end consumers with high valuation for the product bundle. As his production costs are increasing, the manufacturer gets hurt from a generic consumable industry if he stays in the market. However, if the manufacturer with a high production cost ($c_d > c_{dB0}$) leaves the market to the generic manufacturers, he could still collect the positive value generated by the used durable goods by setting a higher retail price for the new product bundles. In addition, the availability of the generic consumables increases the demand for used durable goods, which in return, increases the price of the product and his profits. Nonetheless, due to extremely high durable good production costs ($c_d \geq 1 - 2p_G - s_{d2}(1 - 2s_G)$), he does not find it profitable to enter any of the markets.

We also find that by making its durable good compatible with the generic substitutes, the manufacturer starts producing branded consumables where he was not producing if he had proprietary consumables ($c_d < c_{d1}$). Further, he reduces his production of consumables for higher costs ($c_{d1} < c_d < c_{d0}$). The availability of the cheaper alternative generated by the generic consumable industry induces the consumers to consider a higher price for the used durable good, which the manufacturer could obtain by his control on the market.

Therefore, the profitability of having a generic consumable industry depends on the industry characteristics.

Corollary 2.4.4. Impact of Efficient Generic Consumable Industry *The range of parameters under which the equilibrium with a generic consumable industry exists expands as the industry becomes more efficient at making the consumable, i.e. the generic consumables manufacturers possess a high quality-to-cost ratio relative to the manufacturer.*

Proof. We can compute the point $c_B^p = p_G + s_{d2}(1 - s_G)$ and $c_d^p = 1 - 2p_G - s_{d2}(1 - 2s_G)$ as the intersection point of thresholds c_{dB0} and c_{dG}. As p_G or s_{d2} drops, c_B^p also decreases and c_d^p increases. Similarly, an increase in s_G leads to decrease in c_B^p and an increase in c_d^p. □

When the generic consumable industry produces a higher quality consumable or reduces its production cost, the substitutes become more attractive to the consumers. Since the manufacturer can obtain this additional value with a high priced new product bundle, the manufacturer's motivation to consider a generic consumable industry increases. Furthermore, when the manufacturer's durable good deteriorates at a high rate, consumers would be less interested in purchasing a consumable due to the interdependence between the durable good and the consumable. However, an industry that could offer a higher quality or more affordable alternative could influence this interdependence and increase the appeal to the manufacturer's product for a low quality used durable good. As a result, the manufacturer is more willing to accommodate a generic industry with high efficiency in consumable production. Later in Section 2.4.3, we discuss how the manufacturer's optimal decision is influenced with the variations in making the components.

As a numerical example, consider the same manufacturer in Section 2.4.1 whose product deteriorates with $s_{d2} = 0.85$, who is faced with a generic industry with $s_G = 0.5$ and $p_G = 0.2$. Figure 2.3 shows the cost parameters (c_B, c_d) for which competitive consumable market with both branded and generic consumables (GB) and competitive consumable market with only generic consumables (G) are feasible strategies for the manufacturer. The dashed lines in the figure represent the manufacturer's decisions in the incompatible consumable market. In the following section, we compare the profits in both market structures.

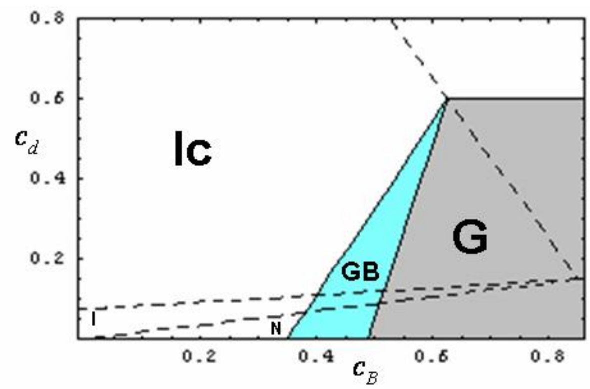


Figure 2.3: Optimal Strategies for a Compatible Manufacturer when $s_{d2} = 0.85,\ s_G = 0.5,\ p_G = 0.2$.

2.4.3 Optimal Design Strategy

In order to find the optimal design strategy for the manufacturer we challenge the incompatible market with a generic consumable industry. We consider several numerical examples in order to assess the benefit of a generic competitive industry to the manufacturer as well as to explore the sensitivity of the optimal design strategies with respect to the model parameters. In all of the cases, $c_B < s_{d2}$ and $c_B + c_d < 1$ hold to produce some branded consumable and new product bundles, respectively; and $p_G < s_{d2}s_G$ is satisfied for consumers to derive positive value from a generic consumable.

First, we consider a situation where the durable goods manufacturer and the generic consumable manufacturers are close in production efficiency. Particularly, we compare the case that the manufacturer could serve the whole market with his consumable ($q_n = q_B$) if he kept his durable good design compatible only with his own consumable to the case when he allows the entry of generic consumable manufacturers.

Proposition 2.4.5. Manufacturer's Compatibility Decision

When $max\left\{c_{d2},\, c_{dB0}\right\} < c_d < min\left\{1 - 2p_G - s_{d2}\left(1 - 2s_G\right),\, c_{dG}\right\}$*, the manufacturer designs his durable good compatible with the generic consumable industry.*

The proof easily follows from $\pi\left(q_n^{**},\, q_B^{**}\right) \leq \pi\left(q_n^{FOC},\, q_B^{FOC}\right)$. Although the generic consumables would cannibalize some demand for the manufacturer's consumable product, they also differentiate the market for the durable good. The manufacturer, therefore, welcomes such entry and stays in the consumable market as long as they offer sufficiently differentiated consumables. Moreover, the manufacturer could always receive the positive value of the used durable good by adjusting its sales price for the new product bundle.

Next, we examine a numerical example where we compare the profits of the incompatible and competitive market structures with respect to the model parameters. We will look closely into the results of one specific instance ($s_{d2} = 0.85$, $s_G = 0.5$, $p_G = 0.2$) and compare the profit functions for the manufacturer derived in Sections 2.4.1 and 2.4.2. Figure 2.4 demonstrates our results for the specific parameter values. Similar results can be easily derived for other values of s_{d2}, s_G and p_G.

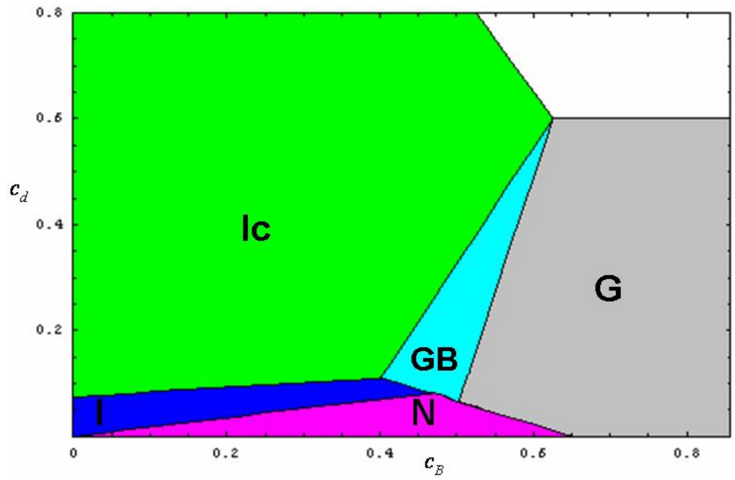


Figure 2.4: Optimal Design Strategies for the Manufacturer when $s_{d2} = 0.85$, $s_G = 0.5$, $p_G = 0.2$

We discussed in Section 2.4.1 how the manufacturer's decision to create a consumable market is influenced by the production costs, c_d and c_B, and the deterioration rate. As seen in Figure 2.4, we can suggest when it becomes profitable to have a generic consumable industry.

Observation 1. *When the generic consumable industry has a higher efficiency in consumable production process relative to the manufacturer ($s_G c_B > p_G$), the manufacturer allows a competitive generic consumable market by making his product compatible.*

When the generic consumables industry has a higher efficiency at making the consumables, i.e. the industry could provide a generic consumable at a higher quality-to-cost ratio relative to the manufacturer ($s_G c_B > p_G$), the manufacturer would allow the entry of the industry depending also on the production cost of his durable good. For low values of c_d, a cheaper alternative generic consumable improves the manufacturer's earnings when it becomes costlier to produce the branded consumable. This can be seen in the transition between regions of incompatible $\{I, N\}$ and compatible $\{GB, G\}$ strategies in Figure 2.4.

In the incompatible market as the durable good production gets costlier for the manufacturer ($c_d > c_{d0}$), he ceases to produce any new product bundles, as shown in Proposition 2.4.1. This production strategy changes when an alternative generic consumable becomes available.

Observation 2. *The presence of a generic consumable industry with a more efficient production process relative to the manufacturer induces the manufacturer to produce new product bundles at high production costs, otherwise, the manufacturer would not consider serving the market.*

We can prove this observation easily. When the generic industry has a higher quality-to-cost ratio, the production characteristics of the generic consumable industry creates additional value for the manufacturer than with the branded consumable, i.e. $s_{d2} s_G - p_G > s_{d2} - c_B$. This condition further proves that $c_{d0} \leq c_d < 1 - 2p_G - s_{d2}(1 - 2s_G)$ for such parameter values. Furthermore, when each durable good has a very high production cost

$(c_d > 1 - 2p_G - s_{d2}(1 - 2s_G))$, the manufacturer does not even enter the product market despite a low cost generic consumable alternative.

It is straightforward to derive similar results for various efficiency levels of the generic consumables industry. Our findings do not change, but the manufacturer's decision to accommodate the generic consumable industry depends on the efficiency levels of the industry. When the generic consumable manufacturers increase their efficiency ($s_G \uparrow,\ p_G \downarrow$), we find that the manufacturer is more willing to accommodate the generic consumable industry. Similarly, a drop in efficiency ($s_G \downarrow,\ p_G \uparrow$) makes the generic consumables a less attractive option to the manufacturer. In addition, the manufacturer's durable good quality influences the efficiency of the industry due to dependency between the durable good and consumable. To illustrate this, Figure 2.5 presents an example of a more efficient industry relative to the example in Figure 2.4 ($s_{d2} = 0.85,\ s_G = 0.6,\ p_G = 0.1$).

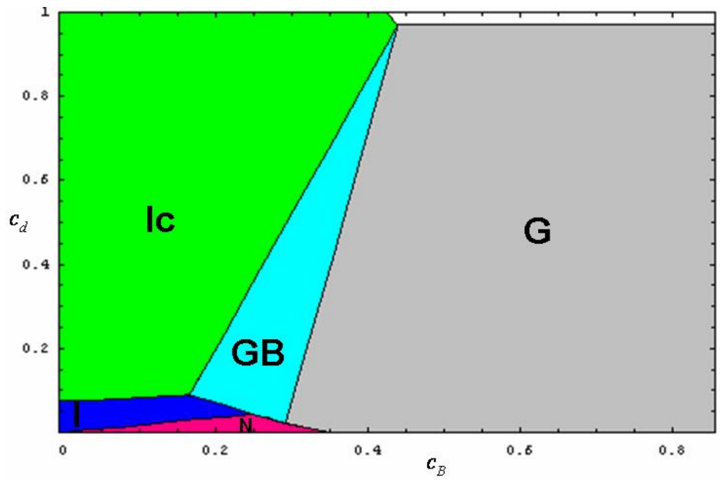


Figure 2.5: Optimal Design Strategies for the Manufacturer when $s_{d2} = 0.85$, $s_G = 0.6$, $p_G = 0.1$.

2.5. Conclusion

During the design stages of product bundles that are composed of a durable good and a contingent consumable, such as a printer and a cartridge, the manufacturer has to consider the interdependence between two components and the life-cycle of the product bundle. Since the technological life of the durable good is long relative to the physical durability of the consumable, the manufacturer's design decision has a significant impact on the long-term profitability of the firm. In this chapter, we consider the optimal design decision faced by a manufacturer, who may choose to make its durable good compatible with the consumables of a generic consumable industry. Whereas several situational factors determine the specific way in which a manufacturer might design its product, some are distinctive in their impact. In particular, we focus on the costs of producing the durable and the consumable, the rate at which the performance of the durable deteriorates, and the quality level of the generic consumable relative to the consumable produced by the manufacturer.

While the compatibility decision creates competition in the consumables market, competition in the generic consumable industry reduces the generic consumable price to production cost. Further, the increase in the number of affordable generic substitutes creates increased demand for the used durable goods and thereby, some positive value for all used durable goods. Therefore, a central consideration in the manufacturer's design decision on compatibility is the positive value generated by the generic substitutes. In this chapter, we study the conditions of this important decision by paying attention to the manufacturer who exploits the availability of generic substitutes for the consumable by designing its product to be compatible with them.

Our results show that generic consumables serve the manufacturer the best when they can differentiate the market for the durable goods and generate positive value for the used durable goods. The value of compatibility decision is greater if the generic manufacturers have a more efficient production process, i.e. they could make consumables at a lower quality-to-cost ratio relative to the manufacturer. The fact that compatibility is not always a profitable alternative in any situation depends on the positive value for the used durable goods that the generic manufacturers can generate. The optimal strategies are characterized by thresholds on the production cost of the manufacturer.

Our research makes several contributions to theory and practice. First, our work identifies the effect of generic contingent components on the durable goods in the profitability of the firms. This is especially significant in a globally competitive market where low cost and considerably simple technology consumables are often quickly produced by generic firms. Second, when the original consumable manufacturer is faced with a generic consumable industry that is more efficient in making the consumable, it is expected for the manufacturer to deter the entry of potentially efficient competitors. Contrary to the conventional wisdom, our findings suggest that he could actually improve his profit earnings after the entry of the generic industry. Third, we develop a concise analytical framework for understanding design decisions on compatibility with a rival industry, which takes into account the different factors that affect ex post market structure. Managers of firms that provide similar products may find this framework valuable in considering the impact of competition before making a compatibility decision.

Although the stylized assumptions of our model let us study the central questions in detail, several assumptions and their influence on our findings need to be acknowledged. First, we only consider the relation between a durable good and a contingent consumable. This limits the applicability of our model to certain product categories. Another limitation of our model is that we focus on a two period model. However, most products are used for several periods. A different model that allows the interaction between the durable good and the consumables for several number of periods could demonstrate the manufacturer's strategy, consumers' expectations and compatibility decisions, and hence, yield different results.

A potential extension of our work could build on our analysis and develop a framework for evaluating the impact of competition for the durable goods, firms that face competition for their durable goods may be more willing to accommodate third-party manufacturers to increase their consumer demand. In addition, we can try our model with different distribution functions for the consumer valuations that could generate different insights. Investigating these issues will enhance our understanding of inter-firm interactions in such industries and consumer behavior.

Chapter 3

Commercializing Component Innovations: The Roles of Firm Capabilities and Network Effects

3.1. Introduction

In many technology-intensive industries, firms have become increasingly specialized in designing and manufacturing certain parts of a product, while relying on external sources for other essential component technologies. Therefore, products sold to end-consumers are produced by integrating many functional modules. This combination of technological specialization and modularity of product architecture permits component-level innovators to consider broader avenues of commercializing their technological breakthroughs beyond simply using them in their own products. A firm's commercialization strategy for a component level innovation can have significant implications, particularly when the potential recipient of component-level knowledge also competes with the innovator in the product market.

Technological innovations often result in increasing not only the performance of an individual product, but also the magnitude of the network benefits that can accrue to users in many products such as mobile phones, interactive software and media players. If a firm licenses her innovation to rivals, she may be able to benefit from the increase in network benefits in the industry. However, since rival firms would be able to increase the quality of the products that they offer, the innovator must trade-off the benefits of increased network effects against the costs of increased competition when considering a commercialization strategy. In this chapter, we model and compare alternative commercialization strategies for the component innovator when sharing a breakthrough with a rival can increase the network value of the component.

The manner in which the component innovator commercializes her technology depends not only on the value the breakthrough adds to her own product, but also on the rival's ability to integrate the component technology with his own product. In some situations, the firm that develops a revolutionary innovation may not be the best suited to commercializing it. For example, when the small software firm, Upstartle, developed a web-based word-processing technology called Writely, it lacked the scale, synergy, and ability to fully exploit the capabilities of this software. Upstartle allowed itself to be acquired by Google who, by integrating Writely into its existing suite of products was in a better position to obtain economic benefits from the new technology.

Further, the commercialization strategy is influenced by the extent to which sharing the component technology can strengthen network effects between products. For example, consider the approach Nokia has taken in commercializing its versatile and powerful application platform for smart phones, the S60 (formerly known as Series 60). A smartphone user derives more value from a software component like S60 if a wider array of applications are available for this platform. Since application developers are attracted to more popular platforms, the consumers derive a greater utility from a smartphone with a more popular application platform. Therefore, in addition to installing S60 on its own mobile phones, Nokia has also actively licensed the platform to rival manufacturers like Lenovo, LG and Samsung (Electronic Engineering Times, 2002). Similarly, Research-in-Motion (RIM) Technologies' innovation resulted in a dramatic improvement in the performance of personal digital assistants (PDAs) and the advent of the phenomenally successful Blackberry. In this situation, RIM could have kept its technology to itself (at least until others developed similar functionalities), but it chose not to. Instead, it licensed its software to a host of rivals, including PalmSource, Nokia, and Motorola (Business Week, 2004).

In networked markets, licensing technological innovations to rivals can also serve to overcome incompatibilities between various products. As an illustrative example, an innovative cellular phone manufacturer might achieve a breakthrough with respect to the component technology that allows photographs to be taken, stored, manipulated, and transferred. However, if the innovator's and rival's products use different file formatting standards, consumers of one product would not be able to share their photographs with consumers of the other one. The media sharing service Vizrea is available for free to users of mobile phones that have S60 installed. But a subscriber is unable to share photos instantly with a friend whose phone is not S60 enabled. By licensing the S60 suite, Nokia has effectively increased the level of compatibility with other cellular phones.

