DUAL SALES CHANNEL MANAGEMENT WITH PRICE COMPETITION

by

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Abstract

A significant number of manufacturers have started to sell their products through company-owned stores as well as through independent retailers. More interestingly, many do so in direct competition with their retailers. In addition, growth in the use of the Internet for commerce and developments in logistics have increased the ways a manufacturer might reach its end customers.

In this thesis, we study a manufacturer's problem of managing its direct sales channel alongside an independently-owned bricks-and-mortar retail channel, when the channels compete in price. We develop multi-stage game theoretical models of the relation between the manufacturer and the retailer. We study two different dual channel models: In Model 1, the manufacturer's direct channel is online, whereas the retail channel is traditional. In this model, we assume a population of consumers that are heterogeneous in their channel preferences. Our focus is on understanding how consumer valuation and the relative attractiveness of the channels affect the manufacturer's dual channel strategies. In Model 2, we did not specify particular channel formats. In this model, our focus is on the interaction of the dual channel strategy with the double marginalization issue. To this end, we compare the results in centralized and decentralized scenarios under different price sensitivity combinations in the two channels. We also illustrate our findings in the two models through numerical examples.

İKİLİ SATIŞ KANALLARININ FİYAT REKABETİ ALTINDA YÖNETİLMESİ

Gamze Belen

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Anahtar Kelimeler: ikili kanallar, doğrudan kanal, perakende satış kanalı, fiyat rekabeti, oyun teorisi, tedarik zinciri kontratları, çifte tekel karı, müşteri tercihleri

Özet

Önemli sayıda üretici ürünlerini hem kendi mağazalarından hem de bağımsız perakendeciler üzerinden satmaya başlamıştır. Çoğu üretici bunu perakendecilerle doğrudan rekabet içinde yapmaktadır. Buna ek olarak, ticaret için İnternet kullanımının artması ve lojistikteki gelişmeler, üreticilerin müşterilere ulaşma yollarını arttırtmaktadır.

Bu tezde, üreticilerin fiyat rekabeti ortamında hem bağımsız geleneksel perakendeci kanalları hem de kendi doğrudan satış kanallarını yönetme problemi üzerinde çalıştık. Üretici ve perakendeci arasındaki ilişkiyi oyun kuramı kullanarak çok aşamalı şekilde modelledik. İki farklı ikili kanal modelini çalıştık: Model 1'de üreticinin doğrudan kanalını İnternet, perakendeci kanalını ise geleneksel olarak ele aldık ve müşterilerin kanal tercihlerinde heterojen olduğunu varsaydık. Müşterinin ürüne değer biçmesinin ve kanalların göreceli çekiciliğinin üreticinin ikili kanal stratejilerini nasıl etkilediğini araştırdık. Model 2'de, belirli kanal biçimleri belirtmedik. Bu modelde, ikili kanal stratejisinin çifte tekel karı problemi ile etkileşimi üzerine odaklandık. Bu amaçla, farklı fiyat duyarlılığı kombinasyonları ele alınarak merkezileşmiş ve dağıtılmış senaryoların sonuçlarını karşılaştırdık. Her iki modeldeki bulgularımızı sayısal örnekler kullanarak da açıkladık.

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CHAPTER 1

1 INTRODUCTION

Recently, “channel management” has arisen as an important area of study for both operations management and marketing. Channel management is a process by which a company creates formalized strategies for servicing customers within a specific channel. A distribution channel is a chain of intermediaries, each passing the product down the chain until it reaches to the end-customer. For a company, distribution channel choice is a significant decision to make, because there have been major developments that broaden the feasible set of sales and the environment has become very competitive. After producing the product, how to bring it to the intended customers is a crucial strategic issue. Since market conditions, tastes, and technology are rapidly changing, companies are experimenting with various alternative distribution strategies including selling direct, through vertically-integrated retailers, through independent retailers, through franchised retailers, or through a multi-channel distribution system involving some combination of these alternatives (Table 1-1).

Table 1-1: Alternative Distribution Strategies

	Ownership	
Format of the channel	**Retailer**	**Manufacturer**
Online	Retailer sells her products through the Internet. Ex: Amazon, ebay, ebebek, etc.	Manufacturer reaches his customers through online stores. Ex: HP, Dell, IBM, Pioneer Electronics, Cisco System, Estee Lauder, Sony, etc.
Physical	Retailers sell her products in physical stores. Ex: Toshiba, Boyner, Darty, etc.	Manufacturers open their manufacturer-owned stores. Ex: Polo Ralph Lauren, DKNY, Liz Claiborne, and Armani, Zara, etc.

A significant number of manufacturers have redesigned their channel structures. Some manufacturers sell their products through direct sales channel (either through company-owned stores or through online stores) as well as through independent retailers. Such systems are known as “dual sales channels”. In this case, the manufacturer simultaneously acts as a supplier as well as a competitor to the retailer. Customers’ choice of channels depends on their needs and characteristics and also on the characteristics of products. For instance, price sensitive customers might patronize the online store for a lower price whereas service-sensitive customers might patronize the traditional retail channel. Most of the manufacturer-owned stores are opened out of the city centers and customers may not prefer to travel so far to buy their needs. A customer may buy a book from an online store, but may be unwilling to buy a more expensive and valuable product over the Internet.

Selling through the direct channel offers a number of advantages. To begin with, the manufacturers may want “go direct” in part to motivate retailers to perform more effectively. The threat to sell in the direct channel might induce greater sales in the traditional retail channel (the independent retailer lowers its price and increases sales volume) and the manufacturer can increase his profits in the retail channel. Moreover, it helps the manufacturer improve overall profitability by reducing double marginalization. In addition to this, the manufacturer may increase its market coverage and profit by servicing to the different needs of customer segments with separate channels. Consequently, a number of top suppliers in a variety of industries have started to open their own stores. For example, Nike opened a Niketown store in downtown Chicago to reach individual consumers (Collinger 1998). A number of well-known manufacturers such as Polo Ralph Lauren, DKNY, Liz Claiborne, and Armani have their company-owned stores and also independent retailers such as Macy’s and Nordstrom that carry these brands in their stores. Goodyear opened Goodyear Tire Centers to sell the products through his own stores as well as through independent retail stores (Bell et al. 2002).

The dual channel strategy might also offer some benefits to the retailer. The introduction of the direct channel can be accompanied by a wholesale price reduction. Since each channel member influences other channel members’ decisions, the retailer can exercise some control over the manufacturer. Consumers may benefit from the opportunity of speaking to more knowledgeable salespeople in company-owned stores, and this might trigger sales in the retail channel.

Opening a direct channel, however, may lead to severe problems. Since the manufacturer becomes a competitor for the retailer, the retailer can think that the manufacturer steals her business and cannibalize her sales. This leads to "channel conflict". Since problems affect manufacturer profits, the manufacturer has an incentive to use contractual mechanisms which would help control the retailer who sell his product. Some manufacturers try to convince retailers that their direct channels attract attention of customer segments that would otherwise not buy. On the other hand, some other manufacturers had to stop direct sales to avoid channel conflict.

More recently, the use of Internet for commerce has created new opportunities to manufacturers for accessing to end customers efficiently. As a result, many manufacturers have started selling directly online, complementing their existing retail distribution channels. Selling online potentially can increase the market for a manufacturer and reduce the costs of operations. Independent structure of the Internet business gives the opportunity of being more flexible and independent to get the business up and running quickly. The customers get the chance of searching through the Internet and comparing a product with another one in a short time. Online stores offer greater time-savings. Customers can also order products from other countries. Manufacturers may offer price discounts on Internet sales and if customers require no retail sales effort, then buying from the Internet may become more profitable.

In real world, a number of top companies sell their products through their online stores. HP, for example, has been operating an online direct channel, hpshopping.com, since 1998. Levi's also reaches its consumers through jeans-online. Nike, Dell, Pioneer Electronics, Estee Lauder, Sony etc. are other examples of manufacturers engaging in direct online sales.

Selling through the Internet, however, causes a number of disadvantages. Retailers become concerned that Internet sales may affect sales from a retail store since customers can buy at a lower price on the Internet and a new channel threatens existing channel relationships. This results in channel conflict, similar to company-owned stores' disadvantages. Levi Strauss & Co. is one of the companies that experienced channel conflict. Independent retailers of Levi Strauss & Co. reacted when Levi's started to sell his products through his online store (Bucklin et al. 1997). Avon Products Inc. (Machlis 1998c), IBM (Nasiretti 1998), Bass Ale (Bucklin et al. 1997), the former Compaq (McWilliams 1998), Mattel (Bannon 2000), and others have reported similar conflicts. The customers also face a number of disadvantages such as waiting for product delivery and paying for shipping. In addition, a customer may want to touch, taste or smell the product instead of a virtual description on the internet.

In this thesis, we determine how a manufacturer can effectively manage its direct channel and an independent bricks-and-mortar retail channel when the channels compete in price. To do so, we develop two models that incorporate the key characteristics of the dual sales management with price competition. Both models are game-theoretic and contain three stages: (1) Contracting stage where the manufacturer offers a wholesale price contract to the retailer; (2) A pricing game where the firms determine the channel prices in a simultaneous-move game; (3) Consumer choice stage where a number of consumers choose which channel to buy from. We solve these models with backwards induction and obtain the equilibrium outcome for a given set of model parameters.

In the first model, the manufacturer's direct channel is in *online* format whereas the retailer's channel is in *traditional (physical)* format. We study how consumer preferences towards the channel formats affect the manufacturer's dual channel strategy. We determine the manufacturer's optimal dual channel strategy as a function of the customers' valuation of the product and their relative preference towards the direct online channel. To do so, we compare the results from a set of six possible channel strategies including dual, direct-only and retailer-only structures.

In the second model, we do not specify particular formats for the channels. The consumer demand in each channel is modeled as a function of the prices in both channels. Our focus is on understanding how the dual channel strategy of the manufacturer interacts with the double marginalization issue. To this end, we first study a benchmark case in which a centralized firm owns both the manufacturer and the retailer. Next, we study a decentralized case with independent firms, and compare the results with the centralized case to assess the inefficiencies due to double marginalization.

We illustrate our discussion through numerical examples and figures. To this end, we coded the models in Mathematica and Matlab.

We use game theory to model the relationship between the manufacturer and the retailer. Next, we provide background information on game theory.

Game Theory

Game theory is the study of multiperson decision problems and strategic behavior. Game theory helps us understand the observed phenomena when multiple decision makers who are strategically dependent interact (Gibbons 1992). In game theory, *players*-the decision makers, *rules*- the order of moving for the players, *outcomes*- the outcomes for each possible set of actions by the players and *payoffs*- the players' preferences over the possible outcomes are the basic elements of a game. Bidding in an auction, firms' price-setting behavior, a firm's entry into a new industry, a commuter's time to leave home to avoid traffic etc. are some known examples of games. Moreover, game theorists have performed very important developments using game theory. For instance, economists have innovated auctions of radio spectrum licenses for cell phones, computer scientists have developed new software algorithms and routing protocols, political scientists have improved election laws, military strategists have created notions of strategies of deterrence and biologists have determined the species that become extinct by using game theory[1]. Game theory is a significant tool, because it develops methodologies that apply in principle to all interactive situations.

Game theory has also become popular in business. In business, interactions with customers, suppliers, other business partners, and competitors as well as interactions across people and different organizations within the firm play a significant role in any decision. There are consulting firms that apply innovative thinking and practical tools, detect business value, define a plan of action and solve business issues using game theory. IBM Business Strategy Consulting, NERA Economic Consulting, Criterion Economics etc. are some of the popular consulting firms that use game theory as a tool to analyze business issues.

In game theory, when making a decision, the outcome for each player depends on the actions of others. In business, most firms consider other players' actions, particularly competitors, while making their decisions. Advanced Micro Device's (AMD) action against Intel, his rival, is a good example to illustrate how competitors' choices impact a firm's decisions (Spooner 2002). Intel dropped the prices of its desktop processors. Just days after Intel's action, AMD cut its prices of desktop and mobile Athlon processors to stay competitive on prices. AMD's price-chopping illustrates that AMD observed its rival, Intel's actions and slashed its prices, because it did not want to give up market

[1] http://www.gametheory.net

share gains. In this example, the companies compete in price in order to gain market share. Companies that engage in price competition generally do not benefit from such competition. In this example, both Intel and AMD would have done better if they kept their prices higher instead of cutting prices. In game theory, this phenomenon is illustrated by the well-known “Prisoners dilemma” (see Gibbons 1992 for further information). Game theory is also used in designing markets and auctions. As an example, The Federal Communications Commission (FCC) used game theory to design an auction for the next generation of paging services. The auctions’ results were better than expected (Bennett 1994).

The analysis of game-theoretical models rests on certain assumptions. Decision makers are assumed to be expected utility maximizers and expected to be rational. In game theory, players make a simple choice, and know how their choices and the choices of other players combine to determine monetary payoffs. Standard equilibrium analysis assume that all players form beliefs based on an analysis of what others might do, choose the best response, and adjust best responses and beliefs until they are mutually consistent. In sequential-move (multi-stage) games, a player is assumed to anticipate the outcome of a latter stage when making his decision at a prior stage. Although widely used in theoretical models, such assumptions are known to be violated in practice and there are deviations from a game-theoretical model’s predictions.

We develop game-theoretical models in this thesis. As a future study, one can conduct decision-making experiments with human decision makers based on our theoretical results. To support such a future study, we conducted background research on the topic of behavioral and experimental economics. We decided to include this work as part of this thesis (Appendix A) although we did not conduct any experiments.

CHAPTER 2

2 LITERATURE SURVEY

There is a growing literature on dual channel management, reviewed by Tsay and Agrawal (2004a), and by Cattani et al. (2004). Most papers in this area study competition in price and/or marketing effort. Bell et al. (2003) study price competition and compare the results of two cases; a single manufacturer selling to three independent retailers and again a single manufacturer selling to three independent retailers, but one of which is his own store. Ahn et al. (2002) consider price competition between independent retailers and manufacturer-owned stores where the manufacturer stores are in remote locations. Chiang et al. (2003) find that the manufacturer is more profitable even if no sales occur in the direct channel. Kumar and Ruan (2002) study the strategic forces that influence the manufacturer’s decision when there are two types of customers: retail-loyal customers and brand-loyal customers. Ingene and Parry (1995(b), 1998, 2000) study issues of channel coordination faced by a manufacturer and two retailers that compete on price.

Tsay and Agrawal (2001) consider a single manufacturer whose end customer market is sensitive to both price and sales effort. The authors study the inefficiency due to double marginalization within the reseller channel. Rhee and Park (2000) and Chiang et al. (2003) see the direct channel as a way to keep prices low by combating double marginalization. Bell et al. (2003) mention that the manufacturer can tolerate some degree of relative inefficiency in retailing to avoid double marginalization.

A number of researchers study service competition between different firms (not necessarily in a dual channel setting). In Hall and Porteus (2000), customers may switch to a competitor if they receive poor service. Bernstein and Federgruen (2002) examine an oligopoly in which sales are awarded based on the competitors’ service levels. Lal (1990) examines the coordination of a franchise system in which the retailers engage in service competition. Winter (1993), Iyer (1998), and Tsay and Agrawal (2000) consider retailers that compete directly along both price and service competition. Chen et al.

(2008) study a manufacturer's problem of managing his direct online sales channel together with a retail channel, when the channels compete in service.

Tsay and Agrawal (2004b) evaluate three different distribution strategies, retailer-only, direct-only and dual channel, focusing on channel conflict. Cattani et al. (2006) analyze a scenario where a manufacturer opens up a direct Internet channel that is in competition with the traditional retail channel. However, different from Tsay and Agrawal (2004b)'s study, their formulation explicitly models the channel preferences of heterogeneous customers. Hendershott and Zhang (2006) analyze a model with a manufacturer and multiple, heterogeneous intermediaries. Their empirical research reveals that using direct sales benefit both the consumers and the upstream firms with market power, but on the other hand intermediaries suffer from increased competition from direct sales.

Most of the research consider deterministic demand and ignores the effects of inventory. Boyaci (2005) and Seifert et al. (2006) are exceptions. Boyaci (2005) considers a setting where a manufacturer sells through both a direct channel and a traditional channel, but his research focuses on stocking levels under stochastic demand and on developing mechanisms for supply chain coordination. Seifert et al. (2006) assume that a manufacturer has a direct market that serves a different customer segment than the retail channel. The authors provide insight into the setting by which supply chains with direct and indirect channels can be integrated and operated in a mutually beneficial way with stochastic demands. Netessine and Rudi (2006) model the dual strategy as a noncooperative game among a number of retailers and a wholesaler. The authors analyze comparative advantages of inventory ownership in the traditional channel and risk pooling under drop-shipping.

Supply chain contracting research is also relevant to our work. Katok and Wu (2006) investigate the performance of the wholesale price, the buyback, and the revenue-sharing contracts in a newsvendor setting. These three contacting mechanisms are compared in the controlled laboratory setting and the subjects in the experiments either play a retailer or a supplier against a computer-simulated opponent. These authors suggest games in which both players are human as a future research direction. Ho and Zhang (2007) find that contrary to the standard economic theories, the introduction of the fixed fee does not increase channel efficiency and the two-part tariff and the quantity discount contracts are not equivalent. Katok et al. (2006) investigate the effect of the length of the review period and the magnitude of bonus for meeting or exceeding the service-level target. Keser and Paleologo (2004) suggest an experimental investigation of a simple supplier-retailer wholesale price contract in a world of stochastic demand. In the model, the supplier offers the wholesale price and the retailer chooses the order quantity. These authors observe that the wholesale price contract yields an efficiency that is not significantly different from the equilibrium prediction. Cui, Raja and Zhang (2006) study how fairness may affect channel coordination. These authors show that the manufacturer can coordinate the channel with a simple wholesale price above its marginal cost when channel members are concerned about *fairness*.

We also conducted a literature search on the areas of behavioral and experimental economics. We present this work in Appendix A.

CHAPTER 3

3 MODEL-1

In this section, we consider a single manufacturer (he) who sells a product through both his direct online channel and a traditional (physical) retail channel (she). We study how the manufacturer can manage these two channels when the channels compete in price.

The market for the product consists of *N* consumers. Each consumer may buy the product from either the direct channel or the retail channel, or may not buy at all. We assume that consumers are heterogeneous in their channel preferences and that they are uniformly distributed along a unit-length line. The two channels are located at the two ends of this line as shown in Figure 3-1. We measure the distance of a particular consumer from the direct channel with the distance *d*, which we refer to as "the mental distance to the direct channel". A consumer with small *d* value prefers the direct channel more than a consumer with a high *d* distance. This characterization of the consumer population is similar to the well-known "*linear city*" model of Hotelling (1929).

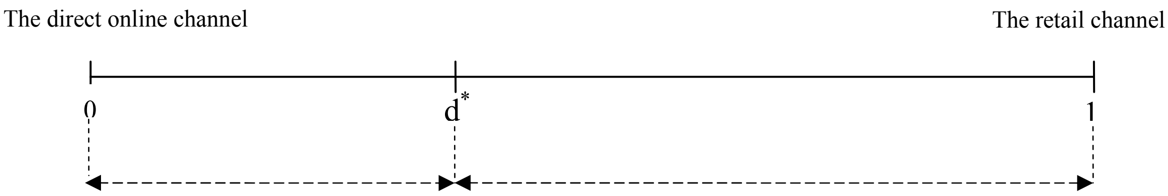

Figure 3-1: The Consumer Population

We model the relationship as a three-stage game, as presented in Figure 3-2. The sequence of events is as follows:

At stage 1, the manufacturer sets the wholesale price *w* and offers the contract to the retailer. The retailer accepts the contract if his profit is non-negative; i.e., if $\Pi_r^* \geq 0$. Note that we assume a retailer reservation profit level of zero without loss of generality.

At stage 2, the firms engage in a “pricing game”. Given the wholesale price, the retailer sets the selling price P_r in the retail channel, and the manufacturer sets the selling price P_d in the direct channel. Each decision maker makes his/her decision without observing the other’s decision, leading to a simultaneous-move game.

At stage 3, consumer demand is realized. Depending on the sales prices P_r and P_d and a number of other model parameters, each consumer decides which channel to buy from, or not to buy at all. The retailer observes q_r, the demand in the retail channel (quantity sold in this channel), orders this quantity from the manufacturer and satisfies the demand in the retail channel. Note that the retailer procures to order, that is, we are not interested in inventory. The manufacturer directly satisfies the demand in the direct channel (quantity sold in this channel), q_d. He operates make to order. The manufacturer can satisfy all demand, i.e. there is no capacity constraint.

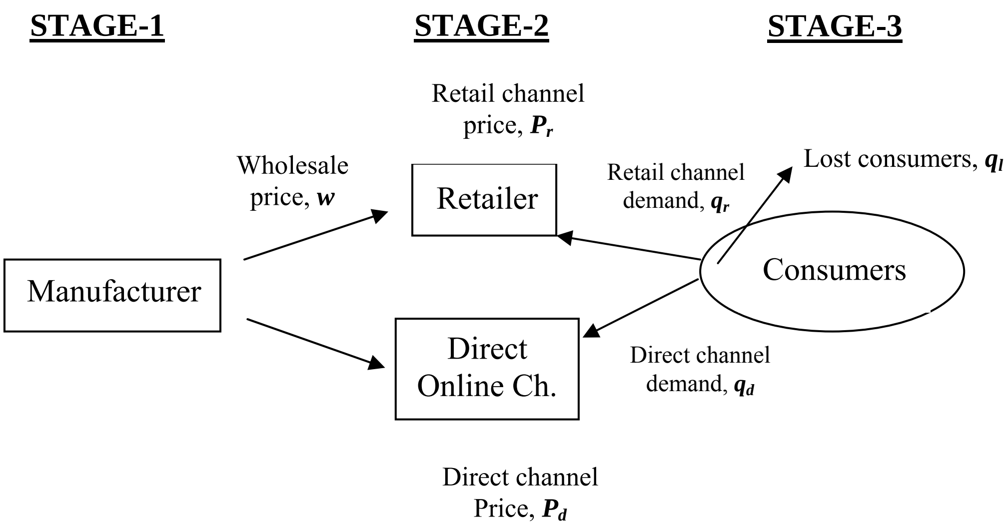

Figure 3-2: Sequence of Events

We solve the three-stage model with backwards induction. First, we characterize the demand satisfied through the direct and the retail channels in stage 3. Next, we study stage 2, the pricing game. At this stage, both the manufacturer and the retailer know how the market will be split at stage 3, based on the prices they set, however, each of them is unaware of the other’s decision. Given w, we establish the best responses of the manufacturer and the retailer to each others’ actions. We then solve these functions simultaneously to determine the Nash equilibrium of the pricing game. Finally, at stage 1, we solve for the manufacturer’s optimal wholesale price, w. Next, we explain the consumers' channel choice process in detail. Each consumer derives a value v from buying the product. In his channel choice decision, the consumer compares the utilities he would obtain by buying the product from the two channels. These utilities depend on the distance d of the consumer which represents his "mental distance" from the direct channel. The consumer with distance d derives the following utility from buying the product from the direct channel

$$u_d(d) = v - P_d - kd.$$

Here, the parameter "$k \geq 0$" denotes the unattractiveness of the direct channel relative to the retail channel. We refer to it as "the direct channel relative preference disadvantage parameter", or "the disadvantage parameter" for short. Note that the utility of the consumer decreases in his distance d, in the sales price P_d that the manufacturer determines, and in the disadvantage parameter k, which is a model parameter.

The utility that this consumer derives from buying from the retail channel is

$$u_r(d) = v - P_r - (1-d).$$

Note that we do not have a parameter similar to k in this formulation. The parameter k denotes the relative disadvantage of the direct channel compared to the retail channel, and hence it suffices to introduce it only in the direct channel utility expression.

To determine how the consumer population will be split between the two channels, we determine the consumer who is indifferent between buying from the two channels. As seen from Figure 3-1, this consumer is located at d^* such that

$$d^*(P_r, P_d) \equiv \min\{\{d \mid u_d(d) = u_r(d)\}, 1\} = \min\left\{\frac{1+P_r-P_d}{1+k}, 1\right\}. \qquad (3\text{-}1)$$

Given this characterization of d^*, the channels' respective demands are as follows:

$$q_d(P_d, P_r) = Nd^*(P_d, P_r) = N\frac{1+P_r-P_d}{1+k},$$

$$q_r(P_d, P_r) = N[1-d^*(P_d, P_r)] = N\frac{k+P_d-P_r}{1+k}.$$

Note that this split is valid when the consumer with distance d^* derives a positive utility from buying the product. Other cases are also possible. Depending on P_d and P_r, both channels might not be operative. In addition, not all of the consumer market might be covered (i.e., there might be lost consumers). Based on these possibilities, we analyze three cases each containing two subcases, as illustrated in Table 3-1.

Table 3-1: Channel Strategies

Channel strategies	**Dual channel**	**Direct Channel Only**	**Retail Channel Only**
Full coverage	Case 1a	Case 2a	Case 3a
Partial coverage	Case 1b	Case 2b	Case 3b

Before moving on to the detailed analysis of these cases, we briefly list a number of assumptions:

- If a consumer is indifferent between the two channels (i.e., the consumer at distance d^*) and if he derives positive utility, he will buy from the direct channel.
- If the manufacturer's profit is the same for more than one case, we assume that he chooses the case that provides the highest profit for the retailer.

