

DISSERTATION PROPOSAL

**ESSAYS ON THE EFFECTS OF INFORMATION TECHNOLOGY
ON ECONOMIC ACTIVITY AND BUSINESS PROCESS COORDINATION**

Joung Yeon (JY) Kim

Ph.D. Candidate

Purdue University

Krannert School of Management

403 West State Street

West Lafayette, IN 47907-2056

kim189@purdue.edu

December 30, 2005

TABLE OF CONTENTS

1. INTRODUCTION.....	3
2. OBSOLESCENCE AND CONSUMER IMPATIENCE IN IT PROCUDTS PRICING DECISIONS.....	5
2.1. Introduction and Problem Motivation.....	5
2.2. Model Formulation and Assumptions.....	7
2.3. Consumer’s Choices.....	10
2.4. Producer’s Choices.....	13
2.5. Measuring Consumer Time Preference: Intel Case Study.....	21
2.6. Conclusions and Contributions.....	24
3. YIELD MANAGEMENT FOR IT SERVICE INDUSTRY THROUGH E-LANCING ...	25
3.1. Introduction and Problem Motivation.....	25
3.2. Related Literature.....	30
3.3. Model Development and Assumptions.....	32
3.4. Numerical Computation.....	39
3.4 Research Status and Contributions.....	44
4. WINNER DETERMINATION IN IT SERVICE ONLINE AUCTIONS.....	47
4.1. Introduction and Problem Motivation.....	48
4.2. Theoretical Basis and Research Hypotheses.....	48
4.3. Research Methods.....	52
4.4 Research Status and Contributions.....	53
5. REFERENCES.....	56
6. APPENDICES.....	63

1. INTRODUCTION

The essays in this dissertation proposal examine how Information Technology (IT) affects economic activities and business process coordination. The first essay considers the pricing issues of sequential versions of IT-intensive products. Pricing the overlapping generations of an IT product line is a complicated task. IT-intensive product manufacturer must decide on prices and the extent of innovation in order to maximize profit by making both versions attractive to consumers. I propose an analytical model to examine the effect of product obsolescence and consumer time preference, the most important characteristics of IT products, on the pricing decision of IT-intensive products such as software and computer hardware. I derive the optimal pricing strategies for overlapping generations and examine the nature of equilibrium solutions. The presented analytical model can be also used to measure the consumer time preference for the given product. Using Intel's microprocessor pricing data and the analytical solution, Intel's practice is analyzed.

The second and third essays address two different issues emerging in online IT service marketplaces. The second essay deals with the strategic use of reverse online auctions, a typical e-lancing tool to assign jobs to workers, from the IT human capital management perspective. Given the difficulty of adjusting a firm's IT workforce capacity, the nature of IT projects, demand uncertainty, and growing competition among IT vendors, IT service firms cannot avoid occasionally holding some excess workforce. By utilizing its excess workforce by means of e-lancing, a service provider can prevent price competition in the conventional channel, reach customers in the online channel, and hence increase profits. I reduce the IT human capital utilization problem to the stochastic knapsack problem and employ Markov decision theory in

order to obtain the global optimal admission control over the set of all policies. The model considers an IT service firm which receives projects through two channels: a conventional procurement channel and an online spot market such as *Elance Online* (www.elance.com). The proposed model determines optimal admission policies to maximize the expected total discounted profit over infinite horizon. I illustrate numerical examples to characterize the structure of optimal policy.

While the second essay focuses on the IT service provider's perspective, the second essay considers the client's problem in an online IT service marketplace. The second essay investigates patterns of bid evaluation in an online auction market for IT service where a large percentage of contracts consist of offshore software development. I propose a conceptual model and empirically test determinants for winner selection for a successful system development in an online auction for e-lancing. Data on recently closed 2,432 projects and related 22,115 bids in the software and technology category in an online service marketplace were collected and will be used to test the relationships between a bid's different attributes and the likelihood of winning the auction. Given the current lack of guidance for clients to choose the "right" winner, the present study will contribute by providing clients with efficient bid evaluation strategies for selecting the best bid likely to result in a successful project. Furthermore, given the high percentage of auctions closing without a contract, the guidelines for bid evaluation will help lower bid evaluation costs thereby increasing the number of contracts awarded.

2. OBSOLESCENCE AND CONSUMER IMPATIENCE IN IT PRODUCTS PRICING DECISIONS

2.1. Introduction

Pricing the overlapping generations of an IT-intensive product line is a complicated task. Pricing a new version too low may result in a cannibalization of the old version product. If the price of the new version is too high, the new version will fail to attract enough consumers. I investigate this pricing issue by modeling a game between consumer's self selection and the IT product manufacturer's profit maximization. The model considers a monopolist who sells sequential and overlapping generations. The focus in this paper is particularly on modeling the effects of obsolescence and consumer patience, two of the most important characteristics of IT goods, on the optimal pricing policy. The analytic analysis answers the optimal pricing strategies of successive generations of an IT-intensive good. I also examine the Intel's PC microprocessors data in the context of the analytical result.

The IT-intensive products such as computer components or software are characterized by the rapid, sequential introduction of new and improved versions, which causes a significant amount of product obsolescence. The rapid introduction of IT intensive product should be distinguished from the sequential introduction of other durable goods because of the significant performance improvement at each introduction (Dhebar, 1996). Consumers purchase a new version of non-IT durable good when the current one does not function properly any more. In other words, the motivation of non-IT durables purchases is depreciation. Depreciation of fixed assets is based on technical characteristics such as its performance and physical life (Moonitz, 1943). By contrast, obsolescence, the motivation of IT-intensive durables purchases, is based on

economic and technological change. Levinthal and Purohit (1989) define product obsolescence as the relative loss in value due to styling changes (style obsolescence) or quality improvement (functional obsolescence). The decrease in value by obsolescence is resulted from its relatively inferior quality, compared by a superior product in the market, not by itself being less productive. Therefore, the extent of obsolescence is highly associated with the extent of the improvement in the new version.

Another important characteristic of IT-intensive products that I focus on in this paper is durability. Due to the durability of IT durables, consumers consider purchases as capital investments and assess the asset's future value as well as the present value like any capital assets. Note that given the fast technological improvement in IT-intensive markets, consumers face a "buy or wait" decision problem where they have to decide whether to buy and pay for the currently available product now or to wait for the improved product available in the future. In such consumer's intertemporal tradeoff decision, consumers' discount factor plays a key role to assess present value of the future asset. The discount rate can be interpreted as the rate of impatience. Consumers who have lower discount factor value products in the present more than products available in the future, therefore are more impatient. Most economic and marketing research assumes the identical discount rate for all products. However, it is hard to apply this assumption when the focus is on IT products. Certainly, consumers have different levels of impatience for computers and for furniture. Consumers have different discount factor over different industry and even over the different products within the same industry. Following the Winer (1997)'s argument that consumers have different discount rate for different products, I focus on the product-level discounting, specifically, technology specific discounting.

2.2. Model formulation and assumptions

I extend the 2-period monopoly models proposed by Dhebar (1994) and Kornish (2001). I consider a monopolist who faces decisions on the prices of overlapping generations of an IT intensive good. A firm sells only Version 1 in Period I. The firm introduces a new and improved product, Version 2, and sells it along with Version 1 in Period II. Allowing both versions in Period II is a more realistic setting that reflects the current markets of IT goods such as microprocessors. The timeline is illustrated in Figure 2.1.

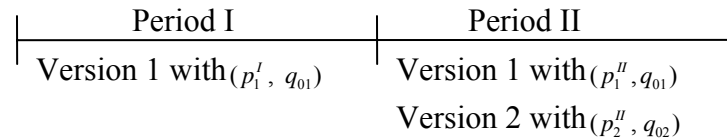


Figure 2.1. Model timeline

The monopoly setting is not restrictive because the model focuses on the introductory prices of the products (Purohit, 1994). For example, the incumbent firm has a monopoly in many high-tech markets until the patent expires or competitors are able to introduce their own versions of the product. In the particular case focused in this paper, Intel has a larger market share in the high end processors market than in the low end processors market. Intel has maintained 85 to 90% market share of sales of microprocessors for IBM-compatible PCs over the time span of my data, 1996-1999 (Computer Reseller News, Jun/29/1998 and Microprocessor Report, Nov/16/1998). Intel's dominant market share is even higher in high-end processor markets than in the aggregated market (Computerworld Dec/12/1998). Considering the fact that the high end processor of today is moving into the low end processors category in the future, it is not difficult

to see that Intel has a monopoly power at the new processor's introduction. Although their focus was primarily on the 386 and 486 microprocessors, an empirical study by Wilson and Warren-Boulton (1995) also supports that Intel had monopoly power in a distinct market for high-end microprocessors. Their pricing data show that the effects of entry were localized only at the low end of Intel's product line.

Note that microprocessors and other computer components are purchased by intermediaries (i.e., computer manufacturers) not directly by end users. I assume that these intermediaries are in the perfect competition and produce homogeneous products (i.e., PCs) with the purchased microprocessors. It allows us to regard the demand of intermediaries as the representation of the end users' demand. A consumer may buy zero or one of the products available in each period and consumers don't participate in secondhand markets. I assume that the consumer's valuation for the product is separable in quality q and consumer index v , which is standard in the product-positioning literature (Moorthy and Png, 1992; Dhebar, 1994; and Kornish, 2001). The consumers' willingness to pay of generation j given that he holds generation i is given as $W(q_{ij}, v) = f(q_{ij}) \cdot g(v)$. The incremental benefit of version j given that the consumer holds version i , $f(q_{ij})$, is increasing in q_{ij} . The consumer's valuation for a given product, $g(v)$, is strictly increasing in v and normalized in $[0,1]$. Consumer index v is uniformly and continuously distributed over the interval $[0,1]$. I denote δ as the one-period discount factor. All consumers share a common discount rate. Summary of notations is provided in Table 2.1.

The model focuses on the rapid technological improvement and hence I assume technology improving in present value: $f(q_{01}) < \delta f(q_{02})$. This assumption particularly characterizes IT product. In IT product markets, the manufacturer introduces a low quality first and a higher quality later because the higher quality is available later than lower quality. However, in non-IT

durable good markets, manufacturer introduces higher quality first and lower quality later in order to prevent cannibalization, i.e. the seller delay the lower quality to keep the high-value consumers purchasing low-end products. For example, hard copy books are released earlier than paperback versions, theater version of movie is released to capture high-value consumers who enjoy dynamic sound and screen nearly a year before the same movie is released at DVD rental store (Riggins and Narasimhan 2001).

q_{ij}	The incremental quality level from generation i to generation j
v	Consumer index
$W(q_{ij}, v)$	Consumer's willingness to pay for given q_{ij} and v .
$f(q_{ij})$	The incremental benefit of version j given that the consumer holds version i
$g(v)$	Consumer's valuation for the given product
δ	The one-period discount factor
p_1^I	Price of Version 1 in Period I
p_1^{II}	Price of Version 1 in Period II
p_2^{II}	Price of Version 2 in Period II
R_k^L	Revenue of Period k in Region L
R_k^{L*}	Equilibrium revenue of Period k in Region L

Table 2.1 Summary of Notations

Another assumption is that the monopolist never set the price of Version 1 in Period II greater than the previous price in Period I, i.e., $p_1^I \geq p_1^{II}$. It implies that the monopolist first sells to high-end-consumers and then cuts the price later to attract the low-end-consumers. The skimming

pricing policy for each product has been well-accepted as the optimal pricing strategy both by practitioners and academics in durable good markets such as the video-games market (Nair, 2004). I also assume there is no repeat purchase of the products with the same quality. That is, consumer who buys Version 1 in Period I will never buy Version 1 again in Period II.

2.3. Consumer's choices

In this section, I describe consumers' self selection of whether to purchase the product or to wait without a purchase. Depending on the consumer's type, $v \in [0,1]$, a consumer will maximize his surplus by deciding to purchase or not in each period. I first derive the following five possible alternatives in consumer's optimal purchasing strategies. The detailed derivations are provided in the appendix.

A consumer will not purchase anything in either period if and only if

$$\{v : 0 \leq v \leq 1, g(v) < \min\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^{II}}{f(q_{01})}, \frac{p_2^{II}}{f(q_{02})}, \frac{p_1^I + \delta p_2^{II}}{f(q_{01}) + \delta f(q_{12})}\right)\}. \quad (1)$$

A consumer will purchase Version 1 in the second period only if and only if

$$\{v : 0 \leq v \leq 1, \frac{p_1^{II}}{f(q_{01})} \leq g(v) < \min\left(\frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}, \frac{p_1^I + \delta p_2^{II} - \delta p_1^{II}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}\right)\}. \quad (2)$$

A consumer will purchase Version 1 in the first period only if and only if

$$\{v : 0 \leq v \leq 1, \max\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}\right) \leq g(v) < \min\left(\frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II}}{f(q_{12})}\right)\}. \quad (3)$$

A consumer will purchase Version 2 in the second period only if and only if

$$\{v : 0 \leq v \leq 1, \max\left(\frac{p_2^{II}}{f(q_{02})}, \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}\right) \leq g(v) < \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\}. \quad (4)$$

A consumer will purchase Version 1 in the first period and Version 2 in the second period if and only if

$$\{v : 0 \leq v \leq 1, \max(\frac{p_1^I + \delta p_2^II}{f(q_{01}) + \delta f(q_{12})}, \frac{p_2^II}{f(q_{12})}, \frac{p_1^I + \delta p_2^II - \delta p_1^II}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}, \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}) \leq g(v) \}. \quad (5)$$

Since these five strategies must form a mutually exclusive and collectively exhaustive partition of the $g(v)$ line (Kornish, 2001), I partition the (p_1^I, p_1^II, p_2^II) space into three regions such that these regions cover the entire half-space and satisfy $p_1^I \leq p_1^II$.

Region I (moderate pricing of two versions) :

$$\text{If } \frac{f(q_{02})}{f(q_{01})} p_1^I \leq p_2^II \leq \frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1^I \text{ and } p_1^II \leq p_1^I \quad (6)$$

Region II (relatively high pricing of version 2) :

$$\text{if } \frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1^I \leq p_2^II \text{ and } p_1^II \leq p_1^I \quad (7)$$

Region III (relatively low pricing of version 2) :

$$\text{If } p_2^II \leq \frac{f(q_{02})}{f(q_{01})} p_1^I \text{ and } p_1^II \leq p_1^I. \quad (8)$$

Based on the above partition, consumer's purchase patterns for any given set of prices of two overlapping versions are analyzed. The detailed proof of Proposition 1 is provided in the appendix.

PROPOSITION 1. *For each of three regions defined above, there exist the following segments of the consumer group.*

In Region I, there exist five consumers purchase patterns:

- The consumers with $\{v: g(v) \leq \frac{P_1^{\text{II}}}{f(q_{01})}\}$ buy nothing;

- The consumers with $\{v: \frac{P_1^{\text{II}}}{f(q_{01})} \leq g(v) < \frac{P_1^{\text{I}} - \delta P_1^{\text{II}}}{(1-\delta)f(q_{01})}\}$ buy only Version 1 in Period II;

- The consumers with $\{v: \frac{P_1^{\text{I}} - \delta P_1^{\text{II}}}{(1-\delta)f(q_{01})} \leq g(v) < \frac{\delta P_2^{\text{II}} - P_1^{\text{I}}}{\delta f(q_{02}) - f(q_{01})}\}$ buy only Version 1 in Period I;

- The consumers with $\{v: \frac{\delta P_2^{\text{II}} - P_1^{\text{I}}}{\delta f(q_{02}) - f(q_{01})} \leq g(v) < \frac{P_1^{\text{I}}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\}$ buy only Version 2 in

Period II;

- The consumers with $\{v: \frac{P_1^{\text{I}}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \leq g(v)\}$ buy Version 1 in Period I and Version 2

in Period II.

In Region II, there exist four purchase patterns:

- The consumers with $\{v: g(v) < \frac{P_1^{\text{II}}}{f(q_{01})}\}$ buy nothing;

- The consumers with $\{v: \frac{P_1^{\text{II}}}{f(q_{01})} \leq g(v) < \frac{P_1^{\text{I}} - \delta P_1^{\text{II}}}{(1-\delta)f(q_{01})}\}$ buy only Version 1 in Period II;

- The consumers with $\{v: \frac{P_1^{\text{I}} - \delta P_1^{\text{II}}}{(1-\delta)f(q_{01})} \leq g(v) < \frac{P_2^{\text{II}}}{f(q_{12})}\}$ buy only Version 1 in Period I;

- The consumers with $\{v: \frac{P_2^{\text{II}}}{f(q_{12})} \leq g(v)\}$ buy Version 1 in Period I and Version 2 in Period II.

In Region III, there are three purchase patterns:

- The consumers with $\{v: g(v) < \frac{P_2^{\text{II}}}{f(q_{02})}\}$ buy nothing;

- The consumers with $\{v: \frac{P_2^{\text{II}}}{f(q_{02})} \leq g(v) < \frac{P_1^{\text{I}}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\}$ buy only Version 2 in Period

II;

- The consumers with $\{v : \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \leq g(v)\}$ buy Version 1 in Period I and Version

2 in Period II.