The various strategies used by the firms in these examples, and several others, to bring a component innovation to the market may be broadly grouped under three categories: (a) *Captive use* that makes the innovator the sole firm with the component technology; (b) *Licensing* to a rival, subsequent to which the innovator competes with the rival in the product market; (c) *Selling Out*, which we define as accepting a fixed payment in return for giving a rival exclusive rights to the innovation. The merits and disadvantages of each strategy depend on technological characteristics of the innovation as well as the competitive forces in the industry. We capture these situational elements in a model where the prospective recipient of the component technology may already produce a competing product.

We focus on products that are vertically differentiated, and find that the innovator is generally more willing to share (license or sell-out) her component technology with competitors whose capability to develop other components for the product and integrate it with the component technology are significantly different from her own abilities. This insight extends to situations in which the competitor already has a presence in the market. Our analysis shows that in product classes with stronger network effects, component innovations have a greater likelihood of being licensed. Although this may result in the emergence of closely competing end-products, it leads to widespread adoption of the component technology itself, thus benefiting the innovator. This explains the seemingly counter-intuitive behavior of innovators with radical breakthroughs, who willingly license or sell-out to close competitors.

The modeling framework developed in this chapter extends prior research in this area in several important and realistic dimensions. A significant portion of this work deals with interactions between a component innovator and a rival who is stronger in other aspects of product development. The model also captures the interdependence between the competitor's capability and the network value added to the component by licensing to him. The relative attractiveness of different commercialization strategies also depend on the change in compatibility between existing products due to technology sharing.

The remainder of our chapter is organized as follows. The next section reviews literature relevant to this work. Section 3.3 details our model. We analyze the optimal strategy for the technology innovator in uncontested markets in Section 3.4 and in contested markets in Section 3.5. We conclude with a discussion of our results and insights in Section 3.6.

3.2. Literature Review

The central issue that we consider in this research concerns the comparison of various commercialization alternatives for innovators in industries that are characterized by vertical differentiation and network effects. Here we briefly review the two streams of literature that closely relate to our work: licensing of innovations; and network externalities and their effect on new product strategy.

The study of technology licensing has been a subject of longstanding interest in the economics literature. This literature has dealt in depth with the questions of what technologies should be licensed, to whom, and how licensing contracts should be structured (see Kamien (1992) for a detailed survey). An important factor in these decisions is whether or not the innovator (who holds the patent on the technology) is active in the product market. Several papers have assumed that innovators do not compete with their licensees, and have focused on the problem of selecting the form of licensing and the number of licensees that should be considered (Kamien and Tauman, 1986; Kamien et al., 1992; Katz and Shapiro, 1986; Erat et al., 2006). In contrast, we focus on a firm that possesses a component-level breakthrough that can be licensed to a competitor, whose capacity to develop other components for the end-product may be quite different from the innovator. As we elaborate in § 4.3, the component innovator in our model also has the freedom to determine whether she wants to participate in the product market, the technology market, or both. Other papers that consider licensing to potential rivals either do not consider product differentiation (Arora et al., 2001; Erkal, 2005; Katz and Shapiro, 1985; Costa and Dierickx, 2002, 2005; Fauli-Oller and Sandonis, 2003), or assume that licensing will lead to the creation of rivals whose production processes continue to be inferior to the innovator's (Fosfuri and Roca, 2004; Shepard, 1987; Sun et al., 2004; Gallini and Winter, 1985; Rockett, 1990).

Understandably, the literature has generally ignored a more recent trend in technological innovation. Many significant advances often arise at small and entrepreneurial firms that, unlike more established firms, may not have the complementary expertise required to develop other necessary components and launch the final product (Gans and Stern, 2003). One of the main contributions of our research is to extend some insights from the existing licensing literature to instances where the innovator's ability to commercialize the technology might be *weaker* than that of a potential licensee. Further, with the notable exception of Costa and Dierickx (2005), papers that model licensing to rivals as an interactive, game-theoretic process have assumed that the primary purpose of the technology is to improve production processes. However, it is well known that product patents are more effective than process patents in permitting the innovator to derive income from licensing (Levin et al., 1987). As a result, a technology that improves the quality of final products or creates new product classes is more likely to be patented than a technology that merely reduces production costs for existing products (Cohen and Klepper, 1996). Therefore, in this work, we focus on innovations that lead to enhancements in product quality rather than reductions in production cost. Because these innovations effect the extent of differentiation among products, they are fundamentally different from those that reduce costs.

Most of the early work debating the value of licensing to a rival focuses on the rent dissipation that occurs due to increased competition and revenues that are directly realized from licensing (Arora and Fosfuri, 2003). But in markets with network externalities of consumption, licensing can play a more strategic role. Network externalities are said to exist when the value a consumer derives from a product depends on the number of users who have compatible products. For discussions of the origins and impacts of network effects, see Kauffman et al. (2000); Katz and Shapiro (1985); and Farrell and Saloner (1985). When consumers value the presence of similar users in the network, firms may use several levers such as compatibility (Baake and Boom, 2001; Bental and Spiegel, 1995), pricing (Dhebar and Oren, 1985; Xie and Sirbu, 1995) and encouragement of clones (Conner, 1995; Economides, 1996) to compete effectively. If licensing results in moving products to a common technological standard, it can also increase the compatibility between products offered (Garud and Kumaraswamy, 1993). Therefore, we consider situations in which licensing has the potential to create compatibility between products that would not be compatible otherwise.

Our work is closest in spirit to two of the aforementioned papers. Conner (1995) argues that in the presence of positive network externalities, an incumbent firm might benefit by encouraging a compatible clone to enter, even if it can costlessly thwart this entry. Sun et al. (2004) extend this work and discuss conditions under which a firm can benefit by developing its own clone (that is through product line extension) instead of licensing to create an external clone. Both of these papers examine how the entry of a rival affects the profits of the innovator, and assume that if the rival enters, he produces a lower quality product than does the innovator. However, many technological innovations occur in industries that already include more than one firm. If entry barriers are high, the only practical candidates to whom the technology can be licensed will already be in the industry, and will continue to be there even if the technology is not licensed. Moreover, when innovation occurs at the component level, the firm that achieves a breakthrough in one particular component technology may not necessarily have the best overall product quality. In such cases, the innovator must consider whether to license her breakthrough to a firm that has higher levels of quality in other component technologies, which would allow him to offer a product of greater overall performance quality to the market.

In our model, we address these issues by allowing for the possibility that the innovator will face a rival even if she does not license her technology, and by relaxing the assumption that the product introduced by the rival/licensee is necessarily inferior than that introduced by the innovator. By allowing for these possibilities, we are able to explore some practical issues related to how technological innovations should be licensed among existing rivals in an industry.

3.3. Model

In this section, we introduce our assumptions concerning consumer preferences, the industry structure and the technology sharing decisions made by an innovator and her rival. Throughout the chapter, we adopt the convention of using feminine pronouns to refer to the innovator and masculine pronouns for the rival/licensee.

3.3.1 The Market

We assume that consumers derive utility in two ways: the intrinsic value of being able to use the product in isolation, plus an additional value from being able to interact with a network of other consumers. To allow for differentiation among consumers, we assume that their valuation for quality, v, is uniformly distributed on the interval $[-N, 1]$[1], and normalize the number of consumers in the market to 1. A consumer with valuation v receives the following utility from a product, indexed by j, that has quality s_j:

$$U_j\left(v;\ s_j, Q_j\right) = \left(v + \theta Q_j\right) s_j \tag{3.1}$$

where Q_j represents the number of other consumers who have products that are compatible with product j, and θ is a parameter indicating the strength of the network effects. Throughout our analysis, we assume that $\theta < 8/9$, which is slightly more restrictive that the standard assumption that $\theta < 1$ to ensure that the demand function be downward sloping. Allowing for $\theta \in (8/9, 1]$ complicates the analysis and contributes little additional insight. However, we do discuss the implications of this restriction in Appendix B.1.

In the utility function shown in Equation 3.1, vs_j can be interpreted as the intrinsic utility that the consumer would obtain from the product if he

[1]The main reason that we allow for negative valuations is to avoid situations in which the market is covered in equilibrium. Further, we assume that N is sufficiently large such that the whole market ($1 + N$ consumers) will not be covered under any of the scenarios we consider in this chapter.

However, a negative valuation can be interpreted as a situation in which the disutility that a consumer has from searching for and obtaining the product is greater than the utility that he receives from using it.

were to use it in total isolation, while $\theta Q_j s_j$ represents the additional utility that he receives from interacting with other users in the network. It is worth noting that this utility function implies that consumers do not differ in their willingness to pay for network effects, yet the network benefits a consumer derives from his or her product are proportional to the quality of the product ($\theta Q_j s_j$). Researchers who have studied markets with network effects previously have also used similar models (Conner, 1995; Sun et al., 2004). This is characteristic of many common products with network benefits such as instant messengers and document managers. For example, while all subscribers to a cell phone network find it convenient to converse with each other, only those with special handsets are able to use more advanced network features such as instant picture messaging.

It should also be recognized that the utility function in (3.1) allows us to consider the implications of compatibility between two different products, depending upon how we define Q_j. For example, let d_1 and d_2 be the installed bases for two different products respectively. If the two products are incompatible, then $Q_1 = d_1$ and $Q_2 = d_2$. Alternatively, if the two products are compatible, then $Q_1 = Q_2 = d_1 + d_2$.

3.3.2 The Innovator and the Licensing Opportunity

We adopt the perspective of an innovative firm that has achieved a component innovation that will allow her to introduce a product of quality s. The quality of the final product depends both on the quality of the focal component (where the innovation is applied) as well as on other components that are contained in the final product. Without loss of generality, we normalize $s = 1$ in the rest of this chapter. To maintain our focus on the comparison of inter-firm technology transfer options, we assume that the only participants in the industry are this innovator and one potential licensee who may or may not be able to offer a rival product if the component technology is not licensed.

We focus on two dimensions along which the innovator may be distinguished from her rival/licensee: the fixed cost that each firm would need to invest in order to develop and launch the end-product, and the performance quality of the product that each firm could launch. Let K represent the fixed development cost that would be incurred by the rival if he were to introduce a product that incorporates the new technology. Such costs are typically incurred in designing and developing other components for the product, and in installing the production and distribution infrastructure for the new product. Although the innovator also incurs development costs, we assume that much of her cost has already been incurred in obtaining the technological breakthrough and that her incremental investment for product development is less than that for the rival. For simplicity, we assume that these incremental development costs are zero for the innovator.

The second dimension along which the two firms differ is in terms of their capabilities regarding the other complementary component technologies. Although the innovation that we are considering improves the performance of a single component in the product, the overall product quality experienced by the consumer is a function of the performance of this component as well as all of the other components in the product. Without loss of generality, we assume that the total quality of the innovator's product is equal to 1, and consider how access to the innovation will affect the total quality of the rival's product. Let α_0 be the total quality level of a product that the rival could introduce without access to the innovation, and $\alpha > \alpha_0$ be the total quality of the product that he could introduce if he incorporates the innovation into his product. In addition to expertise on complementary components, the parameter α may also represent a composite of several attributes of the rival such as component integration ability that the rival may have acquired by producing similar products, his distribution and service systems, his brand equity and production efficiency[2].

We devote most of our analysis to situations in which licensing the technology would not alter the ordering of product quality between the two firms, i.e. either $0 \leq \alpha_0 < \alpha < 1$, or $1 < \alpha_0 < \alpha$. We refer to these two cases as the rival being either *weaker* (*stronger*) than the innovator. In general we assume that although licensing can improve the quality of the rival's product, it cannot allow him to *leap-frog* the innovator. However we do consider leap-frogging for the special case where $\alpha_0 = 0$ and $\alpha > 1$. This represents the situation in which the rival does not currently offer a product in the category, but if he did, he would be able to produce a higher quality product than the

[2]It may also depend on attributes of the technology itself (such as modularity), which determine the efficacy with which another firm can use the innovator's invention.

innovator. For example, one could argue that when RIM developed its PDA software, other firms that were already producing large volumes of cellular phones had capabilities in other component technologies that may have allowed them to offer higher total quality products than RIM if they had access to the innovative software.

Throughout our analysis, we assume that, if the innovator licenses her technology, then her product will be network compatible with the rival's product. However, we consider situations in which, in the absence of licensing, the two products would be incompatible. Although it is possible that a component level innovation would not create compatibility between incompatible products, these situations are not very interesting. Nevertheless, we briefly discuss the implications of insurmountable incompatibility for technology licensing in our conclusions.

Finally, we assume that the marginal costs of production are identical for the two firms and that these costs can be normalized to zero. As described in (Krishnan and Zhu, 2006), in many industries in which technological innovation plays a large role, e.g. pharmaceuticals, electronics, software and entertainment, the marginal costs are negligible relative to the cost of development. In addition, to avoid trivial situations in which a rival is unable to enter a market even when the technology is licensed exclusively to him, we assume that K is not prohibitively high - in particular, we assume $K \leq 3.33114$.

3.3.3 Strategies for the Innovator

The innovator has three options with respect to her participation in the product market and the technology market: licensing, selling out, and captive use. We discuss the different merits and mechanics of these different approaches below.

Licensing. When the innovator licenses the component technology, the quality of her licensee's product increases from α_0 to α. Also, by establishing a common technological platform, licensing ensures that the products manufactured by the two firms are compatible with each other. Whereas the increase in the licensee's product quality leads to stronger competition in many cases, this leads to the creation of a large base of users, and consequently, increases each consumer's willingness to pay for the end-products. In some cases, by licensing the technology to a firm with superior capabilities in complementary components, she might reap the networking benefits without increasing competitive intensity.

When two products are available, each consumer purchases the product that maximizes his or her surplus. The stronger (weaker) firm serves the high-end (low-end) segment of the market. We can identify two critical levels of consumer valuation, $v_l \leq v_h$, such that consumers with valuations in $[v_l, v_h)$ purchase from the low-end firm while consumers with valuations in $[v_h, 1]$ purchase from the high-end firm and consumers with valuations in $[-N, v_l)$ purchase nothing. Let $Q_h(p_h, p_l)$ and $Q_l(p_h, p_l)$ denote the network sizes of the high-end and low-end firms, respectively. In the particular case where licensing leads to a common technological platform, we set $Q_h(p_h, p_l) = Q_l(p_h, p_l) = 1 - v_l$. The marginal consumers v_h and v_l can be characterized as follows

$$\begin{array}{lcl} (v_h + \theta Q_h(p_h, p_l))\,\alpha_h - p_h & = & (v_h + \theta Q_l(p_h, p_l))\,\alpha_l - p_l \\ (v_l + \theta Q_l(p_h, p_l))\,\alpha_l - p_l & = & 0 \end{array} \tag{3.2}$$

The corresponding demands for the high-end and the low-end firms are represented by $d_h(p_h, p_l) = 1 - v_h$ and $d_l(p_h, p_l) = v_h - v_l$, respectively. Subsequently, the high-end firm with development cost K_h and the low-end firm with K_l set prices p_h and p_l simultaneously to maximize their profits, $\pi_h = p_h d_h(p_h, p_l) - K_h$ and $\pi_l = p_l d_l(p_h, p_l) - K_l$, respectively. We find the Nash equilibrium prices set by the two firms and the corresponding profits.

We assume that the innovator makes a Take-It-or-Leave-It (TIOLI) offer to the rival[3]. She offers to share the technology with the rival for a fixed licensing fee, F[4]. If the offer is accepted, the innovator and the licensee produce compatible products of qualities 1 and α, respectively. The innovator's product will be perceived as the high-end product if $\alpha < 1$. Similarly, when the licensee is stronger than the innovator, i.e. $\alpha > 1$, the highest valuation consumers buy the licensee's product, while consumers with intermediate valuations buy the innovator's product.

[3]Our approach is sufficient to understand when licensing will occur, even if it overstates the profits that might be earned by the innovator compared to a more sophisticated modeling approach like Bargaining.

[4]Several authors have compared various forms of licensing contracts involving fixed fees and royalties with regard to their efficiency in coordinating the incentives of the licensor and the licensee (Erkal, 2005; Kamien, 1992; Sun et al., 2004). However, our intention is to analyze the relative appropriateness of various forms of commercialization. Contracts with royalties require stringent monitoring processes, which are often cumbersome and difficult to enforce in practice.

Selling Out. Under this option, the innovator surrenders the right to use the component technology to her rival. This is a common exit strategy for innovators in knowledge-based industries such as Bio-Tech (Forbes, 2005), which relieves them from the burden of developing and marketing a product based on their innovation. The technology elevates the quality of the acquirer's product from α_0 to α, and additionally, he does not face competition from the innovator.

As before, we assume that the innovator may offer a TIOLI contract to sell the technology for a fixed price to her rival. To ensure that the innovator will not develop a product that will eventually compete with the rival, firms often incorporate specific clauses in such contracts that gives the acquiring firm the exclusive right to incorporate the component technology into a product. The rival becomes a monopolist firm and sets a price in order to maximize its profit.

Captive Use. And finally, the innovator may find it advantageous to not share the technology with her rival. When the innovation is captively used in a new product introduced in an uncontested market, the innovator acts as a monopolist, and prices her product to maximize her profit. When the market is contested, the demands for the two products depend on the rival's product quality α_0 as well as the initial compatibility between them. In contested markets, the innovator may benefit from the rival's presence even though licensing may not occur. On the other hand, the rival may force the innovator to enter into a mutually detrimental price war without actually benefiting significantly from the process himself. In such cases, the innovator may benefit by *buying out* the rival, in addition to captively using the component technology, to maximize the market potential for the innovation. As in the licensing and selling out cases, we assume that the acquisition is preceded by a TIOLI offer from the innovator, and followed by her price-setting.