3.1 Case-1 Dual Channel

In this channel strategy, the manufacturer sells his product through both the direct channel and the retail channel. According to the utilities that the consumers derive from the channels, the market is either fully covered or there exists lost sales.

3.1.1 Case-1a Dual Channel - Full Coverage

In this case, both channels are operative and there is no lost consumer as illustrated in Figure 3-3. Consumers with $d \le d^*$ buy from the direct channel and consumers with $d > d^*$ buy from the retail channel. Figure 3-3 also presents the utility values as a function of the consumers' distances *d*.

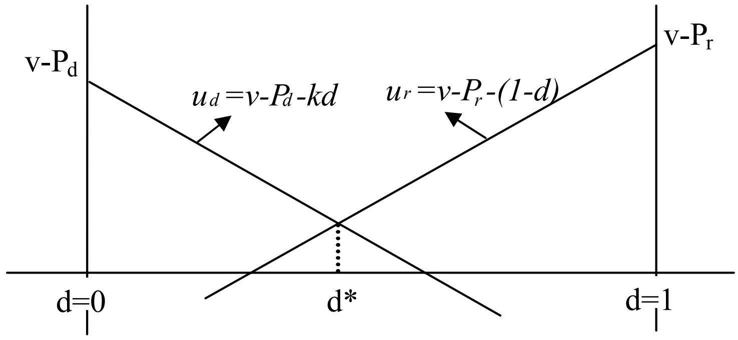

Figure 3-3: Consumer Utility Functions in Dual Channel-Full Coverage Case

The following conditions on $P_r, P_d, v,$ and k needs to be satisfied for this case to be observed:

i) $d^* \in [0,1]$, which requires $-1 \le P_r - P_d \le k$,

ii) $u_d(d^*) = u_r(d^*) \ge 0$, which requires $v(1+k) - P_d - k(1+P_r) \ge 0$,

iii) $\Pi_r(P_d, P_r) \ge 0$, which requires $(P_r - w)q_r \ge 0 \Leftrightarrow P_r \ge w$.

From the definition of d^* in (3-1), the consumer demands are realized as follows:

$$q_d(P_d, P_r) = N\frac{1+P_r-P_d}{1+k}, \qquad q_r(P_d, P_r) = N\frac{k+P_d-P_r}{1+k}.$$

Next we solve the second stage pricing game. At this stage, we determine the best response functions of the manufacturer and the retailer to each others' actions and solve these functions simultaneously to determine the prices in the Nash equilibrium.

The manufacturer aims to maximize his profit through the sales in the direct online channel and the retail channel. Hence, given his w from stage 1, the manufacturer's objective in stage 2 is

$$\max_{P_d} \Pi_m = q_d(P_d, P_r)P_d + q_r(P_d, P_r)w.$$

We substitute the quantity functions into the manufacturer's objective function and obtain $\max_{P_d} \Pi_m = \frac{N}{1+k}\left(-P_d^2 + (1+P_r+w)P_d + (k-P_r)w\right)$. The first-order condition gives

$$\frac{\partial \Pi_m}{\partial P_d} = \frac{N}{1+k}\left(w+1+P_r-2P_d^*\right) = 0, \quad \frac{\partial^2 \Pi_m}{\partial P_d^2} = \frac{-2N}{1+k} < 0,$$

$$P_d^*(P_r) = \frac{1+w+P_r}{2}. \tag{3-2}$$

This function illustrates the manufacturer's price choice in the direct channel for any price that the retailer might set in his channel. From (3-2), we observe that when the retailer sets a higher price, the manufacturer responds by setting a higher price.

Next, we solve the retailer's problem

$$\max_{P_r} \Pi_r = q_r(P_d, P_r)\left(P_r - w\right).$$

We substitute the quantity functions into the retailer's objective function and obtain $\max_{P_r} \Pi_r = \frac{N}{1+k}\left(-P_r^2 + \left(k + P_d + w\right)P_r - \left(k + P_d\right)w\right)$. The first-order condition gives

$$\frac{\partial \Pi_r}{\partial P_r} = \frac{N}{1+k}(w + k + P_d - 2P_r^*) = 0, \quad \frac{\partial^2 \Pi_r}{\partial P_r^2} = \frac{-2N}{1+k} < 0,$$

$$P_r^*(P_d) = \frac{k + w + P_d}{2}. \qquad (3\text{-}3)$$

Similar to the manufacturer's best response, we observe that when the manufacturer sets a higher price in the direct online channel, the retailer responds by setting a higher price in the retail channel.

We solve (3-2) and (3-3) simultaneously and determine the prices in equilibrium as follows:

$$P_d^*(w) = \frac{1}{3}\left(2 + k + 3w\right), \qquad P_r^*(w) = \frac{1}{3}\left(1 + 2k + 3w\right).$$

We observe that the sales prices in both channels increase if the wholesale price increases or if the online channel disadvantage parameter *k* increases. For a given increase in *k*, the retail channel price increases more than the direct channel price. This is because an increase in *k* makes the direct channel less attractive in the consumers' eye. Hence, the manufacturer cannot increase his price in the direct channel as much as the retailer.

One expects the direct channel selling price to decrease when the direct channel becomes more disadvantageous. However, this is not the case, because there exists a strategic interaction. When *k* increases, the retailer increases her sales price to take advantage of the situation. This, however, allows the manufacturer to increase his selling price in the direct channel, although not as much as the retailer. The reason behind this result is that the total market size *N* is constant in this model and it does not decrease when both channels increase their prices. If *N* depended on prices, the results would be different.

Given P_d and P_r, the sales quantities are found as

$$q_d^* = N\frac{2+k}{3(1+k)}, \qquad q_r^* = N\frac{1+2k}{3(1+k)}.$$

We observe that the quantities sold in the channels are independent of the wholesale price *w* (as long as the case conditions are satisfied). The quantities sold depend on the disadvantage parameter, *k*, of the direct channel. Intuitively, when the direct channel becomes more disadvantageous, the consumers migrate from the direct channel to the retail channel (if they are willing to buy the product).

Next, we rewrite the case conditions using the P_d and P_r expressions:

i) To have $d^* \in [0,1]$,

$-1 \le P_r^*(w) - P_d^*(w) \le k \Leftrightarrow k \ge -\frac{1}{2}$. This condition always holds because $k \ge 0$.

ii) To have $u_d(d^*) = u_r(d^*) \ge 0$,

$v(1+k) - P_d - k(1+P_r) \ge 0 \Leftrightarrow w^* \le v - \frac{(2k+1)(k+2)}{3(1+k)}$. This condition provides an upper bound on the possible wholesale price values that the manufacturer can set at stage 1.

iii) To have $P_r^*(w) \ge w$,

$\frac{1}{3}\left(1+2k+3w\right) \ge w \Leftrightarrow \left(1+2k\right) \ge 0$, which always holds.

At stage 1, we solve for the manufacturer's optimal wholesale price w^*. Note that the manufacturer's *w* decision needs to satisfy $w \ge 0$, and also the upper bound from condition (ii). Hence, his problem becomes

$$\max_{w \ge 0 \text{ and } w \le v - \frac{(2k+1)(k+2)}{3(1+k)}} \Pi_m = q_d P_d(w) + q_r w.$$

We substitute the values of P_r, P_d, q_r, q_d in equilibrium into the manufacturer's profit function to obtain

$$\max_{w \ge 0 \text{ and } w \le v - \frac{(2k+1)(k+2)}{3(1+k)}} \Pi_m(w) = \frac{N}{9(1+k)}\left(4+k^2+9w+k(4+9w)\right).$$

The manufacturer's profit Π_m is linearly increasing in w. Hence, the manufacturer would choose the highest possible w value. We study two subcases based on the range of w.

Case 1a-i

If $v-\frac{(2k+1)(k+2)}{3(1+k)}>0$, then $w^*=v-\frac{(2k+1)(k+2)}{3(1+k)}$, since the manufacturer sets the highest possible wholesale price value to maximize his profit.

The sales quantities in equilibrium are $q_d^*=N\frac{2+k}{3(1+k)}$ and $q_r^*=N\frac{1+2k}{3(1+k)}$.

Next, we substitute w^* into the price and the profit equations to obtain the values in equilibrium as

The prices are $P_d^*=-\frac{2k+k^2-3v(1+k)}{3(1+k)}$ and $P_r^*=\frac{-1+3v+k(-2+3v)}{3(1+k)}$.

The profits are $\Pi_m^*=N\frac{(-2-5k^2+k(9v-11)+9v)}{9(1+k)}$ and $\Pi_r^*=N\frac{(1+2k)^2}{9(1+k)}$.

Case 1a-ii

If $v-\frac{(2k+1)(k+2)}{3(1+k)}\le 0$, then the manufacturer sets the wholesale price as $w^*=0$. He considers that instead of selling only to a part of the market, it is better to set w as low as possible and make the retailer sell through the retail channel as well. Consequently, all the market is covered.

The sales quantities in equilibrium are $q_d^*=N\frac{2+k}{3(1+k)}$ and $q_r^*=N\frac{1+2k}{3(1+k)}$.

Next, we obtain the price and profit values in equilibrium as

The prices are $P_d^*=\frac{1}{3}(2+k)$ and $P_r^*=\frac{1}{3}(1+2k)$.

The profits are $\Pi_m^*=\frac{N}{9}\left(\frac{(2+k)^2}{1+k}\right)$ and $\Pi_r^*=\frac{N}{9}\left(\frac{(1+2k)^2}{1+k}\right)$.

3.1.2 Case-1b Dual Channel - Partial Coverage

In this case, both channels are operative, however some consumers are lost. The direct channel and the retail channel have local monopoly power and the market is not totally covered, as shown in Figure 3-4. That is, the consumer located at d^* who would be indifferent between the two channels derives a negative utility from buying the product and hence does not buy. We define d_1 as the location of the consumer who derives zero utility from the direct channel in this setting; $u_d(d_1) = v - P_d - kd_1 = 0 \rightarrow d_1 = \frac{v - P_d}{k}$. Similarly, the location of the consumer who derives zero utility from the retail channel in this setting is defined as d_2; $u_r(d_2) = v - P_r - (1 - d_2) = 0 \rightarrow d_2 = 1 - v + P_r$.

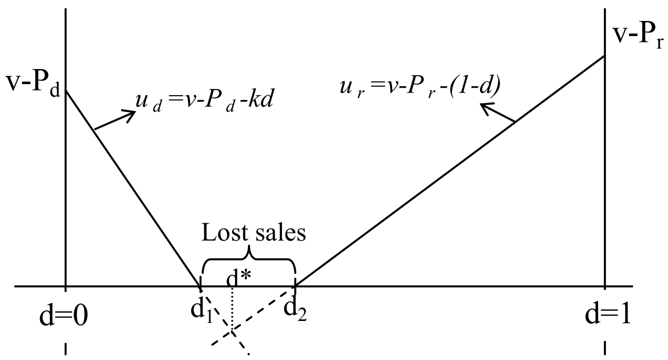

Figure 3-4: Consumer Utility Functions in Dual Channel-Partial Coverage Case

For this case, the following conditions should be satisfied:

i) $d^* \in [0,1]$, which requires $P_r - P_d \geq -1$ and $P_r - P_d \leq k$,

ii) $u_d(d^*) = u_r(d^*) \leq 0$, which requires $v(1+k) - P_d - k(1+P_r) \leq 0$,

iii) $d_1 \geq 0$, which requires $P_d \leq v$,

iv) $d_2 \leq 1$, which requires $P_r \leq v$,

v) $\Pi_r(P_d, P_r) \geq 0$, which requires $(P_r - w)q_r \geq 0 \Leftrightarrow P_r \geq w$.

As seen from Figure 3-4, the demands in the direct and retail channel are $q_d(P_d, P_r) = Nd_1 = N\left(\frac{v - P_d}{k}\right)$ and $q_r(P_d, P_r) = N(1 - d_2) = N(v - P_r)$. Note that demand in each channel is independent of the price in the other channel because each firm acts as a local monopoly as long as the case conditions are satisfied. Hence, we do need to search for a Nash equilibrium. Given *w*, we solve for the problems of the manufacturer and the retailer independently.

The manufacturer's problem is to maximize his profit through the sales in the direct online channel and the retail channel. His objective is

$$\max_{P_d} \Pi_m = q_d(P_d, P_r)P_d + q_r(P_d, P_r)w.$$

At stage 2, we solve for the selling prices independently. We substitute the quantity functions into the manufacturer's objective function and obtain $\max_{P_d} \Pi_m = N\left(\frac{vP_d - P_d^2}{k} + \left(v - P_r\right)w\right)$. The first-order condition is

$$\frac{\partial \Pi_m}{\partial P_d} = \frac{N}{k}\left(v - 2P_d^*\right) = 0.$$

The second-order condition is satisfied and the manufacturer's optimal direct online channel price is calculated as $P_d^* = \frac{v}{2}$. Note that P_d^* does not depend on w or on P_r, because as mentioned, each firm acts as a local monopoly.

Next, we solve for the retailer's problem

$$\max_{P_r} \Pi_r = q_r(P_d, P_r)\left(P_r - w\right).$$

We substitute the quantity functions into the retailer's objective function and obtain $\max_{P_r} \Pi_r = \left(-P_r^2 + \left(v + w\right)P_r - vw\right)$. The first-order condition is

$$\frac{\partial \Pi_r}{\partial P_r} = N\left(v - 2P_r + w\right) = 0.$$

The second-order condition is satisfied and the retailer's optimal sales price is calculated as $P_r^*(w) = \frac{v + w}{2}$.

Given P_d and P_r, the sales quantities are as follows:

$$q_d^* = N\left(\frac{v}{2k}\right), \qquad q_r^*(w) = N\left(\frac{v - w}{2}\right).$$

Next, we rewrite the case conditions using the P_d and P_r expressions,

i) To have $d^* \in [0,1]$,

$P_r^* - P_d^* \geq -1 \Leftrightarrow w^* \geq -2$; this is always true since $w^* \geq 0$. On the other hand, the other inequality provides a constraint for w^*; $P_r^* - P_d^* \leq k \Leftrightarrow w^* \leq 2k,$

ii) To have $u_d(d^*) = u_r(d^*) \le 0$, $v(1+k) - P_d^* - k(1+P_r^*) \le 0 \Leftrightarrow w^* \ge \left(\frac{v}{k} + v - 2\right)$, hence we have a lower bound on w^*.

iii) To have $d_1 \ge 0$, $P_d^* \le v \Leftrightarrow \frac{v}{2} \le v.$ This condition always holds.

iv) To have $d_2 \le 1$, $P_r^* \le v \Leftrightarrow w^* \le v$,

v) To have $P_r^*(w) \ge w$, $\frac{v+w}{2} \ge w \Leftrightarrow w^* \le v.$

We determine the following constrains on "*w*" by considering all of the related conditions above

$$\max\left(0, \frac{v}{k} + v - 2\right) \le w^* \le \min\left(2k, v\right).$$

At stage 1, we find the manufacturer's wholesale price, w^*. The manufacturer problem is

$$\max_{\max(0,\frac{v}{k}+v-2)\le w\le\min(2k,v)} \Pi_m = q_d P_d + q_r w.$$

We substitute the values of P_r, P_d, q_r, q_d in equilibrium into the manufacturer's profit function to obtain

$$\max_{\max(0,\frac{v}{k}+v-2)\le w\le\min(2k,v)} \Pi_m(w) = \frac{N}{4}\left(\frac{v^2}{k} + 2w(v-w)\right).$$

We determine that one of the roots of the objective function is negative, whereas the other is positive. In addition, we have $w \le v$ as a case constraint. Hence, the constraints on *w* can be simplified to the following:

$$\left(\frac{v}{k} + v - 2\right) \le w^* \quad \textit{and} \quad w^* \le 2k.$$

The manufacturer aims to maximize his profit, so we check for the first and the second order conditions

$$\frac{\partial \Pi_m}{\partial w} = N\left(\frac{v}{2} - w\right) = 0, \qquad \frac{\partial^2 \Pi_m}{\partial P_d^2} = -N < 0,$$

$$w^* = \frac{v}{2}.$$

This is what the manufacturer would set as the wholesale price in the absence of the constraints. Next, we study how the constraints affect the manufacturer's decision. We have $v \ge 0$, and $k \ge 0$, but there is not a particular relation between these two parameters. Hence, considering the range of w and the value that maximizes the manufacturer's profit, we consider three subcases. Let $\theta \equiv \left(\frac{v}{k} + v - 2 \right)$ to simplify the expressions.

Case 1b-i

In this subcase, we assume that $\theta > 2k$, then there is no solution.

Case 1b-ii

If $\theta = 2k$ and $2k \leq v$, then $w^* = \theta = 2k$. Hence, this case is only possible when $v = 2k$.

We substitute w^* into the price and the profit equations. The prices in equilibrium are $P_d^* = \frac{v}{2} = k$ and $P_r^* = \frac{v+w}{2} \Leftrightarrow P_r^* = \frac{v+2k}{2} = 2k$.

We substitute the values of prices into $d_1 = \frac{v - P_d}{k}$ and $d_2 = 1 - v + P_r$ to calculate the resulting threshold distance values as $d_1^* = \frac{v}{2k} = 1$ and $d_2^* = 1 - \frac{v}{2} + k = 1$.

Given d_1^* and d_2^*, we find that all the market is covered by the manufacturer, as shown in Figure 3-5. Hence, this subcase reverts to *Case 2a* in which there is only the direct channel and it provides full coverage (we study this case in the following section). The sales quantities in equilibrium are; $q_d^* = N\left(\frac{v}{2k}\right) = N$ and $q_r^* = N\left(\frac{v-w}{2}\right) \Leftrightarrow q_r^* = N\left(\frac{v-2k}{2}\right) = 0$.

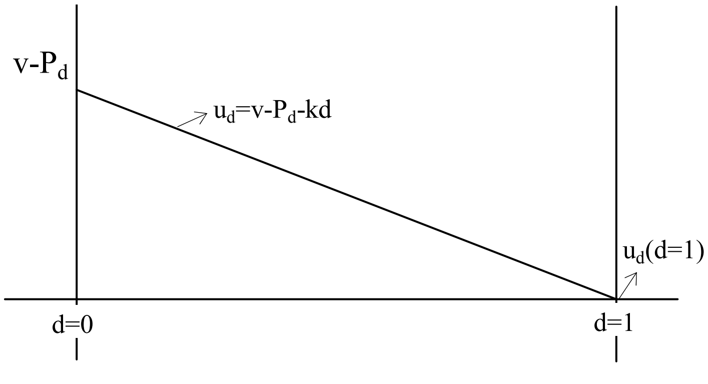

Figure 3-5: Consumer Utility Functions in Dual Channel-Partial Coverage Case 1b-*ii*

The profits in equilibrium are

$$\Pi_m^* = \frac{N}{4}\left(\frac{v^2}{k} + 2w(v-w)\right) \Leftrightarrow \Pi_m^* = \frac{N}{4}\left(\frac{v^2}{k} + 2kv - 4k^2\right) = Nk \text{ and } \Pi_r^* = 0.$$

Case 1b-iii

If $\theta < 2k$, then we study three subcases based on the range of *w*,

Case 1b-iii-a

If $\frac{v}{2} < \theta < 2k$, then $w^* = \theta = \left(\frac{v}{k} + v - 2\right)$.

We substitute w^* into the price and the profit equations to obtain the values in equilibrium.

The prices in equilibrium are $P_d^* = \frac{v}{2}$ and $P_r^* = \frac{v+w}{2} \Leftrightarrow P_r^* = v + \frac{v}{2k} - 1$.

The threshold distance values are $d_1^* = \frac{v}{2k}$ and $d_2^* = \frac{v}{2k}$.

The quantities in equilibrium are $q_d^* = N\left(\frac{v}{2k}\right)$ and $q_r^* = N\left(1 - \frac{v}{2k}\right)$.

In this subcase, the market is totally covered because $d_1^* = d_2^*$ (see Figure 3-6). Hence, for this subcase, *case 1b* reverts to *case 1a* because we achieve full coverage by the two channels.

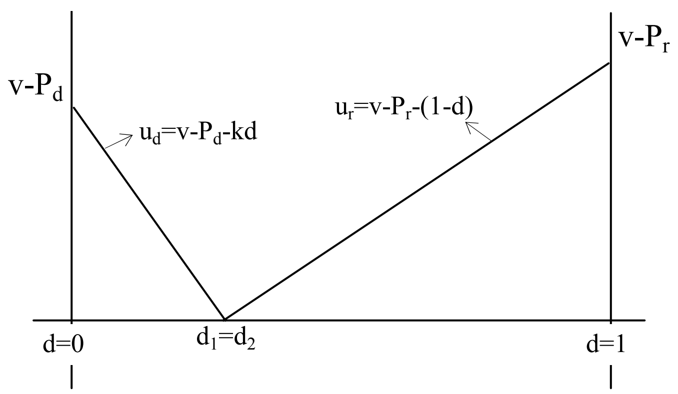

Figure 3-6: Consumer Utility Functions in Dual Channel-Partial Coverage Case 1b-*iii-a*

The profits in equilibrium are; $\Pi_m^* = N\left(-\frac{v^2}{2k^2}+\frac{2v}{k}+v-2-\frac{v^2}{4k}\right)$ and $\Pi_r^* = N\left(1-\frac{v}{2k}\right)^2$.

Case 1b-iii-b

If $\theta \le \frac{v}{2} < 2k$, then $w^* = \frac{v}{2}$. As we calculated before, the manufacturer's profit function is concave and has achieves the maximum for $w^* = \frac{v}{2}$.

We substitute w^* into the price and the profit equations to get the values in equilibrium.

The prices in equilibrium are $P_d^* = \frac{v}{2}$ and $P_r^* = \frac{v+w}{2} \Leftrightarrow P_r^* = \frac{3v}{4}$.

The resulting threshold distance values are $d_1^* = \frac{v}{2k}$ and $d_2^* = 1-\frac{v}{4}$.

The sales quantities in equilibrium are $q_d^* = N\left(\frac{v}{2k}\right)$ and $q_r^* = N\left(\frac{v-w}{2}\right)$ $\Leftrightarrow q_r^* = N\frac{v}{4}$.

In this case, there exits lost consumers (see Figure 3-7).

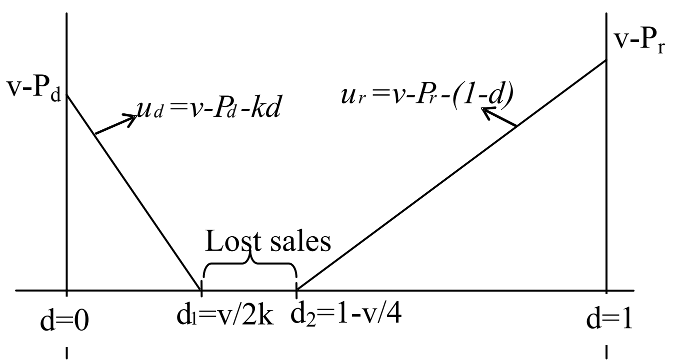

Figure 3-7: Consumer Utility Functions in Dual Channel-Partial Coverage Case 1b-*iii-b*

The profits in equilibrium are $\Pi_m^* = \frac{N}{4}\left(\frac{v^2}{k} + 2w(v-w)\right) \Leftrightarrow \Pi_m^* = \frac{N}{4}\left(\frac{v^2}{k} + \frac{v^2}{2}\right)$ and $\Pi_r^* = \frac{N}{4}(v-w)^2 \Leftrightarrow \frac{Nv^2}{16}$.

Case 1b-iii-c

If $\theta < 2k \le \frac{v}{2}$, then the case conditions are not satisfied because $\theta \equiv \left(\frac{v}{k} + v - 2\right)$ and $k \ge 0$ cannot be satisfied together. For this subcase, there is no feasible region and consequently, there exits no possible solution.

3.2 Case-2 Direct Channel Only

In this case, the manufacturer sells only through the direct channel. Hence, there is no need to consider any action related to the retailer (such as the contract or P_r). We consider the full and partial market coverage subcases.

3.2.1 Case-2a Direct Channel Only - Full Coverage

In this case, the direct channel serves all the consumers in the market as illustrated in Figure 3-8.

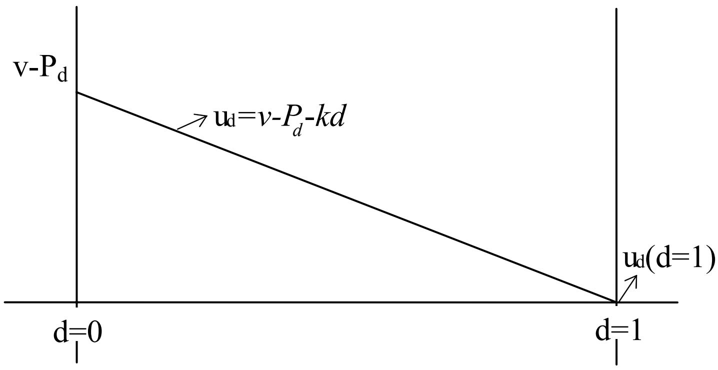

Figure 3-8: Consumer Utility Functions in Direct Channel Only -Full Coverage Case

Next, we define the conditions on P_d, v and k such that this case is observed. The only condition is that the utility of the consumer located at $d = 1$ (the one who has the least desire to buy from the direct online channel) satisfies $u_d(d=1)\geq 0$. This requires $P_d \leq v-k$.

