Pricing and Market Segmentation Using Opaque Selling Mechanisms

Chris K. Anderson  
Cornell University School of Hotel Administration, cka9@cornell.edu

Xiaoqing Xie  
Shanghai University of Finance and Economics

Follow this and additional works at: http://scholarship.sha.cornell.edu/articles

Part of the Hospitality Administration and Management Commons, and the Sales and Merchandising Commons

Recommended Citation

This Article or Chapter is brought to you for free and open access by the School of Hotel Administration Collection at The Scholarly Commons. It has been accepted for inclusion in Articles and Chapters by an authorized administrator of The Scholarly Commons. For more information, please contact hlmdigital@cornell.edu.
Pricing and Market Segmentation Using Opaque Selling Mechanisms

Abstract
In opaque selling certain characteristics of the product or service are hidden from the consumer until after purchase, transforming a differentiated good into somewhat of a commodity. Opaque selling has become popular in service pricing as it allows firms to sell their differentiated products at higher prices to regular brand loyal customers while simultaneously selling to non-loyal customers at discounted prices. We develop a stylized model of consumer choice that illustrates the role of opaque selling in market segmentation. We model a firm selling a product via three selling channels: a regular full information channel, an opaque posted price channel and an opaque bidding channel where consumers specify the price they are willing to pay. We illustrate the segmentation created by opaque selling as well as compare optimal revenues and prices for sellers using regular full information channels with those using opaque selling mechanisms in conjunction with regular channels. We also study the segmentation and policy changes induced by capacity constraints.

Keywords
revenue management, marketing pricing, segmentation, auctions, buyer behavior

Disciplines
Hospitality Administration and Management | Sales and Merchandising

Comments
Required Publisher Statement
Abstract

In opaque selling certain characteristics of the product or service are hidden from the consumer until after purchase, transforming a differentiated good into somewhat of a commodity. Opaque selling has become popular in service pricing as it allows firms to sell their differentiated products at higher prices to regular brand loyal customers while simultaneously selling to non-loyal customers at discounted prices. We develop a stylized model of consumer choice that illustrates the role of opaque selling in market segmentation. We model a firm selling a product via three selling channels: a regular full information channel, an opaque posted price channel and an opaque bidding channel where consumers specify the price they are willing to pay. We illustrate the segmentation created by opaque selling as well as compare optimal revenues and prices for sellers using regular full information channels with those using opaque selling mechanisms in conjunction with regular channels. We also study the segmentation and policy changes induced by capacity constraints.

Online travel sales

The selling of travel related services, e.g. hotel rooms and airline seats online has dramatically changed how service firms reach customers. Initial thoughts about online selling were very positive as firms had new channels to reach customers enabling increased opportunities for segmentation. Over time service providers have increased efforts to move customers back to company direct distribution channels (company websites and call centers) in an effort to control sales costs and commissions while maintaining direct contact with the customer to facilitate loyalty programs and other marketing efforts.

One of the early evolutions in online distribution of travel services was opaque selling. Pipeline started this evolution with its opaque selling of airline seats in 1998. Lastminute.com, Hotwire.com and Priceline.com, unlike other online distribution channels such as Expedia.com, Travelocity.com and Booking.com, offer customers opaque products with aspects of the service provider concealed until the transaction has been completed. For instance a customer purchasing a hotel room through Hotwire can not specify the hotel they wish to stay at, but rather only its star rating and general location within the destination city. Customers do not know the identity or exact location of their non-refundable selection property until after purchase. Opaque travel sites offer service providers a convenient channel to segment customers and distribute discounted products without cannibalizing or diluting full priced products. The opaque channels naturally segment customers as regular full price paying customers desiring to stay at the hotel of their choice with full cancellation flexibility are unique from those willing to purchase the discounted, non-refundable opaque product at the unknown service provider. Similar to the opaque posted price model of Hotwire, Priceline offers opaque services but without posted prices. Priceline’s name-your-own-price model is similar to Hotwire where consumers only know the star level and region for a hotel. On Priceline, consumers post bids for the opaque service, having to then wait for the service provider to accept or reject their offer. While opaque selling originated in the United States, it is now quite common globally as Hotwire and Lastminute.com (a subsidiary of Travelocity) now sell opaque hotel rooms across Europe with Blink Booking and HallSt.com recent European opaque selling startups in Europe. For a more detailed description of Priceline’s name-your-own-price model see Anderson (2009) or on Hotwire’s posted price opaque model see Anderson and Xie (2012).