3.4. Commercialization in Uncontested Markets

Our analysis applies the standard approach of backward induction. We derive the equilibrium prices at which the firm(s) sell their respective products under various strategies and the corresponding profits. Subsequently, we compare the innovator's profits across these approaches and derive conditions under which licensing, selling out and captive use are optimal. In this section, we focus on the situation in which the rival does not currently have a product in the category, i.e. $\alpha_0 = 0$, which we refer to as an *uncontested market*. Further, since the rival plays a competing role in the market only if the technology is licensed, we use the terms *licensee* and *rival* interchangeably when we discuss uncontested markets. Commercialization of innovations in contested markets is considered later in § 3.5.

3.4.1 Interactions with a Weaker Licensee

When the innovator is stronger than the licensee ($\alpha < 1$), the innovator is able to generate larger profits as a monopolist with her own product than rival could if his lower quality product were the only one in the market.

Therefore, it is not profitable to sell out the innovation. The innovator's central decision therefore, is to determine whether to license the innovation to its rival (and compete with him) or remain a monopolist. Her strategy depends on both the relative strength (α) of the rival and on the strength of network effects in the market (θ).

When the licensee is weaker than the innovator, licensing leads to the emergence of a weakly competitive clone ($\alpha < 1$) of her product. Weak clones are useful in establishing a wide installed base for the technology, which she could have created only by significantly reducing the price of its product. If it is beneficial to license, she sets a licensing fee F_w that will induce the licensee to accept the TIOLI offer. Let p_i and p_c represent the prices that the innovator and the competitor set subsequently to maximize their respective revenues.[5] If $p_c > p_i$, no consumer buys the rival's product. However, since the rival can always lower his product's price to increase demand, this never occurs in equilibrium. For any $\alpha p_i \geq p_c$, there exists a marginal consumer v_i that is indifferent between the innovator's and rival's product, and a marginal consumer v_c that is indifferent between buying the rival's product and not buying at all. As we show in (3.4) below, $\alpha p_i > p_c$ in equilibrium. All consumers with valuations in $[v_c, v_i)$ purchase from the rival while consumers with valuations in $[v_i, 1]$ purchase from the innovator and consumers with valuations in $[-N, v_c)$ purchase nothing. Let us use superscript w to indicate the prices

[5]In the rest of the chapter, we use subscripts i and c to refer to demands, prices and profits for the innovator's and her competitor/licensee's products, respectively.

and profits when the rival is weaker than the innovator.

By setting the network sizes $Q_i\left(p_i,\, p_c\right) = Q_c\left(p_i,\, p_c\right) = 1 - v_c$ and finding the marginal consumers v_i and v_c in (3.2), the corresponding demands for the situation when the rival is weaker are

$$\begin{aligned} d_i^w\left(p_i,\, p_c\right) &= \tfrac{\alpha(p_c+(1-\alpha)-p_i(1-\theta))-\theta p_c}{\alpha(1-\theta)(1-\alpha)} \\ d_c^w\left(p_i,\, p_c\right) &= \tfrac{\alpha p_i - p_c}{\alpha(1-\alpha)} \end{aligned} \tag{3.3}$$

We solve the following profit maximization problems for the innovator and the rival, simultaneously. We obtain the Nash equilibrium prices of the two firms p_i^w, p_c^w and the corresponding profits π_i^w, π_c^w as

$$\begin{aligned} p_i^w\left(\alpha\right) &= \frac{2\left(1-\alpha\right)}{4-\left(\alpha+3\theta\right)} \\ p_c^w\left(\alpha\right) &= \frac{\alpha\left(1-\alpha\right)}{4-\left(\alpha+3\theta\right)} \end{aligned} \tag{3.4}$$

$$\begin{aligned} \pi_i^w\left(\alpha\right) &= \frac{4\left(1-\alpha\right)}{\left(4-\left(\alpha+3\theta\right)\right)^2} \\ \pi_c^w\left(\alpha\right) &= \frac{\alpha\left(1-\alpha\right)}{\left(4-\left(\alpha+3\theta\right)\right)^2} - K \end{aligned} \tag{3.5}$$

In order to extract from the rival the benefits of licensing the technology, the innovator sets a licensing fee of $F_w = \pi_c^w\left(\alpha\right)$ in an uncontested market.

Alternatively, if the innovator captively uses the innovation in an uncontested market, there exists marginal consumer v_m, such that all consumers in $(v_m,\, 1]$ buy the product.

$$v_m = \frac{p_m - \theta}{\left(1-\theta\right)} \tag{3.6}$$

The demand for the product at this price is given by $1 - v_m$. Maximizing the monopoly profit, $p_m(1 - v_m)$, the price and revenue expressions in this case, p_m^* and π_m^*, are given by

$$p_m^* = \frac{1}{2}\,;\ \pi_m^* = \frac{1}{4(1-\theta)} \tag{3.7}$$

In the following proposition, we derive conditions under which the innovator can profit by licensing in an uncontested market. The conditions are based on a set of thresholds with respect to K and α. The exact functions that define all thresholds presented in the chapter are given in Technical Supplement at the end of this chapter [6]. To distinguish these results from those in which the innovator faces a competitive product regardless of whether she licenses, we use the subscript M in α_M^w to indicate the setting in which she would be in an uncontested market if she did not license.

Proposition 3.4.1. Licensing to a Weaker rival in an Uncontested Market

When the rival is weaker than the innovator ($\alpha < 1$)*, the innovator's optimal strategy can be characterized as follows:*

a) For each $\theta \in [0, 8/9)$*:*

i) There exists a threshold $K^w(\theta)$ *such that the innovator does not license her innovation if* $K \geq K^w$*.*

ii) If $K < K^w$*, there exists a threshold* $\alpha_M^w(\theta, K)$ *such that the innovator*

[6] We include the independent parameters for the thresholds when they are introduced, and suppress the parameters in subsequent discussions.

licenses her innovation if $0 \leq \alpha \leq \alpha_M^w(\theta, K) \leq 1$*. Otherwise, the innovator uses the captive use strategy.*
b) The threshold, $\alpha_M^w(\theta, K)$*, is increasing in* θ *and decreasing in* K*. The threshold* $K^w(\theta)$ *is increasing in* θ*.*

Proposition 3.4.1 shows that in an uncontested market with entry costs ($K < K^w$), the innovator could find it profitable to license an innovation to her rival, even when she has the option of becoming a monopolist. To understand the above result, note that licensing has two consequences for the innovator - increased competition due to presence of another product and stronger network effects owing to a wider installed base. While the adverse effect of competition is larger when α is higher, the complementary value of another product contributing to the innovator's network increases with θ. As a result, when θ is smaller, the innovator licenses only if the rival would produce a lower quality imitation of its own product. However, as θ increases, the value of network benefits increases, allowing the innovator to license the technology to a rival whose product is closer in quality to its own product. This is reflected in the relationship between α_M^w and θ. If the entry cost exceeds K^w, the maximum possible licensing fee would not justify technology sharing from the innovator's perspective. Since the synergistic benefits increase with θ for both firms, the innovator finds the licensee's presence in the market desirable even at higher costs at higher levels of θ. As a result, K^w increases with θ.

The relationship between α_M^w and θ is illustrated in Figure 3.1. When $\theta = 0.5$, the innovator will not license the technology to a rival with $\alpha = 0.65$

even if the rival does not incur *any* development cost ($0.65 < \alpha_M^w(0.5, 0) = 0.6$). However, if the strength of network effects increases to $\theta = 0.6$, she would license to the same rival because $\alpha_M^w(0.6, 0) = 0.7$.

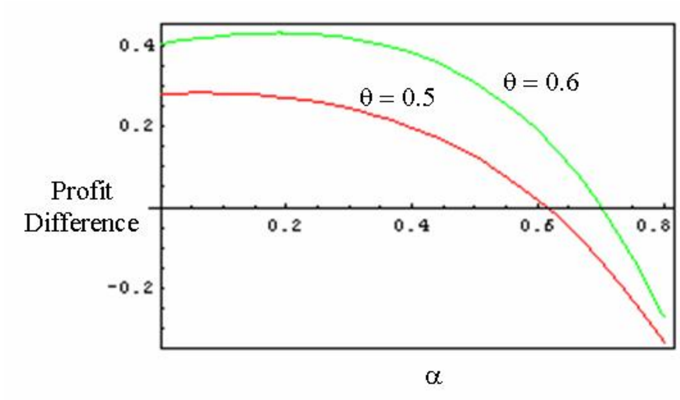


Figure 3.1: Profit Difference Curves for the Licensor between Licensing to a Weaker Licensee and Captively Using the Innovation in an Uncontested Market, for the values of $\theta = 0.5$ and $\theta = 0.6$.

The benefit of competition in a networked environment has been studied before. Conner (1995) and Sun et al. (2004) suggest that an innovator might encourage an imitation of her product by rivals when network externalities are present and show that such an inducement might generate not only a larger installed base, but also higher demand for the innovator's product, than when the innovator acts as a single product monopolist. They show that an increased user base could help the innovator's profits more than the increased competition hurts it. In these circumstances, an innovator has an incentive to *accommodate* an imitation even if it violates the patent protecting the component technology - we refer to such clones as *infringing imitations*. We know from Conner that there exists a threshold $\bar{\alpha}(\theta)$ such that the innovator would benefit from an infringing imitation only if $\alpha \leq \bar{\alpha}(\theta)$.

Proposition 3.4.2. Licensing and Infringing Imitation

In an uncontested market, the innovator licenses its innovation to a weaker rival, but does not accommodate an infringing imitation by the same rival if $\bar{\alpha}(\theta) < \alpha \leq \alpha_M^w(\theta, K)$.

Further, for each value of θ, $\bar{\alpha}(\theta) \leq \alpha_M^w(\theta, K)$.

While encouraging an infringing imitation increases the profit that the innovator derives from her own product, by licensing she can also extract all of the rival's increase in profits. As a result, even in some cases where the innovator might shun imitation fearing increased competition, she will license the use of the component technology for a fee $\left(\bar{\alpha}(\theta) < \alpha \leq \alpha_M^w(\theta, K)\right)$.

3.4.2 Interactions with a Stronger Licensee

In many industries, young and entrepreneurial firms are frequently at the forefront of innovation. Such firms may license their innovations to more established firms that may be able to bring to market that is perceived as having higher total quality. This case can be captured in our model by setting $\alpha_l = 1$ and $\alpha_h = \alpha$ in (3.2). The innovator offers to license her technology for a fixed licensing fee, F_s, through a TIOLI contract. As was the case for the weaker licensee, it can be shown that, in equilibrium, there will be two critical levels of consumer valuation, $v_i < v_c$, such that consumers with valuations in the interval $(v_c, 1]$ buy the higher quality product, while consumers in $(v_i, v_c]$

buy the lower quality product. These valuations for the marginal consumers, v_i and v_c, can be characterized by setting $Q_i(p_i,\ p_c) = Q_c(p_i,\ p_c) = 1 - v_i$. To distinguish the equilibrium prices and profits in this case from those when the the rival is weaker, we use the superscript s to denote a stronger rival.

For the case in which the licensee is stronger than the innovator, the demands for the two products can be characterized as follows, so long as $p_c \geq \alpha p_i$ (Note that, it is easy to confirm that $p_c > \alpha p_i$ in equilibrium):

$$\begin{aligned} d_c^s(p_i,\ p_c) &= \tfrac{(\alpha-1)+p_i(1-\alpha\theta)-p_c(1-\theta)}{(1-\theta)(\alpha-1)} \\ d_i^s(p_i,\ p_c) &= \tfrac{p_c-\alpha p_i}{\alpha-1} \end{aligned} \tag{3.8}$$

Simultaneously maximizing the profit functions for the innovator, we compute the Nash equilibrium prices set by the two firms p_i^s, p_c^s and the total profits π_i^s, π_c^s:

$$\begin{aligned} p_i^s(\alpha) &= \frac{(\alpha-1)}{\alpha(4-3\theta)-1} \\ p_c^s(\alpha) &= \frac{2(\alpha-1)\alpha}{\alpha(4-3\theta)-1} \end{aligned} \tag{3.9}$$

$$\begin{aligned} \pi_i^s(\alpha) &= \frac{\alpha(\alpha-1)}{(1-\alpha(4-3\theta))^2} \\ \pi_c^s(\alpha) &= \frac{4(\alpha-1)\alpha^2}{(1-\alpha(4-3\theta))^2} - K \end{aligned} \tag{3.10}$$

Just as we did for the case of a weaker rival, we assume that, if the innovator licenses her innovation to a rival who could not introduce a product without it, she can can set the licensing fee to $F_s = \pi_c^s(\alpha)$.

Alternatively, the innovator can consider selling-out, by granting the licensee exclusive rights to the technology. If exclusive rights to the technology are acquired by the rival, he sets a monopoly price of p_{cm} for the new product. All consumers in $(v_{cm}, 1]$ buy the product, where v_{cm} represents the valuation of the consumer who is indifferent between buying the rival's product and not purchasing.

$$v_{cm} = \frac{p_{cm} - \theta\alpha}{\alpha(1-\theta)} \tag{3.11}$$

The demand for the product at this price is given by $1 - v_{cm}$. The licensee maximizes his revenue, $p_{cm}(1 - v_{cm})$. The optimal price and revenue are given in (3.12).

$$\begin{aligned} p^*_{cm}(\alpha) &= \frac{\alpha}{2} \\ \pi^*_{cm}(\alpha) &= \frac{\alpha}{4(1-\theta)} - K \end{aligned} \tag{3.12}$$

The innovator charges a fee $F = \pi^*_{cm}(\alpha)$ in this case. While the apparent choices include captive use, licensing and selling out, the captive use option is sub-optimal for an innovator facing a stronger rival ($\alpha > 1$) when the rival does not incur any product development costs ($K = 0$).

In the following proposition, which parallels Proposition 3.4.1, we derive conditions under which the innovator can profit by licensing to a stronger rival in a market that would be uncontested without licensing. As we did in the previous proposition, we use the subscript M to indicate that the innovator would be in an uncontested market if she did not license. The superscripts cs, sl and lc denote the threshold α values between captive use (c), selling out (s) and licensing (l) strategies. For example, α^{cs}_M denotes the value of α that makes the uncontested innovator indifferent between selling out and captively using the technology.

Proposition 3.4.3. Licensing to a Stronger rival in an Uncontested Market

In uncontested markets ($\alpha_0 = 0$) with a stronger rival, there exists a threshold K^s such that the optimal strategy can be characterized as follows,

a) If $K < K^s$, then there exist two thresholds, $\alpha_M^{cs}(\theta, K) < \alpha_M^{sl}(\theta, K)$, such that the innovator uses the captive use strategy if $1 \leq \alpha \leq \alpha_M^{cs}(\theta, K)$, sells out the technology if $\alpha_M^{cs}(\theta, K) < \alpha \leq \alpha_M^{sl}(\theta, K)$, and licenses the technology if $\alpha_M^{sl}(\theta, K) < \alpha$.

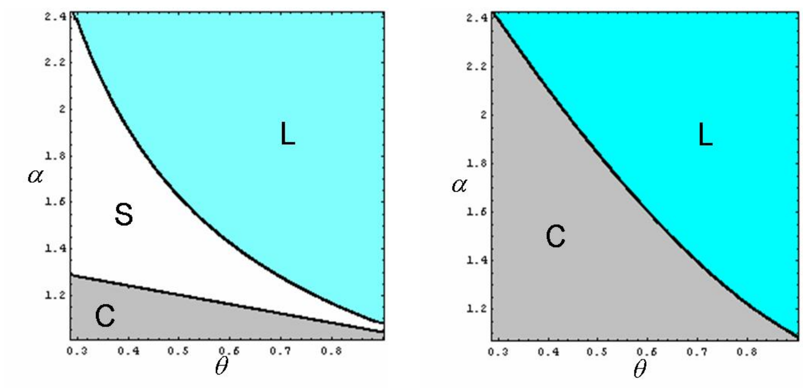
b) If $K \geq K^s$, then there exists a threshold $\alpha_M^{lc}(\theta, K) > 1$ such that the innovator uses the captive use strategy if $1 \leq \alpha \leq \alpha_M^{lc}(\theta, K)$, and licenses the technology if $\alpha_M^{lc}(\theta, K) < \alpha$. In this case, the innovator never sells out the technology.

c) $\alpha_M^{cs}(\theta, K)$, $\alpha_M^{sl}(\theta, K)$, $\alpha_M^{lc}(\theta, K)$ and K^s are monotonically decreasing in the strength of network effects θ.

As Proposition 3.4.3 shows, the weak innovator may sell her technology to a stronger rival in many circumstances. Whereas a stronger innovator perceives the market for technology sharing as an additional opportunity to increase her revenues, transactions in technology transfer may be the primary source of revenues for the weak innovator. Therefore, if the licensee's development cost is not excessive ($K < K^s$), selling out is a profitable exit strategy for the innovator if the licensee is strong enough to overcome development costs $(\alpha > \alpha_M^{cs}(\theta, K))$, yet not so strong that both products can coexist without indulging in severe price competition $\big(\alpha < \alpha_M^{sl}(\theta, K)\big)$.

Selling out, however, is not always a viable exit strategy. While the licensee's development cost K does not affect the revenues of the two firms after licensing, the development cost K limits the size of the licensing fee F that can be collected by the innovator. As a result, her incentive to license or sell the innovation decreases with K. Consequently, the innovator should be more inclined to either use the captive use or licensing strategies when the rival incurs a larger development cost. As a result, we find that when $K \geq K^s$, selling out is never optimal.

To further understand the conditions that determine the optimal commercialization strategy, we consider a numerical example. Suppose the basic quality of the innovator's product is $s = 1$. Figure 3.2 shows the industry parameters $(\theta,\ \alpha)$ for which captive use (C), selling out (S) and licensing (L) are optimal strategies for the innovator. We separately consider two cases where the development costs are significantly high $(K \geq K^s)$ and low $(K < K^s)$.



a. $K < K^s$ **b.** $K \geq K^s$

Figure 3.2: Commercialization Strategy in an Uncontested Market with a Strong rival for various values of α and θ.
(a) $K = .1$, (b) $K = .5$

Consider the case in which the rival incurs significant development costs if he licenses or purchases the right to use the innovation ($K \geq K^s$). In Figure 3.2.b, we see that the innovator prefers to captively use the technology when there are neither strong network effects nor large improvements in product quality from licensing. From § 3.4.1, recall that the innovator trades off the benefit of having a larger network against the cost of increased competition. Therefore, when network effects are stronger, the innovator is more willing to license smaller innovations to the rival though the reduced product differentiation leads to more intense competition. This is reflected in the inverse dependency of α_M^{lc} on θ.