Assuming that the condition is satisfied, the direct online channel has demand $q_d(P_r,P_d)=N$ if $P_d \leq v-k$ (i.e., if all consumers are willing to buy from the direct online channel) (see Figure 3-8).

The profit function of the manufacturer is $\max_{P_d}\Pi_m = q_d(P_d,P_r)P_d$. Then his optimal selling price and optimal profit are as follows:

$$P_d^* = v-k, \qquad \Pi_m^* = N(v-k).$$

3.2.2 Case-2b Direct Channel Only - Partial Coverage

In this case, the manufacturer chooses to sell only to a part of the market. The market is "not totally covered," in that some consumers do not buy (see Figure 3-9). The manufacturer might choose to leave out consumers with $d > d_1^*$, because selling to these consumers require the manufacturer to reduce the selling price. Hence, in some cases, it might be better to serve only to part of the market, by keeping a high selling price.

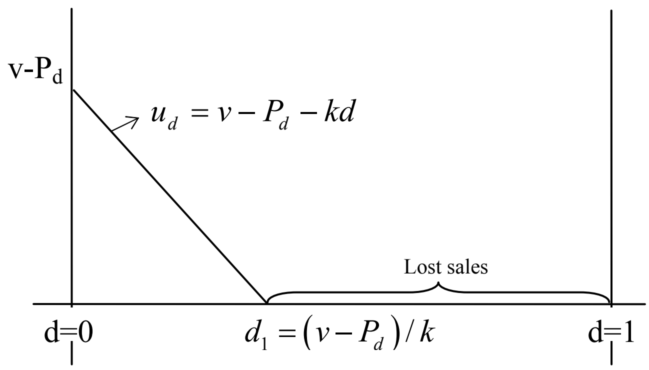

Figure 3-9: Consumer Utility Functions in Direct Channel Only -Partial Coverage Case

The only condition to observe this case is: $0 \leq d_1 = \dfrac{v-P_d}{k} \leq 1$ requires $P_d \leq v$ and $P_d \geq v-k$.

If the condition is satisfied, then the demand is, $q_d^*(P_d,P_r) = N\left(\dfrac{v-P_d}{k}\right)$. As a result, the market is "not covered".

The objective function of the manufacturer is $\max_{P_d} \Pi_m = q_d(P_d, P_r)P_d$. Substituting the demand function, this becomes $\max_{P_d} \Pi_m = \frac{N}{k}\left(-P_d^2 + vP_d\right)$. We check for the first-order and the second-order conditions,

$$\frac{\partial \Pi_m}{\partial P_d} = \frac{N}{k}(v - 2P_d^*) = 0, \qquad \frac{\partial^2 \Pi_m}{\partial P_d^2} = -\frac{2N}{k} < 0,$$

$$P_d^* = \frac{v}{2}, \text{ if } P_d^* \geq v - k \Leftrightarrow 2k \geq v \text{ is satisfied.}$$

By substituting the optimal direct online channel price value into the demand and profit functions , we determine the optimal sales quantity and profit of the manufacturer as follows:

$$q_d^* = N\frac{v}{2k}, \qquad \Pi_m^* = N\left(\frac{v^2}{4k}\right).$$

Intuitively, if the online channel relative preference disadvantage parameter, k increases, both the sales quantity and the manufacturer's profit decrease. On the other hand, if the consumer valuation v increases, the manufacturer's sales and profit would increase.

3.3 Case-3 Retail Channel Only

In *Case 3*, the direct channel does not exist and there is no need to calculate P_d. The manufacturer sells his product only through the retail channel. At stage 1, the manufacturer offers the wholesale price to the retailer. At stage 2, if the retailer accepts the contract, she sets her selling price, P_r. At stage 3, consumer demand is realized. Again, we study two subcases depend on the market coverage.

3.3.1 Case-3a Retail Channel Only - Full Coverage

In this case, all consumers buy from the retail channel as illustrated in Figure 3-10.

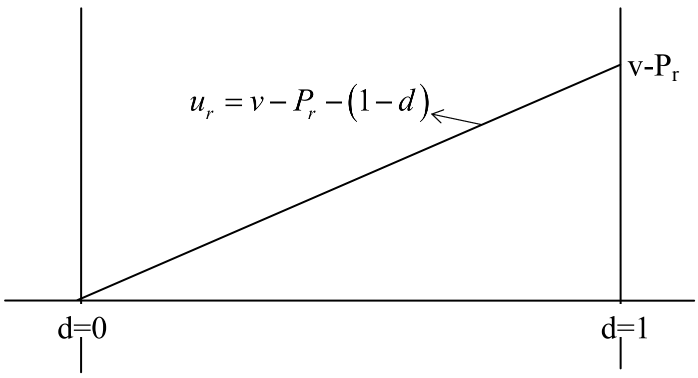

Figure 3-10: Consumer Utility Functions in Retail Channel Only - Full Coverage Case

For this case to be observed, the following conditions should be satisfied:

i) $u_r(d=0) \geq 0$, which requires $P_r \leq v-1$,

ii) $\Pi_r(P_d, P_r) \geq 0$, which requires $(P_r - w)q_r \geq 0 \Leftrightarrow P_r \geq w$.

If the conditions are satisfied, the retail channel demand is $q_r^*(P_d, P_r) = N$ Hence, the objective function of the retailer is, $\max_{P_r} \Pi_r = q_r(P_d, P_r)(P_r - w) = N(P_r - w)$.

This function is linearly increasing in P_r. Hence, the retailer sets the maximum sales price value that the constraints permit, which is $P_r^* = v-1$.

The manufacturer's objective is, $\max_{0 \leq w \leq v-1} \Pi_m = q_r(P_d, P_r)w = Nw$. This function is linearly increasing in *w*. Since $w^* \leq P_r^* = v-1$, the manufacturer sets $w^* = v-1$

We substitute the values in equilibrium into the profit functions. We find that the retailer cannot make any profit, $\Pi_r^* = 0$ and the manufacturer's profit is $\Pi_m^* = N(v-1)$.

3.3.2 Case-3b Retail Channel Only - Partial Coverage

In this case, the retailer chooses not to serve all consumers in the market, as illustrated in Figure 3-11. Some consumers are lost.

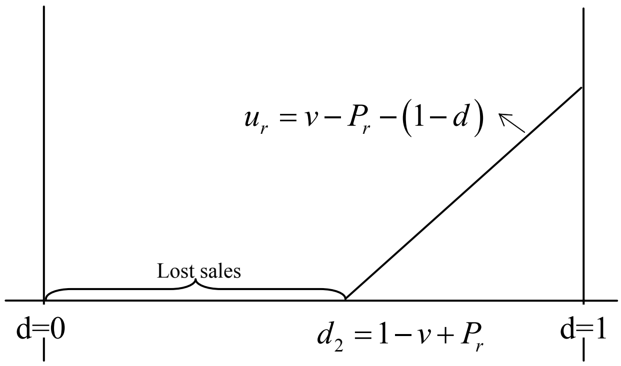

Figure 3-11: Consumer Utility Functions in Retail Channel Only – Partial Coverage Case

Let d_2 denote the distance of the consumer who is indifferent between buying from the retail channel or not buying. We have $d_2 = 1 - v + P_r$. The following conditions on P_r, v, and k need to be satisfied for this case to be observed:

i) $d_2 \in [0,1]$, which requires $(v-1) \le P_r \le v$,

ii) $\Pi_r(P_d, P_r) \ge 0$, which requires $(P_r - w)q_r \ge 0 \Leftrightarrow P_r \ge w$.

If the conditions are satisfied, the demand is $q_r(P_r) = N(v - P_r)$.

The retailer's objective is $\max\limits_{v-1 \le P_r \le v} \Pi_r = q_r(P_r - w)$. Substituting the demand function, we obtain $\max\limits_{P_r} \Pi_r = N\left(-P_r^2 + (v+w)P_r - vw\right)$. This function is concave in P_r, and the first order condition yields $P_r^* = \dfrac{v+w}{2}$. Given P_r, the sales quantity is found as $q_r^*(w) = N\left(\dfrac{v-w}{2}\right)$.

Next, we rewrite the case conditions using the P_r expression:

i) To have $(v-1) \le P_r^* \le v$, $(v-1) \le \dfrac{v+w}{2} \le v \Leftrightarrow (v-2) \le w \le v$,

ii) To have $P_r^*(w) \ge w$, $\dfrac{v+w}{2} \ge w \Leftrightarrow w \le v.$

We determine the following constraints on "w" by considering all related conditions

$$\max\left(0, v-2\right) \le w^* \le v.$$

The manufacturer's objective is $\max\limits_{\max(0,v-2)\le w\le v} q_r w$. Substituting the value of q_r, we obtain $\max\limits_{\max(0,v-2)\le w\le v} \Pi_m = N(v-P_r)w \Leftrightarrow \max\limits_{\max(0,v-2)\le w\le v} \Pi_m = N\left(\frac{v-w}{2}\right)w$. From the first-order ans second-order conditions,

$$\frac{\partial \Pi_m}{\partial w} = \frac{N}{2}\left(v-2w\right) = 0, \qquad \frac{\partial^2 \Pi_m}{\partial w^2} = -N < 0,$$

$$w^* = \frac{v}{2}.$$

This is the wholesale price that the manufacturer would set in the absence of the constraints. The manufacturer's objective function has roots at $w = 0$ and $w = v$. Considering this finding and the constraints, w^* must be in the range $\left[0, v\right]$. Thus, we study two subcases:

Case 3b-i

If $\frac{v}{2} \ge (v-2) \Leftrightarrow v \le 4$, then $w^* = \frac{v}{2}$. We substitute the value of w^* into the sales quantity, price and profit functions to determine the equilibrium values:

The retail channel's equilibrium price is $P_r^* = \frac{v+w}{2} \Leftrightarrow P_r^* = \frac{3v}{4}$.

The retail channel's equilibrium sales quantity is $q_r^* = N\left(\frac{v-w}{2}\right) \Leftrightarrow q_r^* = N\frac{v}{4}$.

As a result, the equilibrium profits are

$$\Pi_r^* = q_r^*(P_r^* - w^*) \Leftrightarrow \Pi_r^* = N\frac{v^2}{16},$$
$$\Pi_m^* = q_r^* w^* \Leftrightarrow \Pi_m^* = N\frac{v^2}{8}.$$

Case 3b-ii

If $\frac{v}{2} < (v-2) \Leftrightarrow v > 4$, then $w^* = v-2$. Substituting w^* into relevant equations, we determine the following:

The retail channel's equilbirum price is $P_r^* = \dfrac{v+w}{2} \Leftrightarrow P_r^* = v-1.$

The retail channel's equilibrium quantity sold is $q_r^* = N\left(\dfrac{v-w}{2}\right) \Leftrightarrow q_r^* = N.$

The profits in equilibrium are $\begin{aligned}\Pi_r^* &= q_r^*(P_r^* - w^*) \Leftrightarrow \Pi_r^* = N, \\ \Pi_m^* &= q_r^* w^* \Leftrightarrow \Pi_m^* = N(v-2).\end{aligned}$

When the manufacturer sets $w^* = v-2$, the market is totally covered. For these values, *case 3b* reverts to *case 3a* Hence, the only relevant solution for *Case 3b* is the one we identified in *Case 3b-i*.

3.4 Numerical Illustration of the Manufacturer's Optimal Channel Strategy

Our model has only two parameters: the value *v* the consumer derives from the product and *k*, the direct channel relative preference disadvantage parameter. In this section we provide graphical illustrations of how the equilibrium values of the wholesale price w, direct channel price P_d, retail channel price P_r, direct channel sales quantity q_d, retail channel sales quantity q_r, the manufacturer's profit Π_m and the retailer's profit Π_r change with respect to these two parameters.

The outcome for a given parameter set belongs to one of the six types of possible "cases" as summarized in Table 3-1. Each of these cases corresponds to a "channel strategy" for the manufacturer because the manufacturer determines which case to use. We use the notation in the Table 3-2 in references to these six strategies (or, cases).

Table 3-2: Notation for Channel Strategies

Channel Strateies	**Dual Channel**	**Direct Channel Only**	**Retail Channel Only**
Full coverage	DuF	DiF	ReF
Partial coverage	DuP	DiP	ReP

Recall that a case might not be "feasible" for a given (v,k) couple if the parameters do not satisfy the case's necessary conditions (as discussed in Sections 3.1, 3.2 and 3.3). To determine the equilibrium outcome for a given (v,k) couple, we compare the manufacturer's profit in each "feasible" case. We choose the case in which the manufacturer's profit is the largest. If more than one case provide the largest profit for the manufacturer, we choose the case among these in which the retailer's profit is the highest. If both profits are the same for a number of cases, we choose the optimal case considering the following priority order; dual channel full coverage, dual channel partial coverage, direct channel full coverage, direct channel partial coverage, retail channel full coverage and retail channel partial coverage. We developed and used a Matlab code to determine the optimal equilibrium outcome for the manufacturer.

Table 3-3 provides the strategy choices for a sample set of (v,k) pairs. The details are provided in Appendix B. Figures 3-12 to 3-20 provide a graphical illustration of the equilibrium values. Note that the v values in Table 3-3 are listed in descending order so as to provide the same angle of view with the subsequent figures.

Table 3-3: Sample Results of the Optimal Strategies

v \ k	0	0.25	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5	2.75	3
3	DiF	DiF	DiF	DiF	DuF	ReF	ReF	ReF	ReF	ReF	ReF	ReF	ReF
2.75	DiF	DiF	DiF	DiF	DuF	ReF	ReF	ReF	ReF	ReF	ReF	ReF	ReF
2.5	DiF	DiF	DiF	DiF	DuF	ReF	ReF	ReF	ReF	ReF	ReF	ReF	ReF
2.25	DiF	DiF	DiF	DiF	DuF	ReF	ReF	ReF	ReF	ReF	ReF	ReF	ReF
2	DiF	DiF	DiF	DiF	DuF	ReF	ReF	ReF	DuP	ReF	ReF	ReF	ReF
1.75	DiF	DiF	DiF	DiF	DiP	ReF	ReF	DuP	DuP	ReF	ReF	ReF	ReF
1.5	DiF	DiF	DiF	DiP	DiP	DuP	DuP	DuP	DuF	DuF	DuF	DuF	DuF
1.25	DiF	DiF	DiF	DiP	DuP	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF
1	DiF	DiF	DiP	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF
0.75	DiF	DiF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF
0.5	DiF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF
0.25	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF	DuF

We observe that the full-coverage strategies DiF, DuF and ReF dominate the table. The partial coverage strategies DiP and DuP are observed in the boundaries between the three dominant full-coverage strategies. The sixth strategy ReP is not observed.

When the relative disadvantage of the direct channel k is low and the consumer valuation v is high, the manufacturer prefers to sell only through the direct channel (DiF strategy). He manages to satisfy the whole market demand (Figure 3-15). These are the parameter combinations for which the manufacturer achieves the highest profit (Figure 3-19). Within this strategy, the manufacturer reduces the direct channel sales price if consumer valuation decreases or if the disadvantage parameter increases (Figure 3-13).

Starting from the high-v, low-k region, when the k value increases, the direct channel is put into a disadvantage. For k=*1*, the manufacturer switches to the dual channel full coverage strategy (DuF strategy). He begins to use the retail channel to serve the consumers that have high d value.

If the k value increases further (while v is high), the manufacturer abandons his direct channel and begins to sell only through the retail channel (ReF strategy). Although the retailer satisfies all consumer demand (Figure 3-16), her profit level is zero (Figure 3-20), because the wholesale price is equal to the sales price (Figure 3-12 and Figure 3-14). Note that the wholesale price, retailer's sale price and the profit values within this strategy are increasing in consumers' valuation v (Figure 3-12, Figure 3-14, Figure 3-19 and Figure 3-20). However, these values are independent of k because the direct channel is inoperative in this strategy.

For low valuation v values, the dual channel full coverage (DuF) strategy is dominant. In this strategy, neither channel can set a very high sales price because consumers would not pay so much (Figure 3-13 and Figure 3-14). Hence, the manufacturer decides to use both channels to better serve the consumers. Low-d consumers are served through the direct channel and high-d consumers are served through the retail channel. Within this strategy, as k increases, both channels increase their sales prices, but the retail channel increases its price more because of the increasing disadvantage of the direct channel (Figure 3-13 and Figure 3-14). Unlike the sales prices, the quantities sold in the channels do not change much with respect to changes in k (Figure 3-15 and Figure 3-16). The manufacturer has to offer a low wholesale price because he needs to keep the retail channel in business (Figure 3-12). Hence, the manufacturer's lowest profits are observed with these parameter combinations whereas the retailer enjoys her highest profits (Figure 3-19 and Figure 3-20).

The partial-coverage strategies are only observed at the boundaries for average values of v and k. By definition, some consumers are lost with these strategies (Figure 3-17 and Figure 3-18). For example, starting from the DiF strategy region, if k increases and v decreases, the manufacturer first switches to the DiP strategy. That is, he continues to sell only through the direct channel, but because consumer valuation decreases and because the relative disadvantage of the direct channel increases, he does not aim to serve high-d consumers. If k increases and v decreases further, the manufacturer switches to the dual channel full coverage strategy (DuF strategy) and uses the retail channel to serve consumers with high d values. Starting from the ReF-strategy region with average relative inconvenience k values (1.25-2.00), as the consumer valuation v decreases, the manufacturer first switches to the DuP strategy. Due to the decreasing consumer valuation, the manufacturer aims to use both channels to reach all consumers efficiently. When v decreases further, the manufacturer has to switch to a full-coverage strategy (DuF).