Opaque selling is common across all facets of travel; with air travel, the consumer is unaware of the itinerary (connections and layover durations) or airline and with rental cars, the consumer does not know the type of car or rental firm until after paying for the service. Green and Lomanno (2012) provide a detailed analysis of the hotel distribution landscape where they indicate that 2.3% of hotel bookings are opaque whereas about 7.1% are made through regular full information online travel agents (OTAs). Similarly they indicate that the OTA share of
transactions are increasing and can be as high as 30% or 40% for independent hotels. The level of opacity or uncertainty varies across the different opaque channels as some choose to offer cancellation opportunities as in the case of Lastminute.com, provide user generated feedback (review scores) as in the case of Hotwire.com, or list some of the amenities offered by the service provider. Similarly the degree of opacity may also be impacted by the market, as markets with fewer similar competitors offer decreased opacity over markets with a larger number of service providers.

Opaque selling has recently started to receive interest in the academic literature, most of the early research has focused on models similar to Priceline’s name-your-own-price (NYOP) bidding mechanism where customers post bids for opaque services. Anderson (2009) provides a detailed background on the nature of Priceline’s NYOP model as well as a dynamic programming based model for the setting of prices by firms on Priceline. Fay (2004) develops a stylized model of a monopolist firm using a NYOP channel and investigates whether repeat bidding should be allowed. Strictly speaking, Priceline does not allow repeat bidding within a 24 hour period but there are numerous methods to circumvent this limitation, see BiddingforTravel.com for examples. Fay indicates that partial repeat bidding, i.e. repeat bidding by knowledgeable customers may be less profitable than complete repeat bidding. Fay (2008) extends the monopolist model to a duopoly model with firms pricing into two consumer segments. One segment is loyal to a particular service provider, the second has preferences distributed between the two firms along a line as in the traditional Hotelling model (Hotelling, 1929). Fay (2008) is the first paper to investigate how product opacity affects the market. Fay studies two competing service providers selling products to two types of customers (business and leisure) on both an opaque posted price channel and a traditional distribution channel. Fay shows that opaque selling benefits the monopoly service provider when customers have heterogenous values for products. Shapiro and Shi (2008) extend the model of Fay (2008) to N firms with the number of firms indicating the degree of opacity - uncertainty in knowledge of service provider increases with number of firms. Shapiro and Shi focus on providing a rationale for opaque selling. They explain why service providers are willing to distribute products through opaque travel sites such as Priceline and Hotwire and lose the advantage of product differentiation. Similarly Wang, Gal-Or, and Chatterjee (2009) develop a game theoretic model of a supplier using both regular posted price full information channels as well as a NYOP channel to reach heterogeneous customers. They develop a two-stage game where suppliers set posted prices in period 1 and after observing demand in period 1, set threshold prices on NYOP channel in period 2. Consumers observe fixed posted prices in the first period then decide to buy (at posted prices) or bid in period 2. Fixed posted prices combined with demand uncertainty results in the NYOP channel generating improved revenues for the service provider.


Related research looks more generally at opaque selling where prices are posted but some aspect of the service or service provider is hidden i.e. the selling mechanism similar to that provided by Hotwire.com. Jiang (2007) develops a Hotelling type model to illustrate how a firm should price on regular full information channels versus opaque channels. Jiang indicates that opaque selling can be Pareto improving for both customers and suppliers when customers are differentiated in their willingness to pay. Jiang compares opaque selling and regular selling (selling full-information products), providing insight when to implement opaque selling. Jerath, Netessine, and Veeraraghavan (2010) compare opaque selling with last-minute direct selling and obtain the conditions under which opaque selling is preferred. In their model two firms of equal capacity offer a differentiated service via three channels: regular posted price, posted last-minute sales, and last-minute sales through an opaque intermediary. Their goal is to investigate under what market conditions a firm should directly offer last-minute discounts versus offer those discounts through an intermediary. Jerath et al. relax the posted price rigidity of Wang et al. (2009) through introduction of the direct last-minute discounts. They conclude that direct last-minute selling is preferred
over the opaque intermediary when consumer valuations are high or if the service offerings are relatively homogeneous. Anderson and Xie (2012) use a nested logit model in combination with logistic regression and dynamic programming to illustrate how a service firm can optimally set prices on an opaque sales channel. The choice model allows the characterization of consumer tradeoffs when purchasing opaque products while the dynamic programming approach allows the characterization of the optimal pricing policy as a function of inventory and time remaining.