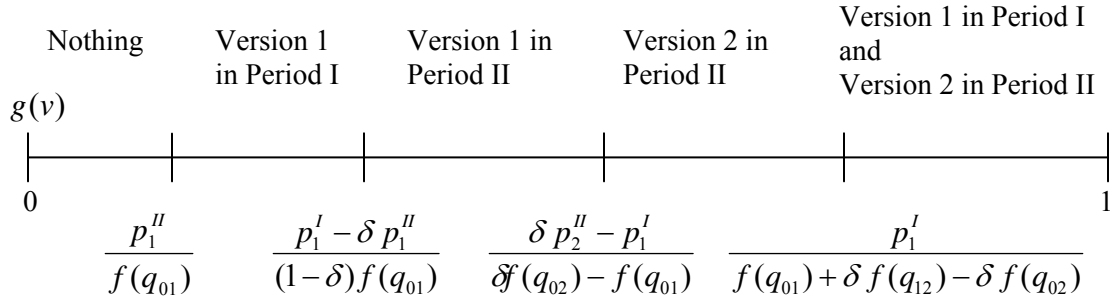


Figure 2.2. Purchase pattern in Region I

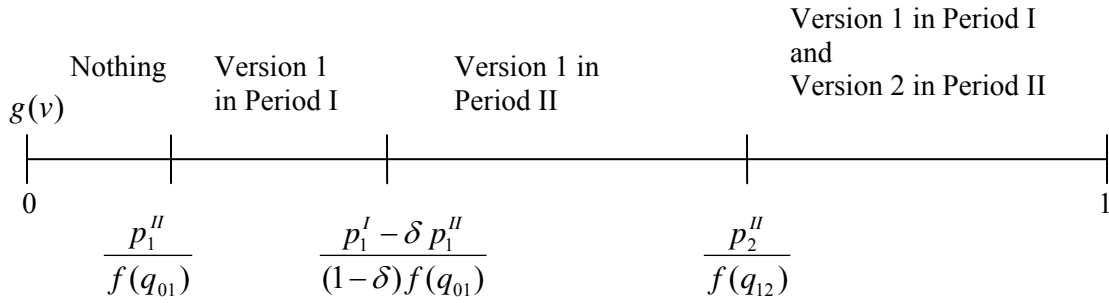


Figure 2.3. Purchase pattern in Region II

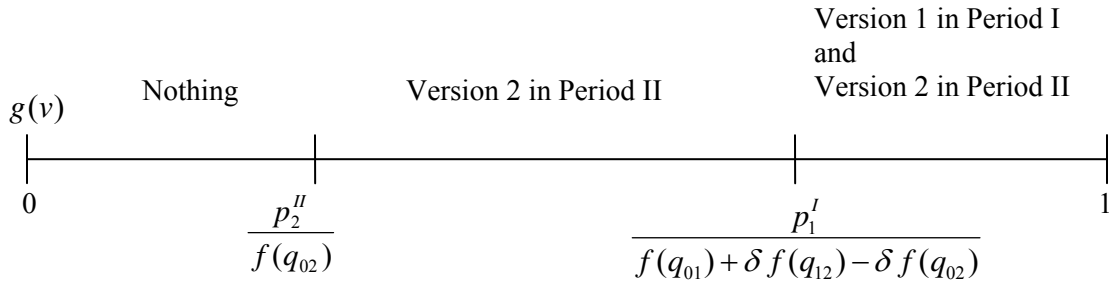


Figure 2.4. Purchase pattern in Region III

2.4. Producer's Problem

Based on the consumer purchase pattern analyzed in the previous section, I solve the two-period game between consumers and firm. Each of three regions partitioned in previous section

has a different objective function of the producer's profit maximization problem because each region has a different consumer purchase pattern. I work backward and begin with Period II. The boundary conditions defining each region serve as constraints in Period II problem. Period II solutions are the optimal prices in Period II and these are functions of the price in Period I. Any conditions required to satisfy the potential solutions in Period II are handed over to the set of constraints of Period I problem.

In Region I, since $g(v) = v$ and v is uniformly and continuously distributed over the interval $[0,1]$, consumers with consumer index v in the set $[\frac{p_1''}{f(q_{01})}, \frac{p_1' - \delta p_1''}{(1-\delta)f(q_{01})}]$ purchase Version 1 and consumers with v in $[\frac{\delta p_2'' - p_1'}{\delta f(q_{02}) - f(q_{01})}, 1]$ purchase Version 2 in Period II. The corresponding

demands are $(\frac{p_1' - \delta p_1''}{(1-\delta)f(q_{01})} - \frac{p_1''}{f(q_{01})})$ for Version 1 and $(1 - \frac{\delta p_2'' - p_1'}{\delta f(q_{02}) - f(q_{01})})$ for Version 2. The

firm's optimal choices of prices are obtained from the following revenue maximizing problem.

$$R_2^*(p_1', p_1'', p_2'') = \max_{p_1'', p_2''} p_1'' \left(\frac{p_1' - \delta p_1''}{(1-\delta)f(q_{01})} - \frac{p_1''}{f(q_{01})} \right) + p_2'' \left(1 - \frac{\delta p_2'' - p_1'}{\delta f(q_{02}) - f(q_{01})} \right) \quad (9)$$

subject to non-negative price and demand constraints

$$p_1'', p_2'' \geq 0 \quad (10)$$

$$\frac{\delta p_2'' - p_1'}{\delta f(q_{02}) - f(q_{01})} \leq 1 \quad (11)$$

and the boundary conditions of Region I

$$\frac{f(q_{02})}{f(q_{01})} p_1' \leq p_2'' \leq \frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1' \quad (12)$$

$$p_1'' \leq p_1'. \quad (13)$$

In Period I, consumers in two sets $\left[\frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})}, \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})} \right]$ and $\left[\frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}, 1 \right]$ purchase Version 1 and the demand for Version 1 is $\left(\frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})} - \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} \right) + \left(1 - \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right)$. Then the firm's revenue

maximization problem is:

$$R_1^* = \max_{p_1^I} p_1^I \left[\left(\frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})} - \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} \right) + \left(1 - \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right) \right] + \delta R_2^I(p_1^I, p_1^{II}(p_1^I), p_2^{II}(p_1^I)) \quad (14)$$

subject to

$$p_1^I \geq 0 \quad (15)$$

$$\frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \leq 1 \quad (16)$$

Similarly, the producer's profit maximization problems in Region II and III are formed and presented in the appendix. From those profit maximization problems in the three regions, the following seven potential equilibrium solutions are obtained. The Proposition 2 contains these seven potential solutions and its proofs are presented in the appendix. Note that each potential equilibrium strategy imposes a certain condition on the relationship between the extent of obsolescence that consumers realize, $f(q_{01})/f(q_{02})$, and the discount factor, δ , in order to be feasible. The revenue generated by each potential solution is depicted in Figure 2.5.

PROPOSITION 2. The subgame perfect equilibrium price in each region is the one which

generates the greatest revenue among the following potential solutions $(p_1^{I^}, p_1^{II^*}, p_2^{II^*})$:*

$$\left(\frac{f(q_{01})(1-\delta)}{2+\delta}, \frac{1}{2} p_1^{I^*}, \frac{p_1^{I^*} f(q_{02})}{f(q_{01})} \right) \quad \text{if } \frac{f(q_{01})}{f(q_{02})} \geq \frac{3\delta^2}{(1+2\delta)} \quad \text{in Region I} \quad (\text{RI-1})$$

$$\left(\frac{f(q_{01})(\delta f(q_{02}) - f(q_{01}))}{2\delta f(q_{02}) - f(q_{01})}, \frac{1}{2} p_1^{I^*}, \frac{p_1^{I^*} f(q_{02})}{f(q_{01})} \right) \quad \text{if } 2\delta - 1 \leq \frac{f(q_{01})}{f(q_{02})} < \frac{3\delta^2}{(1+2\delta)} \quad \text{or } \frac{2\delta(1+2\delta)}{3(1+\delta)} < \frac{f(q_{01})}{f(q_{02})}.$$

in Region I (RI-2)

$$\left(\frac{f(q_{01})(1-\delta)(\delta f(q_{02}) - f(q_{01}))}{2\delta f(q_{02}) - f(q_{01}) - \delta f(q_{01})}, \frac{1}{2} p_1^{I^*}, \frac{f(q_{12}) p_1^{I^*}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right) \quad \text{if } \frac{q_{01}}{q_{02}} < \frac{2\delta}{1+\delta}.$$

in Region I (RI-3)

$$\left(\frac{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}{2}, \frac{p_1^{I^*}}{2}, \frac{f(q_{12})}{2} \right) \quad \text{if } f(q_{01})/f(q_{02}) < 4\delta/(8-7\delta+3\delta^2)$$

in Region II (RII-1)

$$\left(\frac{(1-\delta)}{(2-\delta)} f(q_{01}), \frac{p_1^{I^*}}{2}, \frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1^{I^*} \right) \quad \text{in Region II} \quad (\text{RII-2})$$

$$\left(\frac{f(q_{01})}{2}, p_1^{II^*} \leq p_1^{I^*}, \frac{f(q_{02})}{f(q_{01})} p_1^{I^*} \right) \quad , \text{ if } f(q_{01})/f(q_{02}) > 2\delta \text{ (i.e. } \delta \in (0, 0.5])$$

in Region III (RIII-1)

$$\left(\frac{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}{2}, p_1^{II^*} \leq p_1^{I^*}, \frac{f(q_{02})}{f(q_{01})} p_1^{I^*} \right) \quad \text{in Region III} \quad (\text{RIII-2})$$

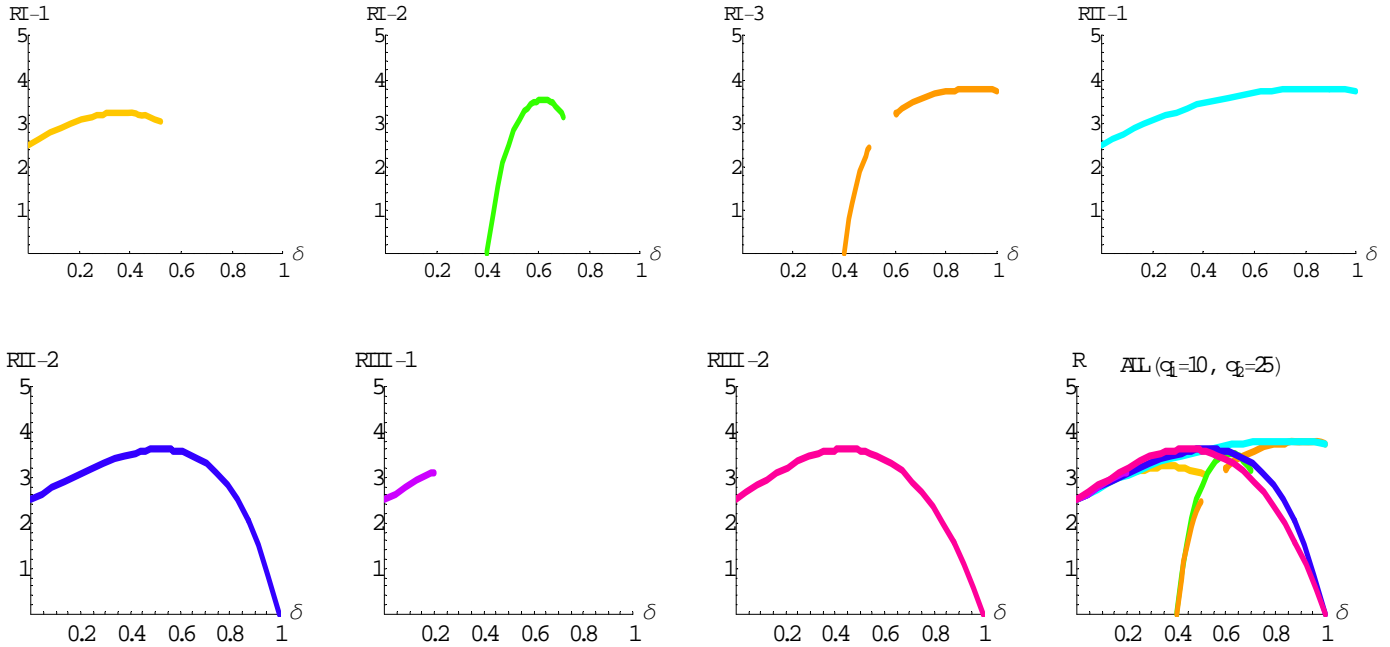


Figure 2.5. The firm's revenues at seven potential equilibriums

The firm will choose the strategy which generates the largest revenue among these equilibriums given the discount factor and the extent of quality improvement. Due to the complexity of equilibrium solutions, it is impossible to determine the global optimal solution in a symbolic form. Therefore, I conducted a comparative statics analysis of the degree of obsolescence, $f(q_{01})/f(q_{02})$ (Figure 2.6) as well as of the discount factor, δ (Figure 2.7.). The sensitivity analysis has been conducted and the result shows that two solutions (RII-1) and (RIII-2) always comprise the highest envelope among the seven revenue functions. In other words, only either of these two solutions can be the dominant strategy given the varying value of $f(q_{01})/f(q_{02})$ and δ . The key result is that the solution (RII-1) is the dominant strategy as the discount factor increases (i.e., consumer are more patient) or the degree of obsolescence that

consumers realize increases (See Figure 2.6 and Figure 2.7). The solution (RIII-2) is preferred over any other strategies when the opposite is true.

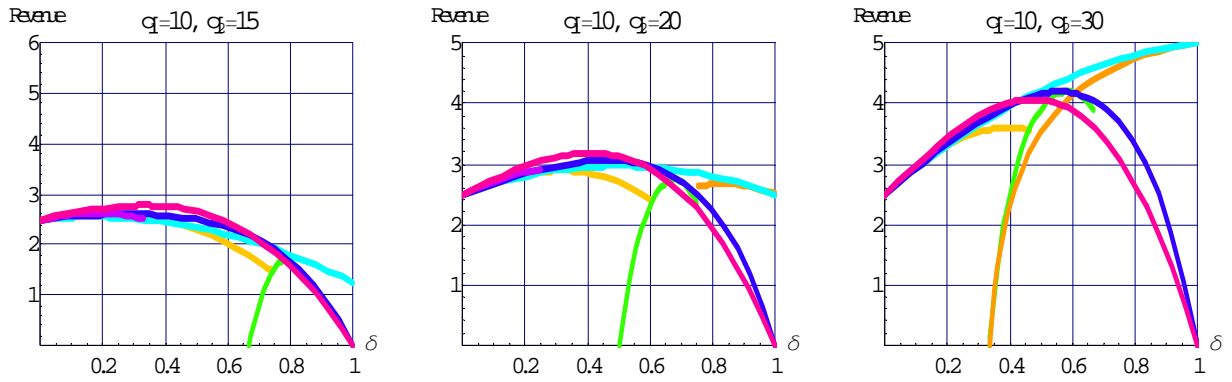


Figure 2.6. Revenue changes with the extent of obsolescence

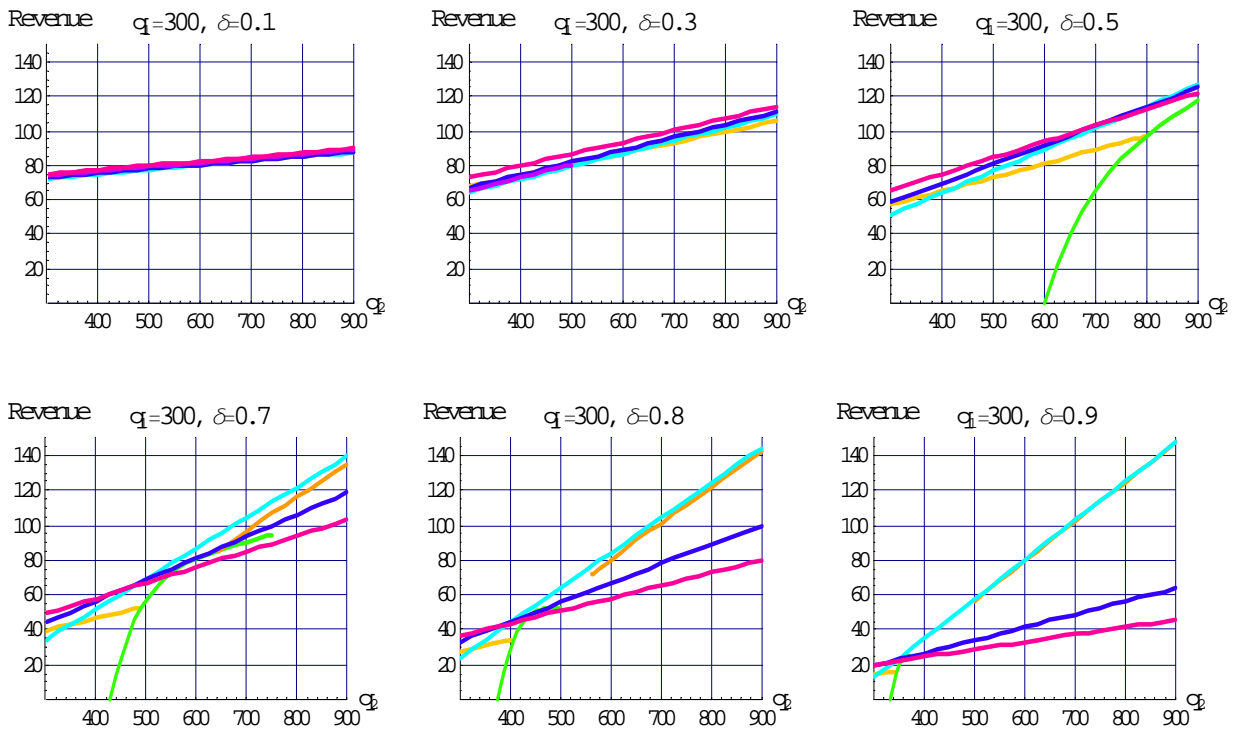


Figure 2.7. Revenue changes with the discount factor

Since one of two solutions can be the optimal strategy depending on the level of consumer patience and the degree of obsolescence, I obtain the conditions under which each one is preferred. Also, its graphical representation is provided in Figure 2.8 to help understand.

PROPOSITION 3. *There exists a threshold for the extent of innovation that characterizes the preferred equilibrium. RII-1 is preferred to RIII-2 if*

$$\frac{f(q_{01})}{f(q_{02})} \leq \frac{(3-\delta)\delta^2}{1+\delta} \text{ when } \delta \in (0, \frac{1}{3}]$$

or if $\frac{f(q_{01})}{f(q_{02})} \leq \frac{4\delta}{8-7\delta+3\delta^2}$ when $\delta \in [\frac{1}{3}, 1)$.