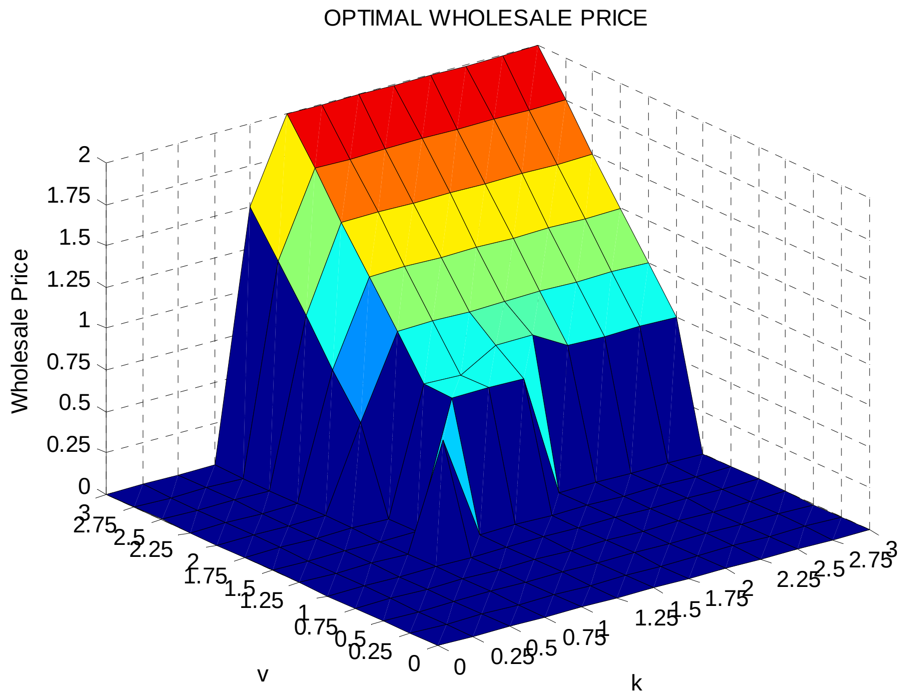

Figure 3-12: w^* Based on the Parameters v and k

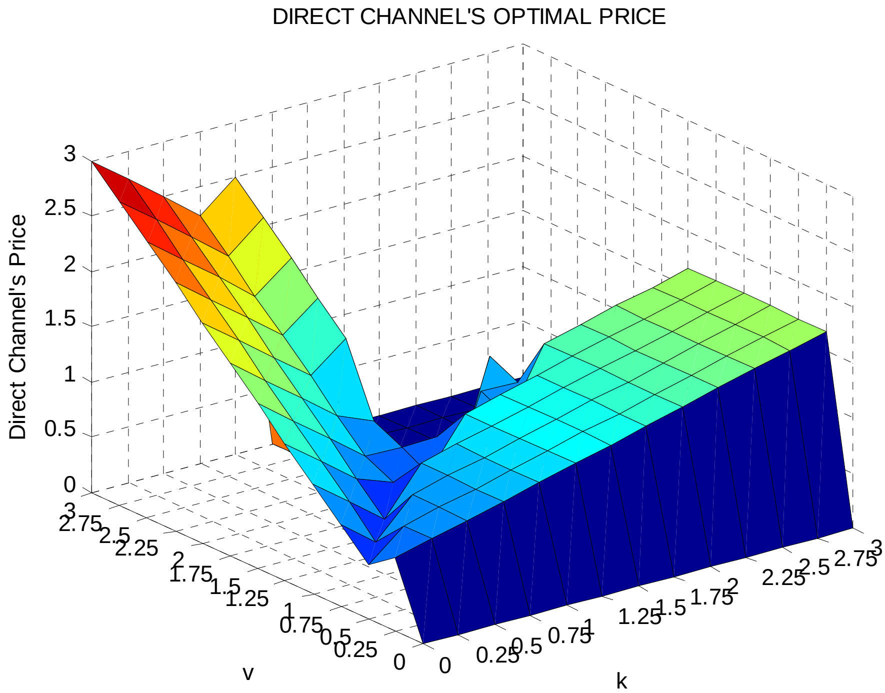

Figure 3-13: P_d^* Based on the Parameters v and k

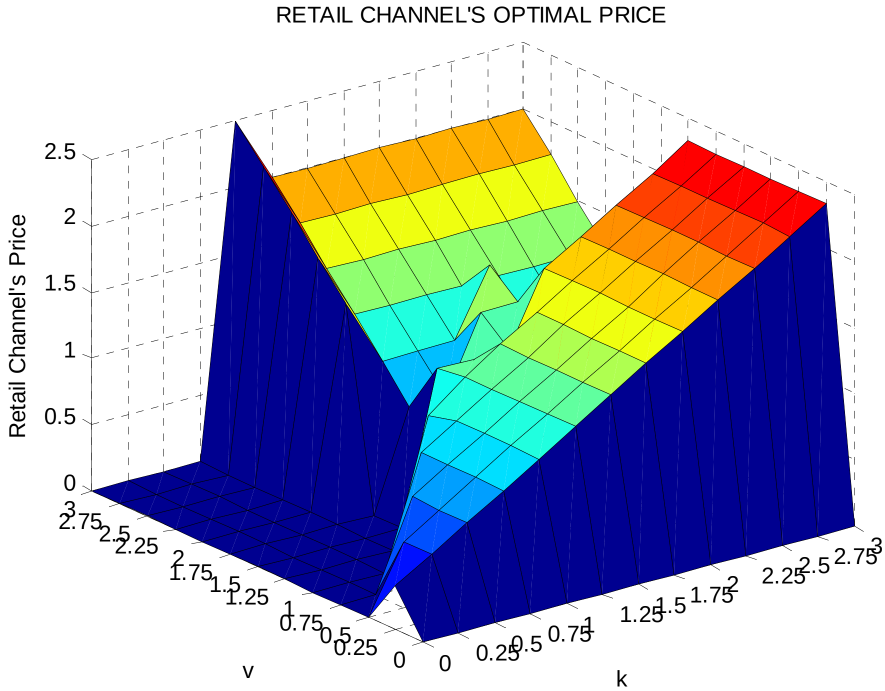

Figure 3-14: P_r^* Based on the Parameters v and k

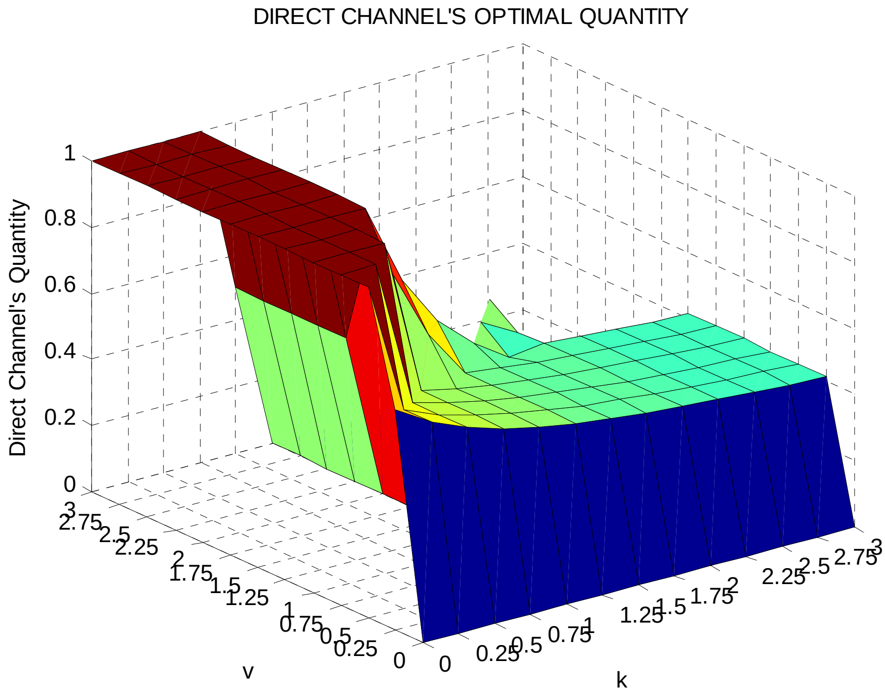

Figure 3-15: q_d^* Based on the Parameters v and k

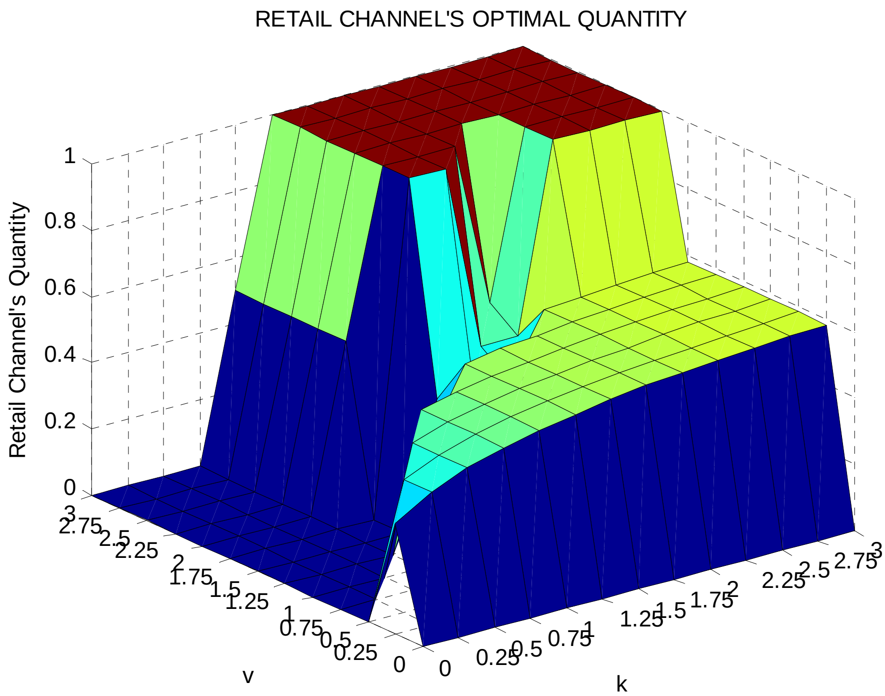

Figure 3-16: q_r^* Based on the Parameters v and k

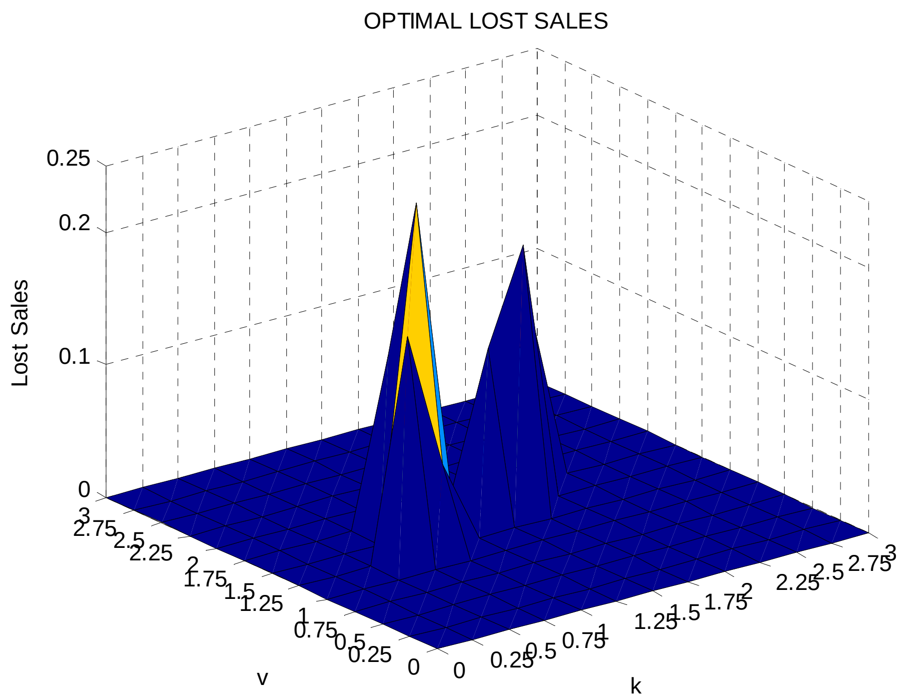

Figure 3-17: q_l^* Based on the Parameters *v* and *k*

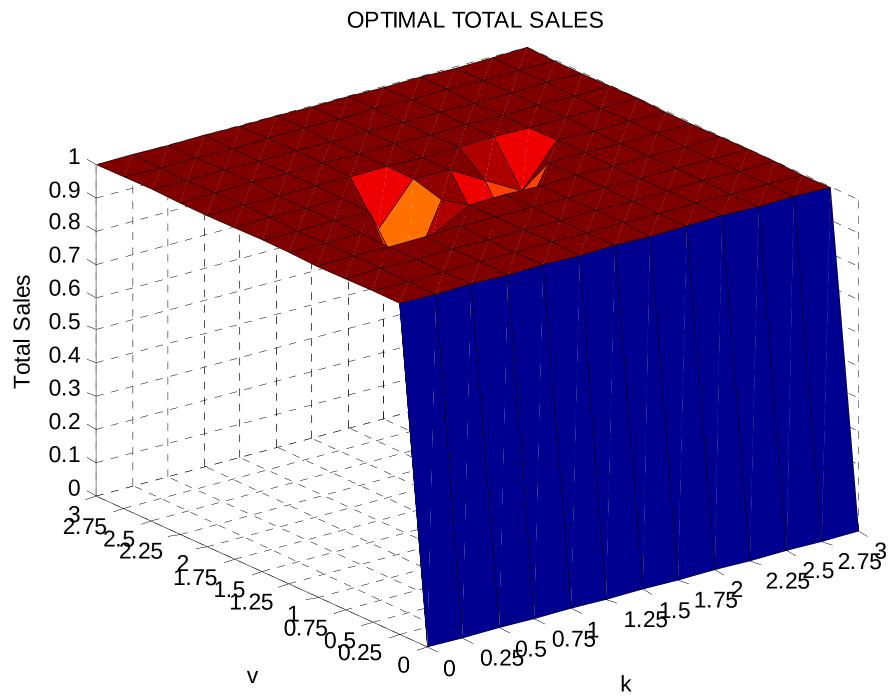

Figure 3-18: q_t^* Based on the Parameters *v* and *k*

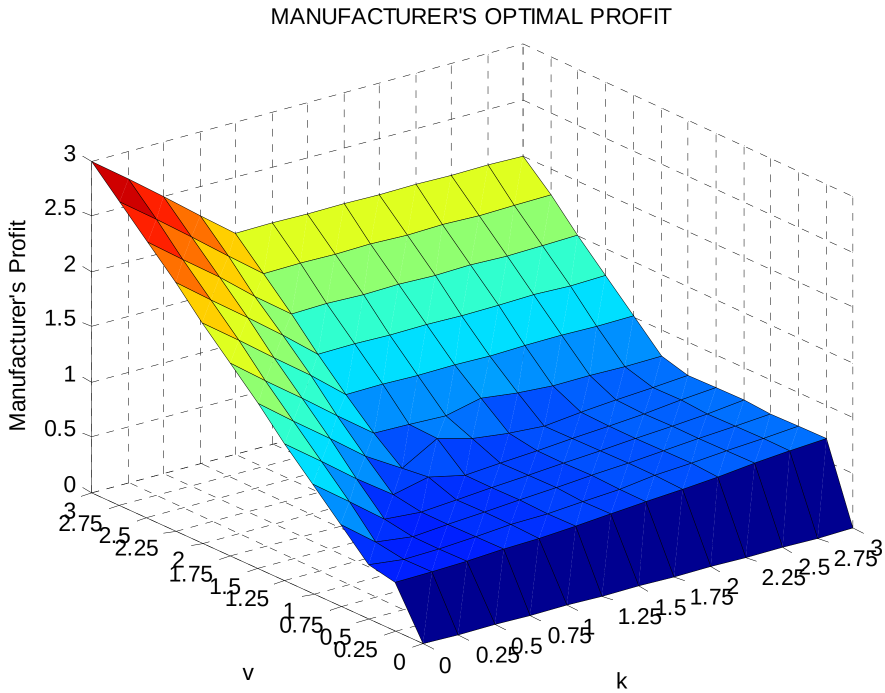

Figure 3-19: Π_m^* Based on the Parameters v and k

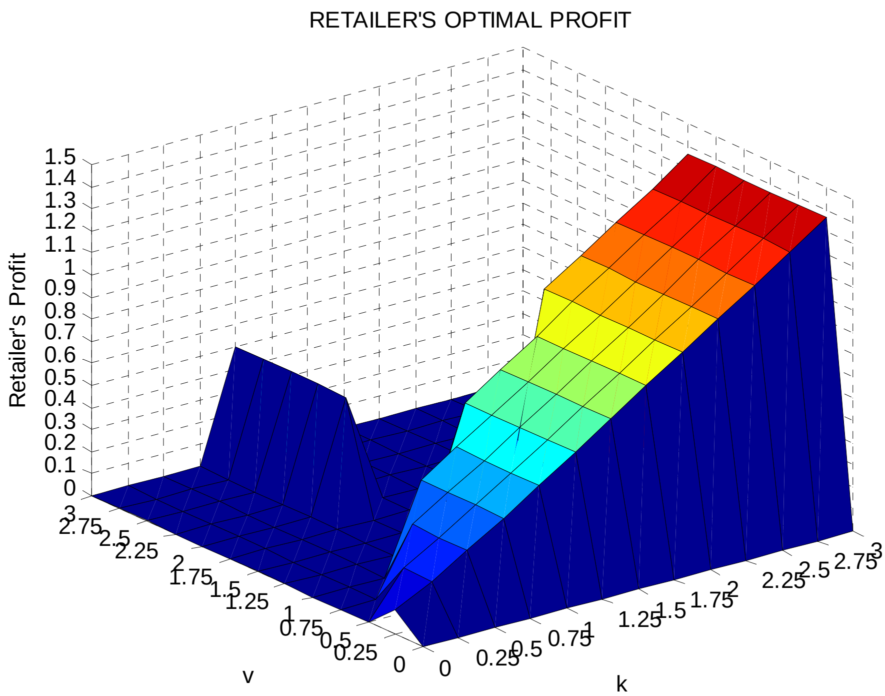

Figure 3-20: Π_r^* Based on the Parameters v and k

CHAPTER 4

4 MODEL-2

We consider a supply chain in which a manufacturer with a traditional channel partner (a retailer) opens a direct channel that is in competition with the retail channel. First, we will consider the problem of a *centralized firm* that owns both the direct channel and the retail channel to obtain a benchmark. Next, we will consider the *decentralized case* where the manufacturer and the retailer are independent decision makers and each aims to maximize his/her own profit. Comparing the two cases, we will determine the effect of decentralized decision making.

Consider a single manufacturer (he) and a single retailer (she). The manufacturer distributes his product through **1.** His wholly-owned channel (the direct channel) **2.** An independent bricks-and-mortar (physical) retail channel. For simplicity, we assume that the manufacturer produces his product without any cost. Channels engage in price competition.

The sequence of events is as follows (and summarized in Figure 4-1):

At stage 1, the manufacturer sets the wholesale price *w* and offers the contract to the retailer. If the retailer's profit is nonnegative $(\Pi_r^* \geq 0)$, she accepts the contract.

At stage 2, the manufacturer and the retailer engage in a simultaneous-move price competition game. The manufacturer sets P_d, the selling price in the direct channel, without observing the retailer's decision for the retail channel. The retailer sets P_r, the selling price in the retail channel, without observing the manufacturer's decision for the direct channel.

At stage 3, consumer demand is realized based on the prices at both channels. The manufacturer directly satisfies the demand in the direct channel q_d. He operates make to order. The retailer observes q_r, the demand in the retail channel, and orders this quantity from the manufacturer to satisfy demand. The retailer procures to order, that is, we are not interested in inventory. Note that the manufacturer can produce to meet all demand, i.e. there is no capacity constraint.

Both the manufacturer and the retailer aim to maximize their own profits.

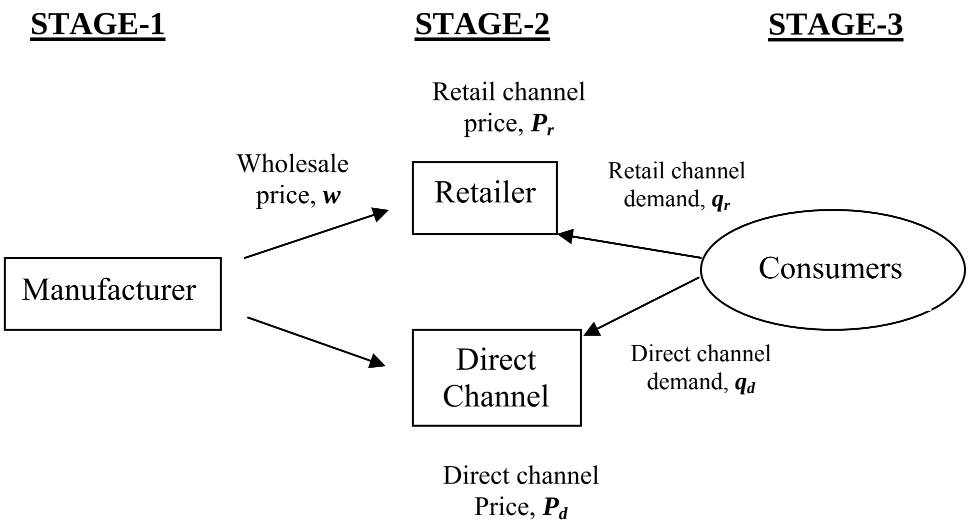

Figure 4-1: Sequence of Events

Next, we explain the model details and outline how we solved the model with backwards induction.

At stage 3, the demand in the direct channel depends on the prices in both channels as follows:

$$q_d(P_d, P_r) = 1 - b_d P_d + P_r. \tag{4-1}$$

Here b_d is the price sensitivity parameter in the direct channel where $b_d > 0$ since the two players act as competitors to each other. Intuitively, the demand in the direct channel is decreasing in the price in that channel and increasing in the price of the retail channel.

The demand in the retail channel is as follows:

$$q_r(P_d, P_r) = 1 - b_r P_r + P_d. \tag{4-2}$$

Similarly, here $b_r > 0$ is the price sensitivity parameter in the retail channel. Consumer demand functions imply that the demand in a channel might be positive even if the selling price in the other channel is set to zero. This is because there might be factors other than prices that affect the consumers' channel choice, such as product availability, lead time etc. that we do not explicitly model.

At stage 2, for a given wholesale price w from stage 1, the manufacturer's objective is

$$\max_{P_d} \Pi_m = q_d(P_d, P_r)P_d + q_r(P_d, P_r)w.$$

Because the unit production cost is zero, the manufacturer's profit margin in the direct channel is equal to the direct channel price, P_d. And his profit margin for a unit sold in the retail channel is equal to the wholesale price *w*.

The retailer also aims to maximize her profit. Hence, the retailer's objective at stage 2 is

$$\max_{P_r} \Pi_r = q_r(P_d, P_r)\left(P_r - w\right).$$

Here the term $(P_r - w)$ is the profit margin in the retail channel.

We solve the three-stage model with backwards induction. First, we determine the sales quantity (i.e. the demand) through the direct and the retail channels at stage 3 given the pricing decisions of the manufacturer and the retailer. Next, we determine the Nash equilibrium of the pricing game at stage 2 by defining the manufacturer's and the retailer's best response functions given a wholesale price *w*. Finally, we solve for the manufacturer's optimal wholesale price *w* at stage 1.

Once we determine the equilibrium w^* as a function of the model parameters b_d and b_r, we determine the outcome by solving forward the three stage game. Given w^*, we determine the Nash equilibrium prices (P_d^*, P_r^*) at stage 2. Then at stage 3, we obtain the equilibrium sales quantities (q_d^*, q_r^*) in the channels. Finally, we determine the manufacturer's and the retailer's equilibrium profits by plugging the values in equilibrium into the profit functions.

The retailer can guess the Nash equilibrium out of the price competition game. When she is offered the wholesale price *w*, she can solve the problem. If $\Pi_r^* \geq 0$, the retailer accepts the contract, otherwise she rejects the contract and the game ends. Note that there is no uncertainty with regard to the parameters b_d, b_r of the problem, and all information is common to both firms (i.e. no information asymmetry). Note that the reservation profit of the retailer is taken to be equal to 0 without loss of generality.

4.1 The Centralized Supply Chain: A Benchmark

To provide a benchmark, we first consider the centralized case in which there is only one decision maker, the centralized firm. The centralized firm owns both the direct and the retail channels and he determines the prices, P_d and P_r. The profit of the centralized firm is the maximum profit that a decentralized supply chain can achieve.

The centralized firm' profit function is;

$$\max_{P_{dc},P_{rc}} \Pi_c = q_{dc}(P_{dc}, P_{rc})P_{dc} + q_{rc}(P_{dc}, P_{rc})P_{rc}.$$

The terms q_{dc} and q_{rc} denote the quantities sold in the direct and retail channels, respectively. They are given as

$$q_{dc}(P_{dc}, P_{rc}) = 1 - b_d P_{dc} + P_{rc}, \qquad (4\text{-}3)$$

$$q_{rc}(P_{dc}, P_{rc}) = 1 - b_r P_r + P_{dc}. \qquad (4\text{-}4)$$

First, to obtain the optimal P_{dc} and P_{rc} pair, we should show that the profit function is jointly concave in P_{dc} and P_{rc}. This requires the following two conditions[2],

(1) $\dfrac{\partial^2 \Pi_c}{\partial P_{dc}^2} < 0$,

(2) $\left(\dfrac{\partial^2 \Pi_c}{\partial P_{dc}^2}\dfrac{\partial^2 \Pi_c}{\partial P_{rc}^2}\right) - \left(\dfrac{\partial^2 \Pi_c}{\partial P_{dc}\partial P_{rc}}\dfrac{\partial^2 \Pi_c}{\partial P_{rc}\partial P_{dc}}\right) > 0$.

Substituting (4-3) and (4-4), the centralized firm's profit function becomes

$$\max_{P_{dc},P_{rc}} \Pi_c = (1 - b_d P_{dc} + P_{rc})P_{dc} + (1 - b_r P_{rc} + P_{dc})P_{rc}.$$

We determine the second order derivatives as follows:

[2] Let $F: U \to R^1$ be a 2 times continuously differentiable or C^2 function whose domain is an open set U in R^1. Suppose that $\frac{\partial F}{\partial x_i}(x^*)=0$ for $i=1,\ldots,n$ and that the n leading principal minors of $D^2F(x^*)$ alternate in sign

$$\left|\frac{\partial^2 F}{\partial x_1^2}\right| < 0, \begin{vmatrix} \frac{\partial^2 F}{\partial x_1^2} & \frac{\partial^2 F}{\partial x_2 \partial x_1} \\ \frac{\partial^2 F}{\partial x_1 \partial x_2} & \frac{\partial^2 F}{\partial x_2^2} \end{vmatrix} > 0, \begin{vmatrix} \frac{\partial^2 F}{\partial x_1^2} & \frac{\partial^2 F}{\partial x_2 \partial x_1} & \frac{\partial^2 F}{\partial x_3 \partial x_1} \\ \frac{\partial^2 F}{\partial x_1 \partial x_2} & \frac{\partial^2 F}{\partial x_2^2} & \frac{\partial^2 F}{\partial x_3 \partial x_2} \\ \frac{\partial^2 F}{\partial x_1 \partial x_3} & \frac{\partial^2 F}{\partial x_2 \partial x_3} & \frac{\partial^2 F}{\partial x_3^2} \end{vmatrix} < 0, \ldots$$

at x^*. Then, x^* is a strict local maximum of F.

$$\frac{\partial^2 \Pi_c}{\partial P_{dc}^2} = -2b_d, \quad \frac{\partial^2 \Pi_c}{\partial P_{rc}^2} = -2b_r, \quad \frac{\partial^2 \Pi_c}{\partial P_{dc}\partial P_{rc}} = 2, \quad \frac{\partial^2 \Pi_c}{\partial P_{rc}\partial P_{dc}} = 2.$$

Hence, the Hessian becomes[3],

$$\begin{bmatrix} -2b_d & 2 \\ 2 & -2b_r \end{bmatrix}.$$

The first order leading principal minor $H(\Pi)(P_{dc}, P_{rc})$ is $-2b_d < 0$, satisfying condition (1). Condition (2) is satisfied for $4(b_d b_r - 1) > 0$. Therefore, Π_c is a jointly concave function in (P_{dc}, P_{rc}) for $b_d * b_r > 1$, which we formulate as a formal assumption next:

ASSUMPTION 1. The parameters b_d and b_r satisfy $b_d * b_r > 1$.

Intuitively, this assumption requires either b_d and b_r to be large enough. Because if both b_d and b_r are small, the centralized firm can make infinite profit by increasing P_{dc} and P_{rc} to infinity. Under Assumption (1) the optimal P_{dc} and P_{rc} are found from the first order conditions as follows:

$$\frac{\partial \Pi_c}{\partial P_{dc}} = 1 - 2b_d P_{dc} + 2P_{rc} = 0, \qquad P_{dc}^*(P_{rc}) = \frac{1 + 2P_{rc}}{2b_d}. \qquad (4\text{-}5)$$

$$\frac{\partial \Pi_c}{\partial P_{rc}} = 1 - 2b_r P_{rc} + 2P_{dc} = 0, \qquad P_{rc}^*(P_{dc}) = \frac{1 + 2P_{dc}}{2b_r}. \qquad (4\text{-}6)$$

By solving these two functions simultaneously, we determine the centralized firm's optimal prices as follows:

$$P_{dc}^*(b_d, b_r) = \frac{1 + b_r}{2(b_r b_d - 1)},$$
$$P_{rc}^*(b_d, b_r) = \frac{1 + b_d}{2(b_r b_d - 1)}.$$

Given the prices, we determine the resulting sales quantities from (4-3) and (4-4) as follows:

[3] The Hessian matrix is the square matrix of the second-order partial derivatives of a function.

$$q_{dc}^* = \frac{1}{2}, \qquad q_{rc}^* = \frac{1}{2}. \tag{4-7}$$

By substituting, (P_{dc}^*, P_{rc}^*), and, (q_{dc}^*, q_{rc}^*) into the profit function of the centralized firm, we obtain the maximum profit in the centralized case as

$$\Pi_c^*(b_d, b_r) = \frac{2 + b_d + b_r}{4(b_d b_r - 1)}.$$

4.2 The Analysis

We solve the game with backwards induction. At stage 3, demand is realized. Next we solve stage 2, the pricing game. At this stage, we determine the best responses of the manufacturer and the retailer and solve them simultaneously to determine the prices in the Nash equilibrium. The manufacturer aims to maximize his profit through the sales in the direct channel and the retail channel. Hence, given his w from stage 1, the manufacturer's objective in stage 2 is

$$\max_{P_d} \Pi_m = q_d(P_d, P_r)P_d + q_r(P_d, P_r)w. \tag{4-8}$$

We substitute (4-1) and (4-2) into (4-8). We observe that the objective function is strictly concave in P_d. Thus, the first-order-optimality condition is necessary and sufficient to find the maximizer of (4-8). The manufacturer's best response direct channel price P_d^* is obtained from the first-order condition as a function of P_r.

$$\frac{\partial \Pi_m}{\partial P_d} = 1 + P_r + w - 2b_d P_d^* = 0, \qquad \frac{\partial^2 \Pi_m}{\partial P_d^2} = -2b_d < 0,$$

$$P_d^*(P_r) = \frac{1 + P_r + w}{2b_d}. \tag{4-9}$$

From (4-9), we observe that when the retailer sets a higher price, the manufacturer responds by setting a higher price in the direct channel.

Next, we solve for the retailer's problem,

$$\max_{P_r} \Pi_r = q_r(P_d, P_r)(P_r - w). \tag{4-10}$$

We substitute (4-2) into (4-10). Using the first-order optimality condition, we compute the retailer's best response retail channel price, P_r^* as a function of P_d,

$$\frac{\partial \Pi_r}{\partial P_r} = 1 + P_d + wb_r - 2b_r P_r^* = 0, \qquad \frac{\partial^2 \Pi_r}{\partial P_r^2} = -2b_r < 0,$$

$$P_r^*(P_d) = \frac{1 + P_d + wb_r}{2b_r}. \tag{4-11}$$

We observe that when the manufacturer sets a higher price in the direct channel, the retailer responds by setting a higher price in the retail channel.