While there is an extensive body of research on the use of auctions, very little of this research looks at the simultaneous use of auctions and posted prices. Firms can use auctions to reach customers whom may not otherwise purchase, as posted prices may be too high. Conversely auctions potentially dilute revenues as customers willing to pay posted (full prices) may purchase (at lower prices) via the auction. The opaque nature of Priceline’s NYOP model helps to avoid this dilution. Etzion, Pinker, and Seidmann (2006) is one of the few auction related papers that looks at the simultaneous use of auctions and posted prices. Similar to our development they look at a firm with excess supply facing consumers who strategically choose to purchase at posted prices or bid (resorting to posted prices if their bid fails). Different from our model, consumers do not face any product opacity with the auction but do incur a waiting cost associated with bidding. van Ryzin and Vulcano (2004) look at firm using posted prices as well as an auction mechanism, unlike our model of endogenous channel choice (strategic customers similar to Etizon et al.) they assume separate streams of customers to each channel with the seller deciding on inventory allocation across the channels. Huang and Sosic (2011) and Caldentey and Vulcano (2007) also look at firms using auctions in concert with posted prices. Both assume customers arrive according to a poisson process and focus on dynamic inventory management strategies for the seller. Huh and Janakiraman (2008) illustrate the optimality of (s, S) inventory management policies for firms using several different selling mechanisms (including name-your-price mechanisms) in settings where firms can replenish inventory at prescribed costs. Cai, Chao, and Li (2009) investigate the potential benefits of a NYOP retailer in addition to a posted price channel with consumers allowed to return to posted price channels upon failed bid attempts.

We develop a stylized model of consumers looking to acquire travel services through either full information or opaque channels (both posted price and bidding). Consumers choose their channel or sequence of channels (in the case of bidding first followed by posted prices) that maximizes their surplus. Our paper is unique from the literature in that it is the only paper that investigates a firm using two opaque (posted and bidding) channels simultaneously with regular full information posted price channels. Second, prior research assumes two or more exogenous customer segments (i.e. business and leisure) with the opaque channels targeted at the leisure or price sensitive segment; whereas we develop endogenous consumer segments where consumers choose the channel of their choice by maximizing their surplus. Our goal is to illustrate how opaque channels naturally segment consumers as well as how firms should use and price into these channels as a function of the degree of their opacity. We also discuss the segmentation and policy changes induced by capacity constraints. We show that simultaneously selling through regular and opaque channels even in the presence of tight capacity constraints helps firms to segment consumers, differentially pricing into different willingness to pay segments and improve revenues (over the absence of opaque pricing).

**Model development**

We develop a model of strategic channel choice by consumers. As our model is one of channel choice versus choice of service provider, we look at how prices are set across channels versus across firms, here strategic consumers choose the channel or sequence of channels which maximizes their surplus. The seller can potentially offer its products across three selling mechanisms: a posted full information market, posted opaque market with certain aspects of the product hidden and a name your price opaque auction mechanism. Unlike previous research which assumes exogenous consumer behavior we model endogenous consumer behavior where all consumers act strategically as they optimally choose the channel (or sequence of channels) that maximizes their surplus. For ease of exposition we will refer to the full information channel as the regular (REG), the opaque posted price channel as opaque (OPQ) and the opaque channel with bidding as BID. For comparison purposes, think of our regular channel as a firm’s website (Marriott.com, Hilton.com or USAirways.com) or a typical online travel agent similar to Expedia, Orbitz or Travelocity, the posted opaque channel analogous to Hotwire.com, and our bidding model similar to Priceline’s name-your-own-price model.
Each customer $i$ looking to acquire service has an independent reference price or valuation $v_i$ for a level of service. Similar to Wang et al. (2009) we assume $v_i$ uniformly distributed between 0 and 1, i.e. its density function $f(v_i) = 1$ for $0 \ll v_i \ll 1$ and 0 otherwise. The service provider posts a price $P_1$ on the regular channel and fully discloses all service provider characteristics. The service provider posts price $P_2$ on the opaque posted price channel and reveals the full information after the purchase. The service provider also sets a threshold price $R$ on the opaque bidding channel. The customer, if they choose to bid, bids $B_i$ on the bidding channel. Similar to Hann and Terwiesch (2003), Spann et al. (2004) and Ding, Eliashberg, Huber, and Saini (2005), with limited knowledge of the value of the threshold $R$, customers expect $R$ to be distributed uniformly over $[0,1]$. As a result customers believe their bid of $B_i$ will be accepted by the service provider with a probability of $B_i$.