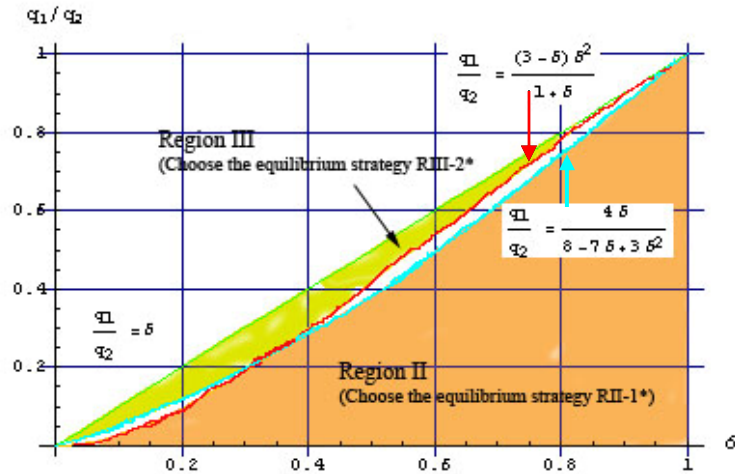
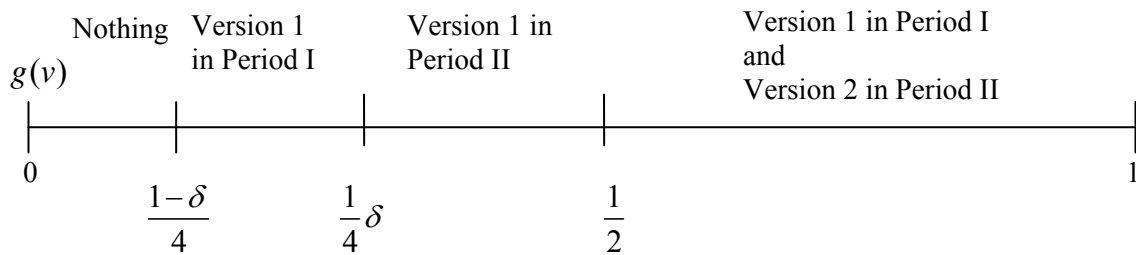


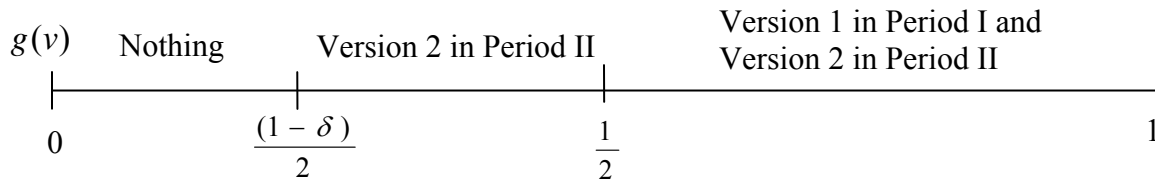
Figure 2.8. Graphical representation of Proposition 3

The interpretation of Proposition 3 is that, given the level of consumer's impatience, as consumers realize higher degree of obsolescence from the old version, their willingness to pay for the new product increases and the optimal strategy for the firm is pricing the new version relatively high (choosing Region II). Also, given the extent of technological improvement in the new version, as consumers are more patient (i.e., higher discount factor), their valuation of the

future version increases, hence the best strategy for the firm is pricing the new version relatively high (choosing Region II). Region III is vice versa. It is noticeable that the strategies RII-1 and RIII-2, which comprise the highest envelopes in Figure 2.6 and Figure 2.7, generate the consumer purchase patterns where half of the total demand buys both versions in both periods, i.e., the old version in the first period as well as the new version in the second period (See Figure 2.9).



(a) Equilibrium purchase pattern with the solution (RII-1)



(b) Equilibrium purchase pattern with the solution (RIII-2)

Figure 2.9. Equilibrium purchase patterns

2.5. Measuring Consumer Time Preference: Intel Case Study

Using Intel's CPU chip data and the analytical model presented in the previous sections, Intel's pricing strategy is analyzed and the consumer's patience in the CPU market is measured. Data on the performance (i.e., quality) and the introduction dates of Intel microprocessors were collected. The snapshot of data is shown in Figure 2.10 indicating that Intel has been introducing faster and better microprocessors for years. Each data point represents the introduction date and the performance measure of a given microprocessor type. Note that the performance or quality of microprocessors is usually measured by many different industry-standard benchmark programs. Each of benchmark software tests a different aspect of microprocessor capabilities and hence the overall performance is difficult to be represented as a single measure. To compare the quality of microprocessors, I use Intel's iCOMP Index 2.0 which is a collection of benchmarks providing a simple relative measure of microprocessor performance. iCOMP Index 2.0 rating is based on the technical categories including integer, floating-point, and multimedia (www.Intel.com).

Data on the prices of microprocessors were also collected and the complicated pricing pattern of Intel's microprocessors over the past five years is illustrated in Figure 2.11. Each price data point was collected from The Wall Street Journal and IT-related news providers such as CNET and ZDNet. For a given processor type, the first data point represents the price on its introduction date but the last data point doesn't mean that the product is not sold after that point. The data demonstrates that Intel is implementing a skimming pricing strategy whereby the price is reduced over time for a given microprocessor type. However, the focus is on analyzing how the introductory prices of overlapping generations are related to each other, which is not easily observable at the first glance from Figure 2.11.

The discount factor for CPU chip, which I intend to measure in this paper, is not available although the rate of discount for laptop computers has been measured by Sultan and Winer

(1993). Since discount rates for different products are different each other, the discount rate for laptop is not applicable to the PC microprocessor's case. Certainly, the discount rate for the microprocessor chips is different from the economic discount rate which captures time preferences for money (Sultan and Winer 1993; Winer 1997). To measure discount factor, 36 pairs of two sequential versions are formed only if Version 1 was still sold on the introduction date of Version 2. Although it is difficult, in practice, to identify the shape of the function $f(q)$, I assume $f(q)=q$ and $q=iCOMP$ Index for simplicity. It is assumed that Intel has played the equilibrium strategy.

Depending on the discount rate value, each pair of versions is categorized into Region I, II, and III according to the region partitioning criteria, equation (6), (7), and (8). The same set of pairs of versions is categorized into each region according to the prescription in Proposition 4. Assuming that Intel's pricing strategy is the optimal strategy, given a pair of versions, the regions categorized by the two methods, the region partitioning criteria and the prescription in Proposition 3, must be identical. Therefore, the discount factor for microprocessors was selected when a given value of discount factor achieves the maximum number of pairs with the matched regions from the first and second categorizations. When the value of discount factor is between 0.53 and 0.57, the number of pairs with the matched regions was the maximum. Among 39 pairs, 21 pairs show the matched regions when $\delta = 0.53 \sim 0.57$. When the discount factor value is greater than 0.57 or smaller than 0.53, the number of pairs with the matched regions gets smaller. Among those 21 pairs, 20 pairs belong to Region III and only one pair falls into Region II. From this result it can be inferred that Intel has played the optimal pricing strategy (RIII-2), pricing the new version relatively cheaper, for the most cases.

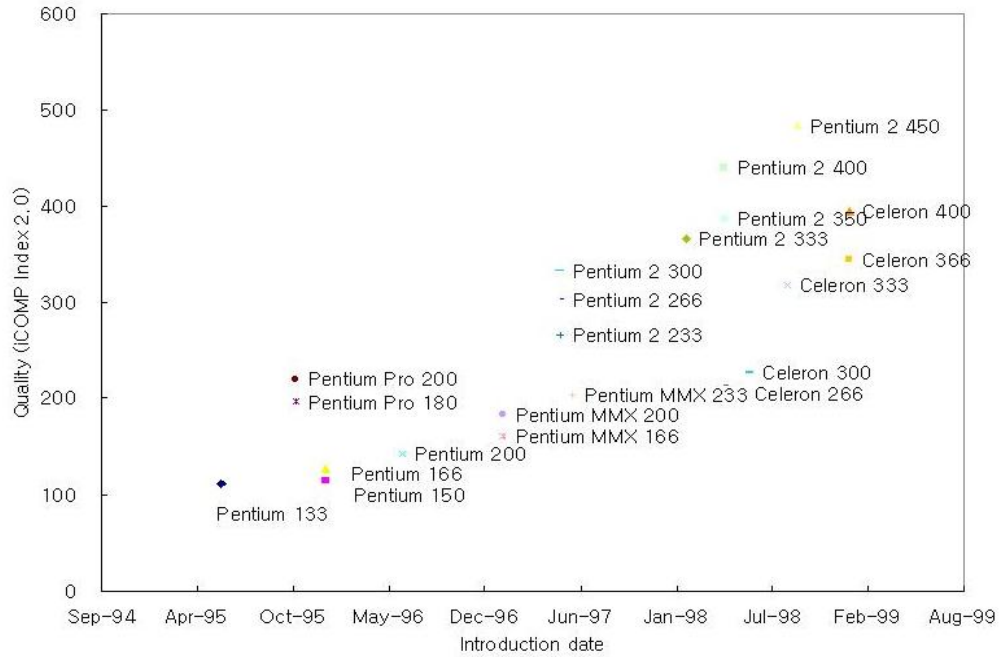


Figure 2.9. Quality improvement of Intel microprocessors

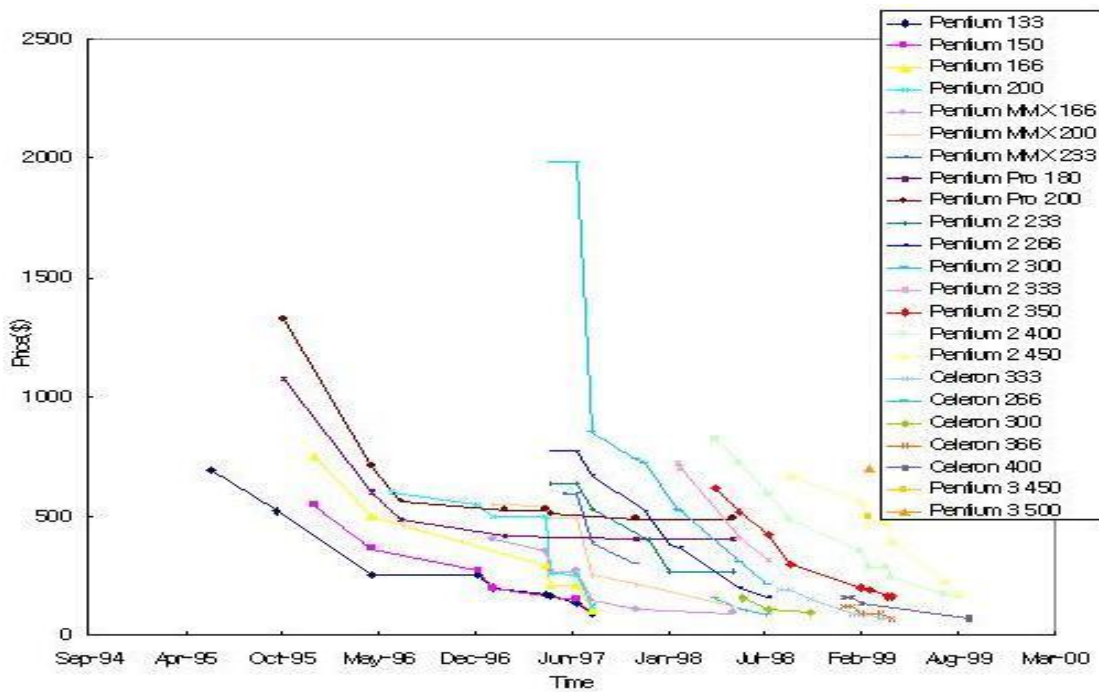


Figure 2.10. Prices of Intel microprocessors

2.6. Conclusions and Contributions

This essay proposes an analytical model considering the pricing issue of sequential versions of IT-intensive products. I derive the optimal pricing strategies for overlapping generations of the IT intensive product and examine the nature of equilibrium solutions. I identify the conditions determining which equilibrium yields the greatest revenue. The equilibrium solution captures the effects of the degree of obsolescence and consumers' impatience. The strategy of pricing a second version relatively high is preferred with higher degree of obsolescence implying that planned obsolescence as consumers are more patient. It is illustrated that the presented analytical model can be used to measure the consumer time preference for the given product. Intel's practice is analyzed and it appears that Intel has been pricing the new version products relatively low considering the degree of obsolescence between versions.

There are many avenues for future research. The difficulty in realization of the conceptual functions of the model such as the benefit function of a given quality level, $f(q_{ij})$, serves as an obstacle against linking the Intel price data and the analytical model. An appropriate way to handle this kind of conceptual functions to be applicable to the data would allow examining the real practice in depth. The coexistence of multiple versions of microprocessor in a period may be taken into account in the future while this research considers only the pair-wise comparison of versions.

3. YIELD MANAGEMENT FOR IT SERVICE INDUSTRY THROUGH E-LANCING

3.1. Introduction and Motivation

The information technology (IT) service industry has been continuously growing at more than 10 percent per year (Gartner Research 2002) since IT outsourcing was acknowledged, decades ago, as a useful strategy for lowering costs, earning economies of scale and accessing specialized resources. Furthermore, offshore IT outsourcing has exploded, spurred by its exclusive advantages of cost savings and large labor pools. At the same time, customers are squeezing IT vendors for price cuts. As a result of these changes in the business environment, substantial competition among offshore and US-based vendors is expected. Giant, global IT-service firms such as Accenture and EDS are opening their own software development centers in India to compete with local companies such as Infosys and Wipro (Kumar and Sinha 2003). The challenge now to IT service providers is how to manage their resource in order to survive the competition.

IT Human capital is the most important resource in a service company since there is no notions of physical products, production facilities, inventory, or supply chain management unlike in a product company. Therefore, adequate staffing is directly related to the firm's profit and has been a crucial task for an IT service provider (Gartner Research 2001). IT human capital has been also acknowledged as a strategic resource and a key asset in the information systems (IS) literature (Ang and Slaughter 2004; Ferratt, Agarwal, Brown, and Moore 2005). However, most of prior work on IT personnel has focused on the individual level in which the unit of analysis is individual (Ang and Slaughter 2001). In this research, the IT human capital management problem of IT service providers is studied from a macro-level perspective in which the focus is

on maximizing the firm's discounted profit over the infinite horizon through an optimal utilization of workforce.

Labor markets for IT firms may behave very differently from standard labor markets in a number of different ways (Saxenian, 1996; Ang and Slaughter 2001). Given the difficulty of timely adjusting a firm's workforce capacity, the nature of IT projects, and demand uncertainty in the market, IT service firms cannot avoid occasionally holding the excess workforce. The fluctuating market demand makes it difficult for IT service providers to adjust the headcount to demand. The high demand for IS/IT during the year-2000 era and dotcom boom led IT providers to aggressively recruit IT professionals. After the dotcom boom faded, companies couldn't lay off the excess workers fast enough (Gartner Research, 2001). Due to the nature of IT projects, each IT project requires a bulk of professionals and hence, IT vendors hold a number of idle workers when large projects are over until they receive new projects. By these reasons, many IT service firms suffer profit loss due to inadequate staffing. But at same time, IT service providers want to maintain their workforce capacity at a sufficient level in order to respond quickly to high market demand or a large project order. Consequently, a firm may hold idle workers when it faces low demand or the termination of a large project.

Maintaining idle workers, however, incurs double costs to the firm without generating any revenue; the wages of the idle employees and the training costs. Myopic remedies to deal with this challenge such as ad-hoc staffing-up and layoff involve high initial sunk costs of staffing-up and potential legal disputes followed by layoff, disabling the firm's agility. Furthermore, when IT service providers have a large number of idle employees, the situation lends itself to price competition among vendors, in a similar fashion observed in the hotel and

airline industries (Kim, Shi and Srinivasan 2004), which would lower their revenues in a long run.

Drawing primarily on Markov decision theory, I develop a model for an IT service provider to control excess workforce by applying the concept of yield management. The staffing problem of an IT service provider has the characteristics shared in hotel and airline industries where yield management has been successfully employed. IT service firms have strict capacity constraints and the costs of making any adjustment – hiring, training, or firing new IT professionals - are high just like in the hotel and airline industries (Kim et al, 2004). Moreover, the inventory of IT professionals can be seen *perishable* just like hotel rooms and airplane seats in that the excess idle workforce incurs operational cost including employees' salary without generating any revenue and the availability will disappear unless used now. Observing these similarities between IT service industry and hotel/airline industries, I develop an Markov decision model for an IT service provider to achieve yield management by effectively reduce excess workers through e-lancing, the secondary online channel, when the market demand of conventional channel is low.

Another motivation of this research stems from the view in which the advances in information technology are affecting firm and market structures, shifting toward more use of decentralized markets rather than hierarchies to coordinate economic activity (Malone, Yates and Benjamin, 1987). The Internet has significantly reduced coordination costs of electronic markets. Moreover, the buyers can access to more number of alternatives, which leads to the higher quality of their choices and the lower production cost in the electronic market structure (Malone et al. 1987). Motivated by these factors favoring decentralized markets over hierarchies in the

Internet age, this research aims at developing an intelligent tool to help IT service providers make agile and flexible staffing decisions taking advantage of the electronic sales channel.

	Elance Online (www.elance.com)	Guru (www.guru.com)	Rent A Coder (www.rentacoder.com)
Description	The largest global online freelancer site. It targets the small and medium businesses throughout various industries.	The site claims to have the largest membership with over 451,000 professionals throughout various industries.	One of the largest coding freelance sites for software buyers and coders.
Client payment method	Clients can divide the project into stages and pay based on each stage.	Clients pay the entire amount of the project fees into an escrow account.	Clients pay the entire amount of the project fees into an escrow account.
Fees for clients	Free	Free	Free
Fees for providers	Providers must pay a monthly fee to retain membership. The membership fees range from \$30 to \$245 monthly.	Basic membership includes a free membership but requires a 10% project transaction fee.	Free membership with a 15% project transaction fee.

TABLE 3.1. Major E-lancing Web Sites

E-lancing is a new market mechanism comprised of electronically connected freelancers (either individuals or organizations) joined into networks to provide IT services (Malone and Laubacher 1998). The most common type of market mechanism for e-lancing, considered as the secondary channel in the model, is the online reverse auction, where the buyers post projects such as software development and website design as a form of RFP (Request for Proposal), and then IT service firms bid for them. Online auctions enable firms to efficiently outsource small

projects that, mostly, involve less than six person-months of effort (Snir and Hitt 2003). Examples of currently operated Web-based IT service markets include Elance Online (www.elance.com), Prosavvy (www.prosavvy.com), RentACoder (www.rentacoder.com) and Guru (www.guru.com). Elance Online is the leading Web-based project marketplace that connects small- and medium-sized businesses with a global pool of IT service providers. More information about several e-lancing Web sites is given in Table 3.1. The e-lancing marketplaces for IT services have been successful since users are Web-savvy and familiar with using auctions in online environments. Moreover, unlike traditional services, the delivery of IT services does not require direct contact between the supplier and the consumer.

Type	Description	Vendors
Managed, hosted e-sourcing service	Provides consulting and hosted application	FreeMarkets, ATKPS, ICG Commerce, Ariba, Ketera, Global eProcure, Perfect Commerce, SnyerDeal, Iasta
Self-service hosted e-sourcing	Provides hosted application	FreeMarkets, ATKPS, Procuri, Ariba, Ketera, Frictionless, Emptoris, B2eMarkets, SAP, Oracle, and various e-markets
Licensed software	Provides licensed product operated behind corporate fire wall	Ariba, SAP, Oracle, PeopleSoft, i2, Portum, ATKTPS, Frictionless, B2eMarkets, others

TABLE 3.2. Major vendors of e-sourcing solutions¹

¹ Source: Forrester Research, Inc. Jan 5, 2004

The online spot market used as the secondary channel in the model also includes reverse auctions embedded in e-sourcing solutions. Various e-sourcing solutions available in the market typically have similar functions to those of Web-based marketplaces such as an RFP generator, a potential supplier database, a support for various reverse auction types and an interactive bid solicitation mechanism (Forrester Research 2004). Major e-sourcing solution vendors in the current market are described in Table 3.2. In addition, the secondary channel in the model may include e-procurement suites provided by vendors such as Elance, PeopleSoft, IQNavigator and Ariba since they typically include an e-sourcing solution.