We determine the Nash Equilibrium, (P_d^*, P_r^*) by solving (4-9) and (4-11) simultaneously under Assumption (1). We determine the prices in equilibrium as follows:

$$P_d^*(w) = \frac{1 + b_r(2 + 3w)}{-1 + 4b_d b_r}, \tag{4-12}$$

$$P_r^*(w) = \frac{1 + w + 2b_d(1 + b_r w)}{-1 + 4b_d b_r}. \tag{4-13}$$

Given P_d^* and P_r^* as a function of w, the sales quantities are obtained as

$$q_d^*(w) = \frac{b_d + 2b_d b_r + w - b_d b_r w}{4b_d b_r - 1},$$

$$q_r^*(w) = \frac{b_r\left[1 + 2w + 2b_d(1 - b_r w)\right]}{4b_d b_r - 1}.$$

At stage 1, we substitute the q_d^*, q_r^* and P_d^*, P_r^* values in (4-8) and (4-10) to determine the profit functions of the manufacturer and the retailer as a function of w,

$$\Pi_m(w) = \frac{-8b_d^2 b_r^2 w(-1 + b_r w) + w(1 + b_r + b_r w) + b_d(1 + 4b_r + b_r^2(4 + 8w + 7w^2))}{(1 - 4b_d b_r)^2}. \tag{4-14}$$

$$\Pi_r(w) = \frac{b_r(1 + 2w + b_d(2 - 2b_r w))^2}{(1 - 4b_d b_r)^2}.$$

The total profit of the supply chain as a function of w is denoted by Π_{t-d} and determined as follows:

$$\Pi_{t-d}(w) = \frac{b_r + w + 5b_r w + 5b_r w^2 + b_d^2(4b_r - 4b_r^2 w^2) + b_d(1 + 8b_r(1 + w) + b_r^2(4 + 4w - w^2))}{(1 - 4b_d b_r)^2}$$

The manufacturer will determine the optimal wholesale price w^* to maximize his profit from (4-14) which is concave in *w*. From the first order condition, we obtain w^* as

$$w^* = \frac{1+b_r+8b_d(1+b_d)b_r^2}{2b_r(-1-7b_db_r+8b_d^2b_r^2)}.$$

Given this w^*, we determine the equilibrium sales prices from (4-12) and (4-13) as follows:

$$P_d^*(b_d,b_r) = \frac{-1+b_r+10b_db_r+8b_db_r^2}{2(-1-7b_db_r+8b_d^2b_r^2)}.$$

$$P_r^*(b_d,b_r) = \frac{-1+b_r-2b_db_r+4b_d(2+3b_d)b_r^2}{2b_r(-1-7b_db_r+8b_d^2b_r^2)}.$$

For these equilibrium prices, we determine the sales quantities in equilibrium as follows:

$$q_r^*(b_d,b_r) = \frac{1+2b_db_r}{1+8b_db_r},$$

$$q_d^*(b_d,b_r) = \frac{1+b_r+2b_db_r+8b_db_r^2}{2b_r+16b_db_r^2}.$$

Given these equilibrium values, we obtain the equilibrium profits of the direct channel, retail channel and total supply chain for a given b_d and b_r as follows:

$$\prod\nolimits_m(b_d,b_r) = \frac{1+(2+4b_d)b_r+(1+16b_d+4b_d^2)b_r^2+8b_db_r^3}{4b_r(-1-7b_db_r+8b_d^2b_r^2)}.$$

$$\prod\nolimits_r(b_d,b_r) = \frac{(1+2b_db_r)^2}{b_r(1+8b_db_r)^2}.$$

$$\prod\nolimits_{t-d}(b_d,b_r) = \frac{-3+2b_r+(1+32b_d+36b_d^2)b_r^2+16b_d(1+8b_d+3b_d^2)b_r^3+64b_d^2b_r^4}{4b_r(-1+b_db_r)(1+8b_db_r)^2}.$$

Comparing the centralized and decentralized scenarios, we determine that the supply chain could achieve the maximum profit when the firms act as an integrated firm (centralized case).

Game theory is the study of the ways in which strategic interactions among independent rational players produce best responses with respect to preferences (or utilities) of those players, none of which might have been intended by any of them.

Although behaving as a centralized firm would give each firm (the manufacturer and the retailer) a better payoff (better profit), self-interest leads to an inefficient outcome with less payoff (less profit).

4.3 Comparative Statics with Respect to the Price Sensitivity Parameters

In this section, we study the effects of the price sensitivity parameters b_d and b_r on the equilibrium outcome of both the centralized and the decentralized cases. Recall that a high price sensitivity parameter makes the channel's customers more sensitive to the sales price in that channel.

4.3.1 Comparative Statics in the Centralized Case

Here we analyze the effects of the price sensitivity parameters b_d and b_r in optimal prices, sales quantities and profit in the centralized case we analyzed in Section 4.1. There is no wholesale price in this case, because there is no need to contract.

4.3.1.1 Comparative Statics with Respect to b_d

We analyze the changes in the decision variables P_{dc}^*, P_{rc}^*, and the outcome q_{dc}^*, q_{rc}^* and Π_c^* with respect to changes in b_d. From (4-15), we observe that when customers become more price sensitive in the direct channel (i.e., when b_d increases), the centralized firm reduces the selling price to keep the direct channel customers.

$$\frac{\partial P_{dc}^*}{b_d} = -\frac{b_r(1+b_r)}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}15)$$

From (4-16), we observe that when customers become more price sensitive in the direct channel, the centralized firm decreases his retail channel price as well. From (4-6), the optimal P_{rc}^* given P_{dc} is $P_{rc}^*(P_{dc}) = \frac{1+2P_{dc}}{2b_r}$. From (4-15), P_{dc}^* is decreasing in b_d. Hence, if the centralized firm changes P_{dc}^* because of a change in b_d, the firm also changes P_{rc}^* accordingly.

$$\frac{\partial P_{rc}^*}{b_d} = -\frac{1+b_r}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}16)$$

Next we consider the optimal sales quantities of the centralized firm in the two channels. From (4-7), the centralized firm reaches his optimal profit when he sells 0.5 units in each channel. This implies that the firm balances the changes in the decision variables of the sales quantity equations. Recall that we have $q_{dc}^* = 1 - b_d P_{dc}^* + P_{rc}^*$. From (4-16), P_{rc}^* is decreasing in b_d. From (4-17), the term $(b_d P_{dc}^*)$ is decreasing in b_d as well. The decreases in the term $(b_d P_{dc}^*)$ and in P_{rc}^* cancel each other and consequently, the centralized firm's optimal sales quantity in the direct channel continues to be equal to 0.5 independent of the changes in b_d.

$$\frac{\partial (b_d P_{dc}^*)}{\partial b_d} = -\frac{1+b_r}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}17)$$

Similarly, we have $q_{rc}^* = 1 - b_r P_{rc}^* + P_{dc}^*$. From (4-15), P_{dc}^* is decreasing in b_d. From (4-18), the term $(b_r P_{rc}^*)$ is also decreasing in b_d. The decreases in the term $(b_r P_{rc}^*)$ and in P_{dc}^* cancel each other and hence, the centralized firm's optimal sales quantity in the retail channel continues to be 0.5 independent of the changes in b_d.

$$\frac{\partial (b_r P_{rc}^*)}{b_d} = -\frac{b_r(1+b_r)}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}18)$$

Recall that $\Pi_c^* = q_{dc}^* P_{dc}^* + q_{rc}^* P_{rc}^*$. The optimum price values P_{dc}^* and P_{rc}^* are decreasing in b_d. The optimal sales quantities are constant at 0.5. Thus, the centralized firm's optimal profit is decreasing in b_d. This is confirmed by (4-19), which illustrates the changes in Π_c^* with respect to b_d.

$$\frac{\partial \Pi_c^*}{\partial b_d} = -\frac{(1+b_r)^2}{4(-1+b_d b_r)^2} < 0. \qquad (4\text{-}19)$$

4.3.1.2 Comparative Statics with Respect to b_r

From (4-20), we observe that the central firm decreases the optimum sales price in the retail channel P_{rc}^* if the price sensitivity parameter in the retail channel increases. In this case, the customers become more price sensitive and the central firm has to reduce price to keep the retail channel's customers.

$$\frac{\partial P_{rc}^*}{\partial b_r} = -\frac{b_d(1+b_d)}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}20)$$

From (4-21), we observe the optimal direct channel price, P_{dc}^* is also decreasing in b_r. From (4-5), the optimal P_{dc}^* as a function of P_{rc} is $P_{dc}^*(P_{rc}) = \frac{1+2P_{rc}}{2b_d}$. An increase in b_r leads to a decrease in P_{rc} from (4-20), which in turn leads to a decrease in P_{dc}^*.

$$\frac{\partial P_{dc}^*}{\partial b_r} = -\frac{1+b_d}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}21)$$

Next we consider the optimal sales quantities. As we observe from (4-7), the optimum sales quantities are both equal to 0.5 independent of the changes in b_r. Recall that $q_{dc}^* = 1 - b_d P_{dc}^* + P_{rc}^*$. From (4-20), P_{rc}^* is decreasing in b_r. From (4-22), the term $(b_d P_{dc}^*)$ is also decreasing in b_r.. The decreases in P_{rc}^* and in $(b_d P_{dc}^*)$ cancel each other and the centralized firm's optimum sales quantity in the direct channel stays constant at 0.5 independent of the changes in b_r.

$$\frac{\partial (b_d P_{dc}^*)}{\partial b_r} = -\frac{b_d(1+b_d)}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}22)$$

Similarly, $q_{rc}^* = 1 - b_r P_{rc}^* + P_{dc}^*$. From (4-21), P_{dc}^* is decreasing in b_r. From (4-23), the term $(b_r P_{rc}^*)$ is also decreasing in b_r. The decreases in P_{dc}^* and in $(b_r P_{rc}^*)$ cancel each other and the centralized firm's optimal sales quantity in the retail channel stays constant at 0.5 independent of the changes in b_r.

$$\frac{\partial (b_r P_{rc}^*)}{\partial b_r} = -\frac{1+b_d}{2(-1+b_d b_r)^2} < 0. \qquad (4\text{-}23)$$

Recall that $\Pi_c^* = q_{dc}^* P_{dc}^* + q_{rc}^* P_{rc}^*$. From (4-20) and (4-21), the optimum price values P_{rc}^* and P_{dc}^* are decreasing in b_r. The optimal sales quantities are constant at 0.5. Thus, the centralized firm's optimal profit is decreasing in b_r. This is confirmed by (4-24), which illustrates the changes in Π_c^* with respect to b_r.

$$\frac{\partial \Pi_c^*}{\partial b_r} = -\frac{(1+b_d)^2}{4(-1+b_d b_r)^2} < 0. \qquad (4\text{-}24)$$

4.3.2 Comparative Statics in the Decentralized Case

Here we analyze the effects of the price sensitivity parameters b_d and b_r in equilibrium prices, sales quantities and profit in the decentralized case that we analyzed in Section 4.2.

4.3.2.1 Comperative Statics with Respect to b_d

From (4-25), we observe that the equilibrium direct channel price P_d^* is decreasing in b_d. That is, the manufacturer sets a lower selling price in the direct channel if that channel's customers become more price sensitive.

$$\frac{\partial P_d^*}{\partial b_d} = -\frac{b_r(17+b_r-16b_d b_r+16b_d(1+5b_d)b_r^2+64b_d^2 b_r^3)}{2(1+7b_d b_r-8b_d^2 b_r^2)^2} < 0. \qquad (4\text{-}25)$$

From (4-26), the equilibrium retail channel price P_r^* is also decreasing in b_d. Recall that b_d does not have a direct effect in the retailer's demand function. However, the sales prices in the channels are determined as the equilibrium of a simultaneous-move game. From (4-11), we know that $P_r^*(P_d) = \frac{1+P_d+wb_r}{2b_r}$ and from (4-25), we know that P_d^* is decreasing in b_d. Thus, when b_d increases, the retailer reduces the price in her channel because the manufacturer reduces the direct channel price. This illustrates the equilibrium dynamics of the model we consider.

$$\frac{\partial P_r^*}{\partial b_d} = -\frac{5+b_r+8b_d b_r+4b_d(4+17b_d)b_r^2+64b_d^2 b_r^3}{2(1+7b_d b_r-8b_d^2 b_r^2)^2} < 0. \qquad (4\text{-}26)$$

Next, we consider how changes in b_d affect the manufacturer's wholesale price choice in stage 1. From (4-27), we observe that w^* is decreasing in b_d. We know from (4-26) that the retail channel's price P_r^* is decreasing in b_d. Hence, if b_d increases, the manufacturer reduces the wholesale price to support the retailer. Otherwise the retailer would not accept the contract and the manufacturer would lose one of his channels.

$$\frac{\partial w^*}{\partial b_d} = -\frac{-7 + b_r + 32b_d b_r + 8b_d(2+7b_d)b_r^2 + 64b_d^2 b_r^3}{2(1+7b_d b_r - 8b_d^2 b_r^2)^2} < 0. \qquad (4\text{-}27)$$

Having determined the effect of b_d in channels' prices, we consider the effects in the sales quantities. From (4-28), we observe that the equilibrium sales quantity in the direct channel is decreasing in b_d. Recall that $q_d^* = 1 - b_d P_d^* + P_r^*$. From (4-29), the term $(b_d P_d^*)$ is decreasing in b_d. It appears that the change in P_r^* dominates the change in $(b_d P_d^*)$ and hence q_d^* is decreasing in b_d. Although the manufacturer reduces the direct channel price, he cannot totally prevent the migration of customers from that channel due to the increase in price sensitivity, because the retailer also reduces her price.

$$\frac{\partial q_d^*}{\partial b_d} = -\frac{3}{(1+8b_d b_r)^2} < 0; \qquad \frac{\partial^2 q_d^*}{\partial b_d} = \frac{48b_r}{(1+8b_d b_r)^3} > 0. \qquad (4\text{-}28)$$

$$\frac{\partial (b_d P_d^*)}{\partial b_d} = -\frac{-1 + b_r + 20b_d b_r + 2b_d(8+31b_d)b_r^2 + 64b_d^2 b_r^3}{2(1+7b_d b_r - 8b_d^2 b_r^2)^2} < 0. \qquad (4\text{-}29)$$

From (4-30), we observe that the equilibrium sales quantity in the retail channel is also decreasing in b_d. One expects that when the direct channel customers become more price-sensitive, and when the retail channel price decreases, the demand in the retail channel will increase. However, the retail channel sales decrease because the direct channel price also decreases.

$$\frac{\partial q_r^*}{\partial b_d} = -\frac{6b_r}{(1+8b_d b_r)^2} < 0. \qquad (4\text{-}30)$$

Next we consider the changes in profits. From (4-31), the manufacturer's equilibrium profit is decreasing in b_d. This is expected because we have $\Pi_m^* = q_d^* P_d^* + q_r^* w^*$ and all q_d^*, P_d^*, q_r^* and w^* are decreasing in b_d.

$$\frac{\partial \Pi_m^*}{\partial b_d} = -\frac{-3 + (2+24b_d)b_r + (1+32b_d+60b_d^2)b_r^2 + 16b_d(1+8b_d)b_r^3 + 64b_d^2 b_r^4}{4(1+7b_d b_r - 8b_d^2 b_r^2)^2} < 0. \quad (4\text{-}31)$$

From (4-32), the retailer's equilibrium profit is also decreasing in b_d. This is not as expected as the effect on the manufacturer's profit. We have $\Pi_r^* = q_r^*(P_r^* - w^*)$ and all q_r^*, P_r^* and w^* are decreasing in b_d. It appears that the changes in q_r^* and P_r^* dominate the change in w^* and hence the retailer's profit is decreasing in b_d. Thus, the manufacturer's support by reducing the wholesale price does not prevent the reduction in the retailer's profit.

$$\frac{\partial \Pi_r^*}{\partial b_d} = -\frac{12(1+2b_d b_r)}{(1+8b_d b_r)^3} < 0. \qquad (4\text{-}32)$$

From (4-33), the equilibrium total channel profit is seen to be decreasing in b_d. This is expected as both firm's profits are decreasing in b_d.

$$\frac{\partial \Pi_{t-d}^*}{\partial b_d} = -\frac{45+2b_r+(1+48b_d+108b_d^2)b_r^2+24b_d(1+16b_d+24b_d^2)b_r^3+64b_d^2(3+16b_d)b_r^4+512b_d^3b_r^5}{4(-1+b_d b_r)^2(1+8b_d b_r)^3} < 0. \qquad (4\text{-}33)$$

4.3.2.2 Comperative Statics with respect to b_r

From (4-34), we observe that the equilibrium retail channel price P_r^* is decreasing in b_r. That is, the retailer sets a lower selling price in the retail channel if that channel's customers become more price sensitive.

$$\frac{\partial P_r^*}{\partial b_r} = -\frac{1+96b_d^4b_r^4+b_d b_r(14+b_r)+32b_d^3b_r^3(-1+2b_r)+2b_d^2b_r^2(1+8b_r)}{2b_r^2(1+7b_d b_r-8b_d^2b_r^2)^2} < 0. \qquad (4\text{-}34)$$

From (4-35), the equilibrium direct channel price is also decreasing in b_r. Remember that b_r does not affect the direct channel's demand directly. However, we determine the sales prices in the channels as the equilibrium of a simultaneous-move game. From (4-9), we know that $P_d^*(P_r) = \dfrac{1+P_r+w}{2b_d}$ and from (4-34), we know that P_r^* is decreasing in b_r. Thus, when b_r increases, the manufacturer reduces the price in his channel because the retailer reduces the retail channel price. This again illustrates the equilibrium dynamics of the model we consider.

$$\frac{\partial P_d^*}{\partial b_r} = -\frac{1+80b_d^3b_r^2+16b_d^2b_r(-1+4b_r)+b_d(17+16b_r)}{2(1+7b_d b_r-8b_d^2b_r^2)^2} < 0. \qquad (4\text{-}35)$$

Next, we consider how the manufacturer's wholesale price choice in stage 1 is affected. From (4-36), we observe that w^* is decreasing in b_r. From (4-34), we know that the retail channel's equilibrium price P_r^* is decreasing in b_r. Hence, if b_r increases, the manufacturer reduces the wholesale price to support the retailer. Otherwise, the manufacturer may lose one of his channels if the retailer refuses the contract.

$$\frac{\partial w^*}{\partial b_r} = -\frac{-1 + b_d(-14 + b_r)b_r + 64b_d^3 b_r^4 + 64b_d^4 b_r^4 + 16b_d^2 b_r^2(2 + b_r)}{2b_r^2(1 + 7b_d b_r - 8b_d^2 b_r^2)^2} < 0. \qquad (4\text{-}36)$$

After we determine the effect of b_r in channels' prices, we consider the effects in the sales quantities. From (4-37), we observe that the equilibrium sales quantity in the retail channel is decreasing in b_r. Recall that $q_r^* = 1 - b_r P_r^* + P_d^*$. From (4-38), we observe that the term $(b_r P_r^*)$ is decreasing in b_r. However, the change in P_d^* dominates the change in $(b_r P_r^*)$ and hence q_r^* is decreasing in b_r. Although the retailer reduces her retail channel price, some customers migrate from the retail channel due to the increase in price sensitivity.

$$\frac{\partial q_r^*}{\partial b_r} = -\frac{6b_d}{(1 + 8b_d b_r)^2} < 0. \qquad (4\text{-}37)$$

$$\frac{\partial (b_r P_r^*)}{\partial b_r} = -\frac{1 + 68b_d^3 b_r^2 + 8b_d^2 b_r(1 + 8b_r) + b_d(5 + 16b_r)}{2(1 + 7b_d b_r - 8b_d^2 b_r^2)^2} < 0. \qquad (4\text{-}38)$$

From (4-39), we observe that the equilibrium sales quantity in the direct channel is also decreasing in b_r. One may think that when the retail channel customers become more price-sensitive, and when the direct channel price decreases, the direct channel demand will increase. However, the direct channel sales decrease, because the retail channel price also decreases.

$$\frac{\partial q_d^*}{\partial b_r} = -\frac{1 + 16b_d b_r + 16b_d^2 b_r^2}{2b_r^2(1 + 8b_d b_r)^2} < 0. \qquad (4\text{-}39)$$

Next, we consider the changes in profits. From (4-40), the retailer's equilibrium profit is decreasing in b_r. We have $\Pi_r^* = q_r^*(P_r^* - w^*)$ and all q_r^*, P_r^* and w^* are decreasing in b_r. It appears that the changes in q_r^* and P_r^* dominate the change in w^* and hence the retailer's profit is decreasing in b_r. Although the manufacturer supports the retailer by reducing the wholesale price, this decrease does not prevent the reduction in the retailer's profit.

$$\frac{\partial \Pi_r^*}{\partial b_r} = -\frac{1 + 24b_d b_r + 60b_d^2 b_r^2 + 32b_d^3 b_r^3}{b_r^2(1 + 8b_d b_r)^3} < 0. \qquad (4\text{-}40)$$

From (4-41), the manufacturer's profit is decreasing in b_r. This is expected because we have $\Pi_m^* = q_d^* P_d^* + q_r^* w^*$ and all q_d^*, P_d^*, q_r^* and w^* are decreasing in b_r.

$$\frac{\partial \Pi_m^*}{\partial b_r} = -\frac{-1 + b_r^2 + 32 b_d^4 b_r^4 + 32 b_d^2 b_r^3 (1 + 2b_r) + 64 b_d^3 b_r^3 (1 + 2b_r) + 2 b_d b_r (-7 + b_r + 8b_r^2)}{4 b_r^2 (1 + 7 b_d b_r - 8 b_d^2 b_r^2)^2} < 0.$$

(4-41)

From (4-42), the equilibrium total channel profit is seen to be decreasing in b_r. This is because both firm's profits are decreasing in b_r.

$$\frac{\partial \Pi_{t-d}^*}{\partial b_r} = -\frac{3 + b_r^2 + 384 b_d^5 b_r^5 + 16 b_d^4 b_r^4 (33 + 64 b_r) + 64 b_d^3 b_r^3 (-3 + 6b_r + 8b_r^2) + 2 b_d b_r (33 + b_r + 12 b_r^2) + 12 b_d^2 b_r^2 (-5 + 4b_r + 16 b_r^2)}{4 b_r^2 (-1 + b_d b_r)^2 (1 + 8 b_d b_r)^3} < 0.$$

(4-42)

4.4 Comparing the Decentralized and the Centralized Cases

Here we compare the results from the decentralized and centralized cases to understand the effects of decentralization. In general, a centralized system is known to be more efficient than a decentralized system because of the incentive conflicts in a decentralized system. In our decentralized case, the prices are determined as the outcome of a simultaneous-move game in which both firms are trying to maximize their own profit without considering the effect of their decision on the other firm's profit. In the centralized case, a single decision maker, the centralized firm, determines the prices to maximize the total profit of the channels. In Section 4.5, we illustrate some of the discussions in this section through a numerical example.

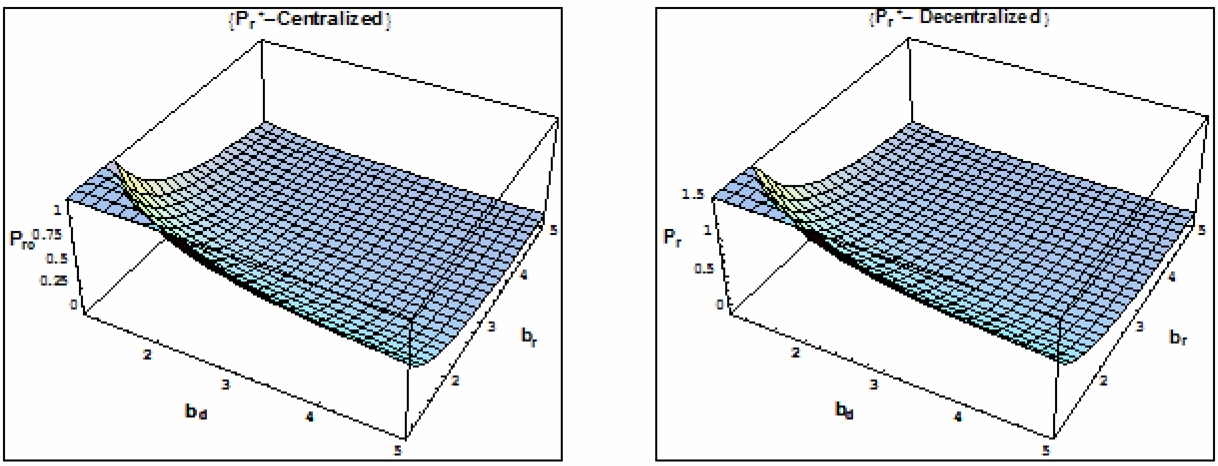

Figure 4-2: The Retail Channel Prices in the Centralized and Decentralized Cases

Figure 4-2 compares the retail channel prices in the centralized and decentralized cases. We observe that for each value of b_d and b_r, the decentralized case has a higher retail channel price than the centralized case. We also confirmed this observation by using the FindInstance function of Mathematica. Figure 4-3 shows the difference $(P_r^* - P_{rc}^*)$, which is always positive.