When a consumer pays $P_1$ at the regular full information channel they are purchasing the branded level of service of choice, here assuming the consumer has an affinity for this branded service. When the consumer pays $P_2$ at a posted opaque channel they know they are receiving a similar product but they don’t know from which service provider - e.g. could be any of 10 3-Star hotels in Times Square NYC. Typically posted price opaque channels like Hotwire.com display only one service provider of each product at a time (e.g. only one 3-Star Times Square hotel). The supplier which is displayed would change over time as transactions occur and inventory is sold with the opaque mechanism adding an element of randomness to which supplier is displayed. Priceline’s opaque bidding channel behaves in a similar fashion, when the consumer submits an offer, $B_i$ (for a 3-Star Times Square hotel) Priceline then randomly selects from the firms that have provided it with inventory to see if they have a price that is less than the consumers offer price. Priceline randomly rotates through all the qualifying hotels (3-Star Times Square hotels) until either a hotel with a price low enough is found or no service provider meets the consumer’s bid. Online boards such as BiddingForTravel.com provide resources and historic results to help consumers in determining how to bid on Priceline. For a more exhaustive discussion of Priceline see Anderson (2009) and Anderson and Xie (2012) for similar detail on posted opaque selling at Hotwire.

The service provider looks to augment its full information channel with the opaque channels in an effort to sell inventory to consumers with lower willingness to pay and less affinity for an individual firm (i.e. willing to forgo some knowledge of the service provider in exchange for discounted prices). The service provider looks to use the opaque channels even though they yield considerably lower revenues (typical discounts at Hotwire and Priceline range from 25% to 50%). Fig. 1 shows sample reservations buildup for a 3.5 star hotel in Dupont Circle Washington DC. The figure shows the average cumulative percentage of reservations over the last week prior to arrival for 6 weeks of arrival dates in the fall of 2008. The figure displays total reservations as well as opaque reservations through each of Hotwire and Priceline. As shown in the figure approximately 50% of all reservations (solid line) are made before 7 days before arrival but almost no opaque reservations (dashed and dotted lines) are made prior to 7 days before arrival with the majority of opaque reservations occurring in the final 2 days before arrival. So while opaque selling tends to be last minute it is occurring simultaneously with regular full information selling as the service provider is using the deeply discounted opaque channels to sell distressed inventory, inventory that would otherwise not be sold, over these final few days prior to arrival. During these last few days prior to the service becoming worthless (hotel bed not occupied or airline seat flying empty) the firm is in essence pricing without capacity considerations (able to meet all demand). Whereas earlier on in the selling process (several weeks or months prior to arrival at the hotel or departure of the aircraft) the firm may not use opaque channels as it prices in consideration of capacity constraints - hoping to sell all inventory at higher prices to the brand loyal customers on the full information channels. As we will also see in later sections, the firm also tends not to use the opaque channels if they are not very opaque. The opaque channels become increasingly less opaque earlier on in the selling process as fewer firms may tend to use them - with opacity as in Shapiro and Shi (2008) directly related to the number of service providers using the opaque channels.
In the following sections we outline optimal prices and the resulting market segmentation for a service provider who has the opportunity to release their products on the regular full information channel, an opaque posted price channel and an opaque channel with bidding. We illustrate our modeling approach when the service provider chooses to list only on the full information channel, optimal prices and the resulting revenue provide a basis to later compare multi-channel strategies. Initially we focus on a firm with no capacity constraint, later extending the formulation to a firm where demand exceeds capacity. For ease of presentation, and without loss of generality, all revenues are normalized to a market of one.