In summary, in this dissertation proposal, I propose how IT service providers can improve productivity by integrating the e-lancing channel into their business model. Specifically, I propose strategic use of online service marketplace, e-lancing, to manage excess capacity of an IT vendor's labor pool. The purpose of the analysis is to investigate the structure of the optimal admission policy for the two channels, the conventional channel and the online channel, by which the IT service firm can dynamically decide to participate in online reverse auctions to receive projects that would occupy idle employees. In this way, the It vendor not only gains additional profits by reaching customers in the online channel, but also avoids price competition in the conventional channel.

3.2. Literature Review

The goal of yield management is to maximize revenue per unit capacity by employing price-discrimination. Many researchers have studied the use of online auction as a secondary channel for yield management to dispose of a firm's excess inventory while the firm sells its products through the primary conventional channel at list price (Pinker et al. 2003; Vulcano, van

Ryzin, & Maglaras 2002). Gallego and van Ryzin (1994) solve the optimal pricing policy as a function of the stock level and the length of the horizon. This price-discrimination approach is preferred when a perishable inventory has to be sold before a deadline, which is typical in retail industry. The presented model enables us to investigate how much discount is allowed in the secondary, e-lancing channel.

However, while I consider the IT workforce of service providers as perishable inventory as discussed in the previous section, the typical IT projects usually require a group of IT professionals simultaneously. Consequently, the price of contracts can be high. The literature suggests that when they are large contracts, not just individual customers' orders, offers should be accepted or rejected. Therefore the decision variables in the model include the binary variable for admission control as well as the bidding price in the secondary channel. There have been extensive efforts on such admission controls combining queueing theory with inventory management (Brumelle and Walczak 2003; Carr and Duenyas, 2000). In Caldentey and Wein (2005), the authors model a single-product manufacturing system for a firm using two selling channels: long-term contracts and a spot market of electronic orders. The manufacturer simultaneously decides on a busy/idle policy for the machine in addition to an accept/reject policy for e-orders. Unlike most prior research on revenue management, the difficulty of modeling the IT human capital utilization problem lies on the fact that an IT service firm produces services, not physical goods. The presented model captures the more complex characteristics of service firm: the IT workers (servers) are rented for a random amount of time and they remain available again in the firm (system) to serve the next project (job) after serving the current job.

The IT human capital utilization problem can be reduced to the stochastic knapsack problem (Ross 1995). A stochastic knapsack consists of c identical servers and K job classes arriving. Each class is characterized by its size, b_k , arrival rate, λ_k and mean holding time, $1/\mu_k$. If an arriving class- k job is admitted into the knapsack, it holds b_k servers for a service time which is exponentially distributed with mean $1/\mu_k$ and releases b_k servers simultaneously after the service time generating a reward, r_k . The objective of the problem is to control admission of jobs into the knapsack in order to maximize total reward. Admission controls in a stochastic knapsack problem have been studied by many researchers with various setups (Ross 1995; Ormeci and Burnetas 2004; Papastavrou, Rajagopalan and Kleywegt 1996). Any of these prior models does not capture all the requirements of the problem. In order to obtain the global optimal admission control solution for the stochastic knapsack problem, I employ Markov decision processes to optimize over the set of all policies (Ross 1995; Ross and Tsang 1989).

3.3. Model Development and Assumptions

The model considers an IT service firm that receives IT projects through two channels: a conventional procurement channel and an online auction spot market. The firm first fulfills the orders from the conventional channel and then decides whether to participate in the online auction depending on the current workforce. The assumptions made in the model are as follows:

- (1) There is neither staff augmentation nor loss during the period considered in the analysis. That is, the total number of IT workers in the firm remains constant.
- (2) The contract price (i.e., the project value) is an increasing function with respect to team size and project duration.

- (3) The pool of IT workers is composed of homogeneous developers/programmers both in terms of their skills and performance. Although each project team in the real world typically consists of a different number of developers with varying skills and experience, I restrict my focus to homogeneous workers at this preliminary stage of analysis. However, the model can be extended to allow heterogeneous workers.
- (4) The effects of employee training and experience on a worker's quality improvement are ignored. However, I may consider introducing the aspect of employee's quality improvement due to training into the model later.
- (5) The market is segmented according to project sizes. Specifically, the conventional channel consists of those projects with larger sizes and slower arrival rates, and projects with smaller size and more frequent arrival rates comprise the online channel.
- (6) The projects of each class arrives according to Poisson distribution with rate λ_i .
- (7) The project duration of each class follows exponential distribution with mean $1/\mu_i$.

The workforce management problem in the IT service firm is modeled as a dynamic admission control problem in a two-class Markovian loss service system with multi-servers receiving random batches. The schematic diagram of the two-class channel system is depicted in Figure 3.1. The summary of notations for a general multi-class channel system is given in Table 3.3.

The IT staff pool in the IT vendor is represented as a pool of multi-servers. The incoming projects are modeled as two customer classes. The first class of projects requires an immediate and high-priority service since there is a significant penalty such as a loss of high-profit orders if the demand in the conventional channel is not satisfied with priority. The second class of projects is served in a low-priority fashion, where the IT service firm is allowed to control the arrival of

the orders by means of auction participation control. The arrival of each project requires a number of IT workers, j_i , simultaneously with probability $g_i(j_i)$, which implies a bulk arrival. If the project is admitted, j_i workers are released at the same time after a project duration with mean $1/\mu_i$.

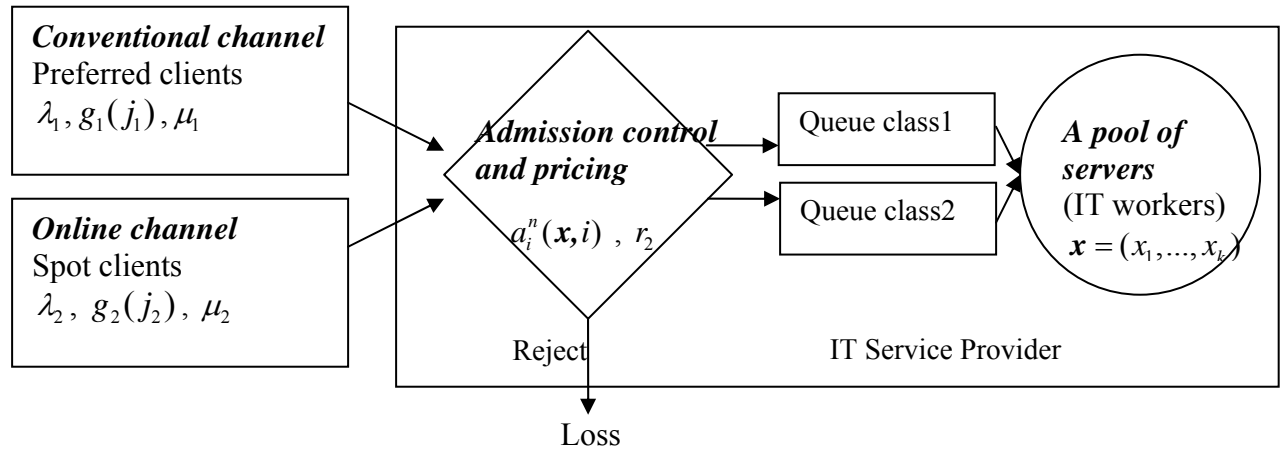


FIGURE 3.1. A schematic model of the system for the e-lancing revenue management

The IT staff pool in the IT vendor is represented as a pool of multi-servers. The incoming projects are modeled as two customer classes. The first class of projects requires an immediate and high-priority service since there is a significant penalty such as $\mu_1 < \mu_2$ if the demand in the conventional channel is not satisfied with priority. The second class of projects is served in a low-priority fashion, where the IT service firm is allowed to control the arrival of the orders by means of auction participation control. The arrival of each project requires a number of IT workers, j_i , simultaneously with probability $g_i(j_i)$, which implies a bulk arrival. If the project is admitted, j_i workers are released at the same time after a project duration with mean $1/\mu_i$.

c	Total number of workers (IT Professionals) in the IT service firm.
K	Total number of channels. ($K=2$)
λ_i	Expected class-i project arrival rate, $\lambda_i = \lambda_i g_i(1) + \dots + \lambda_i g_i(j_i) + \dots = \lambda_i \sum_{j_i=1}^{\infty} g_i(j_i)$
$1/\mu_i$	Expected class-i project duration
j_i	Team size (project load): The number of workers required within one project of class-i.
$g_i(j_i)$	Probability distribution function of team size. $g_i(j_i) = P[\text{team size} = j_i]$
$a^n(\mathbf{x}, i)$	Action parameter for class-i projects when the state is (\mathbf{x}, \mathbf{j}) at the n th decision epochs. 1 for admission and 0 for rejection.
x_i	Number of busy workers working on class-i projects
$\mathbf{x} = (x_1, \dots, x_K)$	Vector of number of busy workers
(\mathbf{x}, i) $= (x_1, \dots, x_K, i)$	State parameter which indicates that x_i class-i jobs are observed in the system when a class i has arrived.
$V_n(\mathbf{x}, i)$	The maximal total expected reward for the system starting in state (\mathbf{x}, \mathbf{j}) over n decision epochs in the horizon.
δ	Discount factor
r_i	Class-i project price per man month
$P(r_2, q)$	Probability of winning the auction given the IT service provider's quality q and bidding price r_2 .

TABLE 3.3. Summary of Notations

I define state $(\mathbf{x}, i) = (x_1, \dots, x_K, i)$, which indicates that x_i workers working on class- i projects are observed in the system when a project of class i has arrived. The state space is:

$$S = \{(x_1, \dots, x_K, i) \mid x_1, \dots, x_K = 0, 1, \dots, c ; \sum_{i=1}^K x_i \leq c ; i = 0, 1, \dots, K\}$$

The system is in state $(\mathbf{x}, 0)$ if there are $\mathbf{x} = (x_1, \dots, x_K)$ busy workers in the system and no arrivals of project. In state $(\mathbf{x}, 0)$, the only action is to leave the system alone and hence action $a=0$ is the only feasible decision. In state $(\mathbf{x}, i \neq 0)$ observed only at arrival epochs, the decision maker may admit or reject the incoming project, so that $a(x_1, \dots, x_K, i \neq 0) \in \{0, 1\}$, where action 0 corresponds to rejecting and 1 to admitting the arriving project. Moreover, state $(\mathbf{x}, i \neq 0)$ refers to the instantaneous states at the arrival epochs. As soon as the admission and rejection decisions are made upon an arrival, the system moves immediately to another state $(x_1, \dots, x_i + a j_i, \dots, x_K, 0)$ according to the decision made.

Note that the original problem is a continuous-time Markov decision process where the times between decision epochs are exponentially distributed with a state-dependent rate. I use the well-known uniformization technique which allows us to obtain the equivalent process with uniform sojourn time distribution in every state (see Lippman 1975). In the uniformized system, the system state is observed at random times which are exponentially distributed with the state-independent, constant transition rate, which is called the uniformization constant. Therefore I can use the algorithms for discrete-time Markov decision process after uniformization. For uniformization, I consider the service completion epochs as fictitious decision epochs in addition to the real decision epochs which are the arrival epochs of projects. Note that uniformization adds more decision points at service completion and fictitious service completion points while the actual meaningful decision needs to be made only at the arrival points. Although it increases

the number of states and hence the number of additions and multiplications, it leads to sparser transition matrices and thus accelerated algorithms (Ross and Tsang 1989; Tijms 1986 pp 213-214, Puterman 1994 Chapter 11). Therefore it is recommended applying uniformization when analyzing continuous-time Markov decision processes.

For the IT human capital utilization problem, I consider a 2-channel system ($K=2$). I define the uniformization constant to be $\lambda_1 + \lambda_2 + c \max(\mu_1, \mu_2)$, the maximum possible rate out of any state. I normalize it by assuming $\lambda_1 + \lambda_2 + c \max(\mu_1, \mu_2) = 1$. At each transition epoch, I have one of the following transitions with the corresponding probability: an arrival of projects with probability $\lambda_1 \sum g_1(j_1) + \lambda_2 \sum g_2(j_2)$, a service completion with probability $x_1 \mu_1 + x_2 \mu_2$, and a fictitious service completion due to uniformization with probability $\{c \max(\mu_1, \mu_2) - x_1 \mu_1 - x_2 \mu_2\}$. Figure 3.2 illustrates the possible transitions and the transition probabilities.

Based on the Bellman equation, the maximal total expected reward for the system starting in state $(x_1, x_2, 0)$ over n decision epochs in the horizon for a 2-class system ($K=2$) yields the following recursive relation:

$$\begin{aligned}
V(x_1, x_2, 0) = & \{ \lambda_1 \max [\sum_{j_1=1}^{c-(x_1+x_2)} g_1(j_1) [V(x_1+j_1, x_2, 0) + j_1 r_1 \frac{1}{\mu_1}], V(x_1, x_2, 0)] \\
& + \lambda_2 \max [\sum_{j_2=1}^{c-(x_1+x_2)} g_2(j_2) [V(x_1, x_2+j_2 P(r_2, q), 0) + j_2 r_2 \frac{1}{\mu_2} P(r_2, q)], V(x_1, x_2, 0)] \\
& + x_1 \mu_1 V(x_1-1, x_2, 0) + x_2 \mu_2 V(x_1, x_2-1, 0) \\
& + (c \max(\mu_1, \mu_2) - x_1 \mu_1 - x_2 \mu_2) V(x_1, x_2, 0) \} / (\delta + 1)
\end{aligned}$$

$$0 \leq \sum_{i=1}^2 x_i + \sum_{i=1}^2 j_i \leq c$$

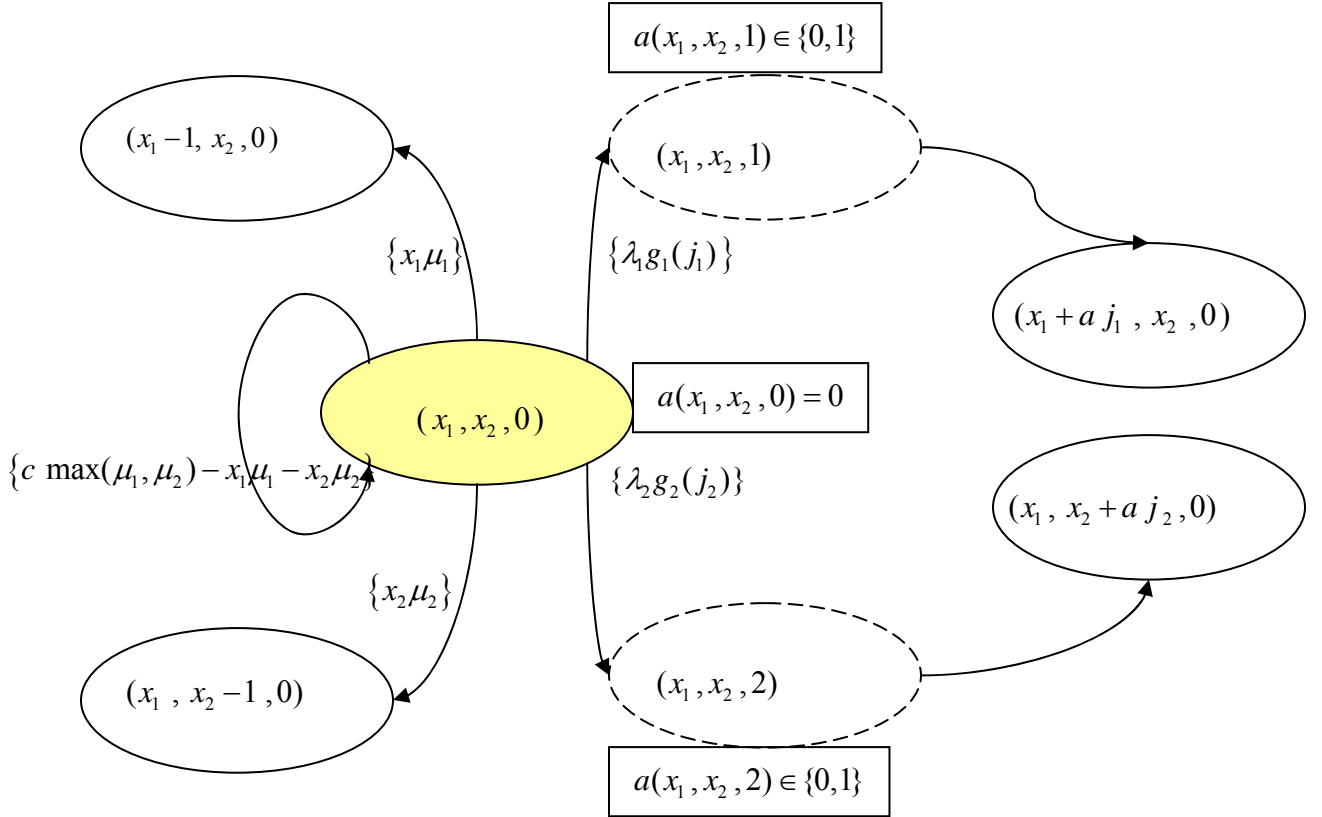


FIGURE 3.2. Symbolic representation of the state transition structure: The numbers in brackets represent the transition probability after uniformization and normalization. The dotted circles represent instantaneous states. Each ending node recursively continues its transition as in state $(x_1, x_2, 0)$ in the center.

The IT service firm's problem is to decide whether to participate in an online auction and determine a bid price. The goal is to dynamically control the auction participation rate and hence the number of idle workers over an infinite horizon. The first two terms represent the admission controls for incoming class- i projects. The manager needs to decide whether to admit ($a^n=1$) or reject ($a^n=0$) the incoming project to maximize the profit. Then, the corresponding state becomes $(x_1 + a j_1, x_2, 0)$ for the incoming class-1 projects and $(x_1, x_2 + a j_2, 0)$ for the incoming class-2 projects regardless of the decision. When the incoming project is admitted, the reward $a_i^n j_i r_i / \mu_i$ is accumulated. The firm's profit from the online spot channel (class-2)

depends on the probability of winning the auction. The probability is a function of the quality of the firm, the bid price, the number of bidders and other parameters (Snir and Hitt 2003). The third and fourth terms represent the service completions of class- i projects. The fifth term is due to the uniformization. Finally, $1/(\delta + 1)$ is multiplied for δ -discounting effect (Tijms 1986; Puterman 1994). The optimal policy is obtained by using the value-iteration algorithm over infinite horizon (See Tijms 1986; Puterman 1994) and the results are illustrated in the next section.

