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Pricing Strategy and Resource Management in the Digital Era

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Introduction

Modern information technologies have caused changes in business practice and hold continued prospects for new innovations. Increased information visibility, and increased ability for two-way multimedia communication between remote entities, makes it possible for firms to experiment with new business models, pricing strategies and resource allocations. This raises a need for formal model-based analysis of new opportunities and new decision problems. The complex nature of such problems makes it essential to development management decision technologies that supplement the model-based decision analysis and provide managers with interactive tools for studying the consequences of new pricing and resource allocation strategies. My dissertation research develops on this theme, by developing mathematical models for analyzing business practices in two specific areas (electronic retailing and broadband internet access services) and by developing decision support systems that enable the deployment and use of these models to improve managerial decisions.

My first essay studies stockout compensation policies for an electronic retailer where the retailer could offer a price discount to compensate for product unavailability during stockout. The electronic retailing context makes it easier to implement the stockout compensation policy, since short-lived price changes (or compensations) can be announced quite costelessly due to lower menu costs. The key finding is that it is optimal for the retailer to set a compensation equal to the expected waiting cost, and I show that the stockout compensation policy results in more efficient operation (it reduces inventory costs and increase market coverage, consumer surplus, and social welfare) as well as increases the retailer's profit.

The second essay develops analytical models and decision support techniques to examine another new business practice, dual mechanism, where an online retailer combines two commonly used selling mechanisms (posted-price and auction). I find that this business practice implements a price discrimination model based on customer's delay sensitivity. Through systematic computational experiments, I demonstrate that the dual mechanism strictly dominates the posted-price mechanism, but that the pure auction mechanism could outperform the dual mechanism.

The third identifies new possibilities for marketing of broadband services and analyzes firm and consumer behavior in the context of multiple classes of services. This essay proposes a definition of QoS in a broadband network, presents a measurement of the proposed QoS, and discuss its implementability. I am currently attempting to examine how the idea of contingency pricing can be applied meaningfully to broadband services to assure customers for high quality services.

The rest of this extended abstract is organized as follows. Section 2 describes my second essay in terms of motivation, problem statement, computational experiments, and DSS model. Section 3 motivates the problem of my third paper, presents preliminary results, and discusses implementability of my proposal.

Dual Mechanism in Electronic Retailing

Motivation

While posted price and auction-based pricing mechanisms have typically been seen as alternatives, the simultaneous use of these mechanisms (by a single firm and for the same product) has grown with the commercialization and widespread use of the Internet. Internet-based pricing technologies give firms a fairly low-cost means to provide and to customize information about prices and related factors, such as delivery times. In some cases, the seller uses the two mechanisms jointly but only to move two separate classes of goods (e.g., in-fashion clothing vs. out-of-style clothing), which is easily explained as a case of quality-based price discrimination. Our focus of this paper is on examining a new selling mechanism, which hereafter we call the Dual Mechanism, on the current Internet: the simultaneous use of a posted pricing scheme with immediate delivery and a multi-unit auction with delivery delayed to the end of the auction. Examples of such practice include Dell Computer and IBM, both manufacturers and direct sellers of computer equipment, and uBid, which is an online reseller. In addition to these large firms, there are many relatively small online retailers on eBay.com who offer a posted price market with immediate delivery and a simultaneous multi-unit auction.

Why would such a Dual Mechanism make sense? Since buyers have the option of purchasing at the posted price, why would any rational buyer ever bid greater in the auction, especially given the delayed delivery? Given this fact, why would the firm have any incentive to sell some units of the product through an auction at a lower price? The purpose of this paper is to explain how this Dual Mechanism affects the complex interplay that the seller faces between revenues and costs. The intuition is that when buyers have time- or delay-sensitive valuations, then the simultaneous offering of these two mechanisms can help the firm exploit heterogeneity in delay sensitivities and separate high-type and low- type buyers.

Moreover, the distinctive aspect of our analysis is that we take into account the cost, specifically the inventory structure, of the seller's operations. The seller holds enough inventory to satisfy only high-type buyers, while it fulfills the demand of low-type buyers without incurring holding costs.