When K is smaller, as Figure 3.2.a shows, the innovator has a larger incentive to sellout to the stronger rival. The decision to stay in the market after licensing, however, depends on θ and α. While the two firms will mutually benefit due to network effects when θ is larger, the products they offer will not be sufficiently differentiated if α is small. Therefore, we find that the innovator should follow the captive use strategy for small values of α ($\alpha < \alpha_M^{cs}$), the rival acquires the innovation for intermediate levels of α $\left(\alpha_M^{cs} < \alpha < \alpha_M^{sl}\right)$, and the two firms compete after licensing when there is sufficient product differentiation $\left(\alpha > \alpha_M^{sl}\right)$. The fact that the thresholds α_M^{cs}, α_M^{sl} and K^s decrease with θ can be attributed to the shift in the tradeoff between network benefits and competition explained above.

3.5. Licensing Innovations in Contested Markets

Thus far, we have considered strategies for exploiting innovations that create new product categories. In accordance, we assumed that a rival will not be able to develop a product that interacts with the innovator's unless the innovator sells out or licenses it to him. In this section, we consider innovations that improve the performance of products in existing product categories.

In particular, we assume that the rival currently manufactures a product of quality α_0 ($\alpha_0 > 0$). By obtaining the right to use the innovation, he will be able to improve the quality to α ($\alpha > \alpha_0$). We consider two cases: the rival is said to be *weaker* when his product is always lower in quality relative to the innovator's product ($\alpha_0 < \alpha < 1$); he is said to be *stronger* if his offering is of higher quality ($1 < \alpha_0 < \alpha$)[7]. Furthermore, a rival who is already

[7]There is also the possibility that the rival's product quality leapfrogs the innovator's after licensing ($\alpha_0 < 1 < \alpha$). While we do not consider this explicitly in this section, we

active in manufacturing a competing product would not incur the additional development costs for other components or installation costs for a distribution infrastructure. Therefore, we ignore these costs in this section by setting $K = 0$.

In a contested market, when the innovator develops an improved component technology, she competes with a rival product, regardless of whether she licenses her innovation. The optimal prices and profits depend on the compatibility between products and the relative strength of the rival. When the innovation is such that the innovator's new product and the rival's competing product are compatible even in the absence of technology sharing, we refer to it as a *compatible* innovation. Here, the innovator's profits are derived by setting $\alpha = \alpha_0$ in (3.5) and (3.10) in § 3.4.1 and § 3.4.2 above.

When the innovation occurs at a fundamental, architectural level, the products may not be compatible prior to licensing. For example, consider the case of a technological innovation that improves the quality of a personal communications device, compatible versions of which are being sold by the two firms. If the innovation serves to increase the fidelity of a data-transfer mechanism, the devices will continue to be compatible when the new technology is incorporated in the innovator's product. However, if the innovation alters the data-transfer protocols in fundamental ways, the two versions will be unable to communicate after the innovator installs the new technology in its products.

---

have already considered a special case ($\alpha_0 = 0$) in § 3.4.2 earlier.

We simply refer to such innovations as *incompatible* innovations. Licensing the technology will unite the two products under a common standard and makes them compatible.

Note that the source of incompatibility between the innovator's and the rival's products lies elsewhere in the product. However, such *persistent incompatibility*, where licensing will not solve the compatibility issue, represents a trivial decision-making scenario for the innovator. When she is facing a weaker (stronger) competitor, the innovator always prefers captive use of the innovation (selling out)[8].

Here we derive the equilibrium prices and profits of the two firms when their products are incompatible. When the innovator faces a weaker rival ($\alpha_0 < 1$), the marginal consumers, v_i and v_c, are identified by setting $Q_i\left(p_i,\, p_c\right) = 1 - v_i$ and $Q_c\left(p_i,\, p_c\right) = v_i - v_c$ in (3.2). The demands for two incompatible products are derived as

$$\begin{aligned} d_i\left(\alpha_0\right) &= 1 - \frac{p_c-(1-\theta)(p_i-\theta)}{\left(\alpha_0-(1-\theta)^2\right)} \\ d_c\left(\alpha_0\right) &= \frac{p_c(1-\theta)-\alpha_0 p_i+\alpha_0\theta}{\alpha_0\left(\alpha_0-(1-\theta)^2\right)} \end{aligned} \tag{3.13}$$

Solving the profit maximization problems for the innovator and the rival simultaneously, the optimal prices and the profits of the innovator and the rival are, respectively,

$$\begin{aligned} p_i^w\left(\alpha_0\right) &= \frac{\alpha_0(2-\theta)-2(1-\theta)^2}{\alpha_0-4(1-\theta)^2}; \qquad p_c^w\left(\alpha_0\right) = \frac{\alpha_0((3-2\theta)\theta-(1-\alpha_0))}{\alpha_0-4(1-\theta)^2} \\ \pi_i^w\left(\alpha_0\right) &= \frac{(1-\theta)\left(\alpha_0(2-\theta)-2(1-\theta)^2\right)^2}{\left(\alpha_0-(1-\theta)^2\right)\left(\alpha_0-4(1-\theta)^2\right)^2}; \quad \pi_c^w\left(\alpha_0\right) = \frac{\alpha_0(1-\theta)((3-2\theta)\theta-(1-\alpha_0))^2}{\left(\alpha_0-(1-\theta)^2\right)\left(\alpha_0-4(1-\theta)^2\right)^2} \end{aligned} \tag{3.14}$$

[8]See Appendix B.6.

Similarly, when the innovator is faced with a stronger rival ($\alpha_c = \alpha_0 > \alpha_i = 1$), we set $Q_c(p_i,\ p_c) = 1 - v_c$ and $Q_i(p_i,\ p_c) = v_c - v_i$ and find v_i and v_c in (3.2). The demands for the two products can be computed as

$$\begin{aligned} d_c(\alpha_0) &= \frac{p_i - p_c(1-\theta) - (1-\alpha_0+\alpha_0\theta)}{\left(\alpha_0(1-\theta)^2-1\right)} \\ d_i(\alpha_0) &= \frac{p_c - \alpha_0(p_i(1-\theta)+\theta)}{\left(\alpha_0(1-\theta)^2-1\right)} \end{aligned} \tag{3.15}$$

Solving the profit maximization problems for the two firms, the optimal product prices and profits can be derived analogous to (3.13) above.

$$\begin{aligned} p_i^s(\alpha_0) &= \frac{(\alpha_0(1-\theta)(1-2\theta)-1)}{4\alpha_0(1-\theta)^2-1}; \quad & p_c^s(\alpha_0) &= \frac{\alpha_0\left(\theta+2\alpha_0(1-\theta)^2-2\right)}{4\alpha_0(1-\theta)^2-1} \\ \pi_i^s(\alpha_0) &= \frac{\alpha_0(1-\theta)(\alpha_0(1-\theta)(1-2\theta)-1)^2}{\left(\alpha_0(1-\theta)^2-1\right)\left(4\alpha_0(1-\theta)^2-1\right)^2}; \quad & \pi_c^s(\alpha_0) &= \frac{\alpha_0^2(1-\theta)\left(\theta+2\alpha_0(1-\theta)^2-2\right)^2}{\left(\alpha_0(1-\theta)^2-1\right)\left(4\alpha_0(1-\theta)^2-1\right)^2} \end{aligned} \tag{3.16}$$

3.5.1 Interactions with a Weaker Rival

Proposition 3.5.1 below identifies the optimal commercialization decision for the innovator when facing a rival who sells a compatible lower quality product ($\alpha_0 < \alpha < 1$), regardless of whether the technology is licensed or not. Subsequently, in Proposition 3.5.2, we consider the licensing of incompatible innovations.

Analogous to the subscript M that represents an innovator in an uncontested market if she did not license, we denote the duopoly with two compatible products with subscript D.

Proposition 3.5.1. ($\alpha_0 < \alpha < 1$) **Compatible Innovation with a Weaker Rival**

a) For each θ, there exist thresholds $\alpha_D(\alpha_0, \theta)$ and $\alpha_{0D}(\theta)$ such that

i) If $\alpha \leq \alpha_D$, then the innovator licenses a compatible innovation to a weaker rival.

ii) If $\alpha > \alpha_D$, then the innovator uses the captive use strategy. Further, unless $\alpha_0 \geq \alpha_{0D}$, the innovator benefits from the rival's presence.

b) The threshold α_D is non-increasing in α_0. Both α_D and α_{0D} are increasing in θ.

Recall that the fundamental trade-off in licensing the technology is between the cost of increased competition and the network benefits due to a wider installed base. We find that the window of licensing (α_0, α_D) is similar to the interval (0, α_M^w) identified earlier in Proposition 3.4.1. Further, if the rival's product is not sufficiently differentiated from the innovator's product ($\alpha_0 > \alpha_{0D}$), price competition dominates network effects.

As the value of network benefits increases with θ, the innovator is increasingly willing to share technologies that reduce product differentiation, i.e. the gap in product quality. Therefore, the threshold α_D increases with θ. More interestingly, we find that the innovator is less willing to license its technology when the rival possesses a higher quality alternative ($\alpha_D \downarrow$ with α_0). While the ex-post network benefits and competitive intensity are not affected by the relative quality of the rival's product, the licensing fee, F^w, that the rival is willing to pay, decreases with α_0. As a result, the innovator finds licensing higher-quality innovations to be unprofitable when α_0 is higher.

In Proposition 3.5.2 below, we present the optimal commercialization strategies when the innovation makes the two products incompatible unless the technology is licensed. For these incompatible innovations, the commercialization strategies are characterized by a pair of thresholds that parallel those in Proposition 3.5.1. However, the behavior of these thresholds with respect to α_0, the initial quality of the rival, is different.

Proposition 3.5.2. $(\alpha_0 < \alpha < 1)$ **Incompatible Innovation with a Weaker Rival**

a) For each θ, there exist thresholds $\alpha_I(\alpha_0, \theta)$ and $\alpha_{0I}(\theta)$ such that

i) If $\alpha \leq \alpha_I$, the innovator licenses an incompatible innovation to a weaker rival.

ii) If $\alpha > \alpha_I$, the innovator uses the captive use strategy. Further, the innovator benefits from the rival's presence in the market unless $\alpha_0 \geq \alpha_{0I}$.

b) The threshold α_I is non-decreasing in α_0.

Similar to the case of licensing compatible innovations, the innovator finds it profitable to license only those incompatible innovations that lie within an acceptable window (α_0, α_I), and acquires the rival's product if its quality is substantially close to her own product's quality ($\alpha_0 > \alpha_{0I}$). For the innovator, licensing is more useful when the innovation is incompatible with a rival's product because licensing makes the two products compatible, in addition to generating revenue through the licensing fee itself. Consider the impact of an improvement in the rival's initial product quality on the licensing decision.

As α_0 increases, the opportunity cost of not licensing is higher for the innovator since she faces stiffer competition from an incompatible product. This increases her willingness to license her technology. Therefore, unlike α_D, the threshold α_I is non-decreasing in α_0.

This difference in the behavior of thresholds α_I and α_D highlights the sensitivity of technology strategy with respect to the fundamental properties of the technology. Recall that α_I and α_D represent the *highest* product qualities that an innovator is willing to give to a rival through licensing. Suppose the rival comes to possess a technology that improves its product quality to $(\alpha_0 + \delta)$ from α_0 without affecting its compatibility (where $\alpha_0 + \delta < \alpha$). Does this turn of events make the innovator more or less willing to share its technology with the rival? According to our results in this section, the answer really depends on whether the two products are compatible or not. Therefore, at higher levels of the rival's product quality α_0, an innovator with a compatible innovation becomes less interested in sharing, whereas an innovator with an incompatible innovation is more likely to license.

3.5.2 Interactions with a Stronger Rival

In this section, we consider the interaction of the innovator with a stronger rival ($\alpha > \alpha_0 > 1$).

Proposition 3.5.3. ($\alpha > 1$) **Licensing to a Stronger rival in a Contested Market**

The optimal commercialization strategy for an innovator competing with a *stronger rival depends on the compatibilities between the products before and after licensing.*

Compatible Innovation. *For each θ, there exists a threshold $\alpha_M^{sl}(\theta)$ such that*

a) The innovator licenses a compatible innovation to a stronger rival iff $\alpha \geq \alpha_M^{sl}$.

b) The innovator sells out her technology to the rival iff $\alpha_0 < \alpha < \alpha_M^{sl}$.

Incompatible Innovation. *For each θ, there exists a threshold $\alpha_{0I}^{l}(\theta)$ such that*

a) The innovator licenses an incompatible innovation to a stronger rival if $\alpha \geq \alpha_M^{sl}$ or if $\alpha_0 \geq \alpha_{0I}^{l} \geq 1$.

b) Otherwise, the innovator sells out her technology to the rival.

First, consider the innovator who licenses a compatible innovation. While consumers universally benefit from improved product quality and the expanded network size, the ability of firms to extract consumer surplus diminishes due to reduced product differentiation. Since her rival is stronger ($\alpha > 1$), the innovator prefers selling out over licensing when α is low $\left(\alpha \leq \alpha_M^{sl}\right)$ in order to avoid aggressive price competition. However, when α is larger, due to the sufficiently large product differentiation, sharing the innovation with her rival does not affect the innovator's ability to stay in the market. Therefore, irrespective of α_0, innovations that boost the rival's product quality significantly will be licensed.

When the innovator faces a stronger rival and develops an incompatible innovation, in addition to the reduction in direct price competition, licensing benefits both firms by increasing the compatibility between their products. Therefore, captive use is never desirable. When $\alpha \geq \alpha_M^{sl}$, the presence of the innovator - after licensing - is not only possible, but also desirable. Therefore, such innovations are licensed. When $\alpha_0 \geq \alpha_{0I}^l$, there is sufficient differentiation between the products to allow the innovator to compete in spite of having an inferior product. Since technology sharing only serves to increase both compatibility and differentiation, selling out is unnecessary. Recall from Proposition 3.4.3 that α_M^{sl} decreases in θ. Therefore, both incompatible and compatible innovations are more likely to be licensed if the network effects in a market are stronger.

3.6. Conclusions

Breakthroughs in critical component technologies provide innovators the ability to differentiate their product from its competition. Yet component innovators such as Upstartle, RIM and Vizrea have sought avenues for commercializing their technologies that extend beyond merely incorporating them in their own products. Their innovations have been licensed despite the fact that the potential recipient(s) also competes with the licensor in the product market. In this chapter, we consider the optimal commercialization decision faced by an innovator, who chooses between captively using the technology in her own product and licensing it to a rival (sometimes, exclusively). Whereas several situational factors determine the specific way in which a firm might commercialize its innovation, some are distinctive in their impact. In particular, we focus on the dependence of this decision on two factors: the strength of network benefits, i.e. the extent to which consumers benefit by using a more popular product, and the relative strength of the competitor, i.e. the existence and ability of the competitor in integrating the innovation into a competing product.

While licensing a component innovation establishes a larger network for the product, it also allows the competitor to close the quality gap between the two products (or extend it). Therefore, a central consideration in commercializing an innovation is the tradeoff between increased competition and greater network benefits. In this research, we advance the study of this important tradeoff by paying attention to the fact that the rival, in many instances, may be able to introduce a product with higher overall quality than the innovator's product.

Our results show that licensing is often the best strategy for a component innovator, even if it comes at the cost of strengthening a significantly weaker competitor. The value of licensing is greater if the strength of network effects are larger, or if licensing helps to overcome incompatibilities between the two products. The fact that licensing is not a profitable alternative in any situation if network effects are non-existent highlights the important role such externalities play in determining commercialization strategy. The optimal strategy depends on whether the innovator's rival is stronger or weaker than the innovator. In each case, the innovator's decisions are characterized by thresholds on the quality of the competitor's product (after licensing). We find that licensing is preferred only if the competitor is significantly weaker (stronger) if the innovator is stronger (weaker) after licensing. This, combined with the fact that licensing is more valuable when network effects are stronger, highlights the importance of the tradeoff between greater competition and the establishment of a stronger network.

Our research makes several contributions to theory and practice. First, to our knowledge, this is the first work to consider the interactions of an innovator with a stronger rival. This is especially significant in environments where important inventions are often driven by firms that do not necessarily have the infrastructure to develop new products from these inventions. Second, we develop a concise framework for categorizing and understanding commercialization decisions, which takes into account the different factors that affect ex post market outcomes. Managers of innovative firms in networked environments may find this framework valuable in considering the capability of their rivals before making a technology sharing decision.

Although the stylization of our model allow us to explore the central questions in depth, several assumptions and their impact on our findings need to be acknowledged. First, analogous to literature (Conner, 1995; Sun et al., 2004), we ignore the differences in consumers' willingness to pay for network effects. This limits the applicability of our model to certain product categories such as communication devices and document management systems. A slightly different model may be required to consider products like video-game consoles, where not all gamers are equally avid fans of multi-player games. Another limitation of our model is that we focus on purely vertically differentiated products. While a different model that focuses on products differentiated on horizontal attributes may yield different results, we believe that the central tradeoff between network effects and competition will continue to be important.

We do not model or consider the state of the industry before the innovation arrives. However, our analysis (in particular, § 3.5) indicates that some innovations may not be worth pursuing in the first place. A potential extension of this work could build on our analysis and develop a framework for evaluating candidate technologies before development by considering ex post commercialization decisions. While we do not consider the possibility of co-developing the component technology, it is common for two seekers of a solution to pool resources towards a mutually benefiting innovation. Finally, while we assume that each firm offers only one product, firms that cater to markets with network effects may offer multiple variants of a product to broaden their network base. Investigating these issues will serve to expand our understanding of inter-firm interactions in such industries.