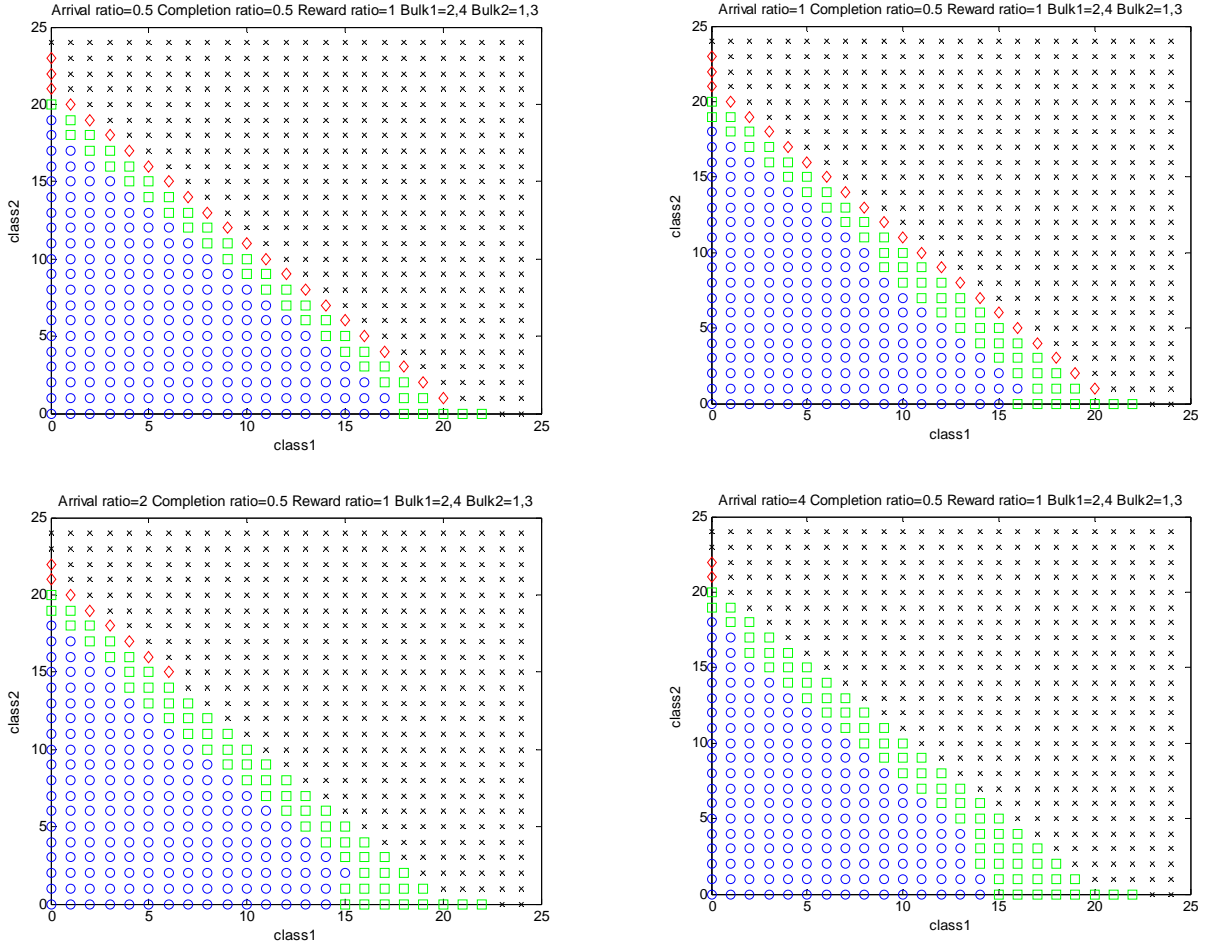
3.4. Numerical Computation

Several numerical examples have been solved by using value-iteration algorithm to investigate the structure of the optimal policy. The primary result is that the optimal policy is not of the threshold type, where the secondary market project (class 2) is admitted if and only if the number of idle workers in the firm is less than a fixed threshold. Rather, the optimal policy is of a more complex form as seen in Figure 3.3, 3.4, and 3.5. This non-threshold policy is easily proved by observing that the value function is not concave, especially when there are not enough idle workers. The complexity of the optimal policy implies that manual, ad-hoc decisions on IT professional staffing might cause excess idle workers and loss in revenue and therefore the presented model is useful as a decision support tool to provide the optimal policy.

The optimal policy appears to depend on the arrival rate ratio, the project duration ratio, the reward ratio, and the bulk sizes in two channels. Although the presented examples assume the uniform distribution of bulk sizes, other distributions could be used. For simplicity, I set $P(r_2, q) = 1$ at this stage but will conduct a further examination of the effect of this online auction parameter. A noticeable result is that the effect of arrival rate ratio on the optimal policy is not as

significant as the effects of project duration and reward. This is due to the nature of the model, in which μ_i and r_i appear to have more impact on the value function than λ_i .

3.4.1. The effect of arrival rate



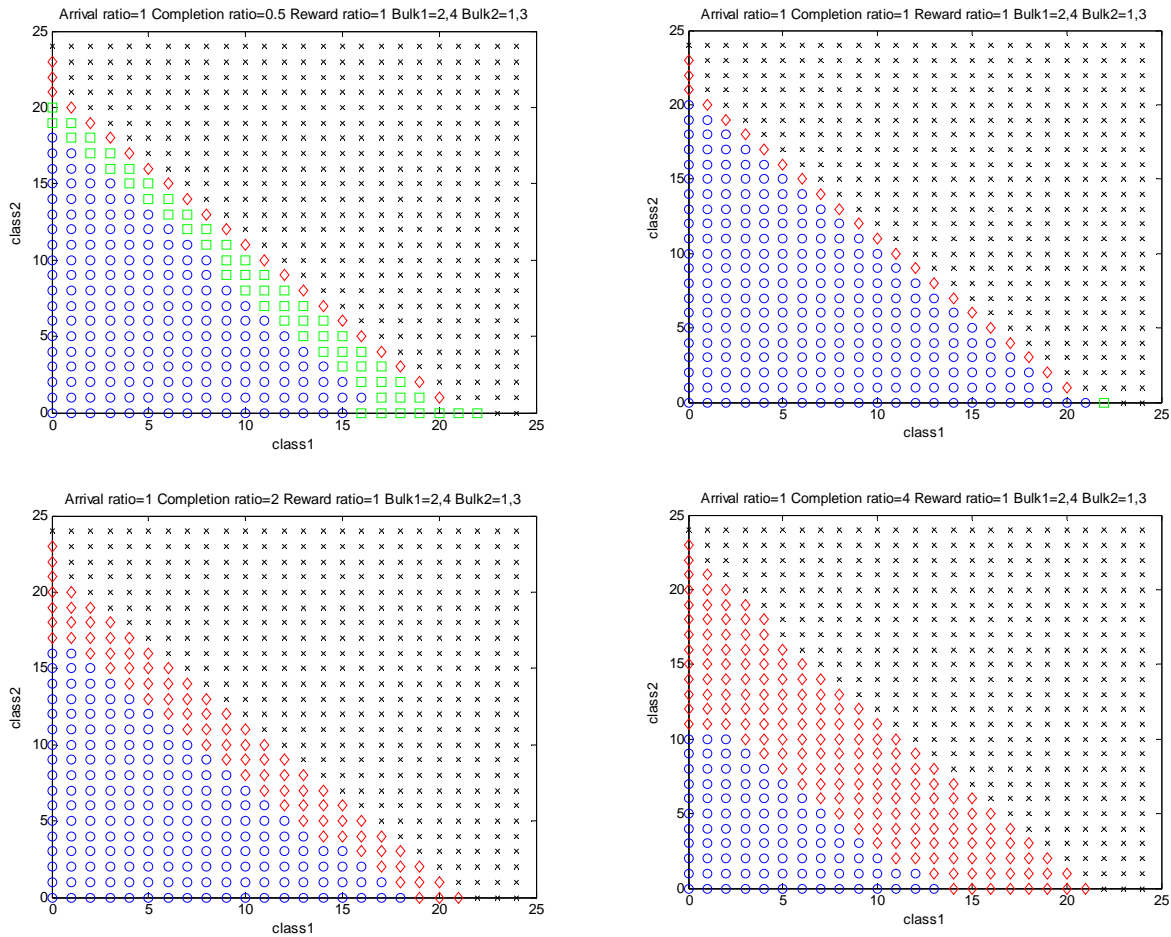
○ - Accept both , □ - Accept class1 and reject class 2
 ◇ - Reject class1 and accept class 2, × - Reject both
 $c=24, \lambda_2 = 4, \mu_1 = 0.1, \mu_2 = 0.2, r_1 = 10, r_2 = 10, j_1 \sim U(2, 4), j_2 \sim U(1, 3)$

FIGURE 3.3. The effect of arrival rates

Keeping other parameters constant, the experiments were performed to examine the effect of arrival rate of projects. As the relative arrival rate of class 1 increases, from $\lambda_1 / \lambda_2 = 0.5$ in the upper left to $\lambda_1 / \lambda_2 = 4$ in the bottom right in Figure 3.3, the system rejects more class-2

projects. In Figure 3.3, when the ratio of the class-1 arrival rate to the class-2 rate is 4 (the lower right plot), the optimal policy shows more square symbols, indicating that the optimal policy accepts more class-1 and rejecting more class-2 in those. As the ratio decreases to 0.5 (the upper left plot), more circles and diamonds with less squares are observed, indicating that the optimal policy accepts both classes in more states and rejects class-1 in some states.

3.4.2. The effect of project duration



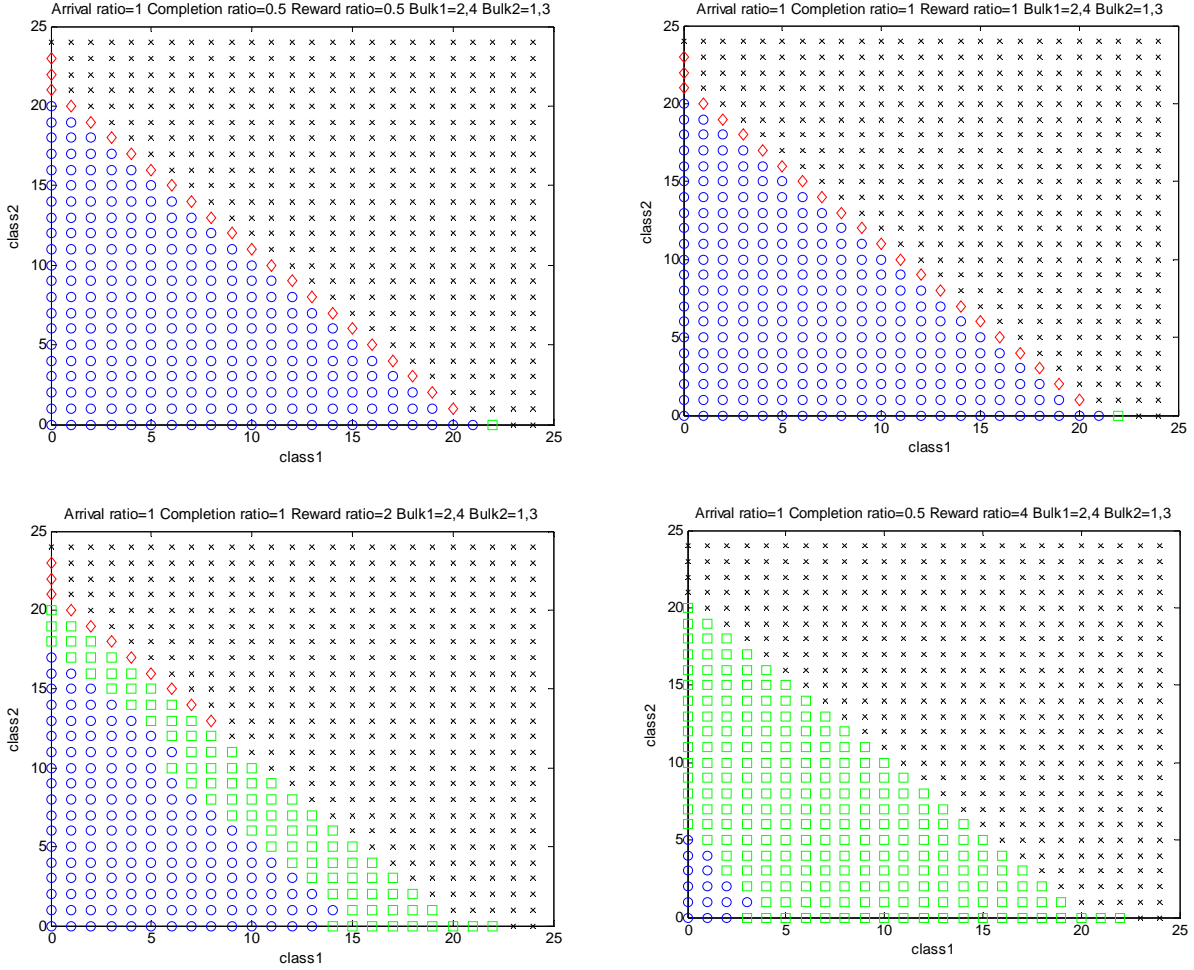
○-Accept both , □ - Accept class 1 and reject class 2
 ◇ - Reject class 1 and accept class 2, × – Reject both
 $c=24, \lambda_1 = 4, \lambda_2 = 4, \mu_1 = 0.1, r_1 = 10, r_2 = 10, j_1 \sim U(2, 4), j_2 \sim U(1, 3)$

FIGURE 3.4. The effect of project duration

The effect of project duration ($1/\mu_i$) is illustrated in Figure 3.4. The relative project duration of class 1 increases, from $\mu_1/\mu_2=0.5$ in the upper left to $\mu_1/\mu_2=4$ in the bottom right, in Figure 4. Note that the project duration is related to the magnitude of the reward as well as the rate of busy workers being released free in the next epoch. With this reason, the impact of project duration appears to be more significant than the impact of the arrival rate. As the relative project duration of class-1 is longer relative to class-2 (See the upper left plot in Figure 3.4), more squares are observed than in other plots indicating that the optimal policy blocks more incoming class-2 projects. It is because the longer project duration of class-1 project makes the class-1 projects more attractive since they generate greater revenue.

3.4.3. The effect of reward

The magnitude of reward of each class is directly related to the attractiveness of the class. It is evident in Figure 3.5 that as the relative reward of class 2 increases, from $r_1/r_2=0.5$ in the upper left to $r_1/r_2=4$ in the bottom right, the optimal policy rejects class-2 projects in more states. An interesting implication of this analysis is that the decision maker can obtain information about how deep discount to offer to online channel clients compared to the primary channel clients in order to maximize the utilization of its workers depending on various other parameters in two channels.



○-Accept both , □ - Accept class1 and reject class 2
 ◇ - Reject class1 and accept class 2 , × – Reject both

$$c=24, \lambda_1 = 4, \lambda_2 = 4, \mu_1 = 0.1, \mu_2 = 0.2, r_1 = 10, j_1 \sim U(2, 4), j_2 \sim U(1, 3)$$

Figure 3.5. The effect of rewards

3.5. Project Status and Concluding Remarks

The numerical experiments to study the effect of team sizes in each class have been conducted. The interpretation of the results is currently in progress. In spite of the availability of abundant numerical examples, it is necessary to obtain a closed-form solution in order to get better general managerial insights and theoretical contribution. Currently, a study to characterize

the mathematical nature of the optimal policy, which is not threshold policy, is being conducted in terms of a closed-form solution.

Historically, the way people do business has been affected by the coordination technology available. Improved network technology, i.e., coordination technology, has introduced new commercial opportunities to e-lancers by providing increased efficiency through reduced transaction costs. This decentralized, individual-oriented electronic market mechanism will be essential for a strategic sourcing to design agile organizations by deploying resources quickly and efficiently in response to diverse market changes. The key contribution of this study is to examine a new revenue model, verify its feasibility and effectiveness, and provide an optimal strategy to successfully implement this revenue model.

One theoretical contribution is to expand the knowledge of yield management literature, concentrated mainly on physical goods, into the IT service industry. From a methodological perspective, the model captures the most important characteristic of IT projects where if a project is admitted, it seizes a random number of workers simultaneously, then it releases all the workers at the same time after occupying for the project duration. In addition, implementing two job classes requiring different service rates with random batch arrivals into the standard Markov decision model is a distinctive contribution, providing a benchmark model which will be useful to investigate various demand control problems of IT service providers. On a practical level, given growing competition in the IT service industry, the analysis of the optimal auction participation control policy will provide managerial insights applicable to the management of excess manpower for offshore and US-based IT service firms such as IBM, Accenture, EDS and other small and medium size service providers.

Certain assumptions, of course, would need to be relaxed to accommodate real world conditions more precisely. Nevertheless, I believe that the model captures the essential factors to analyze the value of the emerging e-lancing market. It would be interesting to incorporate the notion of risk into the model. The model can take the project management risk such as scope-creeping and scheduling overrun into account. This paper considers only one side of e-lancing application where the IT service provider serves as an e-lancer in order to dispose of its available capacity when the market demand is low. Another interesting research topic that I wish to investigate in future is the flexible staffing model with which an IT service provider contracts with individual e-lancers in e-lancing markets for flexible staffing management when market demand is high.

4. VENDOR DETERMINATION IN IT SERVICE ONLINE AUCTIONS

4.1. Introduction and Motivation

With reduced transaction costs provided by Internet marketplaces, online reverse auctions are becoming a popular means for the sourcing of IT services. In currently operated online IT service marketplaces such as *Elance Online* (www.elance.com) and *Guru* (www.guru.com), a client (buyer or auctioneer) posts a Request for Proposal (RFP) describing the project requirements, and then service providers prepare a bid package describing their capabilities and bid prices. When the auction is complete, the client evaluates received bids and selects a winner. These markets are currently quite active, enabling firms to efficiently outsource small-scale projects.

A critical factor for successful information systems (IS) outsourcing is the bidding and vendor selection mechanism (Chaudhury, Nam and Rao 1995). However, little is understood about the process of bid evaluation for e-lancing marketplace. E-lancing for IT services involves a multi-attribute auction, a class of market mechanisms which enables automated negotiation on multiple attributes of a deal (Bichler 2000). Unlike traditional auctions for physical goods, the winner in this type of markets may not necessarily be the one who bids lowest. Buyers find it difficult to select an appropriate sourcing provider in this type of auction partially due to the lack of theoretical and empirical findings in the area with the exceptions of two experimental studies (Bichler 2000; Strecker and Seifert 2004). Chaudhury and colleagues (1995) mathematically analyze the IT service vendor selection mechanism in conventional auctions. However, online auctions are different from conventional auctions in many respects as I discuss in the following section.

The current lack of guidelines for bid evaluation and winner determination has also led to high evaluation costs on the buyer's side. The data in Snir and Hitt (2003) shows that the percentage of auctions that are awarded contracts is only 38% among the 4,887 projects posted on one online service market. It implies that a fairly large number of buyers decide not to award a contract either because they might fail to recognize an efficient bidder or they might not want to incur the high evaluation cost incurred from a large number of bids.