Problem Statement and Formulation

We consider an online retailer who sells a product through a web store and manages inventory using an EOQ-type policy. We assume that customers arrive at the web store at a constant rate, *d*, at each period and that the customer valuations for the product are uniformly distributed between 0 and 1 (i.e., $V\sim U[0,1]$). We also assume that a customer's valuation decreases, due to the waiting time for the product, until she receives it. We model this disutility as a linear function of the customer's valuation and waiting time. Specifically, if a customer with valuation v gets the product after t periods, then the customer's utility is $v(1-wt)$ where w ($0<w<1$) is a constant representing delay sensitivity.

For simplicity, we assume that the lead time between order placement and order arrival is deterministic and that the customers get the product immediately after the retailer ships the product. Without loss of generality, we assume that the retailer delivers the ordered products immediately for the posted price customers, but fulfills the auction winners' delivery at the closing time of the auction. The retailer can purchase the product at unit purchasing cost, c. The inventory costs include an ordering cost, A, per order and a unit holding cost, h, per period. The retailer's objective is maximizing the expected profit per unit time by simultaneously deciding cycle length (T), posted price (p_p), and number of units for the auction (N).

Through our analysis, we have found that, under the Dual Mechanism, there exists an indifference point at each period and that the customers choose either the posted price or auction by comparing this indifference point with their valuation for the product. We omit the details of these results due to the space limit.

Based on our economical analysis of the problem, we have the retailer the retailer's total profit per unit time as

$$\max_{p_p,N,T} \quad \frac{(p_p-c)d\left(T(1-p_p)+\dfrac{p_p-p_a}{w}\ln[p_p]\right)+(p_a-c)N}{T} - \frac{hd\dfrac{(T-t_x)^2(1-p_p)}{2}+hd\left(\dfrac{(t_x-t_y)(2T-t_x-t_y)}{2}+\dfrac{(p_p-p_a)(t_x-t_y+T\ln[p_p])}{w}\right)+A}{T}$$

$$s.t. \qquad N=d\left(t_y+\frac{p_a\ln[p_a]-p_p\ln[p_p]}{w}\right)-1$$

$$p_a\le p_p,\quad 0\le p_p\le 1,\quad 0\le p_p\le 1,\quad N>0,$$

where $t_x = \dfrac{p_p - p_a}{w \cdot p_p}$ and $t_y = \dfrac{p_p - p_a}{w}$.

Computational Experiment and Observations

Because the characteristics of the Dual Mechanism's optimal solution are not tractable, we conduct a computational experiment and discuss some meaningful observations to extend our understanding of the Dual Mechanism. In the experiment, we vary the values of parameters (i.e., $d \in \{200, 400, 800\}$, $h \in \{0.01, 0.05, 0.1\}$, $c \in \{0.1, 0.2, 0.3\}$, $A \in \{3, 5, 10\}$, and $w \in \{0.01, 0.05, 0.1\}$), and derive optimal solutions for the three conventional selling mechanisms: Pure Posted Price (PPP), Pure Auction (PA), and Dual Mechanism. To summarize, we have total 243 cases, and 729 optimal solution sets for the experiment. From the analysis of the computational experiment, we observe the following results:

Observation 1. *The Dual Mechanism strictly dominates the PPP mechanism.*

This observation is not very surprising since the retailer can always be better off by adding the auction market to the posted price market. We note that the Dual Mechanism has two main effects compared to the PPP mechanism. The first effect is the inventory cost savings, and the second is the increased market coverage due to the auction. Therefore, the retailer is able to achieve higher profits by allocating a smaller number of units to the auction market.

Observation 2. *The Dual Mechanism does not always outperform the (PA) mechanism.*

This observation is somewhat counterintuitive because one can think that providing two choices to the customer will increase the retailer's profits. But consider the effect of the Dual Mechanism compared to the PA mechanism. The Dual Mechanism implements a price discrimination model based on the customer's waiting sensitivity. Therefore, this price discrimination can increase the retailer's profit when the loss due to the price discrimination is less than the gain. To implement this discrimination, the retailer has to keep positive stocks for the high type (delay-sensitive) customers. Now consider the case where the customers are not delay-sensitive. Then the retailer cannot gain much profit from the high type but incurs inventory holding costs. Therefore, in this case, the retailer can be strictly better off by choosing the PA mechanism when the customers are not delay-sensitive and the unit holding cost is relatively high.