Technical Supplement: Threshold Values

α_M^w	$\frac{(3\theta-2)+4K\left(4-7\theta+3\theta^2\right)+2(1-\theta)\sqrt{1+9\theta-12K(8-11\theta+3\theta^2)}}{4K(1-\theta)+(5-4\theta)}$
α_M^{cs}	$(4K+1-4K\theta)$
α_M^{sl}	$\frac{2-3\theta+2(1-\theta)\sqrt{1+9\theta}}{\theta(8-9\theta)}$
α_M^{lc}	$\frac{1}{48(\theta-1)}\left(f1+\frac{f2}{f3}+f3\right)$
$\alpha_{0D}(\theta)$	$\frac{2(1-\theta)\sqrt{1+9\theta}-(2-3\theta)}{5-4\theta}$
$\alpha_D(\alpha_0,\theta)$	$\frac{-4(4+5\alpha_0)+24(2+\alpha_0)\theta-9(3+\alpha_0)\theta^2}{20-11\alpha_0+6(-4+\alpha_0)\theta+9\theta^2}$
$\alpha_{0I}(\theta)$	$\begin{cases} \frac{(1-\theta)^2(1-4\theta(2-3\theta))+\sqrt{(3-2\theta)^2(1-\theta)^4(9-4\theta(1+7\theta))}}{2(5-4(2-\theta)\theta)} & \alpha_0 \leq 1-3\theta+2\theta^2 \; and \; \theta \leq 0.5 \\ \frac{\left(1-2\theta^2\right)(4-3\theta)-2(1-\theta)\left(3-8\theta+6\theta^2\right)+2\sqrt{(1-\theta)^2\left(3(1-2\theta)^2(3\theta-8)+(25-12(1-\theta)\theta(8-3\theta))\right)}}{5-4\theta+4(1-s)\theta^2} & 1-3\theta+2\theta^2 \leq \alpha_0 \leq 1 \; and \; \theta \leq 0.5 \\ \frac{3\theta-2+2(1-\theta)\sqrt{1+9\theta}}{5-4\theta} & \theta > 0.5 \end{cases}$
$\alpha_I(\alpha_0,\theta)$	$\begin{cases} \frac{t1-\sqrt{t2}}{t3} & \alpha_0 \leq 1-3\theta+2\theta^2 \; and \; \theta \leq 0.5 \\ \frac{\left(1-2\theta^2\right)(4-3\theta)-2(1-\theta)\left(3-8\theta+6\theta^2\right)+2\sqrt{(1-\theta)^2\left(3(1-2\theta)^2(3\theta-8)+(25-12(1-\theta)\theta(8-3\theta))\right)}}{5-4\theta+4(1-s)\theta^2} & 1-3\theta+2\theta^2 \leq \alpha_0 \leq 1 \; and \; \theta \leq 0.5 \\ \frac{3\theta-2+2(1-\theta)\sqrt{1+9\theta}}{5-4\theta} & \theta > 0.5 \end{cases}$
$\alpha_{0I}^l(\theta)$	$1/(1-3\theta+2\theta^2)$

Table 3.1: Threshold Values

where:

$$
\begin{aligned}
t1 &= -8(1-\theta)^5(2-3\theta) - \alpha_0^3(11-2(7-3\theta)\theta) + \alpha_0^2(1-\theta)(11-\theta(31-18(2-\theta)\theta)) \\
&\quad -2\alpha_0(1-\theta)^3(8-\theta(15-4\theta(4-3\theta))) \\
t2 &= -\left(\alpha_0-4(1-\theta)^2\right)^2\left(\alpha_0-(1-\theta)^2\right)\Big(16\,(1-\theta)^6\,(1+9\theta) - 3\alpha_0^3\,(1-\theta)^2\,(-11+4\theta\,(10-3\theta+9\theta^2)) \\
&\quad +\alpha_0^3\,(-121+12\theta\,(19+\theta\,(-14+3\theta))) + 12\alpha_0\,(1-\theta)^4\,(6+\theta\,(-21+4\theta\,(-8+3\theta)))\Big) \\
t3 &= 2\left(\alpha_0^3\theta - 4\,(1-\theta)^5\,(5-4\theta) - \alpha_0(1-\theta)^3\,(-31+4\theta\,(6+\theta)) - \alpha_0^2(1-\theta)\,(-11+\theta\,(7+3\theta))\right) \\
t4 &= \alpha_0^3\,(-121+12\theta\,(19+\theta\,(-14+3\theta))) + 12\alpha_0\,(1-\theta)^4\,(6+\theta\,(-21+4\theta\,(-8+3\theta))) \\
f1 &= 4K\,(4-3\theta)^2\,(\theta-1) - (28-36\theta+9\theta^2) \\
f2 &= 16K^2\,(4-3\theta)^4\,(\theta-1)^2 + (592-1728\theta+1704\theta^2-648\theta^3+81\theta^4) \\
&\quad -8K\,(-256+1168\theta-2028\theta^2+1656\theta^3-621\theta^4+81\theta^5) \\
f3 &= 64K^3\,(4-3\theta)^6\,(\theta-1)^3 - 48K^2\,(4-3\theta)^3\,(\theta-1)^2\,(64-180\theta+144\theta^2-27\theta^3) \\
&\quad +(-17244+691200\theta-1113120\theta^2+92016\theta^3-40500\theta^4+8748\theta^5-729\theta^6) \\
&\quad +48K\,(-6784+392232\theta-948960\theta^2+1235040\theta^3-92376\theta^4+390096\theta^5-8505\theta^6+729\theta^7) \\
&\quad +96\sqrt{6}\,(\theta-1)^2\,\sqrt[3]{\left(96K^3\,(8-3\theta)\,(4-7\theta+3\theta^2)^3 + (1688-37520\theta+2788\theta^2-810\theta^3+81\theta^4) + f4\right)} \\
f4 &= 32K^2\,(\theta-1)^2\,(956-30840\theta+3240\theta^2-1269\theta^3+162\theta^4) \\
&\quad -2K\,(-6064+226720\theta-316560\theta^2+201240\theta^3-5643\theta^4+567\theta^5)
\end{aligned}
$$

Chapter 4

Collaborating with Competitors in New Product Development

4.1. Introduction

Collaboration among firms have proliferated in various industries such as electronics, manufacturing and pharmaceutical since the early 1980s. However, at the same time competition in these industries has become stiffer than ever before. Why is this occurring? Because, first, innovations require more in-depth understanding of current technology and firms are becoming increasingly specialized in certain technologies. Second, they are inextricably linked by a mutual drive for success, a common direction of the future technology and the need for continuous improvement. Therefore, they are seeking ways of utilizing their know-how and expertise with external partners to gain a position that will lead to superior performance and earnings, though these partnering firms may be competitors in the market (Hamel et al., 1989). In this chapter we examine how the essence of this new interaction between competitors lies in the way collaboration and competition interact.

A good example to the interaction of collaboration and competition comes from the tire industry. In the recent years the tire industry has been witnessing an alliance between the world's two big tire developers and manufacturers, Michelin and Goodyear, to develop a run-flat tire technology, which has attracted the close attention of big tire manufacturers for a past few decades[1]. The run-flat tire is aimed to keep drivers safe from the dangers of a blowout and changing a tire on the road; and lessen the hassles and delays of a flat tire. Michelin has worked on its run-flat tire technology named PAX System that allows the driver to drive at a speed up to 50 miles per hour for 100-150 miles after the tire gets punctured. Although Michelin's achievements in the technological developments related to PAX System has increased the anticipation of PAX System to be the next biggest technological achievement in the tire industry, Michelin has agreed to collaborate with a major competitor, Goodyear, to codevelop the run-flat tire technology, but commercialize it competitively (BusinessWeek, 2004).

As long as the benefits of a strategic alliance between firms outweigh its risks such as revelation of technical information and competitive compromise, collaboration with competitors could be beneficial for various reasons: to have market dominance, to benefit from risk reduction (Kogut, 1991) or to exploit each other's resources (Pfeffer and Novak, 1976; Das and Teng, 2000). In particular, the codevelopment between Michelin and Goodyear in our example is related to the following similar reasons: First, Goodyear's knowledge and expertise in run-flat tire technology helped Michelin to reduce the development risks and allocate its resources more efficiently. In the PAX System,

[1]http://www.goodyear.com/media/pr/nat_2000/22076ms.html

Goodyear's pressure monitoring system is used to monitor the air pressure of the tire. The development of a sophisticated monitoring system would not only have increased Michelin's R&D expenses, but would have also delayed the product's market entry. Secondly, the alliance formation between Michelin and Goodyear could mitigate the potential opportunistic behavior by giving the car manufacturers and the consumers a second source to provide components from an alternative source (Farrell and Gallini, 1988). And finally, a larger aftermarket service network would increase the appeal to this new technological product and thereby, to the cars with PAX System (Cohen and Whang, 1997).

However, the purpose and the benefits of a strategic alliance are not limited to these reasons. An alliance can impact the nature of the supply chain, the vertical relationships in the supply chain, and the decisions of channel members. In our example, the collaboration in codevelopment and the competition in the marketing of the run-flat tire have enhanced the credibility and adoption of the technology by the car manufacturers. The manufacturers increased their investment in accommodating the tire in their cars and enhancing the consumer demand for cars with PAX System because with the Michelin-Goodyear alliance, the codevelopment would provide them a better technology, and moreover, the marketing competition would dampen the tire prices. Nonetheless, this raises an issue for the alliance partners that the alliance partnership should not lead to competitive surrender in order to increase the appeal of the manufacturers. Therefore, firms need to not only consider the role of the characteristics of the alliance on the decisions of the adopters, but also privileges of the alliance partners.

Consequently, the manner in which the customer firm adopts a component technology depends not only on the value of the innovation, but also on the dynamics of the source. For example, as a response to the growing security concerns of the electronic device manufacturers, a large group of hardware and software companies, including Advanced Micro Devices, Hewlett-Packard, IBM, Intel and Microsoft, have formed a security alliance named Trusted Computing Group (TCG) to place hardware-based security technology into a host of consumer and corporate devices. The goal of the TCG is to market security hardware and software technology that will be integrated into various computing platforms, from PCs to mobile phones, by the electronic device manufacturers. Thus, the alliance has increased the appeal to the TCG-compliant functionality and induced the manufacturers to manufacture their products using components with TCG's technology. Among the many forthcoming technologies are Phoenix Technologies' Core Managed Environment and Transmeta's Cruose chip (CNETNews, 2003).

Motivated by these examples, the purpose of this research is to develop a better understanding of the impact of the alliance formation on the nature of the supply chain. We study how the structure and the investment decisions of one level of the supply chain affect other dimensions of channel operations. We are specifically interested in the strategic consequences of collaboration and competition that the alliance between two upstream suppliers can impose upon a downstream original equipment manufacturer (OEM). We explore the tradeoff between the reduced profits of the suppliers due to competition and the demand increase due to investment decisions of the OEM.

In this chapter, our goal is to answer the main research questions: What is the optimal alliance formation for the suppliers? How does the attractiveness of an alliance play a role in affecting the OEM's decision to invest in the demand stimulating activities? Under what conditions is it more valuable for the suppliers to compete rather than collaborate? To investigate these questions, we first consider a situation in which suppliers would form a new organization to develop and market the component. We next consider how the outcome for the OEM and suppliers would change if they codevelop the component, but compete in marketing and sales to the OEM. And finally, we look into the situation where the suppliers may choose not to form any alliance, and compete to develop and market the component independently. In all of these situations we study the tradeoff between the reduced profits due to competition and the demand increase due to investment decisions of the OEM.

The modeling framework developed in this chapter extends prior research by exploring the impact of a merger in the upstream supply chain upon a downstream member. We consider several important parameters, including the OEM's investment in cost reduction, the extent to which the suppliers can stimulate OEM's investment through the type of formation, and the probability of development success that the suppliers can have. Based on our analysis we identify the conditions under which it is beneficial for the suppliers to codevelop and compete in sales. We show that although competition between the suppliers would reduce their earnings from the component sales, it can also help to induce the OEM to increase the investment amount. Therefore, the relative attractiveness of different supplier formations depend on the increase in consumer demand due to stimulating OEM's investment. This explains the counter-intuitive behavior of innovators with radical breakthroughs, who willingly create competition.

The remainder of the chapter is organized as follows: In Section 4.2 we review the literature. Section 4.3 details our model. In Section 4.4, we first analyze the impact of each supplier formation on the OEM's investment decisions. We then compare the profits of the members of the supply chain and demonstrate the optimal formation for the suppliers and the OEM. The final section concludes the chapter.

4.2. Literature Review

Our research is closely related to two main streams of literature: strategic alliances and investments in cost reduction that might enhance demand.

The study of strategic alliances has been a subject of longstanding interest in the literature. The literature has dealt in depth with the reasons and consequences of strategic alliance making process in terms of risk sharing and reducing investment costs (Kogut, 1991), increasing purchasing power (Granot and Sosic, 2005), acquiring interfirm knowledge (Rosenkopf and Almeida,

2003) and managing the uncertainty of resources (Pfeffer and Novak, 1976; Das and Teng, 1998, 2000). A compilation of different perspectives of strategic alliances such as economic, real options, learning and relational can be found in Reuer (2004). However, the alliance would evidently change the dynamics of the market. Therefore, the alliance members have to evaluate their decisions in joining an alliance (Granot and Sosic, 2005) and find coordination mechanisms to align their individual-alliance member incentives (Nault and Tyagi, 2001). (Kalaignanam et al., 2007) examine the partnership between asymmetric new product development alliances and find that there are considerable asymmetries between the larger and smaller firms with regard to the effects of alliance, partner, and firm characteristics on the gains of the partner firms. Similarly, a merger could affect the profits of other participating and non-participating firms (Deneckere and Davidson, 1985; Braid, 1999; Brito, 2003). Our scope is to further explore the impact of a strategic alliance and a merger on the profits and decisions of the participants.

Within the literature on strategic alliances and mergers, our work is closely relevant to Gilbert et al. (2007), who explore whether downstream dealers should merge or remain separate when both the manufacturer and the dealers can make investments to enhance demand. They consider how a merger between two naturally differentiated dealers affects their interaction with a common supplier, and find that the attractiveness of merging depends upon the extent to which end demand can be stimulated by either an upstream supplier or the dealers. Although we also consider the strategic effects of a merger, we consider a merger between two upstream suppliers in their interaction with a downstream OEM, instead of the merger between two rival firms that share a common upstream supplier. And we extend our discussion on the attractiveness of an alliance to different supplier formations such as development alliances. Our work is also related closely to Amaldoss and Rapoport (2005) who study how the structure of competition affects the resources committed by alliance partners to product and market development. They find that individual development increases investments in market but decreases investments in product development. However, we consider how the structure of competition created by an alliance or a joint venture can play a role to create incentives for the downstream OEM to invest in demand stimulating activities.

The development alliance and independent development in our framework suggest a second source to downstream OEM. Therefore, this work also contributes to the literature on second sourcing. There are various uses of second sourcing. Firms can use second sourcing as a commitment not to act opportunistically when a monopolist firm is unable to commit to long-term contracts (Farrell and Gallini, 1988; Klotz and Chatterjee, 1995). In a networked environment the entry of a second source can enlarge the user base and increase the network benefits (Conner, 1995). A buyer can use a second entrant supplier to provide information about the incumbent's costs (Demski et al., 1987). Nonetheless, second sourcing may result in strictly less expected profits (Riordan and Sappington, 1989). To manage the potential gains from a second production source, firms have to evaluate the supply chain dynamics with the presence of a second source. In this chapter we examine the affect of a second source on the tradeoff between increased competition and higher downstream investment to analyze the suppliers' decision of alliance formation.

Because we focus on the impact of a formation on the investment in cost reduction by a downstream OEM to increase demand, our work is also related to the literature on investment in cost reduction. Cost reducing investments play different roles in supply chains. Gupta and Loulou (1998) consider process innovation which can reduce the unit production costs of two manufacturers with differentiated products. They show that manufacturers invest less in cost reduction when the differentiation between the products is low, but they still benefit from independent retailers. Gilbert and Cvsa (2003) show that a manufacturer can stimulate cost reducing or demand enhancing investments from its downstream channel partners by using a ceiling price contract in a supply chain that faces considerable demand uncertainty. Gilbert et al. (2006) consider a situation in which two OEMs compete both in terms of investments in cost reduction and in terms of the prices that they set for their products. They explore the role that an external supplier(s) can play in dampening cost competition between the OEMs when there are opportunities to invest in cost reduction. We also look at how the cost reducing investment decision at one level of the supply chain affects other levels of the channel.

In this chapter we specifically consider a situation in which two upstream suppliers collaborate to stimulate the OEM's investments in cost reduction and the product prices. Thus, we contribute to the literature on strategic alliances by studying the impact of alliances on a firm's choice of investment and analyzing the optimal supplier formation. Throughout the chapter, we adopt the convention of using feminine pronouns to refer to the suppliers and masculine pronoun for the OEM.

4.3. Model

We consider a supply chain in which two suppliers are developing a breakthrough component that would be used in the final product of a downstream OEM. We assume that both suppliers could successfully develop the component with an exogenous probability of P. This is a valid assumption in our framework because each firm may have the expertise and the resources required for a technological breakthrough. For example, Michelin and Goodyear have been working to commercialize the run-flat tire technology since early 1980s and have displayed their competence and potential to succeed through patents they have acquired on this and related technologies. The OEM could procure this breakthrough component only from these suppliers. The suppliers are identical, so if both suppliers are successful, he procures in equal quantities from each supplier. Further, the suppliers do not offer a substitute component that could replace the value of this component. Therefore, if a supplier fails, she will not sell a substitute component and make zero profits. And if both suppliers fail, no profits are made by any of the firms.