### Customer segmentation

As an illustration of our method we provide an analysis of a firm operating on a single full information channel, we then extend this framework to a firm operating on all three channels. The service provider chooses to release products only on REG at price $P_1$ resulting in consumer $i$ having a surplus $CS_i = v_i - P_1$. To later allow comparison of consumer surplus across channels we adopt a utility framework, where the utility for consumer $i$, $U(CS_i)$, resulting from a surplus $CS_i$ is assumed to be linear, i.e. $U(CS_i) = d_j CS_i + C_j$ for channel $j$, $j = 0, 1, 2$ being a channel specific index ($0 =$ REG, $1 =$ OPQ, $2 =$ BID). Table 1 summarizes all model notation. For simplicity, but without loss of generality, we assume $C_0 = 0$ and $d_0 = 1$ for consumers acquiring service from the full information channel. If the firm decided to only use REG, as a result of $C_0 = 0$ and $d_0 = 1$, consumers with valuation higher than price $P_1$ would purchase the item.

Therefore, the expected revenue for the service provider $\pi$ is given by

$$\pi = \int_{P_1}^1 P_1 f(v_i) dv_i = P_1 (1 - P_1) = P_1 - P_1^2.$$  \hspace{1cm} (1)

Taking the derivative of $p$ with respect to $P_1$ and setting it to be zero, we can solve for the optimal price should be posted on REG:

$$P_1^* = \frac{1}{2}.$$

Since $\frac{d^2 \pi}{dP_1^2} = -2 < 0$ we substitute $P_1^*$ back into (1) producing maximum revenue $\pi^* = 1/4$. Moreover, from (1), it is straightforward to see that the maximum revenue is concave in the prices. Fig. 2 illustrates the segmentation created by only selling via full information posted prices (REG) where segment A are consumers with valuations at or above $P_1$, $v_i \gg P_1$, and purchase at $P_1$ and consumers with lower valuations, $v_i < P_1$, being priced out of the market.
If the service provider released inventory on the REG, OPQ and BID simultaneously a series of new consumer segments are created as consumers self select (depending on their valuations) how and if they wish to purchase from the service provider. We summarize these segments in Table 2. All segments are not always present as they depend on how the service provider sets prices.

The firm (potentially) sells inventory on all three channels through the setting of prices \( P_1 \) on REG, \( P_2 \) on OPQ and a bidding threshold i.e. the minimum acceptable bid \( R \) on BID, which is unknown to the consumers (but assumed by consumers to follow a uniform distribution over \([0,1]\)). Consumers incur a cost for purchasing on opaque channels similar to the frictional channel costs measured in Hann and Terwiesch (2003) where the costs are attributed to the increased effort (over REG) from bidding, prepaying on opaque channels or simply researching who the opaque service provider might be. The utility for a consumer purchasing on REG is simply \( U(CS_i) = v_i - P_1 \). As the consumer is not fully aware of all the service provider’s characteristics when purchasing through OPQ we discount the consumer surplus from purchasing on OPQ. Let \( d_1 \) denote the discount factor for purchasing on OPQ and \( c_1 \) denote the cost of buying on OPQ resulting in utility \( U(CS_i) = d_1(v_i - P_2) - c_1 \) from purchasing on OPQ, where \( 0 < d_1 < 1 \). Here \( 1 - d_1 \) represents the opacity of the opaque channel, implying as \( d_1 \) approaches \( 1 \) the channel becomes less opaque as the consumer discounts the surplus less. Similarly, we denote the degree of opacity of the products on the BID channel by \( 1 - d_2 \) and the cost of buying on the BID channel by \( c_2 \). While opaque channel costs (\( c \)) and discount factors (\( d \)) may vary across consumers we assume fixed values across consumers but present comparative statics to illustrate the impacts of changes in these parameters. As indicated in Shapiro and Shi (2008), the degree of opacity is related to the number of competitors using the opaque channel. For example, if there are \( N \) service providers listing their