Observation 3. *Under the Dual Mechanism, delay-sensitive customers pay a strictly higher price compared to the PPP mechanism. However, the Dual Mechanism increases market coverage.*

The higher price can be explained using the inventory cost-saving effect of the Dual Mechanism: the retailer can reduce the holding cost's burden; hence, she can set the posted price higher. The increased market coverage is due to the auction's lower winning price. However, this phenomenon does not extend to the PA mechanism. The explanation is that the movement from the Dual to the PPP mechanism gives the retailer inventory cost savings and increased market coverage, whereas the movement from the PA to the Dual mechanism only gives the price discrimination effect at the expense of increased inventory costs. These different benefits of the Dual mechanism result in the non-symmetric results in our observations.

In summary, these observations can explain why we now observe the Dual Mechanism on the Internet and partly explain the proliferation of the online auction on the Internet.

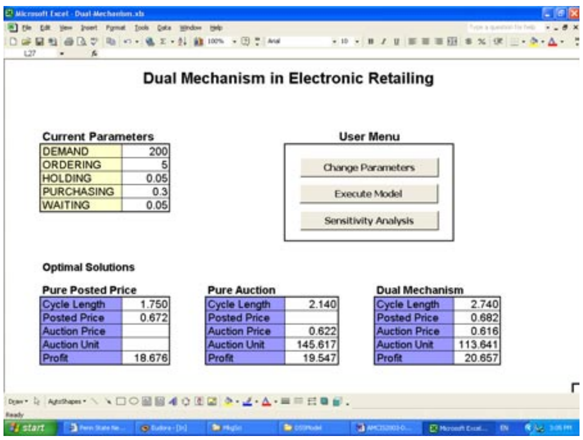
Decision Support System

We have developed a DSS model to help practitioners investigate and examine three conventional mechanisms. Our model uses Microsoft Excel for user interface and GAMS (MINOS) for problem solver. When a user runs the model, the User Interface is displayed. This User Interface window shows current setting of the parameters, user menus, and optimal solutions for each selling mechanism (Figure 1(a)).

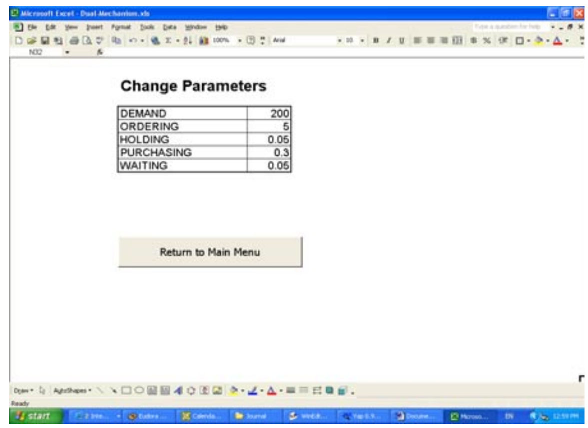
Consistent with our analytical analysis, a user is expected to provide five exogenous parameters (*d, c, A, h, & w*). By clicking the 'Change Parameters' button, the user sees a new interface where specific parameters can be entered (Figure 1(b)).

The second menu relates to the execution of the GAMS model. When the user clicks the 'Execute Model' button, the User Interface delivers the current parameters to our GAMS formulation for each selling mechanism. Then the GAMS (MINOS) solver finds the optimal solutions for each mechanism and returns the optimal solutions to the User Interface. After completing the execution, the User Interface automatically displays the optimal solutions at the bottom of the User Interface window.