We let s be the amount of the component quality which the suppliers may develop and we normalize the quality of the product without the component to one. Hence, the new product with the component has a total quality of $1+s$. Each consumer either purchases a product with the new technological component, or can buy no product since the product does not perform without this component. Their valuation for product quality is uniformly distributed on the interval [0, 1]. We denote a consumer with valuation v as a consumer of type v. A product with new component provides an intrinsic value of $v\,(1+s)$ for a consumer of type v. Therefore, the utility for a product of quality s is given by

$$U\,(v,\,s) \quad = \quad vs \tag{4.1}$$

A consumer of type v has a total valuation of $v\,(1+s)$ if he purchases a product.

Based on the model of consumer valuation in (4.1), let v_c represent the valuation of the marginal consumer who is indifferent between buying a new product with the breakthrough technology and and nothing. All consumers with valuations in $[v_c,\,1]$ purchase a new product from the manufacturer. Consumers with valuations in $[0,\,v_c)$ purchase nothing. The marginal consumer with valuations at v can obtain the same payoff from purchasing a product and nothing, and would have the following incentive compatibility constraint, respectively,

$$v_c\,(1+s)-p \quad = \quad 0 \tag{4.2}$$

where p denotes the price of the product sold by the OEM. Since the OEM produces a quantity q of product, the marginal consumer of type v_c, who is indifferent between buying a product and nothing, will have a valuation of $1-q$, i.e. $v_c = 1-q$. Writing the valuation in (4.2) in terms of quantities, we can find the price function of quantities as

$$p(q) \;=\; (1+s)(1-q) \tag{4.3}$$

We assume that the OEM's marginal cost of production c is constant, constant, and for ease of exposition we normalize the supplier's marginal production cost to zero. Although the assumption of constant production cost is simple, this is a reasonable assumption since, in practice, there could be production costs that are constant in the volume of production for a range of output and a new component technology may be integrated in the OEM's current production process without any additional costs.

We consider that the OEM could invest an amount of r in cost reduction to enhance demand in anticipation of successful development. Hence, the OEM would choose the product quantity to maximize his profit function

$$\pi^{OEM}(q,\, r) \;=\; q\,(p(q) - w - (c-r)) \tag{4.4}$$

where w is the supplier wholesale price. The suppliers are capacity constrained, so the wholesale price they could charge is the maximum price at which the OEM will accept the entire quantity offered by the suppliers. And the supplier i maximizes her profits

$$\pi_{iS}(q,\, r) \;=\; q_i w_i(q,\, r) \tag{4.5}$$

by determining the wholesale price for the optimal quantity demanded by the OEM.

The OEM also incur some fixed investment costs. We assume that the OEM could invest the following amount to achieve the production cost reduction of r:

$$I_r(r) = Kr^2 \tag{4.6}$$

where K is a parameter that determines how costly it is to stimulate the reduction in the production cost. The parameter K determines the relative ease with which investments can be stimulated by cost reduction. Note that the investment function is increasing and convex, reflecting that the level of cost reduction increases investment costs as the OEMs aim to influence a greater cost reduction. For optimal cost reduction to be positive and feasible in each formation, we assume that $K > \underline{K} = \frac{P(2-P)}{9(1+s)}$, which is decreasing in the component quality s and increasing in the probability of success P.

We consider that the interactions between the suppliers and the OEM occur as follows: In the first stage, the suppliers either decide on a collaborative formation, a development alliance or a joint venture, or have no collaborative structure to first develop and then market the component. In the joint venture (JV) suppliers form a monopoly in order to collaborate for the development and marketing of the component. In the development alliance (DA), they codevelop the component, but upon successful development, they compete in marketing of the component. And in independent development (ID), suppliers do not form any kind of collaborative structure in development and marketing and compete with each other in development and marketing.

Subsequently, in the second stage the OEM makes a cost reducing investment without observing the outcome of the technology development, but he is fully informed about the type of the supplier formation. The third stage is concerned with the product quantity decision of the suppliers and the OEM. Each supplier decides on a fixed component production capacity and offers a wholesale price w. The OEM then sells this quantity at the consumer market. In the last two stages, the suppliers play a simultaneous non-cooperative game with complete information.

In the analysis to follow, first we look at the optimal decisions of the firms under a monopoly and a duopoly supplier, and characterize the profits of each firm. Subsequently, we consider the expected profits under each supplier formation. Our method of analysis will be to first assume that the suppliers have chosen one of the formations and examine the suppliers' and OEM's decisions in the subsequent stages. We look at each formation more closely and and examine how the choice of supplier formation interacts with the OEM's investments.

4.4. Analysis

First let us evaluate the profits for the suppliers and the OEM under a monopoly supplier and a duopoly supplier. Depending on their decision of supplier formation, the suppliers would result in a monopoly or a duopoly.

Solving the manufacturer's profit function in (4.4) with the price function in (4.3), we can find the optimal quantity that maximizes the manufacturer's profits as

$$q^* \;=\; \tfrac{1+s-w-c+r}{2(1+s)} \tag{4.7}$$

The suppliers would determine the wholesale price which is determined by their capacity. Since the OEM will accept the entire quantity and the suppliers would not overproduce, the supplier's wholesale price becomes

$$w\left(q,\, r\right) \;=\; 1+s-2\left(1+s\right)q-c+r \tag{4.8}$$

Now we turn to the profits of the suppliers in a monopoly and a duopoly supplier market. In the monopoly supplier market, the supplier maximizes her profit function $\pi_1\left(q,\, r\right)=qw\left(q,\, r\right)$ by determining the wholesale price for the optimal quantity of the OEMs in (4.7),

$$w_{1S}^* \;=\; \frac{s-c+r}{2} \tag{4.9}$$

Hence, we can find the profits for a single supplier and the OEM, respectively, as

$$\pi_{1S}\left(r\right) \;=\; \frac{\left(s-c+r\right)^2}{8s} \tag{4.10}$$

$$\pi_{1S}^{OEM}\left(r\right) \;=\; \frac{1}{4}+\frac{\left(s-c+r\right)^2}{16s} \tag{4.11}$$

Similarly, in the duopoly supplier market, the suppliers, say supplier 1 and supplier 2, maximize their profits, $\pi_1\left(q_1,\, r\right)=q_1w\left(q,\, r\right)$ and $\pi_2\left(q_1,\, r\right)=q_2w\left(q,\, r\right)$ simultaneously where q_1 and q_2 are the supplier 1's and the supplier

2's quantities, respectively, with the overall new products as $q = q_1 + q_2$. We can easily show that the suppliers would produce equal quantities, $q_1^* = q_2^*$ and we can find the optimal wholesale price in (4.8) as

$$w_{2S}^* = \frac{s - c + r}{3} \tag{4.12}$$

Consequently, the profits of each supplier in a duopoly and the OEM are, respectively,

$$\pi_{2S}(r) = \frac{(s - c + r)^2}{18s} \tag{4.13}$$

$$\pi_{2S}^{OEM}(r) = \frac{1}{4} + \frac{(s - c + r)^2}{9s} \tag{4.14}$$

By comparing profit functions of the suppliers, (4.10) with (4.13), and the OEM, (4.11) with (4.14), in a single and two-supplier markets, we can show that the suppliers are better off in a monopoly while the OEM would make higher profits sourcing from a duopoly for a given investment amount. However, the OEM's decision on the cost reduction r could change the suppliers' collaboration strategy.

4.4.1 Strategic Supplier Formations

Until now, we considered the profits for the suppliers and the OEM under a single or a dual source. Next we incorporate the probability of supplier success P into our model and find the optimal investment on the cost reduction by the OEM under each supplier formation: joint venture, development alliance, and independent development. We discuss the merits and mechanics of each formation for the suppliers and the OEM.

Joint Venture

Mergers and joint ventures are a common practice among business ventures. We assume that a joint venture would increase the potential market power for the suppliers. In our model, the two suppliers that are interested in developing the component technology combine their resources and know-how to establish one venture that would develop the component and later market it. Hence, the joint venture would have the following profit function

$$\pi_{JV}(r) = P(2-P)\,\pi_{1S}(r) \tag{4.15}$$

where π_{1S} is computed in (4.10). Since the suppliers in our model are identical, we split the profits of a joint venture equally between the two venture partners, $\pi_{JV1} = \pi_{JV2} = \frac{\pi_{JV}}{2}$. Further, the OEM would maximize the following profit function by investing r

$$\pi_{JV}^{OEM}(r) = P(2-P)\,\pi_{1S}^{OEM}(r) - I_r(r) \tag{4.16}$$

where we have computed π_{1S}^{OEM} in (4.11). Maximizing the profit function in (4.16), we can find the optimal cost reduction that the OEM would apply as

$$r_{JV}^{*} = \frac{P(2-P)(1+s-c)}{16K(1+s) - P(2-P)} \tag{4.17}$$

Development Alliance

Under the formation of a development alliance in our model, the suppliers codevelop the component technology. However, each supplier set her capacity and use her own marketing resources. In this formation, supplier i's profit function is

$$\pi_{DAi}(r) = P(2-P)\,\pi_{2S}(r) \tag{4.18}$$

and the OEM's expected profit function becomes

$$\pi_{DA}^{OEM}(r) = P(2-P)\,\pi_{2S}^{OEM}(r) - I_r(r) \tag{4.19}$$

Similar to the JV case, we maximize the OEM's profits in (4.19) and find the optimal amount of cost reduction that the OEM would apply

$$r_{DA}^{*} = \frac{P(2-P)(1+s-c)}{9K(1+s) - P(2-P)} \tag{4.20}$$

Independent Development

And finally, we consider the case where suppliers choose not to collaborate at the development and marketing stages. If both suppliers are successful, the supplier market becomes a duopoly. Further, one successful supplier could act as a monopolist and charges monopoly price to maximize her profit if the rival supplier fails. Therefore, the expected profit function of supplier i is

$$\pi_{IDi}(r) = P^2\pi_{2S}(r) + P(1-P)\,\pi_{1S}(r) \tag{4.21}$$

and the OEM's expected profit function is

$$\pi_{ID}^{OEM}(r) = P^2\pi_{2S}^{OEM}(r) + 2P(1-P)\,\pi_{1S}^{OEM}(r) - I_r(r) \tag{4.22}$$

Maximizing (4.22) with respect to r, the optimal amount of cost reduction is

$$r_{ID}^{*} = \frac{P(9-P)(1+s-c)}{72K(1+s)-P(9-P)} \tag{4.23}$$

The OEM's optimal investment amount r in each formation depends on his cost reduction parameter K, the probability of the supplier success, P, and the quality of the component, s. The OEM makes a larger investment when the suppliers are more likely to develop the component or could offer a higher quality. Also, if the OEM does not incur a very high production or investment cost, he will also invest a larger amount.

4.4.2 Equilibria Analysis for Supplier Formations

Now we can explore the optimal decisions of the OEM and the suppliers among all formations. Comparing the potential profits that the OEM could generate under each formation, we obtain the OEM's optimal decision.

Proposition 4.4.1. Optimal Investment in Cost Reduction by OEM *For all values of P, s, and c, among the supplier formations (joint venture, development alliance and independent development),*

i) The OEM's equilibrium investment in cost reduction is the largest in a development alliance.

ii) Further, the OEM's equilibrium profit is the largest in a development alliance.

The proof of Proposition 4.4.1 is straightforward by comparing the optimal cost reduction and the profit of the OEM under each formation. Proposition 4.4.1 shows how much the OEM invests with respect to each supplier formation. The OEM invests the largest amount in formations where he can obtain the highest profits from the suppliers; and therefore, the investments in formations where the OEM can use a dual source are higher. In a development alliance, successful development of the technology certainly leads to a duopoly in the market. Duopoly is less likely if the suppliers were developing independently; and would simply not exist in a joint venture. The competition between the suppliers increase the investment amount that the OEM would make in a DA. The total capacity also increases as the OEM invests more in the cost reduction. Further, under ID formation, the OEM would always keep his investment amount less than he would in a DA, but more than he would in a JV. The DA formation is a commitment to a dual source, which induces the OEM to invest larger.

Consequently, we compare the suppliers' profits across each formation and find conditions under which joint venture, development alliance and independent development are optimal. First, we start with collaborative formations, JV and DA. Proposition 4.4.2 summarizes the suppliers' decisions between the collaborative development environments.

Proposition 4.4.2. Suppliers' Decisions to Collaborate
There exists a $\overline{K} = \frac{\left(12+7\sqrt{2}\right)P(2-P)}{24s}$ *such that when* $K < \overline{K}$*, the suppliers would make more profits in a development alliance than in a joint venture. Otherwise, the suppliers would be better off in a joint venture than in a development alliance.*

The proof of this proposition is straightforward by comparing profits in DA and JV. The main tradeoff that the suppliers face is the additional profits that they could make as a monopoly to higher downstream investment in cost reduction by OEM. Proposition 4.4.2 displays how the suppliers evaluate this tradeoff and decide on a formation between the two collaborative supplier formations, DA and JV. We can show that the higher the probability of successful technology development is (high P), the more the suppliers are interested in a DA. When the technology is not very hard to develop for the suppliers, the OEM is more inclined to invest anticipating that the suppliers could develop this component successfully. Further, the OEM is more willing to invest when he can source from two suppliers since the competition would reduce the wholesale price. However, as it becomes harder for suppliers to develop (P decreases), the OEM would reduce his investment amount (r is decreasing in P). Then the OEM's investment becomes less of a contribution to overall supplier profits. Hence, for technologies harder to develop (low P), the suppliers could make more profits as a monopoly in a JV.

Proposition 4.4.2 also demonstrates that the OEM's cost structure influences his investment decision and the supplier formation. The suppliers are better off when they market separately in a DA if the OEM can afford to sufficiently reduce the cost through his investments without incurring high costs $\left(K < \overline{K}\right)$. If the costs of investment are high $\left(K > \overline{K}\right)$, the OEM would also invest less and the suppliers would be better off in a JV charging the monopoly wholesale price. Therefore, analogous to our finding for the OEM in Proposition 4.4.1, Proposition 4.4.2 shows that so long as the investment costs are not excessive, the suppliers who market separately and create competition can also make higher profits by inducing the OEM's investment strategy.

It is also of interest to note that the threshold, $\overline{K}$, is decreasing in s, the magnitude of the quality improvement due to new component. When this improvement is large, the suppliers require the OEM to have more and more attractive cost reduction opportunities in order to justify using a DA instead of a JV. And the OEM is more willing to procure from a monopoly supplier and pay a higher wholesale price since he will receive a higher quality component in return.

In addition, Proposition 4.4.2 also explains the special case in which the OEM has no ability to influence the demand through cost reduction when the new component technology requires very high investment for any amount of reduction. We can consider this case with a very high K $\left(K \gg \overline{K}\right)$. When the OEM cannot stimulate the demand through cost reduction, the suppliers are not concerned about forming a development alliance to increase the OEM's incentives to invest. Therefore, it is never beneficial for the suppliers to create marketing competition.

Further, the suppliers may choose not to participate in any of the formations and develop independently. Next we look into how their decision changes if they also have this option.

Proposition 4.4.3. Independent Development

There exist $K_{LB} = \frac{P\left(36-18P+7\sqrt{(P-2)(9-5P)}\right)}{36(1+s)}$ *and* $K_{UB} = \frac{P\left(48-24P+7\sqrt{2(P-2)(9-5P)}\right)}{48(1+s)}$ *such that when* $K_{LB} < K < K_{UB}$*, the suppliers would not participate in any form of alliance and develop independently.*

Proof. See Appendix. □

Proposition 4.4.3 extends the discussion of Proposition 4.4.2 and explains how the suppliers would decide on a collaborative formation or reject both for different values of P and K. In addition to DA and JV, the ID represents a formation in which the tradeoff between increased OEM's investment and decreased monopoly benefits play a decisive factor for the suppliers, but does not dominate for neither structure. If the suppliers do not form any alliance or joint venture, the individual efforts of each supplier may result in a monopoly or a duopoly. On one hand, the OEM will not reduce his investment amount as low as he would have in a JV. On the other hand, he will not invest as high as in a DA. From the suppliers' perspective, one supplier may become a monopoly, but also she will receive a higher downstream investment than if she were a single supplier. Hence, independent development could become the optimal supplier formation.

Figure 4.1 illustrates our results in an example. When the suppliers are very likely to develop the technology and the OEM does not incur high costs, the suppliers could compensate the reduction in their profits by forming a duopoly with the OEM's investment. This interaction is observed in the region "DA". However, if it gets costly and the suppliers may fail, the OEM would lessen its optimal investment amount. Therefore, the suppliers are less inclined to give up their monopoly profits, as shown in region "JV" in our example. When each of these formations cannot dominate, we observe the region "ID" between "DA" and "JV", where a monopoly or a duopoly supplier is possible.

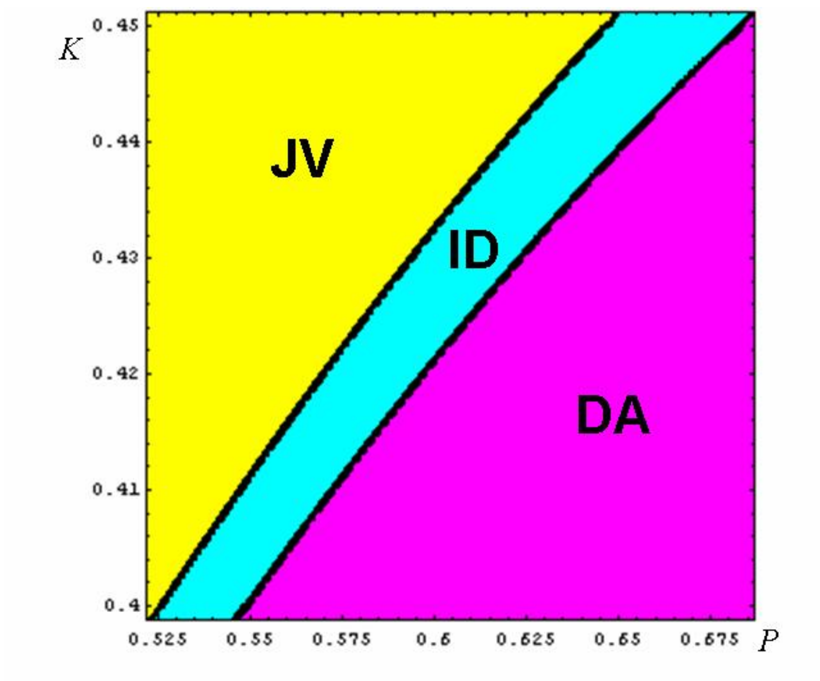


Figure 4.1: Optimal Supplier Formations, $s = 0.8$ and $c = 0.2$.