In this study I attempt to answer the following questions: 1) what factors currently influence winner determination in e-lancing auctions? and 2) what factors affect client satisfaction, i.e. software project success, when the project is completed? To answer these questions, I develop and empirically test a research model. The model includes four major variables as determinants for winner selection for a successful system development. In the first stage of research, the current practices of winner selection in the e-lancing market for IT services are explored. In the second stage, I examine the relationship between each determinant for winner selection and the likelihood of success of the project, which is measured in terms of client satisfaction. The purpose of the analysis is to identify, among the current determinants of winner selection, valid determinants affecting the project's success.

4.2. Theoretical Basis and Research Hypotheses

I investigate the unique characteristics of IT service online auctions, including the multi-attribute procurement process, the aspect of incomplete information, the nature of global vendor participation due to lowered transaction costs, the transparency and publicity of a vendor's reputation in online marketplaces and the high cost of bid evaluation. I identify a set of factors influencing winner determination systematically examining existing literature on IT outsourcing,

software development and online auctions. The factors are categorized into the four classes and I draw hypotheses from each class. The research model is depicted in Figure 4.1. In the rest of this section, I first justify the use of user satisfaction as a measure of system success. Then the theoretical foundation for each determinant for successful winner selection is illustrated.

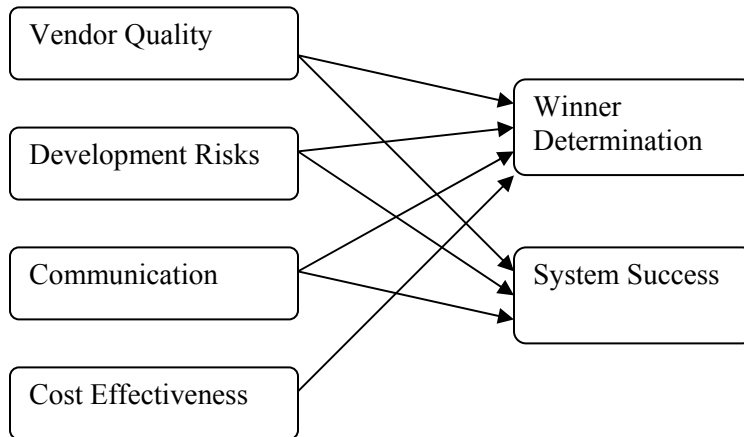


FIGURE 4.1 Research Model for E-lancing

System Success

There are a number of studies identifying good measures of information systems success. Various measures of IS success proposed in the literature include user satisfaction, system quality, system usage, individual impact and organizational impact (Delone and Mclean 1995; Seddon 1997). Among them, user satisfaction has been widely used to evaluate information system success (Delone and Mclean 1995; Yoon, Guimaraes and O’Neal 1995; Doll, Deng, Raghunathan, Torkzadeh and Xia 2004). Further, user satisfaction is acknowledged as one of the most important determinants of information systems success (Somers, Nelson and Karimi 2003). For all these reasons I employ user satisfaction to evaluate system success in this study.

Service Provider Quality

Since IT services procured are likely to be highly customized, in terms of its functionality and development efforts, a buyer's bid evaluation depends on whether the bidder's quality maximizes the buyer's utility. Information system success is directly related to service provider characteristics (Yoon et al. 1995). I refer to vendor quality as the vendor's abilities to minimize conflicts and those technical and social skills accumulated through experience. A vendor who retains such cost and expertise advantages over other competing vendors may be observable to a client by various signals. Given the nature of online environment, a service provider's quality may be determined from that service provider's profile, which list attributes such as its size, maturity, activeness, etc. How well a service provider represents its company profile also affects a client's perception of the service provider's quality (Koppius et al. 2004). Therefore, I formulate hypotheses to test the relationship of the vendor quality to the likelihood of winning the auction and the likelihood of buyer's ex post satisfaction.

Software Development Risks

Winner selection in IT service online auctions is a game of information asymmetry, and there exists uncertainty about the actual cost of delivering a service as well as the true quality of the bidders. Nidumolu (1995) suggests that the difficulty in estimating performance-related outcomes during the project have a direct negative effect on project success. In order to overcome the uncertainty augmented by the online environment, many auction sites provide mechanisms by which risk-averse buyers can lower uncertainty and build trust in bidders (Ba and Pavlou 2002; Pavlou and Gefen 2004). The typical institution-based trust building mechanisms include feedback mechanisms, third-party escrow services, and credit card guarantees. Given the

nature of IT services, technical certificates provided by third-party institutions such as *Microsoft* and *Sun* can also help vendors build credibility. Thus, I formulate hypotheses to test the relationship of the buyer's uncertainty about a vendor performance to the vendor's likelihood of winning as well as the relationship to the likelihood of buyer's ex post satisfaction.

Communication

Effective communication between the user and the developer is essential in the course of a software development project since it prevents reworks, overruns and disputes between the two parties (Brabander, Thiers and Augustijns 1984; Hornik, Chen, Klein and Jiang 2003). It becomes more critical as online marketplaces lead to global software development environments where an inadequate understanding of cultural influences on IS design and development may lead to project failure (Kankanhalli et al. 2004). The obstacles to effective communication include the language and cultural difference between client and service provider. This obstacle increase transaction costs, leads to inefficiency in communication and lower the degree of user involvement, affecting the likelihood of IS project success. However, I postulate that the geographical distance may not have a significant influence on hindering the winner selection in online service marketplaces. It is because, due to the nature of IT service products, communication and delivery of products can be done through telecommunications tools such as the Internet and telephones without a significant difficulty. I formulate hypotheses to test the relationship of difficulty of communication to the likelihood of winning and also the relationship to the likelihood of buyer's ex post satisfaction.

Cost Effectiveness

I also consider the effect of costly bid evaluation. Online markets for IT services are different from traditional procurement markets in that the reduced transaction costs and easy access lead to competitive bidding with a large pool of bidders. Attracting more bids has the advantages of maximizing competition and securing the most competitive price, but these advantages cannot avoid the cost of bid evaluation. When there are a large number of bidders, it is inevitable for buyers in an online market to have a non-negligible cost of evaluating bids (Snir and Hitt 2003; Samuelson 1985). I postulate that the relationship between lower bid price and the probability of winning becomes stronger when there is an excess of bids. In other words, a client with a lower value project and a large number of bidders tends to award a vendor with a lower bid price because he wants to recover the bid evaluation cost he incurred. Therefore I formulate hypotheses to test the effect of an excess of bids on the relationship between the relationship between bid prices and the likelihood of winning.

4.3. Research Methods

The data on recently completed projects were collected from an active online auction, *Elance Online*. The dataset consists of 3,976 projects closed between 4/17/2005 and 10/17/2005 from the *Software and Technology* category. A data collecting agent software retrieves each project's information about the buyer's history (the number of project posted and awarded), the buyer's feedback rating, the project budget, the levels of authentication used to confirm the buyer's identity and ability to use the billing and payment system, the total number of bids received, the dates of project posting and ending, and the average bid amount of the project.

Data on all 30,679 bids involved in those 3,976 sample projects were also collected. Each bids' information includes to which project the bid belongs, whether the bid was awarded, the

bid amount, time to deliver the product if awarded, bid time, the vendor's geographical location, the vendor's recent and total feedback ratings, the vendor's recent and total earnings through the particular online marketplace, the number of reviews that the vendor has received, the verification level of the vendor's credential, the level of qualified vendor screened by the online marketplace (i.e., *Elance Online*), and various certifications that the vendor has achieved.

The average number of bids received per project is 9. The average number of projects posted by the buyers in the sample is 11 and the average number of awarded projects by the buyers in the sample is 7. The average bid amount per project is \$1617 with the standard deviation 2864.3.

4.4. Project Status and Contributions

The variables needed to test the hypotheses are described in Table 4.1. Since the dependent variable is a binary variable which depends on whether the given vendor won the auction or not, I use a logistic regression model to test the hypotheses. Once the relationships between the variables and the winner selection are analyzed, the second phase of analysis will be conducted. In this phase, I represent the success of a project in terms of client satisfaction which is measured by the overall rating the vendor received from the client after the project was completed.

I acknowledge that there are other factors influencing IS project success such as the governance of contractual agreement (Gopal et al. 2003; Laticy and Hirschheim 1993) and client-supplier relationship (Koh, Ang and Straub 2004). For the purpose of this research, the focus is limited to online bid evaluation and successful vendor selection. The result would help understand patterns of bid evaluation in IT service online auctions where a large percentage of

transactions consist of offshore software developments. From a practical point of view, given the lack of guidance for buyers to choose the “right” winner, the present research would contribute by providing buyers with an efficient bid evaluation strategy to select the best bid that is likely to bring a successful project. Furthermore, given the high percentage of auctions that end up without achieving a contract in online markets for IT services, the guidelines for bid evaluation will lower bid evaluation costs and therefore increase the percentage of contracts awarded.

TABLE 4.1 Variable Descriptions

Measurement and Description	
<u>Vendor Quality</u>	
<i>-Activeness</i>	The number of projects received during last six months
<i>-Maturity</i>	The number of projects received during all time
<i>-Vendor size</i>	The number of employees in the vendor
<i>-Vendor Earnings</i>	The cumulated earnings of the vendor
<u>Trust Building</u>	
<i>-Feedback rating</i>	The average feedback rating received in the past
<i>-Institution-proved expertise</i>	The number of technical certificates retained by the vendor
<i>-Institution-based trust</i>	The existence of the institution provided “Preferred” seal. The auction site attaches the seal next to the vendor’s logo on the screen if the vendor satisfies a certain qualification.

Communication

- Geographical distance* This variable captures the transaction cost in communication
- Language* This variable is binary, with zero for the common language, and one for the different language between client and vendor.

Cost Effectiveness

- Relative bid price* Ratio of the bid price to the average bid price. It represents the relative bid price to the other bids for a given project.
- Costly bid evaluation* The ratio of the number of bidders to the average bid price². It measures an excessive bidding. When there is a large number bidder for a low value project, the value of this variable becomes large implying an excessive bidding followed by a high cost of bid evaluation.
-

² I use the average vendor's bids on the project as a proxy for project value as in Snir and Hitt (2003).

REFERENCES

- Ang, S. and Slaughter, S.A. (2001). The Missing Context of Information Technology Personnel: A Review and Future Directions for Research. In R. W. Zmud (Ed.), *Framing the Domains of IT Management: Projecting the Future through the Past*. (Chapter 16, pp. 305-327). Pinnaflex Educational Resources, Inc. Cincinnati, Ohio.
- Ang, S. and Slaughter, S.A. (2004). Turnover of Information Technology Professionals: The Effects of Internal Labor Market Strategies. *The DATA BASE Advanced Information Systems* 35 (3) 11-27.
- Ba, S. and P.A. Pavlou (2002) Evidence of the effect of trust building technology in electronic markets. *MIS Quarterly*, 26 (3), 243-268.
- Bichler, M. (2000) An experimental analysis of multi-attribute auction. *Decision Support Systems*, 29, 249-268.
- Brabander, D., B., G. Thiers, C. Augustijns (1984) Successful Information System Development in Relation to Situational Factors Which Affect Effective Communication Between MIS-users and EDP-Specialists, *Management Science*, 30 (2), 137-155.
- Brancheau, J.C., Janz, B.D., and Wetherbe, J.C. (1996) Key Issues in Information Systems Management: 1994-95 SIM Delphi Results, *MIS Quarterly* 20 (2) 225-242.
- Brumelle, S. and D. Walczak (2003) Dynamic Airline Revenue Management with Multiple Semi-Markov Demand, *Operations Research*, 51 (1), 137-148.
- Caldentey, R. and Wein, L. M. (2005) Revenue Management of a Make-to-Stock Queue, Working paper, Stern School of Business, New York University

- Carr, S. and I. Duenyas (2000) Optimal Admission Control and Sequencing in a Make-To-Stock/Make-To-Order Production System, *Operations Research*, 48 (5), 709-720.
- Chaudhury, A., K. Nam, and H. Raghavrao (1995) Management of Information Systems Outsourcing: A Bidding Perspective. *Journal of Management Information Systems*, 12 (2), 131-159.
- DeLone, W.H. and E.R. McLean (1992) Information Systems Success: The Quest for the Dependent Variable, *Information Systems Research*, 3 (1), 60-95.
- Dhebar, A. (1994) Durable-goods monopolists, rational consumers, and improving products, *Marketing Science*, 13, 1, 100-120.
- Dhebar, A. (1996) Speeding High-Tech Producer, Meet the Balking Consumer, *Sloan Management Review*, 37-49.
- Doll, W.J., Z. Deng, T.S. Raghunathan, G. Torkzadeh, W. Xia (2004) The Meaning and Measurement of User Satisfaction: A Multigroup Invariance Analysis of the End-User Computing Satisfaction Instrument, *Journal of Management Information Systems*, 21(1), 227-262.
- Ferrat T.W., Agarwal R., Brown, C.V. and Moore, J.E. (2005) IT Human Resource Management Configurations and IT Turnover: Theoretical Synthesis and Empirical Analysis, *Information Systems Research*, 16 (3) 237-255
- Forrester Research (January, 2004) Market Overview: E-sourcing 2004 —Hosting Dominates, but Will Slowly Give Way to Behind-the-Firewall Software, Cambridge, MA: Forrester Research.
- Gallego, G. and G. van Ryzin (1994) Optimal Dynamic Pricing of Inventories with Stochastic Demand over Finite Horizons. *Management Science*, 40 (8), 999-1020.

- Gartner Research (2002) Service Providers Must Change Their Business Models, Gartner Inc. October, 2002.
- Gartner Research (2001) Flexible Staffing Models: Breaking the Staff Up/Layoff Cycle?, Gartner Inc., April 2001.
- Gopal, A., K. Sivaramakrishnan, M.S. Krishnan and T. Mukhopadhyay (2003) Contracts in Offshore Software Development. *Management Science*, 49 (12), 1671-1683.
- Herbsleb, J.D. and A. Mockus (2003) An empirical study of speed and communication in globally distributed software development. *IEEE Transactions on Software Engineering*, 29 (6), 481-95
- Hornik, S, H. Chen, G. Klein and J.J. Jiang (2003) Communication Skills of IS Providers: An Expectation Gap Analysis from Three Stakeholder Perspectives, *IEEE Transactions on Professional Communication*, 46 (1), 17-35
- Jarvenpaa, S.L., Shaw, T.R. and Staples, D.S. (2004) Toward Contextualized Theories of Trust: The Role of Trust in Global Virtual Teams. *Information Systems Research* 15 (3), 250-267.
- Kankanhalli, A., B.C.Y. Tan, K.K. Wei, and M. C. Holmes (2004) Cross-cultural differences and information systems developer values. *Decision Support Systems*, 38 (2), 183-196.
- Kim, B.D., M. Shi and K. Srinivasan (2004) Managing Capacity through Reward Programs, *Management Science*, 50 (4), 1526-5501.
- Koh, C., A. Ang, and D.W. Straub (2004) IT Outsourcing Success: A Psychological Contract Perspective, *Information Systems Research*, 15 (4), 356-373.
- Koppius, O. R., E. van Heck, and M. J. J. Wolters (2004) The importance of product representation online: empirical results and implications for electronic markets. *Decision Support Systems*, 38, 161-169.

- Moonitz, M. (1943) The Risk of Obsolescence and the Importance of the Rate of Interest, The *Journal of Political Economy*, 51 (4) 348-355
- Moorthy, K. S. and Png, I.P.L. (1992) Market segmentation, cannibalization, and the timing of product introductions, *Management Science*, 38, 3, 345-359.
- Kornish, L. J. (2001) Pricing for a durable-goods monopolist under rapid sequential innovation, *Management Science*, 47, 11, 1552-1561.
- Kumar, G and J. Sinha (2003) The next hurdle for Indian IT, *McKinsey Quarterly* 2003 Special Ed. (4), 42-54.
- Lacity, M.C. and R. Hirschheim (1993) The Information Systems Outsourcing Bandwagon, *Sloan Management Review*, 35 (1), 73-86.
- Lavina, N. and J.W. Ross (2003) From the Vendor's Perspective: Exploring the Value Proposition in Information Technology Outsourcing, *MIS Quarterly*, 27 (3), 331-364.
- Levinthal, D.A. and Purohit, D. (1989) Durable Goods and Product Obsolescence, *Marketing Science*, 8 (1) 35-54.
- Lippman, A.S. (1975) Applying a New Device in the Optimization of Exponential Queuing Systems, *Operations Research*, 23 (4) 687-710.
- Malone, T. W. and R. J. Laubacher (1998) The Dawn of the E-lance Economy. *HBR*, 76 (5), 144-152.
- Malone, T.W., J. Yates, and R.I. Benjamin (1987) Electronic Markets and Electronic Hierarchies, *Communications of the ACM*, 30 (6) 484-497.
- Nair, H. (2004), "Dynamics of Pricing in Durable Good Markets: Application to 32-bit Console Video, Working paper, Graduate school of business, University of Chicago.

- Nidumolu, S. (1995) The Effect of Coordination and Uncertainty on Software Project Performance: Residual Performance Risk as an Intervening Variable, *Information Systems Research*, 6 (3), 191-219.
- Ormeçi, E. L. and A. Burnetas (2004) Admission control with Batch Arrivals. *Operations Research Letters*, 32, 448-454.
- Pavlou, P. A. and D. Gefen (2004) Building Effective Online Marketplaces with Institution-Based Trust, *Information Systems Research*, 15 (1), 37-60.
- Papastavrou, J.D., S. Rajagopalan and A. Kleywegt (1996) The Dynamic and Stochastic Knapsack Problem with Deadlines, *Management Science*, 42 (12), 1706-1718.
- Pinker, E., A. Seidmann and Y. Vakrat (2003) Managing Online Auctions: Current Business and Research Issues. *Management Science*, 49 (11), 1457 -1484
- Purohit, D. (1994) What should you do when your competitors send in the clones?, *Marketing Science*, 13 (4) 392-411.
- Puterman, M. L. (1994) *Markov Decision Processes*, Wiley-Interscience, New York.
- Riggins, F.J. and Narasimhan, S. (2001) Overcoming Product Cannibalization in the Online Channel using Personalization Technology, Community Access, and Intertemporal Price Discrimination, Working paper, University of Minnesota (MISRC WP 01-23)
- Ross, K. W. (1995) *Multiservice Loss Models for Broadband Telecommunication Networks*, Springer, Great Britain.
- Ross, K.W. and D.H.K. Tsang (1989) Optimal Circuit Access Policies in an ISDN Environment: A Markov Decision Approach, *IEEE Transaction on Communication*, 37 (9), 934-939.
- Samuelson, W. (1985) Competitive Bidding with Entry Costs, *Economic Letters*, 17, 53-57.