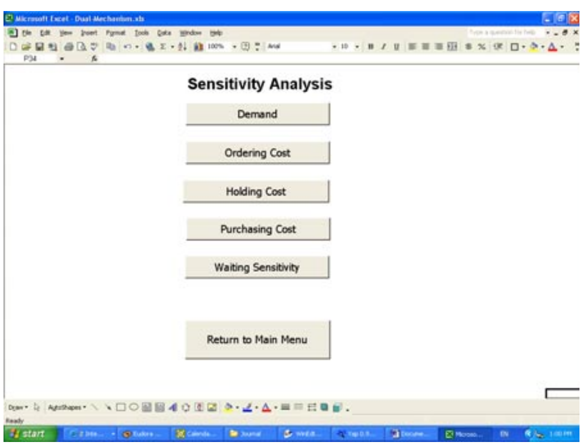
In our model setting, there are five external exogenous parameters that must be provided. However, we believe that there are some parameters about which there might be some uncertainty. So, we develop a Sensitivity Analysis interface where the user can examine the sensitivity of a chosen parameter. When the user clicks the 'Sensitivity Analysis' button, a new interface is displayed (Figure 1(c)). By choosing a specific parameter (among our five parameters), the DSS model executes a sensitivity analysis by varying the value of the parameter for five cases (-10 %, -5%, 0, 5%, 10%) and provides the results with a graphical format as in Figure 1(d).



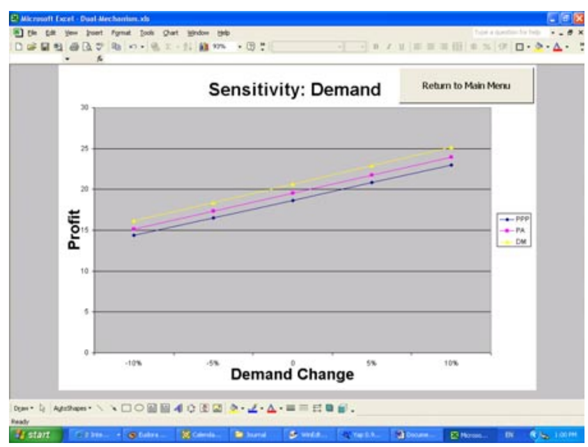
a) Main User Interface Window



b) Parameter Change Window



c) Sensitivity Analysis Menu Window



d) Output of Demand Sensitivity Analysis

Figure 1. DSS Model for Managers

Quality-Contingent Differentiated Pricing for Broadband Services

Motivation

Quality-differentiated pricing, or market segmentation, is a widely used pricing strategy which can yield economic benefits to both sellers and consumers. In the case of Internet access and data transport services, quality-of-service based pricing is considered essential to prevent free riding problems and generate an efficient utilization of the Internet. In the last twenty years, several technical and economic proposals for QoS-based pricing have been introduced, but none widely adopted especially for consumer-oriented services such as broadband Internet access services which offer high-speed and always-on connectivity. Thus, until very recently most broadband access providers offer a single quality level (for home users, at about $45 a month). This policy has limited the adoption of broadband services, because customers who care only about always-on connectivity are not willing to pay the high price for high-speed access.

One critical aspect of quality and pricing for Internet services is the inherent stochasticity in performance level delivered to a user at any time, caused by the best-effort delivery and shared resource utilization in the TCP/IP protocols (up to IPv4). Efforts to introduce QoS-based pricing have focused on reservation of bandwidth for high-priority traffic, differential allocation of capacities for different segments of customers, and weighted routing algorithms. Still, the inherent resource-sharing in packet-switched networks means that throughput rates can only be guaranteed upto some probability of failure. There are also other sources of quality uncertainty, including equipment failure and lack of end-to-end control over resources as shown in Figure 2: an ISP is responsible for traffic and delays between its headend and each end-user's cable modem, but not from the headend to the Internet. In general, most broadband providers offer customers a vague promise of maximum throughput rates, which has little value because communication capacity to the provider system is shared between users.

In the past few months, most broadband providers have announced an intent to offer tiered pricing (Spring 2002). Weber (2002) reported a test for tiered pricing by Cox Communications in Las Vegas (adding a 256kbps tier for $26.95 to their high-speed, $40/month, service). Spring (2002) reports that several broadband ISPs (Comcast, Charter Communications, Cox, Rogers Cable) are testing tiered pricing in some areas. Introduction of tiered pricing is critical to the future of broadband, which is characterized today by excessive capacity and lower-than-predicted demand.