4.5. Conclusions

Strategic alliances could be very beneficial for participants for various operational and financial reasons. Nevertheless, the partnering firms have to consider the impact of their alliance on the supply chain dynamics. Since the non-participants alter their decisions relative to the characteristics of the formation, the alliance formation decision has a significant impact on the profitability of all supply chain members. In this chapter, we consider the optimal alliance formation decision faced by two suppliers, who may choose to collaborate in the development and marketing stages or compete in only marketing stage or both stages. Whereas several situational factors determine the specific way in which they might decide on the alliance formation, we particularly focus on the OEM's investment in cost reduction, the extent to which the OEM can stimulate demand through its investments, and the probability of development success that the suppliers can have.

In this chapter, we study the conditions of this critical decision by paying attention to the suppliers who exploits the OEM's investment decision in cost reduction by choosing an alliance to compete in sales. Our findings suggest that while the decision to compete in marketing reduces the supplier profits, the increase in the OEM's investment stimulates consumer demand for the product with the component and thereby, some additional profits for suppliers. We show that a central consideration in the suppliers' decision on the type of supplier formation, joint venture, development alliance or independent development, is the positive value generated by the OEM's investment.

We present a framework for the supplier formation depending on the parameter values. The likelihood of development alliance formation is greater if the OEM has a more efficient production process, i.e. the OEM could incur lower investment costs or if the suppliers are very likely to develop the technology. The fact that joint venture is not always a profitable alternative depends on the positive value that the OEM can generate. The optimal formation strategies are characterized by thresholds on the investment parameter of the OEM.

Our research makes several contributions to theory and practice. First, our research identifies the effect of alliance formation on the decisions of the supply chain members. This is especially significant in a competitive market where firms need to exploit each other's resources for continuous development, but they have to consider the effects on the non-participants. Second, the suppliers could obtain the highest profits with a monopoly, so it is expected for them to form a joint venture to have market dominance. On the contrary, our findings show that they could actually improve their profits with a development alliance. Third, we develop a simple analytical framework for understanding formation decisions, which takes into account the different factors that affect post-alliance market structure. Managers of innovative firms may find this framework valuable in considering the impact of an alliance before making a formation decision.

Although we have made some stylized assumptions in our model to study the central question, we acknowledge several assumptions and their influence on our findings, and discuss how we can extend our work. First, we only consider two identical suppliers. This limits the applicability of our model to other alliance formations. Also, the suppliers in our model create no synergy in any alliance formation. Even though our results highlight a counter-intuitive interaction between firms, the operational synergy and compatibility between suppliers could extend managers' understanding of supplier interactions on the operational level.

Another limitation of our model is that we focus on a model with complete information. However, most OEMs are not well informed about the technological progress and may not best assess the likelihood of a successful development. In addition, the suppliers may not appraise the rival's likelihood of success. A different model that allows the information asymmetry between the suppliers or between the OEM and the suppliers could alter the suppliers' formation and OEM's investment decisions, and hence, yield different results. Investigating these issues will enhance our understanding of strategic alliances and supply chains.

Chapter 5

Conclusions and Directions for Future Research

In this dissertation, we look into how competition and collaboration in a value chain impact the development and deployment of a product or an innovation. We present analytical models that examine strategic issues related to product design, product development and technology development and deployment and identify how competitive and collaborative forces in a supply chain influence a firm's decisions. Based on our analysis of each model in this dissertation we find that it is essential for firms to evaluate the inter-firm interactions to thrive in the marketplace. As the relationships between firms in a supply chain become increasingly interactive, the growing interdependence between firms may require strategic collaboration. Managing this interaction effectively, firms could benefit from the challenges associated with their interactions with supply chain partners and competitors. Consequently, they should be able to recognize the business tradeoffs and implement the appropriate methodologies that can exploit the strategic interactions in the value chain.

This dissertation analyzes the collaborative and competitive issues in specific contexts of technology and product development and deployment. In chapter 2, we provide one explanation why some firms in multiple industries of of a durable good and a contingent consumable design their durable good compatible with generic consumables of competitors. This research highlights the relation between the inter-firm interactions and how a firm's product provides value to consumers. We show under which conditions the consumers' willingness to pay for a durable good increases when there are more affordable consumables available. Chapter 3 extends the discussion on the inter-firm interactions by considering the commercialization of a component innovation in a network economy. We provide insights on why some firms are more willing to share their component technology while others choose to commercialize it individually. We show that competitors whose capability to develop other components for the product and integrate it with the component technology are significantly different from their own abilities could enable firms to obtain greater profits and market coverage. Finally, in chapter 4, we explore situations in which firms collaborate to develop a component innovation, but market individually; they codevelop and jointly market; and they choose to individually develop and market. We show how competitive strategies between development partners should consider the influence of the supplier formation on the investment incentives of an OEM. First, we identify the conditions for the suppliers who exploit the OEM's investment decision in cost reduction by choosing an alliance to compete in sales. Next we find that while the decision to compete in marketing lessens the supplier profits, the increase in the OEM's investment causes a surge in consumer demand and thereby, some additional profits for suppliers.

The analysis in this research and the models used to derive them can be extended and improved in several ways to enhance our understanding of collaboration and competition in a value chain. Richer models that include competition among the members of the same level in the supply chain could provide valuable and more realistic discoveries and extend the realm of this research framework to additional industries. Another challenging extension of these results would come from considering information asymmetry between firms. Though this is not an easy task, such an analysis would greatly improve our understanding of how firms should implement collaborative and competitive strategies when there are higher risks involved in their decisions due to lack of information. Studying operational issues like capacity planning, procurement, and supply chain contracts represent another avenue for future research to link the research insights to applicability. These extensions would broaden diverse aspects of the managerial issues faced by organizations in a variety of industries. In conclusion, while this dissertation provides a better understanding of strategic issues in collaboration and competition in supply chains, it is only the first step to bring forth many research insights.

Appendices

Appendix A

Managing Revenue Streams for Durable Products with Contingent Services or Consumable Components

A.1. Construction of the Steady State Solution

We want to show that there exist initial states that follow the manufacturer's quantity decisions and converge to the focal point at the steady state. To illustrate this approach, we use backward induction. The initial condition in our problem is the situation where the manufacturer offers all new product bundles, so $a^1(v) = \{N\}$ for all consumers of type v.

Assume, without loss of generality, that the focal point is reached at period $t = 2$, i.e. $q^{2*} = q^{FOC} = \left(q_n^{FOC}, q_B^{FOC}\right)$, which are defined in (2.26) and (2.27), respectively.[1] Since we know that all durable goods in period 2 are used by the consumers who also buy a branded or generic consumable in period 3, the number of consumers who buy a new product or a branded consumable in period 2 is the same as the number of consumers with the same preferences at the steady state, i.e. $q^{2*} = q^{t*}$ for $t \geq 3$. The Bellman equation for the

[1]This assumption is common in the literature with similar methodology Huang et al. (2001); Ferrer and Swaminathan (2006)

manufacturer in period 2 is given as

$$M^2\left(q^2\right) \;=\; \underset{q_n^2, q_B^2}{max}\left\{q_n^2\left(p_n^2 - c_d - c_B\right) + q_B^2\left(p_B^2 - c_B\right) + \delta M^3\left(q^{3*}\right)\right\}$$

and hence, $M^2\left(q^2\right)$ has the same maximum value as the profits at the focal point.

The Bellman equation for a consumer of type v at period 2 is

$$D_v^2\left(a^1(v), q^{FOC}\right) = \underset{a^2(v)}{max}\left\{g_v\left(a^1(v), a^2(v), q^{FOC}\right) + \delta D_v^3\left(a^2(v), q^{FOC}\right)\right\} \tag{A.1}$$

The optimal solution to (A.1), $a^2(v)$, has to satisfy the result of the subsequent period, i.e. $q^{3*} = q^{FOC}$. Thus, since the quantities at period 2 are the steady state quantities and $a^2(v)$ is a function of $a^1(v)$, Equation (A.1) specifies $a^1(v)$ such that it would meet the condition at the steady state, i.e. $q^{2*} = q^{3*}$.

In period 1, the Bellman equation for the manufacturer is

$$M^1\left(q^1\right) \;=\; \underset{q_n^1}{max}\left\{q_n^1\left(p_n^1 - c_d - c_B\right) + \delta M^2\left(q^2\right)\right\}$$

where there are initially no consumables, i.e. $q_B^1 = 0$. The manufacturer only maximizes his profits on the quantity of new product bundles, but his production quantity must be consistent with the consumer behavior at period 1, $a^1(v)$. The Bellman equation for a consumer of type v at period 1 is

$$D_v^1\left(N, q^1\right) \;=\; \underset{a^1(v)}{max}\left\{g_v\left(N, a^1(v), q^1\right) + \delta D_v^2\left(a^1(v), q^1\right)\right\}$$

Backtracking the equilibrium path, we find a threshold condition such that there would be no excess used durable goods, $p_u^2 > 0$, or that some excess amount of used durable goods, $p_u^2 = 0$, in period 2. Using backward induction, the threshold quantity above which there would be no excess durables in period 2 is

$$q_{thresh}^1 \quad = \quad 1 - \frac{p_G}{s_{d2}s_G} - \frac{1 - c_d - (1+\delta)\left(p_G - s_{d2}s_G\right) - s_{d2}}{2 - s_{d2}\left(2 - 4\left(1+\delta\right)s_G\right)}.$$

Therefore, the optimal starting quantity in period 1 depends on the parameter values:

$$q_n^{1*} = \begin{cases} \frac{(1-c_B-c_d-p_G)(1-s_{d2})+(4-4c_B-3c_d-4p_G)s_{d2}s_G+2s_{d2}^2s_G^2}{2(1+s_{d2}s_G)(1-s_{d2}(1-4s_G))} & if\ q_n^1 \leq q_{thresh}^1 \\ Max\left\{\frac{1}{2}\left(1-c_d-c_B\right),\ 1-\frac{p_G}{s_{d2}s_G}-\frac{1-c_d-(1+\delta)(p_G-s_{d2}s_G)-s_{d2}}{2-s_{d2}(2-4(1+\delta)s_G)}\right\} & o/w \end{cases}$$

Consequently, the production quantity of the first period influences the consumer behaviors and market structure in period 2 as well as in period 1, but the steady state is established after period 2.

Appendix B

Commercializing Component Innovations: The Roles of Firm Capabilities and Network Effects

B.1. Proof of Proposition 3.4.1 ($\alpha < 1$)

While we restrict ourselves to $\theta \leq 8/9$ in the paper, most of our results can be extended to $8/9 < \theta < 1$ with minor modifications. We offer a more general statement of Proposition 3.4.1 and a proof below.

Proposition B.1.1. Licensing to a Weaker rival in an Uncontested Market for $0 < \theta < 1$

When the rival is weaker than the innovator ($\alpha < 1$),

a) For each value of θ*, there exist thresholds* $\underline{\alpha}_M^w$ *and* α_M^w *such that the innovator licenses its innovation to a weaker rival if* $\underline{\alpha}_M^w \leq \alpha \leq \alpha_M^w$*. For all other values of* α*, the innovator prefers captive use.*

b) The thresholds α_M^w *is decreasing in* K *and* $\underline{\alpha}_M^w$ *is increasing in* K*.*

c) The thresholds α_M^w *is increasing in* θ *and* $\underline{\alpha}_M^w$ *is increasing in* θ *for small values of* K*.*

Proof. a) The innovator licenses when $F_w + \pi_i^w(\alpha) \geq \pi_m^*$. Since $F_w = \pi_c^w(\alpha)$, using (3.5) and (3.7), the technology is licensed if $\alpha \in [\underline{\alpha}_M^w, \alpha_M^w]$. The licensing window is defined by $\alpha_M^w = \frac{(3\theta-2)+4K\left(4-7\theta+3\theta^2\right)+2(1-\theta)\sqrt{\gamma}}{4K(1-\theta)+(5-4\theta)}$ and $\underline{\alpha}_M^w =$

$\max\left\{0, \frac{(3\theta-2)+4K\left(4-7\theta+3\theta^2\right)-2(1-\theta)\sqrt{\gamma}}{4K(1-\theta)+(5-4\theta)}\right\}$, where $\gamma = 1+9\theta-12K\left(8-11\theta+3\theta^2\right)$. Note that $\gamma \geq 0$ only if $K \leq K^w = \frac{(1+9\theta)}{12(8-11\theta+3\theta^2)}$.

b) It follows directly that $\frac{\partial\alpha_M^w}{\partial\theta} < 0$ for all $\theta \in [0,1]$ and $K \leq K^w$. Since $\lim_{K\to 0}\frac{\partial\alpha_M^w}{\partial\theta}$, we conclude that $\frac{\partial\alpha_M^w}{\partial\theta} \geq 0$ for small values of K.

c) Further, for all $\theta \in [0,1]$ and $K \leq K^w$, $\frac{\partial\alpha_M^w}{\partial K} < 0$ and $\frac{\partial\alpha_M^w}{\partial K} > 0$. □

B.2. Proof of Corollary 3.4.2 ($\alpha < 1$)

Proof. Setting $K = 0$, we obtain $\alpha_M^w = \frac{3\theta-2+2(1-\theta)\sqrt{1+9\theta}}{5-4\theta}$. Adapting the results in Conner (1995), we obtain $\bar{\alpha} = \theta$. It is easy to establish that $0 \leq \bar{\alpha} \leq \alpha_M^w$. □

B.3. Proof of Proposition 3.4.3 ($\alpha > 1$)

The results are summarized in Table B.1.

Commercialization Strategy	**Rival's Development Cost** $K < K^s$	$K \geq K^s$
Captive Use	$1 \leq \alpha \leq \alpha_M^{cs}$	$1 \leq \alpha \leq \alpha_M^{lc}$
Sell Out	$\alpha_M^{cs} < \alpha \leq \alpha_M^{sl}$	-
Licensing	$\alpha_M^{sl} < \alpha$	$\alpha_M^{lc} < \alpha$

Table B.1: Commercialization Strategy in an Uncontested Market with a Strong Rival

Proof. Let $F_S^s(\alpha)$ and $F_L^s(\alpha)$ be the fees charged by the innovator when the technology is sold out (to the rival) and licensed (to the rival) respectively. Since the market is uncontested, $F_S^s(\alpha) = \pi_{cm}^*(\alpha)$ and $F_L^s(\alpha) = \pi_c^s(\alpha)$, where $\pi_{cm}^*(\alpha)$ and $\pi_c^s(\alpha)$ represent the rival's profits under sell-out and licensing, respectively ((3.12) and (3.10)).

The innovator prefers to be acquired by her rival over captive use (C) if $F_S^s > \pi_m^*$, which occurs if $\alpha > \alpha_M^{cs}$. The innovator's profit from licensing is given by $F_L^s(\alpha) + \pi_i^s(\alpha)$. There exists an α_M^{sl} such that $F_L^s(\alpha) + \pi_i^s(\alpha) \leq F_S^s(\alpha)$ iff $\alpha \leq \alpha_M^{sl}$. Further, it can be shown that $\pi_m^* \geq F_L^s(\alpha) + \pi_i^s(\alpha)$ when $\alpha \leq \alpha_M^{lc}$. Let $K^s = 9/\left(-8 + 36\theta + 8\sqrt{1+9\theta}\right)$.

First consider the $K < K^s$ case. When $K < K^s$, $1 < \alpha_M^{cs} < \alpha_M^{sl}$. When $1 \leq \alpha < \alpha_M^{cs}$, $F_S^s(\alpha) \leq \pi_m^*$ and $F_L^s(\alpha) + \pi_i^s(\alpha) \leq \pi_m^*$; therefore, the innovator prefers C. When $\alpha_M^{cs} \leq \alpha < \alpha_M^{sl}$, $F_S^s(\alpha) \geq \pi_m^*$ and $F_L^s(\alpha) + \pi_i^s(\alpha) \leq F_S^s(\alpha)$; therefore, selling out is preferred. Finally, when $\alpha \geq \alpha_M^{sl}$, $F_L^s(\alpha) + \pi_i^s(\alpha) \geq F_S^s(\alpha) \geq \pi_m^*$; therefore, all innovations with $\alpha \geq \alpha_M^{sl}$ are licensed.

The analysis is similar and straightforward for $K \geq K^s$. □

B.4. Proof of Proposition 3.5.1

Proof. Since the rival is weaker, and is not interested in technologies inferior to its own, $\alpha_0 < \alpha < 1$.

Compatible Innovation. If the technology is licensed, the licensing fee is given by $F_L^w(\alpha; \alpha_0) = \pi_c^w(\alpha) - \pi_c^w(\alpha_0)$, where $\pi_c^w(.)$ is defined in (3.5). Similarly, the buy out fee paid by the innovator is given by $F_S^w = \pi_c^w(\alpha_0)$.

Since the innovator will license if $F_L^w \geq \pi_i^w(\alpha)$, she will consider licensing iff $\alpha_0 \leq \alpha \leq \alpha_D(\alpha_0, \theta)$. Similarly the rival will be bought out iff $\alpha_0 \geq \alpha_{0D}(\theta)$. Since $\alpha_D(\alpha_{0D}(\theta), \theta) \leq \alpha_{0D}(\theta)$, we can also conclude that both licensing and buying out are never simultaneously profitable for the innovator. Proofs of parts (c) and (d) follow directly from the expressions above. □

B.5. Proof of Proposition 3.5.2

Proof. We follow the structure defined in Proof of Proposition 3.5.1.