- Saxenian, A. (1996) Beyond Boundaries: Open Labor Markets and learning in Silicon Valley, In M.A. Arthur and D.M. Rousseau (Ed.), *Boundaryless Career*, New York: Oxford University Press, 1996, pp. 23-39.
- Seddon, P.B. (1997) A Re-specification and Extension of the DeLone and McLean Model of IS Success, *Information Systems Research*, 8(3), 240-253.
- Snir, E.M. and L.M. Hitt (2003). Costly Bidding in Online Markets for IT Services, *Management Science*, 49 (11) 1504 –1520.
- Somers, T. M., K. Nelson and J. Karimi (2003) Research Note: Confirmatory Factor Analysis of the End-User Computing Satisfaction Instrument: Replication within an ERP Domain, *Decision Sciences*, 34 (3) 595-632.
- Strecker, S. and S. Seifert (2004) *Electronic sourcing with multi-attribute auctions*. Proceedings of the 37th Annual Hawaii International Conference on System Sciences.
- Sultan, F. and Winer, R.S. (1993) Time Preferences for Products and Attributes and the Adoption of Technology-Driven Consumer Durable Innovations, *Journal of Economic Psychology*, 14, 587-613.
- Tijms, H.C. (1986) *Stochastic Modeling and Analysis: A Computational Approach*, John Wiley & Sons, Great Britain.
- Vulcano, G., G. van Ryzin and C. Maglaras (2002) Optimal Dynamic Auctions for Revenue Management. *Management Science*, 48 (11), 1388-1407.
- Wilson, R.W. and Warren-Boulton, F. R. (1995) Riding the Wave: Exclusionary Practices in Markets for Microprocessors Used in IBM-Compatible Personal Computers, *International Journal of the Economics of Business*, 2 (2) 241-261.

Winer, R.S. (1997) Discounting and Its Impact on Durables Buying Decisions, *Marketing Letters*, 8 (1) 109-118.

Yoon, Y., T. Guimaraes and Q. O'Neal (1995) Exploring the Factors Associated With Expert Systems Success, *MIS Quarterly*, 19 (1), 83-106.

APPENDIX

A1. Derivation of the Five Possible Alternatives in Consumer's Optimal Purchasing

Strategies in Section 2.4

I. The strategy of not buying in either period is optimal if and only if

$$\begin{aligned} f(q_{01})g(v) - p_1^I &\leq 0, \\ f(q_{01})g(v) - p_1^{II} &\leq 0, \\ f(q_{02})g(v) - p_2^{II} &\leq 0, \quad \text{and} \\ f(q_{01})g(v) - p_1^I + \delta(f(q_{12})g(v) - p_2^{II}) &\leq 0. \end{aligned}$$

The following expression is equivalent to the above constraints.

$$\{v : 0 \leq v \leq 1, g(v) < \min\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^{II}}{f(q_{01})}, \frac{p_2^{II}}{f(q_{02})}, \frac{p_1^I + \delta p_2^{II}}{f(q_{01}) + \delta f(q_{12})}\right)\}.$$

II. The strategy of buying Version 1 in the second period only is optimal if and only if

$$\begin{aligned} 0 &\leq f(q_{01})g(v) - p_1^{II}, \\ f(q_{01})g(v) - p_1^I &\leq \delta(f(q_{01})g(v) - p_1^{II}), \\ f(q_{02})g(v) - p_2^{II} &\leq f(q_{01})g(v) - p_1^{II}, \quad \text{and} \\ f(q_{01})g(v) - p_1^I + \delta(f(q_{12})g(v) - p_2^{II}) &\leq \delta(f(q_{01})g(v) - p_1^{II}). \end{aligned}$$

Equivalently,

$$\{v : 0 \leq v \leq 1, \frac{p_1^{II}}{f(q_{01})} \leq g(v) < \min\left(\frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}, \frac{p_1^I + \delta p_2^{II} - \delta p_1^{II}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}\right)\}.$$

III. The strategy of buying Version 1 in the first period only is optimal if and only if

$$\begin{aligned} 0 &\leq f(q_{01})g(v) - p_1^I, \\ \delta(f(q_{01})g(v) - p_1^{II}) &\leq f(q_{01})g(v) - p_1^I, \end{aligned}$$

$$\delta(f(q_{02})g(v) - p_2^{\prime\prime}) \leq f(q_{01})g(v) - p_1^{\prime}, \quad \text{and}$$

$$f(q_{01})g(v) - p_1^{\prime} + \delta(f(q_{12})g(v) - p_2^{\prime\prime}) \leq f(q_{01})g(v) - p_1^{\prime}.$$

Equivalently,

$$\{v : 0 \leq v \leq 1, \max\left(\frac{p_1^{\prime}}{f(q_{01})}, \frac{p_1^{\prime} - \delta p_1^{\prime\prime}}{f(q_{01}) - \delta f(q_{01})}\right) \leq g(v) < \min\left(\frac{\delta p_2^{\prime\prime} - p_1^{\prime}}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{\prime\prime}}{f(q_{12})}\right)\}.$$

IV. The strategy of buying Version 2 in the second period only is optimal if and only if

$$0 \leq f(q_{02})g(v) - p_2^{\prime\prime},$$

$$f(q_{01})g(v) - p_1^{\prime} \leq \delta(f(q_{02})g(v) - p_2^{\prime\prime}),$$

$$\delta(f(q_{01})g(v) - p_1^{\prime\prime}) \leq \delta(f(q_{02})g(v) - p_2^{\prime\prime}), \quad \text{and}$$

$$f(q_{01})g(v) - p_1^{\prime} + \delta(f(q_{12})g(v) - p_2^{\prime\prime}) \leq \delta(f(q_{02})g(v) - p_2^{\prime\prime}).$$

Equivalently, $\{v : 0 \leq v \leq 1, \max\left(\frac{p_2^{\prime\prime}}{f(q_{02})}, \frac{\delta p_2^{\prime\prime} - p_1^{\prime}}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{\prime\prime} - p_1^{\prime}}{f(q_{02}) - f(q_{01})}\right) \leq g(v)$

$$\left. < \frac{p_1^{\prime}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\right\}.$$

V. The strategy of buying Version 1 in the first period and Version 2 in the second period is optimal if and only if

$$0 \leq f(q_{01})g(v) - p_1^{\prime} + \delta(f(q_{12})g(v) - p_2^{\prime\prime}),$$

$$f(q_{01})g(v) - p_1^{\prime} \leq f(q_{01})g(v) - p_1^{\prime} + \delta(f(q_{12})g(v) - p_2^{\prime\prime}),$$

$$\delta(f(q_{01})g(v) - p_1^{\prime\prime}) \leq f(q_{01})g(v) - p_1^{\prime} + \delta(f(q_{12})g(v) - p_2^{\prime\prime}), \quad \text{and}$$

$$\delta(f(q_{02})g(v) - p_2^{\prime\prime}) \leq f(q_{01})g(v) - p_1^{\prime} + \delta(f(q_{12})g(v) - p_2^{\prime\prime}).$$

Equivalently, $\{v : 0 \leq v \leq 1, \max\left(\frac{p_1^{\prime} + \delta p_2^{\prime\prime}}{f(q_{01}) + \delta f(q_{12})}, \frac{p_2^{\prime\prime}}{f(q_{12})}, \frac{p_1^{\prime} + \delta p_2^{\prime\prime} - \delta p_1^{\prime\prime}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}\right),$

$$\left. \frac{p_1^{\prime}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\right) \leq g(v)\}.$$

□

A2. Proof of PROPOSITION 1 in Section 2.4.

REGION I

Under $\frac{f(q_{02})}{f(q_{01})} p_1^I \leq p_2^II \leq \frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1^I$ and $p_1^II \leq p_1^I$,

the upper bound of the buy nothing strategy in (4) is:

$$\min\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^II}{f(q_{01})}, \frac{p_2}{f(q_{02})}, \frac{p_1^I + \delta p_2^II}{f(q_{01}) + \delta f(q_{12})}\right) = \frac{p_1^II}{f(q_{01})}.$$

Therefore, the consumers with $\{v : g(v) \leq \frac{p_1^II}{f(q_{01})}\}$ buy nothing.

The upper bound of the “buy Version 1 in the second period only” strategy in (5) is :

$$\min\left(\frac{p_1^I - \delta p_1^II}{f(q_{01}) - \delta f(q_{01})}, \frac{p_2^II - p_1^II}{f(q_{02}) - f(q_{01})}, \frac{p_1^I + \delta p_2^II - \delta p_1^II}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}\right) = \frac{p_1^I - \delta p_1^II}{f(q_{01}) - \delta f(q_{01})}.$$

So the consumers with $\{v : \frac{p_1^II}{f(q_{01})} \leq g(v) < \frac{p_1^I - \delta p_1^II}{(1 - \delta)f(q_{01})}\}$ buy only Version 1 in Period II.

The lower bound of the “buy Version 1 in the first period only” strategy in (6) is:

$$\max\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^I - \delta p_1^II}{f(q_{01}) - \delta f(q_{01})}\right) = \frac{p_1^I - \delta p_1^II}{f(q_{01}) - \delta f(q_{01})}.$$

The upper bound of the “buy Version 1 in the first period only” strategy in (6) is:

$$\min\left(\frac{\delta p_2^II - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^II}{f(q_{12})}\right) = \frac{\delta p_2^II - p_1^I}{\delta f(q_{02}) - f(q_{01})}$$

Then, the consumers with $\{v: \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} \leq g(v) < \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}\}$ buy only Version 1 in

Period I.

The lower bound of the “buy Version 2 in the second period only” strategy (7) is:

$$\max\left(\frac{p_2^{II}}{f(q_{02})}, \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}\right) = \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}.$$

Therefore, the consumers with $\{v: \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})} \leq g(v) < \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\}$ buy

only Version 2 in Period II.

The lower bound of the “buy Version 1 in the first period and Version 2 in the second Period” strategy in (8) is:

$$\begin{aligned} \max\left(\frac{p_1^I + \delta p_2^{II}}{f(q_{01}) + \delta f(q_{12})}, \frac{p_2^{II}}{f(q_{12})}, \frac{p_1^I + \delta p_2^{II} - \delta p_1^{II}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}, \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\right) \\ = \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \end{aligned}$$

So, the consumers with $\{v: \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \leq g(v)\}$ buy Version 1 in Period I and

Version 2 in Period II.

REGION II

Under $\frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1^I \leq p_2^{II}$ and $p_1^{II} \leq p_1^I$,

the upper bound of the buy nothing strategy in (4) is:

$$\min\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^{II}}{f(q_{01})}, \frac{p_2^{II}}{f(q_{02})}, \frac{p_1^I + \delta p_2^{II}}{f(q_{01}) + \delta f(q_{12})}\right) = \frac{p_1^{II}}{f(q_{01})}.$$

Therefore, the consumers with $\{v: g(v) \leq \frac{p_1^{II}}{f(q_{01})}\}$ buy nothing.

The upper bound of the “buy Version 1 in the second period only” strategy in (5) is :

$$\min\left(\frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}, \frac{p_1^I + \delta p_2^{II} - \delta p_1^{II}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}\right) = \frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}.$$

So the consumers with $\{v: \frac{p_1^{II}}{f(q_{01})} \leq g(v) < \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})}\}$ buy only Version 1 in Period II.

The lower bound of the “buy Version 1 in the first period only” strategy in (6) is:

$$\max\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}\right) = \frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}.$$

The upper bound of the “buy Version 1 in the first period only” strategy in (6) is:

$$\min\left(\frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II}}{f(q_{12})}\right) = \frac{p_2^{II}}{f(q_{12})}$$

Then, the consumers with $\{v: \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} \leq g(v) < \frac{p_2^{II}}{f(q_{12})}\}$ buy only Version 1 in Period I;

The lower bound of the “buy Version 2 in the second period only” strategy (7) is:

$$\max\left(\frac{p_2^{II}}{f(q_{02})}, \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}\right) = \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}. \text{ However, the lower}$$

bound is greater than the upper bound: $\frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} < \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}$ due to

the boundary condition in (10). Therefore, no consumers play the “buy Version 2 in the second period only” strategy in Region II.

The lower bound of the “buy Version 1 in the first period and Version 2 in the second Period” strategy in (8) is:

$$\max\left(\frac{p_1^I + \delta p_2^II}{f(q_{01}) + \delta f(q_{12})}, \frac{p_2^II}{f(q_{12})}, \frac{p_1^I + \delta p_2^II - \delta p_1^II}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}, \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\right) = \frac{p_2^II}{f(q_{12})}$$

the consumers with $\{v : \frac{p_2^II}{f(q_{12})} \leq g(v)\}$ buy Version 1 in Period I and Version 2 in Period II.

REGION III

Under $p_2^II \leq \frac{f(q_{02})}{f(q_{01})} p_1^I$ and $p_1^II \leq p_1^I$, the upper bound of the “buy nothing” strategy in (4) is:

$$\min\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^II}{f(q_{01})}, \frac{p_2^II}{f(q_{02})}, \frac{p_1^I + \delta p_2^II}{f(q_{01}) + \delta f(q_{12})}\right) = \frac{p_2^II}{f(q_{02})}.$$

Therefore, the consumers with $\{v : g(v) < \frac{p_2^II}{f(q_{02})}\}$ buy nothing.

The lower bound of the “buy Version 1 in the second period only” strategy in (5) is lower than the lower bound of the “buy nothing” strategy. Therefore this strategy cannot be included in the mutually exclusive partitions of the $g(v)$ line.

The lower bound of the “buy Version 1 in the first period only” strategy in (6) is:

$\max\left(\frac{p_1^I}{f(q_{01})}, \frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}\right) = \frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})}$. The upper bound of the “buy Version 1 in

the first period only” strategy in (6) is:

$\min\left(\frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II}}{f(q_{12})}\right) = \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}$. However the upper bound is not above the

lower bound and no consumers play of the “buy Version 1 in the first period only” strategy in

Region III.

$$\frac{p_1^I - \delta p_1^{II}}{f(q_{01}) - \delta f(q_{01})} > \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})} \Leftrightarrow (\delta f(q_{02}) - f(q_{01}))(p_1^I - \delta p_1^{II}) > (f(q_{01}) - \delta f(q_{01}))(\delta p_2^{II} - p_1^I)$$

$$\Leftrightarrow (f(q_{02}) - f(q_{01}))p_1^I > (f(q_{01}) - \delta f(q_{01}))p_2^{II} + (\delta f(q_{02}) - f(q_{01}))\delta p_1^{II}$$

The above inequality is always true because

$$\begin{aligned} (f(q_{01}) - \delta f(q_{01}))p_2^{II} + (\delta f(q_{02}) - f(q_{01}))\delta p_1^{II} &< f(q_{02})(1 - \delta)p_1^I + (\delta f(q_{02}) - f(q_{01}))p_1^I \\ &= (f(q_{02}) - f(q_{01}))p_1^I. \end{aligned}$$

The lower bound of the “buy Version 2 in the second period only” strategy (7) is:

$$\max\left(\frac{p_2^{II}}{f(q_{02})}, \frac{\delta p_2^{II} - p_1^I}{\delta f(q_{02}) - f(q_{01})}, \frac{p_2^{II} - p_1^{II}}{f(q_{02}) - f(q_{01})}\right) = \frac{p_2^{II}}{f(q_{02})}.$$

Therefore, the consumers with $\{v: \frac{p_2^{II}}{f(q_{02})} \leq g(v) < \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\}$ buy only

Version 2 in Period II.

The lower bound of the “buy Version 1 in the first period and Version 2 in the second Period”

strategy in (8) is:

$$\max\left(\frac{p_1^I + \delta p_2^{II}}{f(q_{01}) + \delta f(q_{12})}, \frac{p_2^{II}}{f(q_{12})}, \frac{p_1^I + \delta p_2^{II} - \delta p_1^{II}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{01})}, \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}\right)$$

$= \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}$. Therefore, the consumers with $\{v : \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \leq g(v)\}$ buy Version 1 in Period I and Version 2 in Period II.

□

A3. Producer's Region II Profit Maximization Problem Formulation in Section 2.4.

In Period II, consumers in the set $[\frac{p_1^{II}}{f(q_{01})}, \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})}]$ purchase Version 1 and consumers in $[\frac{p_2^{II}}{f(q_{12})}, 1]$ purchase Version 2. The corresponding demands are $(\frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} - \frac{p_1^{II}}{f(q_{01})})$ for Version 1 and $(1 - \frac{p_2^{II}}{f(q_{12})})$ for Version 1. The firm maximizes its revenue as:

$$R_2^{II*}(p_1^I, p_1^{II}(p_1^I), p_2^{II}(p_1^I)) = \max_{p_1^{II}, p_2^{II}} p_1^{II} \left(\frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} - \frac{p_1^{II}}{f(q_{01})} \right) + p_2^{II} \left(1 - \frac{p_2^{II}}{f(q_{12})} \right)$$

subject to non-negative price and demand constraints

$$p_1^{II}, p_2^{II} \geq 0$$

$$p_2^{II} \leq f(q_{12})$$

and the boundary conditions of Region II

$$\frac{f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} p_1^I \leq p_2^{II}$$

$$p_1^{II} \leq p_1^I.$$

In Period I, consumers in the set $[\frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})}, 1]$ purchase Version 1 and the demand for

Version 1 is $(1 - \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})})$. Then the firm's revenue maximization problem in Period I is:

$$R_1^{II*}(p_1^I, p_1^{II}(p_1^I), p_2^{II}(p_1^I)) = \max_{p_1^I} p_1^I (1 - \frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})}) + \delta R_2^{II*}(p_1^I, p_1^{II}(p_1^I), p_2^{II}(p_1^I))$$

subject to

$$p_1^I \geq 0$$

$$\frac{p_1^I - \delta p_1^{II}}{(1-\delta)f(q_{01})} \leq 1.$$

A4. Producer's Region III Profit Maximization Problem in Section 2.4.

In Period II, consumers in the set $[\frac{p_2^{II}}{f(q_{02})}, 1]$ purchase Version 2 and the demand for

Version 2 is $(1 - \frac{p_2^{II}}{f(q_{02})})$. The firm maximizes its revenue in Period II as:

$$R_2^{III*}(p_1^I, p_1^{II}, p_2^{II}) = \max_{p_1^{II}, p_2^{II}} p_2^{II} (1 - \frac{p_2^{II}}{f(q_{02})})$$

subject to non-negative price and demand constraints

$$p_1^{II}, p_2^{II} \geq 0$$

$$p_2^{II} \leq f(q_{02})$$

and the boundary conditions of Region III

$$p_2^{II} \leq \frac{f(q_{02})}{f(q_{01})} p_1^I$$

$$p_1^{\prime\prime} \leq p_1^{\prime}.$$

In Period I, the firm sells Version 1 to consumers in the set $[\frac{p_1^{\prime}}{f(q_{01}) + f(q_{12}) - \delta f(q_{02})}, 1]$

and decides the optimal price of Version 1.

$$R_1^{\prime\prime\prime*}(p_1^{\prime}, p_1^{\prime\prime}(p_1^{\prime}), p_2^{\prime\prime}(p_1^{\prime})) = \max_{p_1^{\prime}} p_1^{\prime} \left(1 - \frac{p_1^{\prime}}{f(q_{01}) + f(q_{12}) - \delta f(q_{02})}\right) +$$

$$\delta R_2^{\prime\prime\prime*}(p_1^{\prime}, p_1^{\prime\prime}(p_1^{\prime}), p_2^{\prime\prime}(p_1^{\prime})).$$

s.t.

$$p_1^{\prime} \geq 0$$

$$\frac{p_1^{\prime}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \leq 1$$

A5. Proof of PROPOSITION 2 (Only for RI-1, RI-2, and RI-3) in Section 2.4.