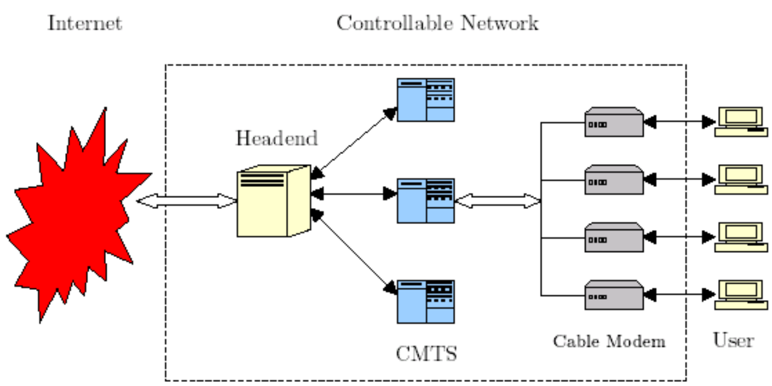


Figure 2. Network Diagram between End Users and Internet

However, introduction of tiered pricing is problematic under QoS uncertainty (potential customers of the higher QoS levels have no incentive to pay the high price unless they can be assured better service) unless the pricing scheme builds in a rigorous mechanism for dealing with quality uncertainty. This is aggravated by the fact that high- and low-value consumers of broadband service have a shared communication channel to the service provider.

Contingency Pricing Proposal for Broadband Services

To implement a tiered pricing policy, a broadband network must be able to offer differential treatment to different categories of users. We propose an alternative scheme for differential treatment, inspired by the broadband industry's newest technology specification *Data Over Cable Service Interface Specification* (DOCSIS) 1.1. This standard specifies the functions of the cable provider's Cable Modem Termination System (CMTS) and the end users' cable modems. Under DOCSIS 1.1, a broadband ISP can assign different service treatments to different customers (for detailed information, see Motorola (2001) and CableLabs Staffs (2001)). Unlike the old control specifications (prior to DOCSIS 1.1, the control mechanisms, typically maximum throughput rate, were installed at each cable modem), the management of different allocation of the routing capacity is controlled by the CMTS. Under the recently announced tiered pricing strategy of broadband ISPs, QoS is promised but it may not be delivered to end users. Moreover, currently there is no rigorous contractual scheme to handle non-performance. The literature on quality uncertainty offers approaches such as money-back guarantees, warranties, and trial periods (see Moorthy and Srinivasan (1995)). In a recent paper, Bhargava and Sundaresan (2000, 2002) propose a quality-contingent pricing scheme and argue that it is especially attractive in the context of IT services. Since the performance can be determined only after using the broadband service, this service can not be returned or repaired, making money-back guarantees and warranties infeasible. Therefore, we build an economic model for our proposal based on Bhargava and Sundaresan (2000, 2002)'s contingency pricing proposal.

We consider an ISP who adopts a contingency pricing scheme with multiple contracts (R_i, R_i): a customer contracts a broadband service at price R_i, and the customer receives a rebate (R_i) if the guaranteed QoS is not delivered. We assume that the ISP has equipment to measure packet delay continuously in small time intervals (e.g., millisecond, second, etc.) for each user. We focus on downstream performance, though the same idea can also be applied to upstream data flow. Since we consider the guarantee within the infrastructure that the ISP is responsible for, we treat the Internet as a single node that sends traffic, destined for specific users, to the ISP.

The ISP's QoS guarantee is only responsible for her own network (i.e., between CMTS to the end users) and consists of two parts (m_{qi}, y_{qi}): given a certain time period, y_{qi} % of packets will be delivered less than m_{qi} milliseconds. Therefore, for the downstream performance, a packet arrival time is stamped at the CMTS, and the corresponding service completion time is measured at the end user's cable modem. We assume that performance is measured by a trusted third party or using equipment & software that has been verified by a trusted agency.

We assume that the ISP serves multiple classes of customers; for example, casual users with email and I-chat, heavy users with multimedia users and large office documents, etc. We also assume that all members in a class share in independent and identical distribution for the number of packet requested per usage (i.e., $X \sim Poisson\,(\lambda_i)$), a distribution for the number of usage during a time period (i.e., $Z \sim Poisson\,(\mu_i)$), and an identical valuation for a packet (α_i) and valuation for the Always-On feature. We note that two main benefits of the broadband services are Always-On feature and High Speed communication. Therefore, expected net surplus of a customer in class *i* is

$$E[U_i] = v_i + E[\text{Utility of High Speed}] \text{ - } (R_i - E[\text{Rebate}])$$

where U_i is the customer's net surplus and v_i is the customer's valuation for the Always-On feature. Let $h(\cdot)$ be the probability density function of the ISP's performance (this function can be estimated from the industry data or appropriate simulation model). Then, we have

$$E[U_i] = v_i + E[\text{Utility of High Speed}] \text{ - } (R_i - \int_0^y h(\cdot)dy)$$