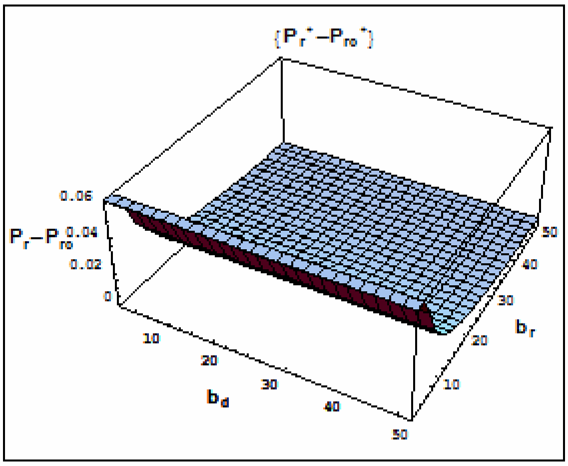

Figure 4-3: The Difference in P_r^* Between Decentralized and Centralized Cases

P_r^* in the decentralized case is higher because in this case, the retailer's profit margin is constrained by the wholesale price w. That is, in the decentralized case, both the manufacturer and the retailer should make a profit out of every sale in the retail channel. In the centralized case, only the centralized firm needs to make a profit, and hence, the firm can afford to set a lower sales price. Figure 4-3 illustrates the difference $(P_r^* - P_{rc}^*)$. We observe that the difference is quickly decreasing in b_r, whereas it is decreasing very slowly in b_d. The decrease is so small that it is not apparent in the figure.

Note that in both centralized and decentralized cases, P_r^* decreases when b_d and/or b_r increases (Figure 4-2). The parameter b_r affects P_r^* directly due to the demand function $q_r^* = 1 - b_r P_r^* + P_d^*$. On the other hand, the parameter b_d affects P_r^* through its effect on P_d^*, as we discussed in Section 4.2.

The difference between the decentralized and centralized cases is related to the well-known "*double marginalization*" issue. As shown in Figure 4-4, the total profit margin in the decentralized case is shared between the manufacturer and the retailer. Each firm considers only his/her own profit margin when making decisions, which leads to channel inefficiency. As a result, consumers are charged a higher retail channel price than in the centralized case. As we discuss in subsequent sections, double marginalization also leads to inefficiencies in other performance measures including the total channel profit.

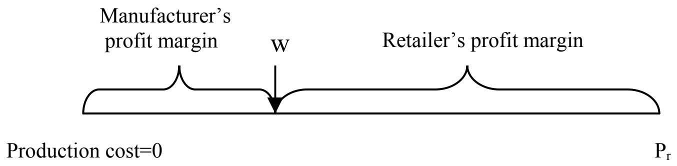

Figure 4-4: Double Marginalization

Figure 4-5 compares the direct channel prices. Although it is not apparent from the figure, the direct channel price in the decentralized case is always higher than the price in the centralized case. We confirmed this observation with Mathematica as well. Figure 4-6 illustrates the difference $(P_d^* - P_{dc}^*)$, which is always positive.

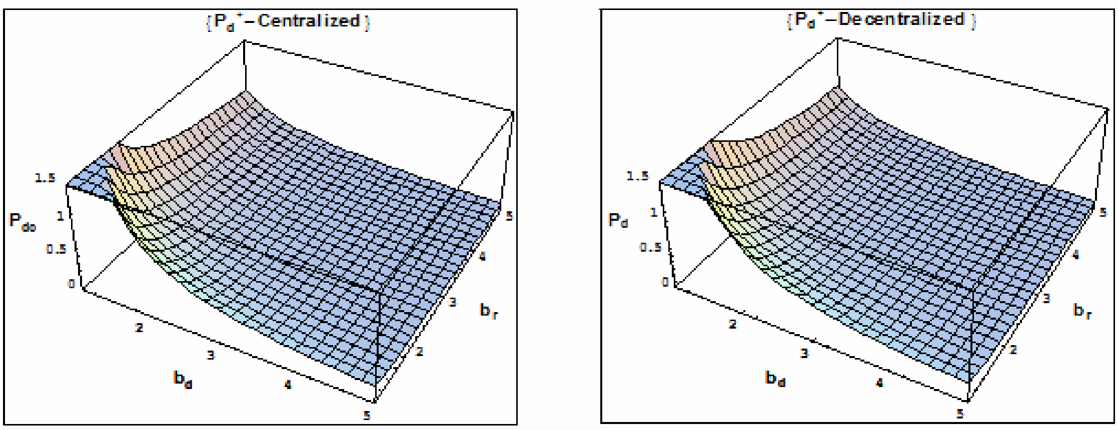

Figure 4-5: The Direct Channel Prices in Centralized and Decentralized Cases

The direct channel price in the decentralized case is higher because the prices in the decentralized case are determined through an equilibrium analysis. The higher retail channel price in the decentralized case (as discussed in Section 4.3.2) cause a higher direct channel price as well.

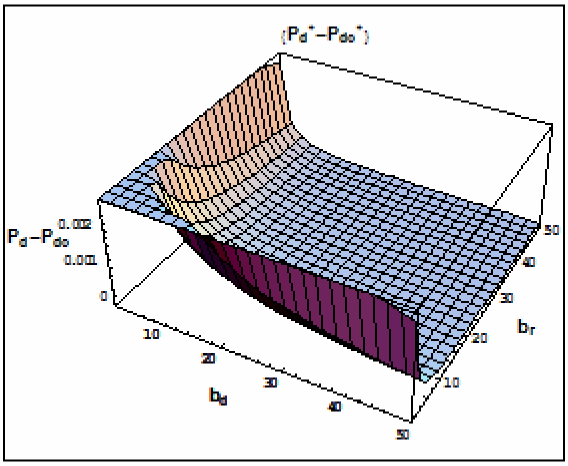

Figure 4-6: The Difference in P_d^* Between Decentralized and Centralized Cases

Note from Figure 4-5 that in both centralized and decentralized cases, P_d^* decreases when b_d and/or b_r increases. The parameter b_d affects P_d^* directly due to the demand function $q_d^* = 1 - b_d P_d^* + P_r^*$. On the other hand, the parameter b_r affects P_d^* through its effect on P_r^*, as we discussed in Section 4.3.2.2.

The direct channel's price difference between the two cases, $(P_d^* - P_{dc}^*)$ (Figure 4-6) is smaller than the difference in the retail channel prices between two cases, $(P_r^* - P_{rc}^*)$ (Figure 4-3). This is because the owner of the direct channel for both cases is the manufacturer; it does not change. However, the owner of the retail channel changes: The owner is the centralized firm in the centralized scenario, whereas the owner is the retailer in the decentralized scenario. This change in ownership causes changes in profit margins.

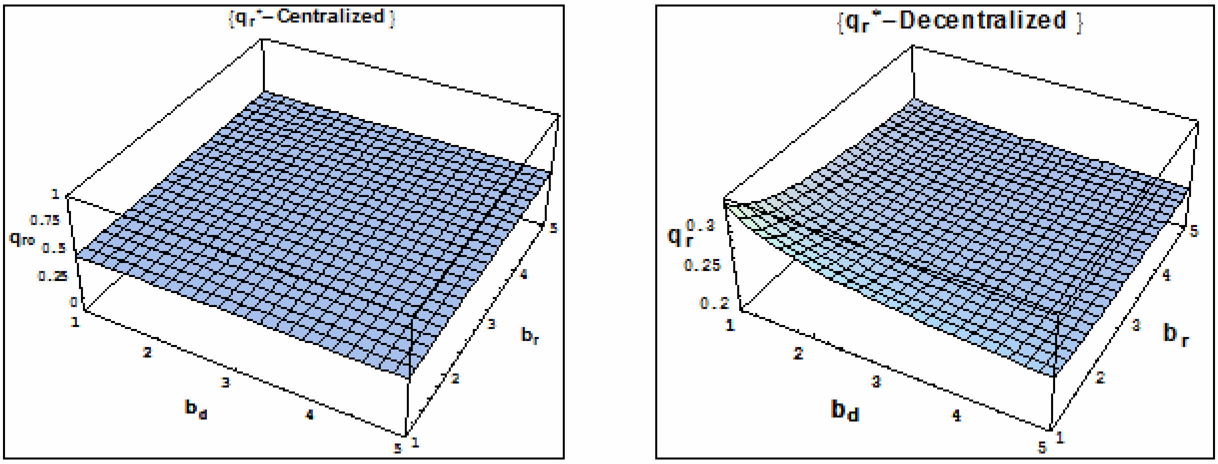

Figure 4-7: The Retail Channel Sales Quantities in Centralized and Decentralized Cases

Figure 4-7 compares the equilibrium retail channel sales quantities as a function of b_d and b_r. We observe that the quantity sold in the decentralized case is always lower than the quantity sold in the centralized case. This is confirmed by Figure 4-8 which illustrates the difference $(q_r^* - q_{rc}^*)$ as being always negative.

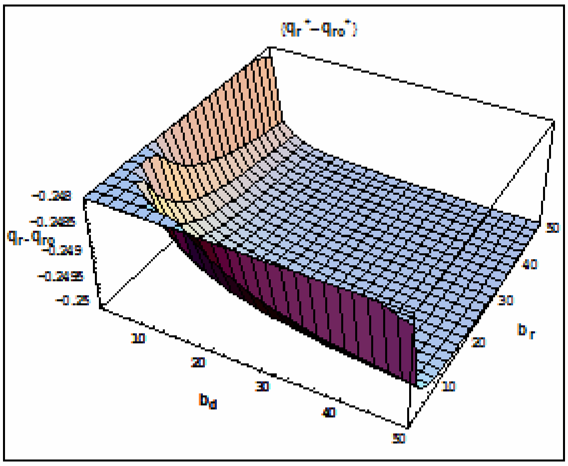

Figure 4-8: The Difference in q_r^* Between Decentralized and Centralized Cases

The retail channel sales quantity is lower in the decentralized case because the retail channel price is significantly higher in the decentralized case, as discussed before. The direct channel price is higher in the decentralized case as well, but this effect is dominated by the retail channel price’s effect. This decrease in sales quantity is another inefficiency that double marginalization causes. The customers purchase less than the system-optimal sales quantity.

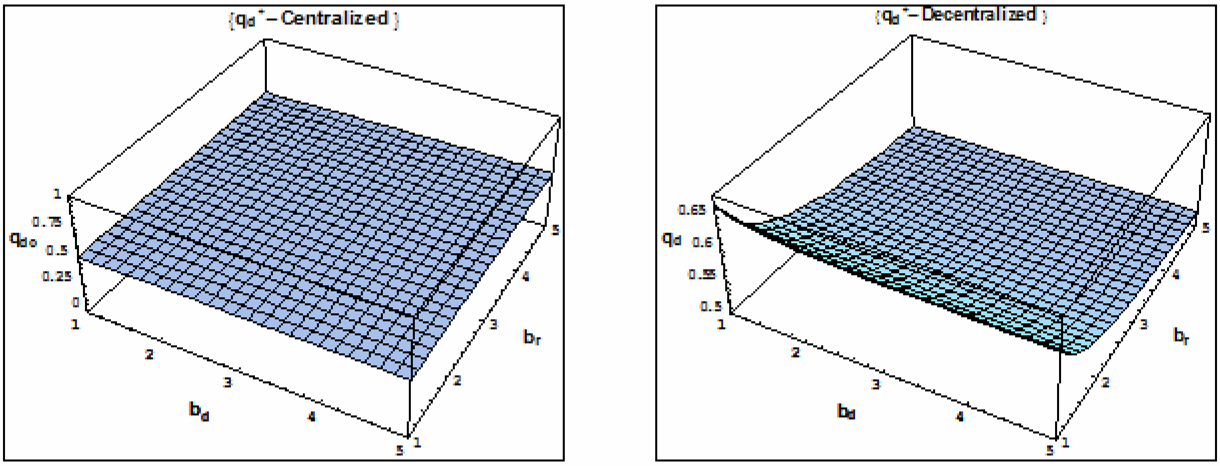

Figure 4-9: The Direct Channel Sales Quantities in Centralized and Decentralized Cases

From Figure 4-9, we observe that the equilibrium direct channel sales quantity in the decentralized case is higher than the quantity in the centralized case for all values of b_d and b_r. Compare this with the equilibrium retail channel sales quantity which was higher in the centralized case. Figure 4-10 presents the difference $(q_d^* - q_{dc}^*)$ which is always positive.

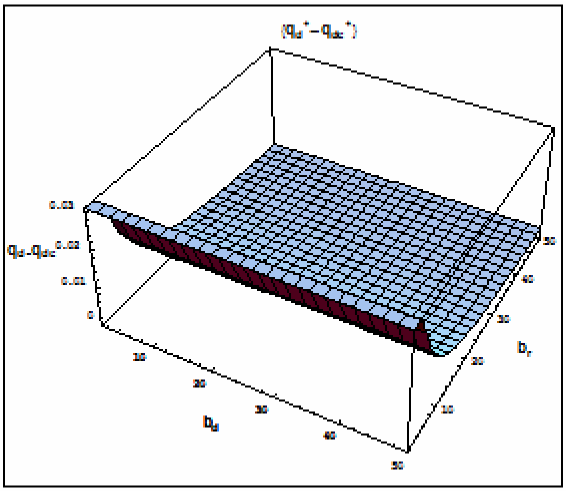

Figure 4-10: The Difference in q_d^* Between Decentralized and Centralized Cases

As mentioned before, the increase in the direct channel price is less than the increase in the retail channel price when moving from the centralized case to the decentralized case. This results in migration of some retail channel customers to the direct channel.

We know that the retail channel sales are higher in the centralized case whereas the direct channel sales are higher in the decentralized case. Next, we compare the total quantities sold in the centralized and the decentralized cases. The difference between the equilibrium total sales in the centralized case (q^*_{t-c}) and the equilibrium total sales in the decentralized case (q^*_{t-d}) is given in (4-43). The term is

$$q^*_{t-d} - q^*_{t-c} = \frac{1 + b_r + 2b_d b_r - 4b_d b_r^2}{2b_r + 16b_d b_r^2} \tag{4-43}$$

From (4-43), we determine that $(q^*_{t-d} > q^*_{t-c})$ if $(b_d > 1$ and $b_r < b_r^{'})$ whereas $(q^*_{t-d} \le q^*_{t-c})$ if $(b_d \le 1)$ or $(b_d > 1$ and $b_r \ge b_r^{'})$ where $b_r^{'} = \frac{1+2b_d}{8b_d} + \frac{1}{8}\sqrt{\frac{1+20b_d+4b_d^2}{b_d^2}}$.

The difference in total sales quantities is illustrated by Figure 4-11.

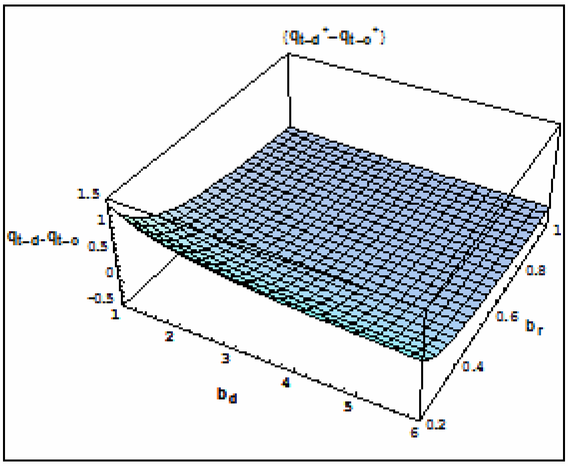

Figure 4-11: The Difference in Total Sales Quantities Between Decentralized and Centralized Cases

Next, we compare the total profits. Figure 4-12 illustrates that the total profit in the centralized case (Pi^*_{t-c}) is always higher than the total profit in the decentralized case (Pi^*_{t-c}). This is due to double marginalization. We can also show this result analytically. $(Pi^*_{t-d} < Pi^*_{t-c})$ if

$$\frac{-3 + 2b_r + (1 + 32b_d + 36b_d^2)b_r^2 + 16b_d(1 + 8b_d + 3b_d^2)b_r^3 + 64b_d^2 b_r^4}{4b_r(-1 + b_d b_r)(1 + 8b_d b_r)^2} < \frac{2 + b_d + b_r}{4(b_d b_r - 1)}$$

This inequality holds for $\left[-4\left(-1+b_r b_d\right)^2\left(-3-4b_r b_d+16b_r^2 b_d^2\right)\right]\overset{?}{<}0$. Under the assumptions $b_r * b_d > 1$; $b_d > 0$ and $b_r > 0$, this is always true.

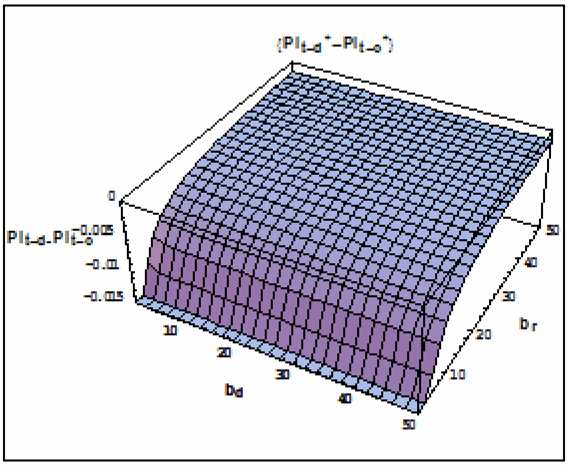

Figure 4-12: The Difference in Total Channel Profits Between Decentralized and Centralized Cases

4.5 Numerical Example for Comparing the Decentralized and the Centralized Cases

Here, we illustrate the comparative statics observations through a numerical example. First, we provide the results for the centralized benchmark case.

Table 4-1 illustrates how the results change when only b_d increases, when only b_r increases and when both b_d and b_r increase. Note that we consider the constraint $b_r * b_d > 1$ in selecting the parameter values. We observe how the centralized firm's prices (decision variables) and resulting profit decrease when b_d and/or b_r increases. On the other hand, the sales quantities remain constant at 0.5

Table 4-1: Numerical Example for the Comparative Statics of the Centralized Case

THE CENTRALIZED CASE						
b_d	b_r	P_{dc}	P_{rc}	q_{dc}	q_{rc}	Centralized Firm's Profit
1	5	0,7500	0,2500	0,5000	0,5000	0,5000
2	5	0,3333	0,1667	0,5000	0,5000	0,2500
3	5	0,2143	0,1429	0,5000	0,5000	0,1786
4	5	0,1579	0,1316	0,5000	0,5000	0,1447
5	5	0,1250	0,1250	0,5000	0,5000	0,1250

b_d	b_r	P_{dc}	P_{rc}	q_{dc}	q_{rc}	Centralized Firm's Profit
5	1	0,2500	0,7500	0,5000	0,5000	0,5000
5	2	0,1667	0,3333	0,5000	0,5000	0,2500
5	3	0,1429	0,2143	0,5000	0,5000	0,1786
5	4	0,1316	0,1579	0,5000	0,5000	0,1447
5	5	0,1250	0,1250	0,5000	0,5000	0,1250

b_d	b_r	P_{dc}	P_{rc}	q_{dc}	q_{rc}	Centralized Firm's Profit
1,1	1,1	5,0000	5,0000	0,5000	0,5000	5,0000
2	2	0,5000	0,5000	0,5000	0,5000	0,5000
3	3	0,2500	0,2500	0,5000	0,5000	0,2500
4	4	0,1667	0,1667	0,5000	0,5000	0,1667
5	5	0,1250	0,1250	0,5000	0,5000	0,1250

Table 4-2 provides the results for the decentralized case. As discussed before, we observe that the prices, sales quantities, wholesale price and profit values in equilibrium all decrease when b_d and/or b_r increases.

Table 4-2: Numerical Example for the Comparative Statics of the Decentralized Case

THE DECENTRALIZED CASE									
b_d	b_r	P_d	P_r	q_d	q_r	w	Manufacturer's Profit	Retailer's Profit	Total Profit
1	5	0,7744	0,3012	0,5268	0,2683	0,2476	0,4744	0,0144	0,4888
2	5	0,3457	0,2173	0,5259	0,2593	0,1654	0,2247	0,0134	0,2381
3	5	0,2226	0,1933	0,5256	0,2562	0,1420	0,1534	0,0131	0,1665
4	5	0,1641	0,1819	0,5255	0,2547	0,1310	0,1196	0,0130	0,1326
5	5	0,1300	0,1752	0,5254	0,2537	0,1245	0,0999	0,0129	0,1128

b_d	b_r	P_d	P_r	q_d	q_r	w	Manufacturer's Profit	Retailer's Profit	Total Profit
5	1	0,2744	1,0061	0,6341	0,2683	0,7378	0,3720	0,0720	0,4439
5	2	0,1790	0,4599	0,5648	0,2593	0,3302	0,1867	0,0336	0,2203
5	3	0,1511	0,2983	0,5427	0,2562	0,2129	0,1366	0,0219	0,1584
5	4	0,1378	0,2208	0,5318	0,2547	0,1571	0,1133	0,0162	0,1295
5	5	0,1300	0,1752	0,5254	0,2537	0,1245	0,0999	0,0129	0,1128

b_d	b_r	P_d	P_r	q_d	q_r	w	Manufacturer's Profit	Retailer's Profit	Total Profit
1,1	1,1	5,0936	5,2486	0,6456	0,3202	4,9574	4,8757	0,0932	4,9689
2	2	0,5303	0,6288	0,5682	0,2727	0,4924	0,4356	0,0372	0,4728
3	3	0,2637	0,3345	0,5434	0,2603	0,2477	0,2078	0,0226	0,2303
4	4	0,1744	0,2297	0,5320	0,2558	0,1657	0,1352	0,0164	0,1515
5	5	0,1300	0,1752	0,5254	0,2537	0,1245	0,0999	0,0129	0,1128

Table 4-3 illustrates the difference between the results in the decentralized and centralized cases when b_d and/or b_r increases. We observe that the difference in prices, quantities, and profits (in absolute terms) decrease as b_d and/or b_r increases.

Table 4-3: Numerical Example for the Comparison of the Decentralized and the Centralized Cases

Comparing the Decentralized and Centralized Cases							
b_d	b_r	P_d-P_{dc}	P_r-P_{rc}	q_d-q_{dc}	q_r-q_{rc}	q_{t-d}-q_{t-c}	**Difference in Total Profit (Decentralized-Centralized)**
1	5	0,0244	0,0512	0,0268	-0,2317	-0,2049	-0,01121
2	5	0,0123	0,0506	0,0259	-0,2407	-0,2148	-0,01187
3	5	0,0083	0,0504	0,0256	-0,2438	-0,2182	-0,01208
4	5	0,0062	0,0503	0,0255	-0,2453	-0,2199	-0,01219
5	5	0,0050	0,0502	0,0254	-0,2463	-0,2209	-0,01225

b_d	b_r	P_d-P_{dc}	P_r-P_{rc}	q_d-q_{dc}	q_r-q_{rc}	q_{t-d}-q_{t-c}	**Difference in Total Profit (Decentralized-Centralized)**
5	1	0,0244	0,2561	0,1341	-0,2317	-0,0976	-0,05607
5	2	0,0123	0,1265	0,0648	-0,2407	-0,1759	-0,02966
5	3	0,0083	0,0840	0,0427	-0,2438	-0,2011	-0,02013
5	4	0,0062	0,0629	0,0318	-0,2453	-0,2135	-0,01523
5	5	0,0050	0,0502	0,0254	-0,2463	-0,2209	-0,01225

b_d	b_r	P_d-P_{dc}	P_r-P_{rc}	q_d-q_{dc}	q_r-q_{rc}	q_{t-d}-q_{t-c}	**Difference in Total Profit (Decentralized-Centralized)**
1,1	1,1	0,0936	0,2486	0,1456	-0,1798	-0,0342	-0,03105
2	2	0,0303	0,1288	0,0682	-0,2273	-0,1591	-0,02720
3	3	0,0137	0,0845	0,0434	-0,2397	-0,1963	-0,01966
4	4	0,0078	0,0630	0,0320	-0,2442	-0,2122	-0,01513
5	5	0,0050	0,0502	0,0254	-0,2463	-0,2209	-0,01225

4.6 Single-Channel Scenarios

In this section, we study the models with only a single channel.

4.6.1 The Direct Channel - Only Scenario

In this scenario, we consider a manufacturer selling his products only through his direct channel. The model is similar to the dual channel model of Section 4, with the exception that there is no retail channel, as illustrated in Figure 4-13. Because there is no retailer, the model does not specify a wholesale price.