Solve backward starting with the second period. From the objective function (9) subject to constraints (10)-(13), the Lagrangian function is:

$$L_2^{\prime} = p_1^{\prime\prime} \left(\frac{p_1^{\prime} - \delta p_1^{\prime\prime}}{(1-\delta)f(q_{01})} - \frac{p_1^{\prime\prime}}{f(q_{01})} \right) + p_2^{\prime\prime} \left(1 - \frac{\delta p_2^{\prime\prime} - p_1^{\prime}}{\delta f(q_{02}) - f(q_{01})} \right) - \lambda_1 \left(\frac{f(q_{02})}{f(q_{01})} p_1^{\prime} - p_2^{\prime\prime} \right) - \lambda_2 (p_2^{\prime\prime} - \frac{f(q_{12})}{f(q_{01}) + \delta f(q_{02}) - \delta f(q_{02})} p_1^{\prime}) - \lambda_3 (\delta p_2^{\prime\prime} - p_1^{\prime} - (\delta f(q_{02}) - f(q_{01}))) - \lambda_4 (p_1^{\prime\prime} - p_1^{\prime}) - \lambda_5 (-p_2^{\prime\prime}) -$$

$\lambda_5 (-p_1^{\prime\prime})$. The first order conditions (FOCs) are as follows:

$$\frac{\partial L_2^{\prime}}{\partial p_2^{\prime\prime}} = 1 - \frac{p_2^{\prime\prime} \delta}{-f(q_{01}) + \delta f(q_{02})} - \frac{p_1^{\prime\prime} + \delta p_2^{\prime\prime}}{-f(q_{01}) + \delta f(q_{02})} + \lambda_1 - \lambda_2 - \delta \lambda_3 + \lambda_5 = 0$$

$$\frac{\partial L_2^I}{\partial p_1^{\prime\prime}} = -\frac{f(q_{12})}{f(q_{01})} + \frac{p_1^I - \delta f(q_{12})}{f(q_{01})(1-\delta)} + p_1^{\prime\prime} \left(-\frac{1}{f(q_{01})} - \frac{\delta}{f(q_{01})(1-\delta)} \right) - \lambda_4 + \lambda_6 = 0$$

$$\frac{\partial L_2^I}{\partial \lambda_1} = p_2^{\prime\prime} - \frac{f(q_{02})}{f(q_{01})} p_1^I \geq 0, \lambda_1 \geq 0, (p_2^{\prime\prime} - \frac{f(q_{02})}{f(q_{01})} p_1^I) \lambda_1 = 0$$

$$\frac{\partial L_2^I}{\partial \lambda_2} = -p_2^{\prime\prime} + \frac{p_1^I f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \geq 0, \lambda_2 \geq 0, (-p_2^{\prime\prime} + \frac{p_1^I f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}) \lambda_2 = 0$$

$$\frac{\partial L_2^I}{\partial \lambda_3} = -\delta p_2^{\prime\prime} + p_1^I + \delta f(q_{02}) - f(q_{01}) \geq 0, \lambda_3 \geq 0, \lambda_3 (\delta p_2^{\prime\prime} - p_1^I - (\delta f(q_{02}) - f(q_{01}))) = 0$$

$$\frac{\partial L_2^I}{\partial \lambda_4} = -p_1^{\prime\prime} + p_1^I \geq 0, \lambda_4 \geq 0, \lambda_4 (p_1^{\prime\prime} - p_1^I) = 0$$

$$\frac{\partial L_2^I}{\partial \lambda_5} = p_2^{\prime\prime} \geq 0, \lambda_5 \geq 0, \lambda_5 (-p_2^{\prime\prime}) = 0$$

$$\frac{\partial L_2^I}{\partial \lambda_6} = p_1^{\prime\prime} \geq 0, \lambda_6 \geq 0, \lambda_6 (-p_1^{\prime\prime}) = 0$$

The FOCs generate the following three potential solutions for $(p_1^{\prime\prime}, p_2^{\prime\prime}, \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6)$.

$$\text{CASE1 } \left(\frac{p_1^I}{2}, \frac{f(q_{02})}{f(q_{01})} p_1^I, -\frac{-p_1^I f(q_{01}) + f(q_{01})^2 + 2\delta p_1^I f(q_{01}) - \delta f(q_{01}) f(q_{02})}{f(q_{01})(f(q_{01}) - f(q_{02}))}, 0, 0, 0, 0, 0 \right)$$

$$\text{CASE2 } \left(\frac{p_1^I}{2}, \frac{p_1^I f(q_{12})}{p_1^I + \delta f(q_{12}) - \delta f(q_{02})}, 0, \right.$$

$$\left. -\frac{-p_1^I + f(q_{01}) - \delta f(q_{02})}{-f(q_{01}) + \delta f(q_{02})} - \frac{2p_1^I \delta f(q_{12})}{(p_1^I + \delta f(q_{12}) - \delta f(q_{02}))(-f(q_{01}) + \delta f(q_{02}))}, 0, 0, 0, 0 \right)$$

$$\text{CASE3 } \left(\frac{p_1^I}{2}, -\frac{-p_1^I + f(q_{01}) - \delta f(q_{02})}{2\delta}, 0, 0, 0, 0, 0, 0 \right).$$

These potential solutions satisfy all equalities of FOCs but do not necessarily satisfy the inequality conditions. The inequalities of FOCs can not be evaluated in Period II problem

because these potential solutions depend on p_1^I , which will be determined in Period I problem.

The conditions needed to satisfy the inequalities of FOCs are handed over to Period I problem.

CASE1:

$$\text{With } (p_1^{\prime\prime}, p_2^{\prime\prime}, \lambda_1) = (p_1^I / 2, \frac{f(q_{02})}{f(q_{01})} p_1^I, -\frac{-p_1^I f(q_{01}) + f(q_{01})^2 + 2\delta p_1^I f(q_{01}) - \delta f(q_{01}) f(q_{02})}{f(q_{01})(f(q_{01}) - f(q_{02}))}),$$

non-negative values for $\lambda_1, \frac{\partial L_2^I}{\partial \lambda_2}, \frac{\partial L_2^I}{\partial \lambda_3}, \frac{\partial L_2^I}{\partial \lambda_4}, \frac{\partial L_2^I}{\partial \lambda_5}$, and $\frac{\partial L_2^I}{\partial \lambda_6}$ from Period II problem must be

ensured in order for CASE1 to be a solution. However, $\frac{\partial L_2^I}{\partial \lambda_4}, \frac{\partial L_2^I}{\partial \lambda_5}$, and $\frac{\partial L_2^I}{\partial \lambda_6}$ are automatically

satisfied by the constraint (18) of Period I problem. Therefore, the non-negative conditions for

$\lambda_1, \frac{\partial L_2^I}{\partial \lambda_2}$, and $\frac{\partial L_2^I}{\partial \lambda_3}$ are added in constraints of Period I problem. In Period I, Lagrangian function

of the objective function (14) subject to the constraints (15) and (16) and the non-negative

conditions for $\lambda_1, \frac{\partial L_2^I}{\partial \lambda_2}$, and $\frac{\partial L_2^I}{\partial \lambda_3}$ is: $L_1^{\prime\prime}(p_1^I, p_1^{\prime\prime}, p_2^{\prime\prime}) = p_1^I [(\frac{\delta p_2^{\prime\prime} - p_1^I}{\delta f(q_{02}) - f(q_{01})} - \frac{p_1^I - \delta p_1^{\prime\prime}}{(1-\delta)f(q_{01})}) +$

$$(1 - \frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})})] - \gamma_1 (-p_1^I) - \gamma_2 (\frac{p_1^I}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} - 1) - \gamma_3$$

$$(\frac{-p_1^I f(q_{01}) + f(q_{01})^2 + 2\delta p_1^I f(q_{01}) - \delta f(q_{01}) f(q_{02})}{f(q_{01})(f(q_{01}) - f(q_{02}))}) - \gamma_4 (\frac{f(q_{02})}{f(q_{01})} p_1^I - \frac{p_1^I f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})}))$$

$$- \gamma_5 (\delta \frac{f(q_{02})}{f(q_{01})} p_1^I - p_1^I - \delta f(q_{02}) + f(q_{01})).$$

The feasible region of Period I problem exists if and only if $\frac{f(q_{01})}{f(q_{02})} \geq 2\delta - 1$.

Proof

From the constraint (18) $p_1^I > 0$. From the constraint (19) $p_1^I < f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})$.

From the non-negative condition for λ_1 , $p_1^I > \frac{(\delta f(q_{02}) - f(q_{01}))f(q_{01})}{2 \delta f(q_{02}) - f(q_{01})}$. From the non-negative

conditions for $\frac{\partial L_2'}{\partial \lambda_2}$, $p_1^I > 0$. From the non-negative conditions for $\frac{\partial L_2'}{\partial \lambda_3}$, $p_1^I \leq f(q_{01})$. Since

$$f(q_{01}) \geq f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02}) \text{ and } \frac{(\delta f(q_{02}) - f(q_{01}))f(q_{01})}{2 \delta f(q_{02}) - f(q_{01})} > 0, \frac{(\delta f(q_{02}) - f(q_{01}))f(q_{01})}{2 \delta f(q_{02}) - f(q_{01})}$$

$\leq p_1^I$ and $p_1^I \leq f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})$. Therefore, the feasible region for p_1^I exists if and only

if $\frac{(\delta f(q_{02}) - f(q_{01}))f(q_{01})}{2 \delta f(q_{02}) - f(q_{01})} \leq f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})$. Then, $\frac{(\delta f(q_{02}) - f(q_{01}))f(q_{01})}{2 \delta f(q_{02}) - f(q_{01})} \leq$

$$f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02}) \Leftrightarrow f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02}) - \frac{(\delta f(q_{02}) - f(q_{01}))f(q_{01})}{2 \delta f(q_{02}) - f(q_{01})}$$

$$= \delta f(q_{01}) \left(\frac{f(q_{02})}{2 \delta f(q_{02}) - f(q_{01})} - 1 \right) \geq 0 \Leftrightarrow \frac{f(q_{01})}{f(q_{02})} \geq 2\delta - 1. \square$$

Solving Period I problem with $\frac{f(q_{01})}{f(q_{02})} \geq 2\delta - 1$, I obtain the solution as follows:

$$(p_1^{I*}, p_1^{II*}, p_2^{II*}) = \left(\frac{f(q_{01})(1-\delta)}{2+\delta}, \frac{1}{2} p_1^{I*}, \frac{p_1^{I*} f(q_{02})}{f(q_{01})} \right), \text{ if } \frac{f(q_{01})}{f(q_{02})} \geq \frac{3\delta^2}{(1+2\delta)} \text{ which is the}$$

solution (RI-1). Also,

$$(p_1^{I*}, p_1^{II*}, p_2^{II*}) = \left(\frac{f(q_{01})(\delta f(q_{02}) - f(q_{01}))}{2\delta f(q_{02}) - f(q_{01})}, \frac{1}{2} p_1^{I*}, \frac{p_1^{I*} f(q_{02})}{f(q_{01})} \right), \text{ if } 2\delta - 1 \leq \frac{f(q_{01})}{f(q_{02})} < \frac{3\delta^2}{(1+2\delta)}$$

which consists a part of the solution (RI-2).

CASE2:

In CASE 2, $(p_1'', p_2'', \lambda_2) = \left(\frac{p_1'}{2}, \frac{p_1' f(q_{12})}{p_1' + \delta f(q_{12}) - \delta f(q_{02})}, -\frac{-p_1' + f(q_{01}) - \delta f(q_{02})}{-f(q_{01}) + \delta f(q_{02})} - \right.$

$\left. \frac{2p_1' \delta f(q_{12})}{(p_1' + \delta f(q_{12}) - \delta f(q_{02}))(-f(q_{01}) + \delta f(q_{02}))} \right)$. The non-negative conditions for $\frac{\partial L_2'}{\partial \lambda_1}$, λ_2 , $\frac{\partial L_2'}{\partial \lambda_3}$,

$\frac{\partial L_2'}{\partial \lambda_4}$, $\frac{\partial L_2'}{\partial \lambda_5}$, and $\frac{\partial L_2'}{\partial \lambda_6}$ in FOCs must be satisfied in order for CASE 2 to be a solution. However,

$\frac{\partial L_2'}{\partial \lambda_4}$, $\frac{\partial L_2'}{\partial \lambda_5}$, and $\frac{\partial L_2'}{\partial \lambda_6}$ are automatically satisfied by the constraint (15). Therefore, the non-

negative conditions for $\frac{\partial L_2'}{\partial \lambda_1}$, λ_2 , and $\frac{\partial L_2'}{\partial \lambda_3}$ are added to the constraints of Period I problem. In

Period I, Lagrangian function from the objective function (14) with the constraints (15) and (16)

and the non-negative conditions for $\frac{\partial L_2'}{\partial \lambda_1}$, λ_2 , and $\frac{\partial L_2'}{\partial \lambda_3}$ is: $L_1''(p_1', p_1'', p_2'') = p_1'$

$$\left[\left(\frac{\delta p_2'' - p_1'}{\delta f(q_{02}) - f(q_{01})} - \frac{p_1' - \delta p_1''}{(1 - \delta)f(q_{01})} \right) + \left(1 - \frac{p_1'}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right) \right] - \gamma_1(-p_1') - \gamma_2$$

$$\left(\frac{p_1'}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} - 1 \right) - \gamma_3 \left(\frac{-p_1' + f(q_{01}) - \delta f(q_{02})}{-f(q_{01}) + \delta f(q_{02})} - \right.$$

$$\left. \frac{2p_1' \delta f(q_{12})}{(p_1' + \delta f(q_{12}) - \delta f(q_{02}))(-f(q_{01}) + \delta f(q_{02}))} \right) - \gamma_4 \left(\frac{f(q_{02})}{f(q_{01})} p_1' - \frac{p_1' f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right) - \gamma_5$$

$$\left(\delta \frac{p_1' f(q_{12})}{p_1' + \delta f(q_{12}) - \delta f(q_{02})} - p_1' - \delta f(q_{02}) + f(q_{01}) \right). \text{ Solving the above Lagrangian function of}$$

Period I, it is straightforward to obtain the solution in CASE 2, $(p_1^{I*}, p_1^{II*}, p_2^{II*})$:

$$\left(\frac{f(q_{01})(1 - \delta)(\delta f(q_{02}) - f(q_{01}))}{2\delta f(q_{02}) - f(q_{01}) - \delta f(q_{01})}, \frac{1}{2} p_1^{I*}, \frac{f(q_{12}) p_1^{I*}}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right). \text{ This complete the}$$

solution (RI-3)

CASE3:

With $(p_1'', p_2'') = \left(\frac{p_1'}{2}, -\frac{-p_1' + f(q_{01}) - \delta f(q_{02})}{2\delta}\right)$, the non-negativity for $\frac{\partial L_2'}{\partial \lambda_1}$, $\frac{\partial L_2'}{\partial \lambda_2}$, $\frac{\partial L_2'}{\partial \lambda_3}$,

$\frac{\partial L_2'}{\partial \lambda_4}$, $\frac{\partial L_2'}{\partial \lambda_5}$, and $\frac{\partial L_2'}{\partial \lambda_6}$ in FOCs must be ensured in order for CASE3 to be a solution. However,

$\frac{\partial L_2'}{\partial \lambda_3}$, $\frac{\partial L_2'}{\partial \lambda_4}$, $\frac{\partial L_2'}{\partial \lambda_5}$, and $\frac{\partial L_2'}{\partial \lambda_6}$ are automatically positive by the assumption $f(q_{01}) < \delta f(q_{02})$ and

the constraint (15). Therefore, the non-negative conditions for $\frac{\partial L_2'}{\partial \lambda_1}$ and $\frac{\partial L_2'}{\partial \lambda_2}$ are added in

constraints of Period I problem. In Period I, Lagrangian function from the objective function (14)

with the constraints (15) and (16) and the non-negative conditions for $\frac{\partial L_2'}{\partial \lambda_1}$ and $\frac{\partial L_2'}{\partial \lambda_2}$ is:

$$L_1''(p_1', p_1'', p_2'') = p_1' \left[\left(\frac{\delta p_2'' - p_1'}{\delta f(q_{02}) - f(q_{01})} - \frac{p_1' - \delta p_1''}{(1-\delta)f(q_{01})} \right) + \left(1 - \frac{p_1'}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} \right) \right] -$$

$$\gamma_1(-p_1') - \gamma_2 \left(\frac{p_1'}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} - 1 \right) - \gamma_3 \left(\frac{f(q_{02})}{f(q_{01})} p_1' + \frac{-p_1' + f(q_{01}) - \delta f(q_{02})}{2\delta} \right) - \gamma_4 \left(-\frac{p_1' f(q_{12})}{f(q_{01}) + \delta f(q_{12}) - \delta f(q_{02})} + \frac{-p_1' + f(q_{01}) - \delta f(q_{02})}{2\delta} \right).$$

obtain the solution of CASE 3, $(p_1^{I*}, p_1^{II*}, p_2^{II*})$:

$$\left(\frac{f(q_{01})(1-\delta)(\delta f(q_{02}) - f(q_{01}))}{2\delta f(q_{02}) - f(q_{01}) - \delta f(q_{01})}, \frac{1}{2} p_1^{I*}, \frac{p_1^{I*} + \delta f(q_{02}) - f(q_{01})}{2\delta} \right), \text{ if } \frac{f(q_{01})}{f(q_{02})} \leq \frac{2}{3} \delta \text{ which was}$$

already counted by the solution obtained in CASE 2.

$$\left(\frac{f(q_{01})(\delta f(q_{02}) - f(q_{01}))}{2\delta f(q_{02}) - f(q_{01})}, \frac{1}{2} p_1^{I^*}, \frac{p_1^{I^*} + \delta f(q_{02}) - f(q_{01})}{\delta} \right) \text{ if } \delta < 0.5 \text{ and } \frac{f(q_{01})}{f(q_{02})} > \frac{2\delta(1+2\delta)}{3(1+\delta)},$$

which completes the rest part of the solution (RI-2) along with the second solution obtained in CASE 1.

□

The solution procedures for other regions are similar. The detailed proofs for (RII-1), (RII-2) and (RIII-1) are omitted to save space but will be provided upon request.