Now, we derive the customer's expected utility from the High Speed feature. We model this utility as linearly correlated to the customer's packet value and total number of packets, but the customer incurs disutility due to the network delay. Considering these, we have

$$\begin{aligned} E[\text{Utility of High Speed}] &= E[\alpha_i \sum_{i=1}^{Z_i} X_i] - \beta E[\alpha_i \sum_{i=1}^{Z_i} X_i E[m_a]] \\ &= \alpha_i \lambda_i \mu_i - \beta \alpha_i \lambda_i \mu_i E[m_a] \end{aligned}$$

where β is a delay constant per unit time. Therefore, a customer in class *i* will take the contract as long as her net surplus is greater than 0. Specifically,

$$E[U_i] = v_i + \alpha_i \lambda_i \mu_i - \beta \alpha_i \lambda_i \mu_i E[m_a] \text{ - } (R_i - \int_0^y h(\cdot)dy) \;\geq\; 0$$

Here we report our preliminary results from a special case of our proposed contingency pricing scheme where there is only one customer class. Under this case, it is obvious that the ISP will choose a contract so that the customers' net surplus is equal to 0. Hence, we have the ISP's profit as

$$\begin{aligned}\pi(R_i, m_{qi}, y_{qi}) &= N_i(R_i - \int_0^y h(\cdot)dy) \\ &= N_i(v_i + \alpha_i\lambda_i\mu_i - \beta\alpha_i\lambda_i\mu_i E[m_a])\end{aligned}$$

Given this profit function, we see the following results:

Proposition 1. *If there is only one customer class, then a) the ISP should utilize all capacity to maximize the profit, and b) as long as* $\int_0^y h(\cdot)dy = \frac{v_i + \alpha_i\lambda_i\mu_i - \beta\alpha_i\lambda_i\mu_i E[m_a]}{R_i}$*, any combination (*$R_i$*,* m_{qi}*,* y_{qi}*) generates an equal profit.*

We are currently attempting to extend our analysis to multiple classes of customer.

Applicability of Proposed QoS Guarantee

To answer whether the proposed QoS guarantee and measurement is practical, we need to answer several important issues for the proposed scheme. These issues include implementability, verifiability, efficiency, and moral hazard problems from ISP and end users.

Unlike the other specifications of broadband services, the new DOCSIS 1.1 provides broadband ISPs ability to set service levels for different types of customers. Furthermore, the new DOCSIS 1.1 requires that CMTS handle this various allocations to end users and store usage information. Therefore, our proposed measurement algorithm can be installed easily at CMTS. In terms of each user's cable modem, it will not be difficult or big burden to implement a system that captures packet delays of the end users.

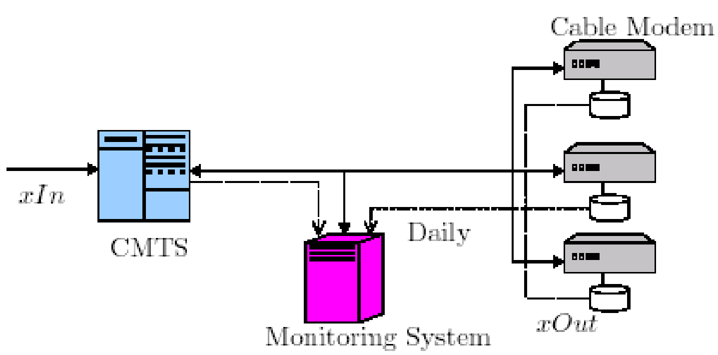


Figure 3. Monitoring of QoS level between CMTS and Cable Modems

To verify the QoS level, the ISP can install a machine between CMTS and all end users (see Figure 3). This machine can communicate with CMTS and each cable modem in a certain time interval (e.g., 10 minutes, 30 minutes, or 1 hour, etc.) and record both CMTS and each cable modem's QoS information. This machine can be operated by third party to increase its credibility.

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