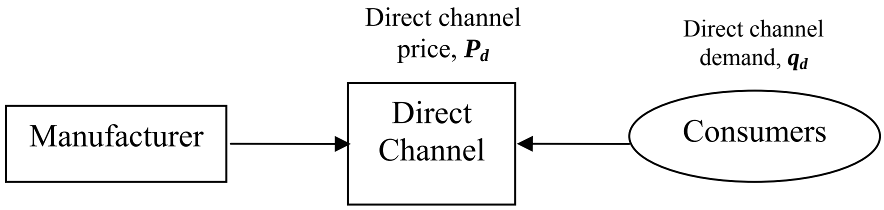

Figure 4-13: The Direct Channel - Only Scenario

The demand in the direct channel depends on the sales price P_d as follows:

$$q_d(P_d) = 1 - b_d P_d. \tag{4-44}$$

The manufacturer aims to maximize his profit. Hence, the manufacturer's objective is

$$\max_{P_d} \Pi_m = q_d(P_d) P_d. \tag{4-45}$$

By substituting (4-44) into (4-45), we observe that the objective function is strictly concave in P_d. Thus, the first-order-optimality condition is necessary and sufficient to find the maximizer. The manufacturer's optimal direct channel price, P_d^* is obtained from the first-order condition as $P_d^*(b_d) = \frac{1}{2b_d}$.

We observe that when the consumers in the direct channel become more price sensitive, the manufacturer responds by decreasing his price. Substituting the optimal price into (4-44), we determine the optimal sales quantity as

$$q_d^*(b_d) = \frac{1}{2}.$$

Substituting q_d^* and P_d^* values into (4-45), we determine the optimal profit of the manufacturer as

$$\Pi_m^*(b_d) = \frac{1}{4b_d}.$$

When the consumers in the direct channel become more price sensitive, the manufacturer's profit decreases although he decreases his selling price. However, the sales quantity does not change, because it is independent of b_d.

4.6.2 The Retail Channel - Only Scenario

In this scenario, we consider a manufacturer selling his product only through an independent retailer. The model is similar to the dual channel model of Section 4, with the exception that there is no direct channel. This model allows us to focus only on the effects of double marginalization without the complicating effects of a dual channel strategy.

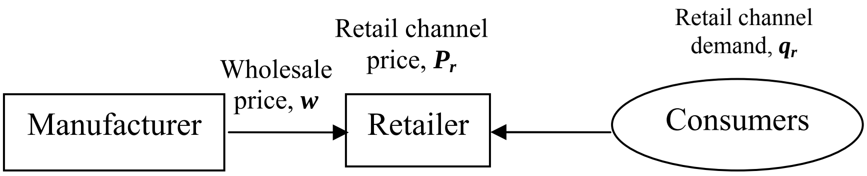

Figure 4-14: The Retail Channel - Only Scenario

The demand in the retail channel depends on the price P_r as follows:

$$q_r(P_r) = 1 - b_r P_r. \quad (4\text{-}46)$$

The retailer's objective given the wholesale price w is

$$\max_{P_r} \Pi_r = q_r(P_r)\left(P_r - w\right). \quad (4\text{-}47)$$

Substituting (4-46) into (4-47), we observe that the objective function is strictly concave in P_r. Thus, the first-order-optimality condition is necessary and sufficient to find the maximizer. The retail channel optimal price, P_r^* is obtained from the first-order condition as $P_r^*(w) = \dfrac{1 + wb_r}{2b_r}$.

We observe that when the manufacturer sets a higher wholesale price w, the retailer responds by setting a higher sales price to increase her profit. Substituting P_r^* into (4-46), we obtain $q_r^*(w) = \dfrac{1 - wb_r}{2}$.

The manufacturer's objective function is

$$\max \Pi_m = q_r(P_r)w. \quad (4\text{-}48)$$

Next, substituting q_r^* and P_r^* values as a function of w into (4-47) and (4-48), we determine the profits of the manufacturer and the retailer as a function of w.

$$\prod_m^*(w) = w\frac{(1-wb_r)}{2}. \quad (4\text{-}49)$$

$$\prod_r^*(w) = \frac{(-1+b_r w)^2}{4b_r}.$$

The manufacturer will determine the optimal wholesale price w^* to maximize his profit in (4-49), which is concave in w and the optimal w^* is obtained from the first-order condition as $w^* = \frac{1}{2b_r}$. Given this wholesale price, the retailer's price would be

$$P_r^*(b_r) = \frac{3}{4b_r}.$$

Given the optimal retail channel price, we determine the optimal sales quantity in the retail channel as

$$q_r^*(b_r) = \frac{1}{4}.$$

Given these optimal values, we obtain the optimal profit levels of the manufacturer and the retailer for a given b_r as follows:

$$\prod_m^*(b_r) = \frac{1}{8b_r}.$$

$$\prod_r^*(b_r) = \frac{1}{16b_r}.$$

Comparing the total profit in this case $(3/16\,b_r)$ with the total profit in the direct-channel-only case $(4/16\,b_d)$ reveals the effect of double marginalization. The direct-channel-only case does not have double marginalization because there is only a single decision maker.

CHAPTER 5

5 CONCLUSION

In this thesis, we focus on two aspects of the dual channel strategy of a manufacturer: consumer preferences towards different channel formats (online or bricks-and-mortar) and the effects of double marginalization. As more and more manufacturers are opening direct sales channels and engaging in price competition with their retailers, understanding these aspects of the dual channel strategy is becoming crucial for survival in the competitive marketplace.

We developed two game-theoretical models to address these issues. In both models, we consider a manufacturer selling products through a direct channel and an independent retail channel. The relation between the manufacturer and the retailer is governed by a wholesale price contract. The firms (channels) engage in simultaneous-move price competition. Market demand in each channel depends on the sales prices of both channels. We solve these models with backwards induction and we illustrate our results with numerical examples. We characterize the wholesale price and the profits of the firms, as well as the sales quantities and sales prices in the channels.

The two models are different along a number of important aspects. The focus of the first model is consumer valuation and preferences whereas the focus of the second model is double marginalization. While the channel demand functions in the second model is exogenously given, these functions in the first model are determined through a consumer choice process, by comparing the utilities that heterogeneous consumers derive from the two channels. The two channels in the first model differ in format (online versus bricks-and-mortar); whereas, there is no such difference in the second model. The channels in the first model share a fixed-size market. In the second model, the channel demands (and the size of the market) is a function of the sales prices in both channels. In fact, the key parameters of the second model are the price-sensitivity parameters of channels. Different from the first model, we consider a centralized firm case in the second model to assess the effects of double marginalization.

The first model allows us to determine optimal dual channel strategies for the manufacturer as a function of the consumer valuation of the product and the relative disadvantage of the online direct channel. We find parameter regions under which the manufacturer should use dual channel, direct-only or retail-only structures. In addition, we determined that the manufacturer shall serve the whole consumer population rather than serving partially for most parameter combinations.

The second model allows us to characterize the inefficiencies due to double marginalization. We show how the sales prices and sales quantities in channels decrease and how channel profits suffer due to decentralization as a function of the price sensitivities in the two channels. We extend the standard inefficiency results in a retail-only channel (which is studied extensively in the literature) into a dual-channel setting.

An interesting future research direction is to conduct an *experimental study* based on the theoretical findings of our models. Like all other game-theoretical models, our models rest on certain theoretical assumptions, which might not capture how human beings make decisions. We would like to see if our assumptions and findings are consistent with real decision-maker behavior. To understand this, we might conduct experiments with human decision makers in which the subjects play the roles of the manufacturer and the retailer in our models and make decisions. We expect to see deviations in subject behavior from our theoretical findings due to behavioral factors such as irrational behavior, risk aversion, loss aversion, or fairness considerations.

Appendix A

Behavioral Economics and Experimental Economics

Game theory is useful in the study of economic problems, but real-life observations often deviate from game theory predictions. At this point, behavioral economics draw attention. Behavioral economics is a sub-field of economics that identifies the ways in which behavior differs from theoretical predictions and shows how this behavior matters in economic contexts. Behavioral economics improve economics by increasing the realism of behavioral underpinnings of economic analysis. As human beings are limited in their capacities to learn, think and act, behavioral economics is a fertile area for studying the implications of these limits. With the rise of behavioral economics, human behavior has become important in economics (Diamond and Vartiainen 2007).

Experimental economics, the application of experimental methods to address economic questions, is a recent branch of economics. Increasing number of economists has begun to use experimental methods to evaluate economic propositions under carefully controlled conditions. Experimental economics is a field that tests whether the predictions of game theory are confirmed by individuals making decisions in a controlled environment (Friedman and Cassar 2004).

Behavioral economics and experimental economics have both differences and similarities. Although behavioral economics rely extensively on experimental data, behavioral economics is a different sub-field than experimental economics at some points. Experimental economists focus on the use of experimentation as a research tool but behavioral economists focus on the psychological insights into economics. On the other hand, both sub-fields accept that their origins trace to psychology and they have become popular in the last quarter of 20^{th} century (Camarer and Loewenstein 2004).

Experimental Economics History

Nineteenth century economists had the traditional view that economics is a non-experimental science. Several practical obstacles towards the use of experimental methods such as impossibility of controlling the key economic variables, and of keeping background conditions fixed were identified. Despite various changes in economists' methodological practice, skepticism towards experimentation took a long time to fade away. A number of innovations at the level of scientific practice helped to introduce the idea of experiments in economics.

Beginning in 1940s, experimental work improved following the growth and development of game theory. Game theory is useful in economics, because it offers predictions of interactive behavior that are clearly established and useful for experimental validation. In these years, economics was in the process of becoming a tool-based science and during this revolution economists came to accept that detailed analysis of several tools were essential to understand the real-world economy. The publication of Von Neumann and Morgenstern's *Theory of Games and Economic Behavior* (1944) contributed to the birth of experimental economics and subsequent developments of game and decision theory. Von Neumann and Morgenstern's work was fruitful for the scientists who were interested in the application to solve scientific, policy, and management problems.

In late 1940s, playing game-theoretical problems became popular in mathematical communities and this helped game theory gain widespread popularity. A number of economists became interested in the idea that laboratory methods could be useful and helpful in economics. In these years, experimental economics evolved in three areas: market experiments, game experiments, and individual choice experiments. Chamberlin (1948) studied with Harvard graduate students to prove the impossibility of pure competition and performed the first market experiment. After that, some researchers conducted market experiments focusing on the predictions of the neoclassical price theory.

In 1950s, extensive experimental projects were pursued at Penn State, Michigan, and Stanford Universities. Tucker (1950) developed what has become known as the "Prisoner's dilemma" to illustrate the difficulty of analyzing certain kinds of games. Others who made individual decision making experiments focused on simpler environments in which strategic behavior is unnecessary and individuals only need to optimize. In 1952, a group of researchers at the University of Michigan ran a two-month seminar that was the first event devoted specifically to the design of experiments in decision processes. In 1954, Ward Edwards at Michigan pioneered the experimental study of Expected Utility Theory. Researchers became increasingly interested in individual decision making experiments to examine the behavioral content of the axioms of expected utility theory. Siegel and Fouraker's (1960) book was significant for the bargaining behavior in game theory. Siegel was known as the first experimenter to highlight the importance of using real incentives to motivate subjects. Since Smith (1962), using experiments with human decision makers to understand the behavioral factors affecting decisions has grown. In 1963-64, a group of researchers working on the psychology of organizations (known as the Carnegie group) made use of a variety of methodologies such as role playing, business games, and simulations. In their projects, human decision makers took managerial decisions in an environment simulated by a computer.

In 1970s, the landscape of experimental economics changed considerably and the field started to separate into sub-disciplines. Amos Tversky began collaborating with Daniel Kahneman on decision making. In 1974, an article by Tversky and Kahneman attracted attention and read widely as a challenge to the view that human beings were rational. Charles Plott and Vernon Smith (1978) started to run experiments and their collaboration led to the creation of the Caltech Laboratory and the training of the second and third generations of experimental economists. In these years, Smith (1976) highlighted the importance of monetary incentives to control subjects' preferences in his papers. In late 1979s and early 1980s, alternative models to expected utility were characterized. In 1980s and 1990s, experimental economics expanded in new directions. Roth (1993) provided a comprehensive overview of the evolution of experimental economics during the period 1930-1960. Roth implied that effective experimental research builds off and enhances what is learned through traditional methodologies. Through this evolution, experiments have focused on developing new behavioral theory to explain the gaps between established economic theory and experimental results.

In 2002, the Nobel Prize in economics was awarded to Vernon Smith, because he had integrated insights from psychological research into economic science, especially concerning human judgment and decision making under uncertainty, and to Daniel Kahneman, because he had established laboratory experiments as a tool in empirical economic analysis especially in the study of alternative market mechanisms[4]. After this award, the growth of experiments as a valid, accepted methodology and the influence of psychological research in that growth have increased (Croson 2005).

Economic experiments are usually applied in academic research to test policies, but they can also be used in business. Businesses have recognized the importance of

[4]http://www.nobelprize.org

experimental economics and have started to use it as a decision tool. Hewlett-Packard Company (HP) began an experimental economics program in 1994 and has developed experimental models to support business decisions. The firm recognized the importance of both experimental methods and economic modeling as tools to support business decisions. HP Research Laboratories[5] have developed in-house experimental economics capabilities instead of relying on academic institutions. The firm has developed experimental models in several areas such as channel management, forecasting, and electronic markets and also has studied the behavior of sales channels under different contractual terms and business policies. In addition to HP, there are other experimental economics laboratories at IBM's T.J. Watson Research Center and at such academic institutions as Caltech, Harvard Business School, and Penn State. A 2003 Newsweek article states: "Companies are always trying to predict future. These days, the field of experimental economics – which replicates market and business scenarios in the lab – is giving the crystal ball an upgrade." (Foroohar 2003).

In conclusion, in just a few decades, economics has been transformed from a discipline where experimental methods were considered ineffective, impractical, and useless, to one where some of the most important advancements are driven by laboratory data. Experimental economics field has seen exponential growth every decade. Experiments have expanded to include an emphasis on developing new behavioral theory to explain gaps between established economic theory and experimental results (Davis and Holt 1992, Guala 2005, Roth, 1995a).

Advantages and Disadvantages of Experiments

Experiments offer a number of advantages. Researchers conduct experiments to explore the reasons why behavior deviates from theory and produce results that are not optimal, and to design treatments that might reduce the deviations. Experiments are used to test and refine theories as well as to characterize new phenomena. Experiments investigate relationships by manipulating treatments to determine the exact effect on specific dependent variables in a way which would not be possible using naturally-occurring data. Although it is rarely possible to control the rules of interaction, the flow of information, and the reward system in the field, all can be controlled in experiments. Moreover, good experiments, whether in economics or in the natural sciences, generally

[5] http://www.hpl.hp.com

involve simplification that permits to see causes and consequences clearly. Computers make it possible to model and simulate sophisticated economic environments.

Experiments also offer advantages over economic (or, empirical) data. One might question why economic data is not used and why researchers create their data using experiments. First, useful data might not exist. Second, there can be useful data, but it might be confidential. Third, collection and verification of economic data might be very expensive. Fourth, it might be very difficult to verify field data since data is generally collected not by economists for scientific purposes, but by government employees or businessmen for other purposes. Fifth, data might not reflect the model that is in consideration. Finally, data may have problems, because there is an absence of control in many areas of economic research (Davis and Holt 1992).

On the other hand, experiments possess some important disadvantages. To begin with, it is disputed how much an experiment reflects the real world. The results from the lab may not be applicable in the field. In addition to this, the effectiveness of experiments may depend on the recognition of some trade-offs and decision makers can skip such key points. The experience level of the subjects may not be same and this can affect the results of the experiments. Subjects may fail to use complete and unbiased instructions in a correct way. Since it is hard to motive the subjects during experiments, their answers to the questions can be poor predictors. Furthermore, it is not always possible to induce critical components for some economic environments in the laboratory. There might be technical difficulties in establishing and controlling the laboratory environment when the purpose of the experiment is to elicit information about individual preferences. Consequently, researchers should always be aware that experimental results might not be fully applicable to the real world.

Experimental results often exhibit deviations from game-theoretical predictions for a number of reasons. First, players usually do not calculate the equilibrium strategies in the way a theorist would do, all they have to do is to respond optimally to the others' decisions in the game under limited time frames. Second, the nature of monetary rewards, experience levels and any intentional deception of players are important. Finally, instructions, location, duration of experiments, and the physical environment also affect the results of games. At this point, control is essential since game theory predictions often depend sensitively on the choices players have, how they value outcomes, the order that they move and what they guess. For game-theoretical models, it is unlikely to think that pure logic alone will be enough, because game theory is about groups of decision makers who consider other groups' decisions and the results usually deviate from predictions.

Experimental Studies in Operations Management

Operations management (OM) is a broad field that includes product development, forecasting, process design and improvement, inventory management, and supply chain management. In the recent years, OM researchers have been using game theory widely. For example, OM literature has produced optimal contracting mechanisms for partners of supply chains using game theory (Cachon 2003). Experiments might be an important tool for testing such game-theoretic results in OM. Hence, OM appears to be a candidate for behavioral economics applications.

Behavioral research in the field of operations management is important since human behavior has a significant influence on the way operating systems work, how they work, and how they respond to management interventions. Behavioral considerations in OM are almost as old as the operations management itself. For instance, in 1920s and 30s, research conducted by Mayo, Roethlisberger, and Dickson examined both the physical influences of the workplace and its psychological aspects (Gino and Pisano 2006). Understanding of human behavior is significant, because the success of OM tools and techniques depend heavily on it. Although environment, characteristics of operations and tools available to OM have changed, one thing has not changed: in the majority of operations people has been a critical component of the system. People influence both the functioning of a system and the way operating systems perform. Recently, a number of researchers have been interested in the use of human experiments in operations management. The implication of human experiments to operational problems branch many sub-disciplines including supply chain management (SCM), production control, quality management, and operations technology (Bendoly et al. 2006).

Supply chain management is one of the areas in which experimental economics methods have been used. SCM is a set of approaches utilized to efficiently integrate multiple decision makers such as suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right time, to the right locations, and at the right quantities (Simchi-Levi et al. 2008). Since supply chains involve multiple decision makers, SCM is a natural area to apply behavioral study. Researchers investigate cooperative and competitive behavior in different institutional settings, including bargaining, reputation systems, and bidding behavior in auctions in supply chains. Recently, controlled human experiments have been used to identify and better understand the behavioral factors that affect efforts to coordinate supply chains. By doing experiments, firms can examine the behavioral impact of reducing ordering and shipping delays, adding point of sale (POS) data sharing systems, and adding inventory information sharing systems.

One of the most known examples of the behavioral experiments in SCM is the beer distribution game (Figure B-1). Beer distribution game is a simulation game created by a group of MIT Sloan School of Management in early 1960s to simulate the ordering and production decisions of four-level multiple decision makers (a retailer, wholesaler, distributor, and manufacturer). Players decide how many cases of beer to order from immediate suppliers to maintain sufficient inventory to fill orders from their immediate customers each week. The objective of a player is to minimize the sum of holding and shortage costs of its firm.

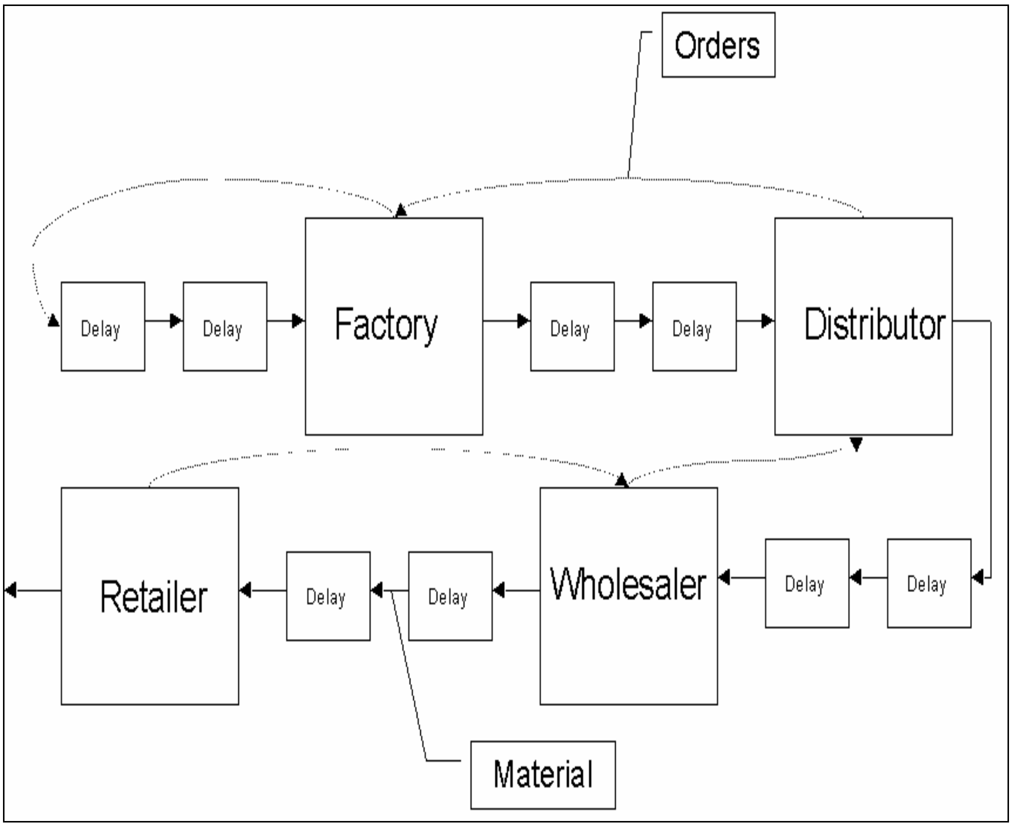

Figure A-1: The Beer Distribution Game

The beer game is related to the "Bullwhip effect" that has been observed in many supply chains: While customer demand does not vary much, the fluctuation in order levels, as well as in inventory and back-order levels increase considerably as one moves up in the supply chain. Procter and Gamble first coined the term bullwhip effect to describe the ordering behavior between customers and suppliers of diapers. Hewlett-Packard is another firm that faces the bullwhip effect (Lee et al. 1997). To mitigate the bullwhip effect, companies should improve communication along the supply chain, work with firms upstream and downstream in the supply chain and enhance sources of forecast data.

Newsvendor problem is another important application area of experiments in SCM. In the newsvendor problem, a decision maker determines the order quantity for a single selling season with stochastic demand. This problem is called the newsvendor problem, because its prototype is the problem faced by a newsvendor trying to decide how many newspapers to stock before observing demand. The objective is to minimize the expected total cost of ordering too much or too little with respect to unknown demand. The theoretical profit-maximizing order quantity is known, however, human subjects' decisions in experiments are observed to deviate from theoretical predictions. Schweitzer and Cachon (2000) conducted the first experimental study of the newsvendor problem and observed a pattern of behavior that is odd for theory with expected profit maximization as well as with alternative risk profiles.

Literature Survey

The evaluation of economic theories under controlled laboratory conditions is a relatively recent development and it has provided an important foundation for bridging the gap between economic theory and observation. In late 1940s and 1950s, a number of economists independently became interested in the notion that laboratory methods could be practical in the economic theories. Chamberlin reported the first market experiment describing an actual experiment with a market under laboratory conditions in 1948. Chamberlin's paper is highly suggestive in presenting the possibilities of experimental techniques in the study of applied market theory. Then, a similar experimental supply and demand model is used by Smith (1962).

A series of experimental games have been designed to study some of the hypotheses of neoclassical competitive market theory. Since these studies, interest in using experiments with human decision makers to understand the behavioral factors affecting decisions has grown. Researchers have used experimental economics methods to test policies in such areas as transportation, emissions trading, water distribution, power transmission networks and natural gas pipelines. There are several studies with a strong game-theoretic component of experimental economics in practice. Plott (1987) presents a classic experimental treatment of problems such as the allocation of airplane slots and strategic agenda manipulation by guiding game-theoretic models. Roth (2002) shows how experimental economics and game theory have been used in the design of US Federal Communications Commission auctions for the rights to radio spectrum and in the design of labor clearing houses for American doctors (see Camerer 2003 for other examples).

Employment of experimental methods has recently increased in the operations management (OM) literature. Bendoly et al. (2006) provide a perspective on the importance of behavioral research to OM field, availability of prior research and the opportunities that lie ahead. Gino and Pisano (2006) emphasize the term “behavioral operations” to explore the theoretical and practical implications of incorporating behavioral and cognitive factors into models of operations. Bolton and Kwasnica (2002) mention that experiments have three primary uses related with behavioral issues such as wind tunnel testing, assessing attitudes towards values and risks, and interactive learning tools.

In the OM literature, experimental methods have mainly been used in three areas: the bullwhip effect, the newsvendor problem and OM contracting. Sterman (1989) is the first to use a simulated industrial production and distribution system, the beer distribution game, to study the causes of bullwhip effect. Furthermore, Sterman (1989) is also the first to demonstrate that the bullwhip effect has behavioral as well as operational causes. In the paper, *an anchoring and adjustment heuristic* for stock management is proposed to explain the subjects’ decision processes. Like Sterman (1989), Lee et al. (1997) are interested in the causes and managerial implications of the bullwhip effect and they develop simple mathematical models of supply chains. They describe four of the most common causes of the bullwhip effect: demand signal processing, rationing game, order batching, and price variations. Chen (1999) extends this research by investigating the effect of irrational behavior on supply chain performance. In the model, demand distribution is stationary and known to participants to demonstrate the importance for upstream members of the supply chain to have access to exact customer demand information. Croson and Donohue (2006) study the behavioral causes of the bullwhip effect and investigate the potential benefit that inventory information sharing offers. Experimental results reveal that bullwhip effect still exits when normal operational causes are removed and that sharing real time inventory information reduces the bullwhip effect but not in the manner expected. Croson et al. (2004) propose a new behavioral cause of the bullwhip effect, *coordination risk*, that triggers order amplification leading the bullwhip effect. According to the model, players place excessive orders to address the perceived risk that their partners in the beer game will not behave optimally.