Incompatible Innovation. When the innovation is incompatible with the rival's existing product, any one of three cases may arise depending on the strength of network effects: (i) If $\alpha_0 \leq \alpha_4(\theta)$ and $\theta \leq .5$, both firms stay and compete in a duopoly; (ii) If $\alpha_4(\theta) \leq \alpha_0 \leq 1$ and $\theta \leq .5$, then the innovator is a monopolist and sets $p_i = \theta$; (iii) If $\theta > .5$, the innovator is a monopolist and sets $p_i = 1/2$, where $\alpha_4(\theta) = 1 - 3\theta + 2\theta^2$.

As above, by comparing F_L^w, F_S^w and π_i^w, π_m, it is straightforward to show that the innovation is licensed iff $\alpha \leq \alpha_I(\alpha_0, \theta)$ and sold out iff $\alpha_0 \geq \alpha_{0I}(\theta)$, where α_I and α_{0I} are defined in the technical supplement at the end of Chapter 3. The rest of the Proposition is easy follows from the expressions. □

B.6. Commercializing Persistently Incompatible Innovations

Proposition B.6.1. Persistently Incompatible Innovation

a) If the rival is weaker ($\alpha_0 < \alpha < 1$)*, the innovator always captively uses her technology. Further, she buys out her rival iff* $0 \leq \alpha_0 \leq \alpha_{0I}(\theta)$*.*

b) If the rival is stronger ($1 < \alpha_0 < \alpha$)*, the innovator always sells out her technology to a stronger rival*

Proof. a) We defined in 3.5.1 when the innovator's product is incompatible with the rival's product, we would have three cases depending on the strength of the network effects: (i) If $\alpha_0 \leq \alpha_4(\theta)$ and $\theta < 8/9$, both firms stay and compete in a duopoly; (ii) If $\alpha_4(\theta) \leq \alpha_0 \leq \alpha_5(\theta)$ and $\theta < 8/9$, then the innovator is a monopolist and sets $p_i = \theta$; (iii) If $8/9 > \theta > .5$, the innovator is a monopolist and sets $p_i = 1/2$, where $\alpha_5(\theta) = (1-\theta)^2$.
By comparing π_i^w and F_S^w, it is easy to show that the innovator use the innovation captively and buys out the rival when $0 \leq \alpha_0 \leq \alpha_{0I}(\theta)$.
b) Proof is similar to part (a). □

B.7. Proof of Proposition 3.5.3

Proof. Since the rival is stronger, and is interested in technologies superior to its own, $\alpha > \alpha_0 > 1$.
Compatible Innovation. If the technology is licensed, the licensing fee is given by $F_L^s(\alpha;\alpha_0) = \pi_c^s(\alpha) - \pi_c^s(\alpha_0)$, where $\pi_c^w(.)$ is defined in (3.5). Similarly, the sell-out fee received by the innovator is given by $F_S^s(\alpha;\alpha_0) = \pi_m^*(\alpha) - \pi_c^s(\alpha_0)$, where $\pi_m^*(\alpha)$ is the monopolist profit received by rival with product quality α.

It can be verified that $F_L^s(\alpha;\alpha_0) + \pi_i^s(\alpha) \geq \pi_i^s(\alpha_0)\ \forall\ \alpha > \alpha_0 > 1$. Therefore, the innovator never prefers captive use. Further, it can be shown that $F_L^s(\alpha;\alpha_0) + \pi_i^s(\alpha) \geq F_S^s(\alpha;\alpha_0)$ iff $\alpha \geq \alpha_M^{sl}$, where α_M^{sl} is defined in the Proof of Proposition 3.4.3. Further, if $\alpha_0 \geq \alpha_M^{sl}$, it is clear that there is no $\alpha\,(>\alpha_0)$ such that $\alpha < \alpha_M^{sl}$. Therefore, selling out is never preferred.

Incompatible Innovation. First consider the case in which $\alpha_0 \geq \alpha_{0I}^{l}(\theta) \geq 1$, where $\alpha_{0I}^{l}(\theta) = 1/\alpha_4(\theta)$. It is easy to verify that $\alpha_{0I}^{l}(\theta) \geq 1$ iff $\theta \leq 0.5$ and that the innovator prefers to license all $\alpha > \alpha_0$ when this is true. In all other cases, by comparing $F_L^s(\alpha; \alpha_0) + \pi_i^s(\alpha)$ and $F_S^s(\alpha; \alpha_0)$, we can show that licensing is more profitable than selling out iff $\alpha \geq \alpha_M^{sl}$. □

Appendix C

Collaborating with Competitors in New Product Development

C.0.1 Proof of Proposition 4.4.3

In Proposition 4.4.2, we have shown that for supplier i, when $K < \overline{K}$, $\frac{1}{2}\pi_{JV}(r^*_{JV}) < \pi_{DAi}(r^*_{DA})$; and when $K \geq \overline{K}$, $\frac{1}{2}\pi_{JV}(r^*_{JV}) \geq \pi_{DAi}(r^*_{DA})$. Next we compare the profits of a supplier in collaboration with the profits that she would make in an independent development. For all values of the parameters, $0 < P < 1$and $s > c > 0$, $\pi_{DAi}(r^*_{DA}) > 0$, $\pi_{ISi}(r^*_{IS}) > 0$ and $\pi_{JV}(r^*_{JV}) > 0$. When $K < \overline{K}$, $\pi_{DAi}(r^*_{DA}) < \pi_{ISi}(r^*_{IS})$ for $K_{LB} < K < \overline{K}$. And similarly, when $K \geq \overline{K}$, $\frac{1}{2}\pi_{JV}(r^*_{JV}) < \pi_{ISi}(r^*_{IS})$ for $K_{UB} > K > \overline{K}$, where $K_{LB} = \frac{P\left(36-18P+7\sqrt{(P-2)(9-5P)}\right)}{36(1+s)}$ and $K_{UB} = \frac{P\left(48-24P+7\sqrt{2(P-2)(9-5P)}\right)}{48(1+s)}$.

Bibliography

Amaldoss, W. and A. Rapoport (2005). Collaborative product and market development: Theoretical implications and experimental evidence. *Management Science 24*(3), 396–414.

Arora, A. and A. Fosfuri (2003). Licensing the market for technology. *Journal of Economic Behavior and Organization 52*(2), 277–296.

Arora, A., A. Fosfuri, and A. Gambardella (2001). Markets for technology and their implications for corporate strategy. *Industrial and Corporate Change 10*, 419–451.

Baake, P. and A. Boom (2001). Vertical product differentiation, network externalities, and compatibility decisions. *International Journal of Industrial Organization 19*(1), 267–284.

Bental, B. and M. Spiegel (1995). Network competition, product quality, and market coverage in the presence of network externalities. *The Journal of Industrial Economics 43*, 197–208.

Bhattacharya, S., A. Robotis, and L. N. V. Wassenhove (2006, April). Installed base management versus selling in monopolistic and competitive environments. INSEAD Working Paper.

Braid, R. M. (1999). The price and profit effects of horizontal mergers in two-dimensional spatial competition. *Economics Letters 62*(1), 113–119.

Brito, D. (2003). Preemptive mergers under spatial competition. *International Journal of Industrial Organization 21*(10), 1601–1622.

Bundschuh, R. G. and T. Dezvane (2003). How to make after-sales services pay off. *McKinsey Quarterly 4*, 116–128.

Business Week (2004, December 6). The squeeze on blackberry.

Business Week (2005a, November 14). Ever wonder why ink costs so much?

Business Week (2005b, May 9). Why hp is pruning the printers.

BusinessWeek (2004, August 16). Michelin: New rubber hits the road.

Church, J. and N. Gandal (2000). Systems competition, vertical merger, and foreclosure. *Journal of Economics & Management Strategy 9*(1), 25–51.

CNETNews (2003, April 8). Tech giants put chips on security alliance.

Cohen, M. A. and S. Whang (1997). Competing in product and service: A product life-cycle model. *Management Science 43*(4), 535–545.

Cohen, W. M. and S. Klepper (1996). Firm size and the nature of innovation within industries: The case of process and product r&d. *The Review of Economics and Statistics 78*(2), 232–243.

Conner, K. (1995). Obtaining strategic advantage from being imitated: When can encouragingclones pay? *Management Science 41*(2), 209–225.

Costa, L. A. and I. Dierickx (2002). Licensing and bundling. *International Journal of Industrial Organization 20*, 251–267.

Costa, L. A. and I. Dierickx (2005). The strategic deployment of quality-improving innovations. *Journal of Business 78*, 1049–1072.

Das, T. K. and B. S. Teng (1998). Resource and risk management in the strategic alliance making process. *Journal of Management 24*(3), 21–42.

Das, T. K. and B. S. Teng (2000). A resource-based theory of strategic alliances. *Journal of Management 26*(1), 31–61.

Debo, L. G., L. B. Toktay, and L. N. V. Wassenhove (2005). Market segmentation and product technology selection for remanufacturable products. *Management Science 51*(8), 1193–1205.

Debo, L. G., L. B. Toktay, and L. N. V. Wassenhove (2006). Joint life-cycle dynamics of new and remanufactured products. *Production and Operations Management 15*(4), 498–513.

Demski, J. S., D. E. M. Sappington, and P. T. Spiller (1987). Managing supplier switching. *The RAND Journal of Economics 18*(1), 77–97.

Deneckere, R. and C. Davidson (1985). Incentives to form coalitions with bertrand competition. *The RAND Journal of Economics 16*(4), 473–486.

Dhebar, A. and S. S. Oren (1985). Optimal dynamic pricing for expanding networks. *Marketing Science 41*(4), 336–351.

Economides, N. (1989). Desirability of compatibility in the absence of network externalities. *The American Economic Review 79*(5), 1165–1181.

Economides, N. (1996). Network externalities, complementarities, and invitations to enter. *European Journal of Political Economy 12*, 211–233.

Electronic Engineering Times (2002, July 15). Cell phone platform licensed.

Erat, S., S. Kavadias, and C. Gaimon (2006, April). Licensing of component technologies. Georgia Institute of Technology Working Paper.

Erkal, N. (2005). Optimal licensing policy in differentiated industries. *Economic Record 81*(252), 51–64.

Farrell, J. and N. T. Gallini (1988). Second-sourcing as a commitment: Monopoly incentives to attract competition. *The Quarterly Journal of Economics 103*(4), 673–694.

Farrell, J. and G. Saloner (1985). Standardization, compatibility, and innovation. *The RAND Journal of Economics 16*, 70–83.

Fauli-Oller, R. and J. Sandonis (2003). To merge or to license: implications for competition policy. *International Journal of Industrial Organization 21*, 655–672.

Ferguson, M. E. and L. B. Toktay (2006). The effect of competition on recovery strategies. *Production and Operations Management 15*(3), 351–368.

Ferrer, G. and J. M. Swaminathan (2006). Managing new and remanufactured products. *Management Science 52*(1), 15–26.

Forbes (2005, 28 February). Biotech buyout binge continues.

Fosfuri, A. and E. Roca (2004). Optimal licensing strategy: Royalty or fixed fee? *International Journal of Business and Economics 3*(1), 13–19.

Gallini, N. T. and R. A. Winter (1985). Licensing in the theory of innovation. *The RAND Journal of Economics 16*, 237–252.

Gans, J. S. and S. Stern (2003). The product market and the market for "ideas": commercialization strategies for technology entrepreneurs. *Research Policy 32*, 333–350.

Garud, R. and A. Kumaraswamy (1993). Changing competitive dynamics in network industries: An exploration of sun microsystems' open systems strategy. *Strategic Management Journal 14*, pp. 351–369.

Gilbert, S. M. and V. Cvsa (2003). Strategic commitment to price to stimulate downstream innovation in a supply chain. *European Journal of Operational Research 150*(3), 617–639.

Gilbert, S. M., Y. Xia, and G. Yu (2006). Strategic outsourcing for competing oems that face cost reduction opportunities. *IIE Transactions 38*(11), 903–915.

Gilbert, S. M., Y. Xia, and G. Yu (2007). The strategic effects of a merger upon supplier interactions. *Naval Research Logistics 54*(2), 162–175.

Granot, D. and G. Sosic (2005). Formation of alliances in internet-based supply exchanges. *Management Science 51*(1), 92–105.

Guide, V. D., R. H. Teunter, and L. N. V. Wassenhove (2003). Matching demand and supply to maximize profits from remanufacturing. *Manufacturing and Service Operations Management 5*(4), 303–316.

Gupta, S. and R. Loulou (1998). Process innovation, product differentiation, and channel structure: Strategic incentives in a duopoly. *Marketing Science 17*(4), 301–316.

Hamel, G., Y. L. Doz, and C. K. Prahalad (1989). Collaborate with your competitors–and win. *Harvard Business Review 67*(1), 133–139.

Huang, S., Y. Yang, and K. Anderson (2001). A theory of finitely durable goods monopoly with used-goods market and transaction costs. *Management Science 47*(11), 1515–1532.

Kalaignanam, K., V. Shankar, and R. Varadarajan (2007). Asymmetric new product development alliances: Win-win or win-lose partnerships? *Management Science 53*(3), 357–374.

Kamien, M. I. (1992). Patent licensing. *Handbook of Game Theory 1*, 331–354.

Kamien, M. I., S. S. Oren, and Y. Tauman (1992). Licensing of cost reducing innovation. *Journal of Mathematical Economics 21*, 483–508.

Kamien, M. I. and Y. Tauman (1986). Fees versus royalties and the private value of a patent. *The Quarterly Journal of Economics 101*(3), 471–492.

Katz, M. L. and C. Shapiro (1985). On the licensing of innovations. *The RAND Journal of Economics 16*(4), 504–520.

Katz, M. L. and C. Shapiro (1986). How to license intangible property. *The Quarterly Journal of Economics 101*(3), 567–590.

Katz, M. L. and C. Shapiro (1994). Systems competition and network effects. *The Journal of Economic Perspectives 8*(2), pp. 93–115.

Kauffman, R. J., J. McAndrews, and Y.-M. Wang (2000). Opening the "black box" of network externalities in network adoption. *Information Systems Research 11*(1), 61–82.

Kim, S.-H., M. A. Cohen, and S. Netessine (2007a). Performance contracting in after-sales service supply chains. *forthcoming in Management Science*.

Kim, S.-H., M. A. Cohen, and S. Netessine (2007b, March). Reliability or inventory? contracting strategies for after-sales product support. Wharton School Working Paper.

Klotz, D. E. and K. Chatterjee (1995). Dual sourcing in repeated procurement competitions. *Management Science 41*(8), 1317–1327.

Kogut, B. (1991). Joint ventures and the option to expand and acquire. *Management Science 37*(1), 19–33.

Krishnan, V. and W. Zhu (2006). Designing a family of development-intensive products. *Management Science 52*(6), 813–825.

Levin, R. C., A. K. Klevorick, R. R. Nelson, and S. G. Winter (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity 1987*(3), 783–831. Special Issue On Microeconomics.

Majumder, P. and H. Groenevelt (2001). Competition in remanufacturing. *Production and Operations Management 10*(2), 125–141.

Maskin, E. and J. Tirole (1988). A theory of dynamic oligopoly, ii: Price competition, kinked demand curves, and edgeworth cycles. *Econometrica 56*(3), 571–599.

Matutes, C. and P. Regibeau (1988). "mix and match": Product compatibility without network externalities. *The RAND Journal of Economics 19*(2), 221–234.

Matutes, C. and P. Regibeau (1992). Compatibility and bundling of complementary goods in a duopoly. *The Journal of Industrial Economics 40*(1), 37–54.

Nault, B. R. and R. K. Tyagi (2001). Implementable mechanisms to coordinate horizontal alliances. *Management Science 47*(6), 787–799.

Peterson, R. A. and V. Mahajan (1978). Multi-product growth models. *Research in Marketing 1*, 201–231.

Pfeffer, G. and P. Novak (1976). Joint venture and internationalisation interdependence. *Administrative Science Quarterly 4*(2), 398–418.

Ray, S., T. Boyaci, and N. Aras (2005). Optimal prices and trade-in rebates for durable, remanufacturable products. *Manufacturing and Service Operations Management 7*(3), 208–228.

Reuer, J. J. (2004). *Strategic Alliances: Theory and Evidence.* Oxford, UK: Oxford University Press.

Riordan, M. H. and D. E. M. Sappington (1989). Second sourcing. *The RAND Journal of Economics 20*(1), 41–58.

Rockett, K. E. (1990). Choosing the competition and patent licensing. *The RAND Journal of Economics 21*, 161–171.

Rosenkopf, L. and P. Almeida (2003). Overcoming local search through alliances and mobility. *Management Science 49*(6), 751–766.

Shepard, A. (1987). Licensing to enhance demand for new technologies. *The RAND Journal of Economics 18*(3), 360–368.

Sun, B., J. Xie, and H. H. Cao (2004). Product strategy for innovators in markets with network effects. *Marketing Science 23*(2), 243–254.

Xie, J. and M. Sirbu (1995). Price competition and compatibility in the presence of positive demand externalities. *Management Science 41*(5), 909–926.

Vita

Sadik Sinan Erzurumlu, the son of Arikan and Sezen Erzurumlu, was born in Izmir, Turkey on February 10, 1976. He received the Bachelor of Science degree in Electrical and Electronics Engineering with Honors from Bogazici University, Istanbul, Turkey in 1999. After graduation, he joined the Operations Research and Industrial Engineering program at the University of Texas at Austin and received the Master of Science degree in Operations Research and Industrial Engineering in 2002. Subsequently, he entered the PhD program in Supply Chain and Operations Management at the McCombs School of Business.

Permanent address: Mithatpasa cad. No:1085/11
Guzelyali, Izmir 35290, Turkey

This dissertation was typeset with LaTeX[†] by the author.

[†] LaTeX is a document preparation system developed by Leslie Lamport as a special version of Donald Knuth's TeX Program.