Croson and Donohue (2002) discuss the beer game experiment, popular as a tool for teaching supply chain management and suggest the benefits that experimental research can bring to supply chain management. They survey results from a series of human experiments to examine the behavioral causes of the bullwhip effect. The authors find cognitive limitations on part of managers; in particular, an underweighting of the supply line. That is, the subjects in the beer game experiments amplify orders because they fail to account adequately for the outstanding orders in transit.. Croson and Donohue (2003) mention that sharing point of sale (POS) data can help reduce the bullwhip effect and reduce supply chain costs when demand is stationary and known. In contrast, Steckel et al. (2004) determine that POS data can bias upstream participants' estimates of future demand, increasing costs when the distribution of consumer demand is nonstationary and unknown. Wu and Katok (2006) study how the bullwhip effect might be mitigated and investigate the effect of learning and communication on the bullwhip effect in supply chains. Croson and Donohue (2005) report the results of an experiment to examine whether giving supply chain partners access to downstream or upstream inventory information is more effective.

Schweitzer and Cachon (2000) conduct the first experimental study on the newsvendor problem. They find that many people, even those who have been exposed to the solution in an MBA classroom, make suboptimal and biased newsvendor choices. It is shown that the pattern of choices is not consistent with risk-aversion, risk-seeking preferences, prospect theory preferences, waste aversion, stockout aversion, or the consequences of undervaluing opportunity costs. Similar to Sterman (1989), the authors offer heuristic as explanation and consider two alternative anchoring and insufficient adjustment heuristics called the *mean anchor* heuristic and the *chasing demand* heuristic. Bolton and Katok (2006) present a laboratory investigation of learning-by-doing in the newsvendor problem and their experiments investigate how experience or feedback can improve newsvendor problem choice by promoting better learning-by-doing.

Experimental methods have also been used in channel contract management research in industry. Hewlett-Packard Company (HP) has recognized the potential of this methodology as a decision support tool. HP uses experiments to shape its policies with retailers, such as return policies, price-protection policies, and minimum advertised-price policies (see, for example, Charness and Chen 2002, Chen and Huang 2005).

Appendix B

Table B-1: Numerical Examples Results

v	k	cs(opt.case)	w*	P_d^*	Pr^*	q_d*	qr*	q_l*	Pi_m^*	Pi_r^*
0,25	0	DuF	0,00	0,67	0,33	0,67	0,33	0,00	0,44	0,11
0,25	0,25	DuF	0,00	0,75	0,50	0,60	0,40	0,00	0,45	0,20
0,25	0,5	DuF	0,00	0,83	0,67	0,56	0,44	0,00	0,46	0,30
0,25	0,75	DuF	0,00	0,92	0,83	0,52	0,48	0,00	0,48	0,40
0,25	1	DuF	0,00	1,00	1,00	0,50	0,50	0,00	0,50	0,50
0,25	1,25	DuF	0,00	1,08	1,17	0,48	0,52	0,00	0,52	0,60
0,25	1,5	DuF	0,00	1,17	1,33	0,47	0,53	0,00	0,54	0,71
0,25	1,75	DuF	0,00	1,25	1,50	0,45	0,55	0,00	0,57	0,82
0,25	2	DuF	0,00	1,33	1,67	0,44	0,56	0,00	0,59	0,93
0,25	2,25	DuF	0,00	1,42	1,83	0,44	0,56	0,00	0,62	1,03
0,25	2,5	DuF	0,00	1,50	2,00	0,43	0,57	0,00	0,64	1,14
0,25	2,75	DuF	0,00	1,58	2,17	0,42	0,58	0,00	0,67	1,25
0,25	3	DuF	0,00	1,67	2,33	0,42	0,58	0,00	0,69	1,36
0,25	3,25	DuF	0,00	1,75	2,50	0,41	0,59	0,00	0,72	1,47
0,25	3,5	DuF	0,00	1,83	2,67	0,41	0,59	0,00	0,75	1,58
0,25	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
0,25	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
0,25	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
0,25	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
0,25	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
0,25	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24
0,5	0	DiF	0,00	0,50	0,00	1,00	0,00	0,00	0,50	0,00
0,5	0,25	DuF	0,00	0,75	0,50	0,60	0,40	0,00	0,45	0,20
0,5	0,5	DuF	0,00	0,83	0,67	0,56	0,44	0,00	0,46	0,30
0,5	0,75	DuF	0,00	0,92	0,83	0,52	0,48	0,00	0,48	0,40
0,5	1	DuF	0,00	1,00	1,00	0,50	0,50	0,00	0,50	0,50
0,5	1,25	DuF	0,00	1,08	1,17	0,48	0,52	0,00	0,52	0,60
0,5	1,5	DuF	0,00	1,17	1,33	0,47	0,53	0,00	0,54	0,71
0,5	1,75	DuF	0,00	1,25	1,50	0,45	0,55	0,00	0,57	0,82
0,5	2	DuF	0,00	1,33	1,67	0,44	0,56	0,00	0,59	0,93
0,5	2,25	DuF	0,00	1,42	1,83	0,44	0,56	0,00	0,62	1,03
0,5	2,5	DuF	0,00	1,50	2,00	0,43	0,57	0,00	0,64	1,14
0,5	2,75	DuF	0,00	1,58	2,17	0,42	0,58	0,00	0,67	1,25
0,5	3	DuF	0,00	1,67	2,33	0,42	0,58	0,00	0,69	1,36
0,5	3,25	DuF	0,00	1,75	2,50	0,41	0,59	0,00	0,72	1,47
0,5	3,5	DuF	0,00	1,83	2,67	0,41	0,59	0,00	0,75	1,58
0,5	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
0,5	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
0,5	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
0,5	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
0,5	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
0,5	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24
0,75	0	DiF	0,00	0,75	0,00	1,00	0,00	0,00	0,75	0,00
0,75	0,25	DiF	0,00	0,50	0,00	1,00	0,00	0,00	0,50	0,00
0,75	0,5	DuF	0,00	0,83	0,67	0,56	0,44	0,00	0,46	0,30
0,75	0,75	DuF	0,00	0,92	0,83	0,52	0,48	0,00	0,48	0,40
0,75	1	DuF	0,00	1,00	1,00	0,50	0,50	0,00	0,50	0,50
0,75	1,25	DuF	0,00	1,08	1,17	0,48	0,52	0,00	0,52	0,60
0,75	1,5	DuF	0,00	1,17	1,33	0,47	0,53	0,00	0,54	0,71
0,75	1,75	DuF	0,00	1,25	1,50	0,45	0,55	0,00	0,57	0,82
0,75	2	DuF	0,00	1,33	1,67	0,44	0,56	0,00	0,59	0,93
0,75	2,25	DuF	0,00	1,42	1,83	0,44	0,56	0,00	0,62	1,03
0,75	2,5	DuF	0,00	1,50	2,00	0,43	0,57	0,00	0,64	1,14
0,75	2,75	DuF	0,00	1,58	2,17	0,42	0,58	0,00	0,67	1,25
0,75	3	DuF	0,00	1,67	2,33	0,42	0,58	0,00	0,69	1,36
0,75	3,25	DuF	0,00	1,75	2,50	0,41	0,59	0,00	0,72	1,47
0,75	3,5	DuF	0,00	1,83	2,67	0,41	0,59	0,00	0,75	1,58
0,75	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
0,75	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
0,75	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
0,75	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
0,75	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
0,75	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24

1	0	DiF	0,00	1,00	0,00	1,00	0,00	0,00	1,00	0,00
1	0,25	DiF	0,00	0,75	0,00	1,00	0,00	0,00	0,75	0,00
1	0,5	DiP	0,00	0,50	0,00	1,00	0,00	0,00	0,50	0,00
1	0,75	DuF	0,00	0,92	0,83	0,52	0,48	0,00	0,48	0,40
1	1	DuF	0,00	1,00	1,00	0,50	0,50	0,00	0,50	0,50
1	1,25	DuF	0,00	1,08	1,17	0,48	0,52	0,00	0,52	0,60
1	1,5	DuF	0,00	1,17	1,33	0,47	0,53	0,00	0,54	0,71
1	1,75	DuF	0,00	1,25	1,50	0,45	0,55	0,00	0,57	0,82
1	2	DuF	0,00	1,33	1,67	0,44	0,56	0,00	0,59	0,93
1	2,25	DuF	0,00	1,42	1,83	0,44	0,56	0,00	0,62	1,03
1	2,5	DuF	0,00	1,50	2,00	0,43	0,57	0,00	0,64	1,14
1	2,75	DuF	0,00	1,58	2,17	0,42	0,58	0,00	0,67	1,25
1	3	DuF	0,00	1,67	2,33	0,42	0,58	0,00	0,69	1,36
1	3,25	DuF	0,00	1,75	2,50	0,41	0,59	0,00	0,72	1,47
1	3,5	DuF	0,00	1,83	2,67	0,41	0,59	0,00	0,75	1,58
1	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
1	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
1	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
1	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
1	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
1	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24
1,25	0	DiF	0,00	1,25	0,00	1,00	0,00	0,00	1,25	0,00
1,25	0,25	DiF	0,00	1,00	0,00	1,00	0,00	0,00	1,00	0,00
1,25	0,5	DiF	0,00	0,75	0,00	1,00	0,00	0,00	0,75	0,00
1,25	0,75	DiP	0,00	0,63	0,00	0,83	0,00	0,17	0,52	0,00
1,25	1	DuP	0,63	0,63	0,94	0,63	0,31	0,06	0,59	0,10
1,25	1,25	DuF	0,00	1,08	1,17	0,48	0,52	0,00	0,52	0,60
1,25	1,5	DuF	0,00	1,17	1,33	0,47	0,53	0,00	0,54	0,71
1,25	1,75	DuF	0,00	1,25	1,50	0,45	0,55	0,00	0,57	0,82
1,25	2	DuF	0,00	1,33	1,67	0,44	0,56	0,00	0,59	0,93
1,25	2,25	DuF	0,00	1,42	1,83	0,44	0,56	0,00	0,62	1,03
1,25	2,5	DuF	0,00	1,50	2,00	0,43	0,57	0,00	0,64	1,14
1,25	2,75	DuF	0,00	1,58	2,17	0,42	0,58	0,00	0,67	1,25
1,25	3	DuF	0,00	1,67	2,33	0,42	0,58	0,00	0,69	1,36
1,25	3,25	DuF	0,00	1,75	2,50	0,41	0,59	0,00	0,72	1,47
1,25	3,5	DuF	0,00	1,83	2,67	0,41	0,59	0,00	0,75	1,58
1,25	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
1,25	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
1,25	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
1,25	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
1,25	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
1,25	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24
1,5	0	DiF	0,00	1,50	0,00	1,00	0,00	0,00	1,50	0,00
1,5	0,25	DiF	0,00	1,25	0,00	1,00	0,00	0,00	1,25	0,00
1,5	0,5	DiF	0,00	1,00	0,00	1,00	0,00	0,00	1,00	0,00
1,5	0,75	DiP	0,00	0,75	0,00	1,00	0,00	0,00	0,75	0,00
1,5	1	DiP	0,00	0,75	0,00	0,75	0,00	0,25	0,56	0,00
1,5	1,25	DuP	0,75	0,75	1,13	0,60	0,38	0,03	0,73	0,14
1,5	1,5	DuP	0,75	0,75	1,13	0,50	0,38	0,13	0,66	0,14
1,5	1,75	DuP	0,75	0,75	1,13	0,43	0,38	0,20	0,60	0,14
1,5	2	DuF	0,00	1,33	1,67	0,44	0,56	0,00	0,59	0,93
1,5	2,25	DuF	0,00	1,42	1,83	0,44	0,56	0,00	0,62	1,03
1,5	2,5	DuF	0,00	1,50	2,00	0,43	0,57	0,00	0,64	1,14
1,5	2,75	DuF	0,00	1,58	2,17	0,42	0,58	0,00	0,67	1,25
1,5	3	DuF	0,00	1,67	2,33	0,42	0,58	0,00	0,69	1,36
1,5	3,25	DuF	0,00	1,75	2,50	0,41	0,59	0,00	0,72	1,47
1,5	3,5	DuF	0,00	1,83	2,67	0,41	0,59	0,00	0,75	1,58
1,5	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
1,5	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
1,5	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
1,5	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
1,5	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
1,5	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24

1,75	0	DiF	0,00	1,75	0,00	1,00	0,00	0,00	1,75	0,00
1,75	0,25	DiF	0,00	1,50	0,00	1,00	0,00	0,00	1,50	0,00
1,75	0,5	DiF	0,00	1,25	0,00	1,00	0,00	0,00	1,25	0,00
1,75	0,75	DiF	0,00	1,00	0,00	1,00	0,00	0,00	1,00	0,00
1,75	1	DiP	0,00	0,88	0,00	0,88	0,00	0,13	0,77	0,00
1,75	1,25	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	1,5	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	1,75	DuP	0,88	0,88	1,31	0,50	0,44	0,06	0,82	0,19
1,75	2	DuP	0,88	0,88	1,31	0,44	0,44	0,13	0,77	0,19
1,75	2,25	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	2,5	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	2,75	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	3	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	3,25	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	3,5	ReF	0,75	0,00	0,75	0,00	1,00	0,00	0,75	0,00
1,75	3,75	DuF	0,00	1,92	2,83	0,40	0,60	0,00	0,77	1,69
1,75	4	DuF	0,00	2,00	3,00	0,40	0,60	0,00	0,80	1,80
1,75	4,25	DuF	0,00	2,08	3,17	0,40	0,60	0,00	0,83	1,91
1,75	4,5	DuF	0,00	2,17	3,33	0,39	0,61	0,00	0,85	2,02
1,75	4,75	DuF	0,00	2,25	3,50	0,39	0,61	0,00	0,88	2,13
1,75	5	DuF	0,00	2,33	3,67	0,39	0,61	0,00	0,91	2,24
2	0	DiF	0,00	2,00	0,00	1,00	0,00	0,00	2,00	0,00
2	0,25	DiF	0,00	1,75	0,00	1,00	0,00	0,00	1,75	0,00
2	0,5	DiF	0,00	1,50	0,00	1,00	0,00	0,00	1,50	0,00
2	0,75	DiF	0,00	1,25	0,00	1,00	0,00	0,00	1,25	0,00
2	1	DuF	0,50	1,50	1,50	0,50	0,50	0,00	1,00	0,50
2	1,25	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	1,5	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	1,75	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	2	DuP	1,00	1,00	1,50	0,50	0,50	0,00	1,00	0,25
2	2,25	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	2,5	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	2,75	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	3	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	3,25	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	3,5	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	3,75	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	4	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	4,25	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	4,5	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	4,75	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2	5	ReF	1,00	0,00	1,00	0,00	1,00	0,00	1,00	0,00
2,25	0	DiF	0,00	2,25	0,00	1,00	0,00	0,00	2,25	0,00
2,25	0,25	DiF	0,00	2,00	0,00	1,00	0,00	0,00	2,00	0,00
2,25	0,5	DiF	0,00	1,75	0,00	1,00	0,00	0,00	1,75	0,00
2,25	0,75	DiF	0,00	1,50	0,00	1,00	0,00	0,00	1,50	0,00
2,25	1	DuF	0,75	1,75	1,75	0,50	0,50	0,00	1,25	0,50
2,25	1,25	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	1,5	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	1,75	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	2	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	2,25	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	2,5	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	2,75	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	3	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	3,25	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	3,5	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	3,75	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	4	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	4,25	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	4,5	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	4,75	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00
2,25	5	ReF	1,25	0,00	1,25	0,00	1,00	0,00	1,25	0,00

2,5	0	DiF	0,00	2,50	0,00	1,00	0,00	0,00	2,50	0,00
2,5	0,25	DiF	0,00	2,25	0,00	1,00	0,00	0,00	2,25	0,00
2,5	0,5	DiF	0,00	2,00	0,00	1,00	0,00	0,00	2,00	0,00
2,5	0,75	DiF	0,00	1,75	0,00	1,00	0,00	0,00	1,75	0,00
2,5	1	DuF	1,00	2,00	2,00	0,50	0,50	0,00	1,50	0,50
2,5	1,25	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	1,5	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	1,75	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	2	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	2,25	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	2,5	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	2,75	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	3	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	3,25	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	3,5	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	3,75	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	4	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	4,25	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	4,5	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	4,75	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,5	5	ReF	1,50	0,00	1,50	0,00	1,00	0,00	1,50	0,00
2,75	0	DiF	0,00	2,75	0,00	1,00	0,00	0,00	2,75	0,00
2,75	0,25	DiF	0,00	2,50	0,00	1,00	0,00	0,00	2,50	0,00
2,75	0,5	DiF	0,00	2,25	0,00	1,00	0,00	0,00	2,25	0,00
2,75	0,75	DiF	0,00	2,00	0,00	1,00	0,00	0,00	2,00	0,00
2,75	1	DuF	1,25	2,25	2,25	0,50	0,50	0,00	1,75	0,50
2,75	1,25	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	1,5	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	1,75	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	2	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	2,25	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	2,5	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	2,75	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	3	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	3,25	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	3,5	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	3,75	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	4	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	4,25	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	4,5	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	4,75	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
2,75	5	ReF	1,75	0,00	1,75	0,00	1,00	0,00	1,75	0,00
3	0	DiF	0,00	3,00	0,00	1,00	0,00	0,00	3,00	0,00
3	0,25	DiF	0,00	2,75	0,00	1,00	0,00	0,00	2,75	0,00
3	0,5	DiF	0,00	2,50	0,00	1,00	0,00	0,00	2,50	0,00
3	0,75	DiF	0,00	2,25	0,00	1,00	0,00	0,00	2,25	0,00
3	1	DuF	1,50	2,50	2,50	0,50	0,50	0,00	2,00	0,50
3	1,25	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	1,5	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	1,75	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	2	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	2,25	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	2,5	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	2,75	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	3	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	3,25	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	3,5	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	3,75	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	4	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	4,25	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	4,5	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	4,75	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00
3	5	ReF	2,00	0,00	2,00	0,00	1,00	0,00	2,00	0,00

3,25	0	DiF	0,00	3,25	0,00	1,00	0,00	0,00	3,25	0,00
3,25	0,25	DiF	0,00	3,00	0,00	1,00	0,00	0,00	3,00	0,00
3,25	0,5	DiF	0,00	2,75	0,00	1,00	0,00	0,00	2,75	0,00
3,25	0,75	DiF	0,00	2,50	0,00	1,00	0,00	0,00	2,50	0,00
3,25	1	DuF	1,75	2,75	2,75	0,50	0,50	0,00	2,25	0,50
3,25	1,25	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	1,5	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	1,75	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	2	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	2,25	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	2,5	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	2,75	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	3	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	3,25	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	3,5	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	3,75	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	4	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	4,25	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	4,5	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	4,75	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,25	5	ReF	2,25	0,00	2,25	0,00	1,00	0,00	2,25	0,00
3,5	0	DiF	0,00	3,50	0,00	1,00	0,00	0,00	3,50	0,00
3,5	0,25	DiF	0,00	3,25	0,00	1,00	0,00	0,00	3,25	0,00
3,5	0,5	DiF	0,00	3,00	0,00	1,00	0,00	0,00	3,00	0,00
3,5	0,75	DiF	0,00	2,75	0,00	1,00	0,00	0,00	2,75	0,00
3,5	1	DuF	2,00	3,00	3,00	0,50	0,50	0,00	2,50	0,50
3,5	1,25	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	1,5	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	1,75	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	2	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	2,25	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	2,5	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	2,75	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	3	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	3,25	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	3,5	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	3,75	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	4	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	4,25	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	4,5	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	4,75	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,5	5	ReF	2,50	0,00	2,50	0,00	1,00	0,00	2,50	0,00
3,75	0	DiF	0,00	3,75	0,00	1,00	0,00	0,00	3,75	0,00
3,75	0,25	DiF	0,00	3,50	0,00	1,00	0,00	0,00	3,50	0,00
3,75	0,5	DiF	0,00	3,25	0,00	1,00	0,00	0,00	3,25	0,00
3,75	0,75	DiF	0,00	3,00	0,00	1,00	0,00	0,00	3,00	0,00
3,75	1	DuF	2,25	3,25	3,25	0,50	0,50	0,00	2,75	0,50
3,75	1,25	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	1,5	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	1,75	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	2	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	2,25	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	2,5	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	2,75	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	3	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	3,25	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	3,5	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	3,75	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	4	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	4,25	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	4,5	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	4,75	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00
3,75	5	ReF	2,75	0,00	2,75	0,00	1,00	0,00	2,75	0,00

4	0	DiF	0,00	4,00	0,00	1,00	0,00	0,00	4,00	0,00
4	0,25	DiF	0,00	3,75	0,00	1,00	0,00	0,00	3,75	0,00
4	0,5	DiF	0,00	3,50	0,00	1,00	0,00	0,00	3,50	0,00
4	0,75	DiF	0,00	3,25	0,00	1,00	0,00	0,00	3,25	0,00
4	1	DuF	2,50	3,50	3,50	0,50	0,50	0,00	3,00	0,50
4	1,25	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	1,5	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	1,75	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	2	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	2,25	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	2,5	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	2,75	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	3	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	3,25	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	3,5	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	3,75	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	4	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	4,25	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	4,5	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	4,75	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4	5	ReF	3,00	0,00	3,00	0,00	1,00	0,00	3,00	0,00
4,25	0	DiF	0,00	4,25	0,00	1,00	0,00	0,00	4,25	0,00
4,25	0,25	DiF	0,00	4,00	0,00	1,00	0,00	0,00	4,00	0,00
4,25	0,5	DiF	0,00	3,75	0,00	1,00	0,00	0,00	3,75	0,00
4,25	0,75	DiF	0,00	3,50	0,00	1,00	0,00	0,00	3,50	0,00
4,25	1	DuF	2,75	3,75	3,75	0,50	0,50	0,00	3,25	0,50
4,25	1,25	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	1,5	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	1,75	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	2	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	2,25	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	2,5	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	2,75	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	3	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	3,25	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	3,5	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	3,75	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	4	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	4,25	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	4,5	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	4,75	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,25	5	ReF	3,25	0,00	3,25	0,00	1,00	0,00	3,25	0,00
4,5	0	DiF	0,00	4,50	0,00	1,00	0,00	0,00	4,50	0,00
4,5	0,25	DiF	0,00	4,25	0,00	1,00	0,00	0,00	4,25	0,00
4,5	0,5	DiF	0,00	4,00	0,00	1,00	0,00	0,00	4,00	0,00
4,5	0,75	DiF	0,00	3,75	0,00	1,00	0,00	0,00	3,75	0,00
4,5	1	DuF	3,00	4,00	4,00	0,50	0,50	0,00	3,50	0,50
4,5	1,25	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	1,5	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	1,75	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	2	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	2,25	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	2,5	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	2,75	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	3	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	3,25	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	3,5	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	3,75	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	4	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	4,25	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	4,5	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	4,75	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00
4,5	5	ReF	3,50	0,00	3,50	0,00	1,00	0,00	3,50	0,00

4,75	0	DiF	0,00	4,75	0,00	1,00	0,00	0,00	4,75	0,00
4,75	0,25	DiF	0,00	4,50	0,00	1,00	0,00	0,00	4,50	0,00
4,75	0,5	DiF	0,00	4,25	0,00	1,00	0,00	0,00	4,25	0,00
4,75	0,75	DiF	0,00	4,00	0,00	1,00	0,00	0,00	4,00	0,00
4,75	1	DuF	3,25	4,25	4,25	0,50	0,50	0,00	3,75	0,50
4,75	1,25	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	1,5	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	1,75	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	2	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	2,25	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	2,5	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	2,75	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	3	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	3,25	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	3,5	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	3,75	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	4	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	4,25	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	4,5	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	4,75	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
4,75	5	ReF	3,75	0,00	3,75	0,00	1,00	0,00	3,75	0,00
5	0	DiF	0,00	5,00	0,00	1,00	0,00	0,00	5,00	0,00
5	0,25	DiF	0,00	4,75	0,00	1,00	0,00	0,00	4,75	0,00
5	0,5	DiF	0,00	4,50	0,00	1,00	0,00	0,00	4,50	0,00
5	0,75	DiF	0,00	4,25	0,00	1,00	0,00	0,00	4,25	0,00
5	1	DuF	3,50	4,50	4,50	0,50	0,50	0,00	4,00	0,50
5	1,25	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	1,5	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	1,75	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	2	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	2,25	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	2,5	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	2,75	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	3	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	3,25	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	3,5	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	3,75	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	4	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	4,25	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	4,5	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	4,75	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00
5	5	ReF	4,00	0,00	4,00	0,00	1,00	0,00	4,00	0,00

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