<table>
<thead>
<tr>
<th>Model notation.</th>
<th>Consumer i’s valuation of the product or desired service level</th>
</tr>
</thead>
<tbody>
<tr>
<td>( v_i )</td>
<td>Price set by the service provider on the REG channel</td>
</tr>
<tr>
<td>( P_1 )</td>
<td>Price set by the service provider on the OPQ channel</td>
</tr>
<tr>
<td>( P_2 )</td>
<td>Price set by the service provider on the BID channel</td>
</tr>
<tr>
<td>( R )</td>
<td>Bidding threshold set by the service provider on the BID channel</td>
</tr>
<tr>
<td>( d_1 )</td>
<td>The discount factor for purchasing on OPQ</td>
</tr>
<tr>
<td>( d_2 )</td>
<td>The discount factor for bidding on BID</td>
</tr>
<tr>
<td>( c_1 )</td>
<td>Consumer cost or dis-utility for purchasing on OPQ</td>
</tr>
<tr>
<td>( c_2 )</td>
<td>Consumer cost or dis-utility for bidding on BID</td>
</tr>
<tr>
<td>( B_{R}(\eta) )</td>
<td>The bid of consumer i in the segment of BID then REG market segment</td>
</tr>
<tr>
<td>( B_{O}(\eta) )</td>
<td>The bid of consumer i in the segment of BID then OPQ market segment</td>
</tr>
<tr>
<td>( B_{B}(\eta) )</td>
<td>The bid of consumer i in the segment of BID only market segment</td>
</tr>
<tr>
<td>( V_1, V_2, V_3, V_5 )</td>
<td>the critical value points in the market segmentation</td>
</tr>
<tr>
<td>( V_7 )</td>
<td>the critical value points in the revenue segmentation</td>
</tr>
</tbody>
</table>

\[ P_1^* = \frac{1}{2} \]

\( \Lambda \) - customers purchasing

---

If the service provider released inventory on the REG, OPQ and BID simultaneously a series of new consumer segments are created as consumers self select (depending on their valuations) how and if they wish to purchase from the service provider. We summarize these segments in Table 2. All segments are not always present as they depend on how the service provider sets prices.

The firm (potentially) sells inventory on all three channels through the setting of prices \( P_1 \) on REG, \( P_2 \) on OPQ and a bidding threshold i.e. the minimum acceptable bid \( R \) on BID, which is unknown to the consumers (but assumed by consumers to follow a uniform distribution over \([0,1]\)). Consumers incur a cost for purchasing on opaque channels similar to the frictional channel costs measured in Hann and Terwiesch (2003) where the costs are attributed to the increased effort (over REG) from bidding, prepaying on opaque channels or simply researching who the opaque service provider might be. The utility for a consumer purchasing on REG is simply \( U(CS) = v_i - P_1 \). As the consumer is not fully aware of all the service provider’s characteristics when purchasing through OPQ we discount the consumer surplus from purchasing on OPQ. Let \( d_1 \) denote the discount factor for purchasing on OPQ and \( c_1 \) denote the cost of buying on OPQ resulting in utility \( U(CS_i) = d_1(v_i - P_2) - c_1 \) from purchasing on OPQ, where \( 0 < d_1 < 1 \). Here \( 1 - d_1 \) represents the opacity of the opaque channel, implying as \( d_1 \) approaches \( 1 \) the channel becomes less opaque as the consumer discounts the surplus less. Similarly, we denote the degree of opacity of the products on the BID channel by \( 1 - d_2 \) and the cost of buying on the BID channel by \( c_2 \). While opaque channel costs (\( c \)) and discount factors (\( d \)) may vary across consumers we assume fixed values across consumers but present comparative statics to illustrate the impacts of changes in these parameters. As indicated in Shapiro and Shi (2008), the degree of opacity is related to the number of competitors using the opaque channel. For example, if there are \( N \) service providers listing their
products on the opaque channel, then in general the consumer’s chance of purchasing from one of them is \( \frac{1}{N} \). And so while we don’t directly model competition, the degree of opacity can be interpreted as a function of \( \frac{1}{N} \) so a market with fewer substitutes will be less opaque (i.e. it’s one of 2 or 3 suppliers, versus 1 of 10) and as we see later as opacity decreases opaque prices need to increase to offset dilution from REG consumers purchasing opaque products.

If consumer \( i \)'s valuation \( v_i \) is such that \( v_i - P_1 \gg d_1(v_i - P_2) - c_1 \) and \( v_i \gg P_1 \), then the consumer will prefer to purchase on the REG (Segment A) versus OPQ. If \( v_i - P_1 < d_1(v_i - P_2) - c_1 \) and \( v_i \gg P_2 + \frac{c_1}{d_1} := V_1 \), then they will choose OPQ to make the purchase (Segment B). The customer will be indifferent to purchasing on REG and OPQ when \( v_i \frac{p_1 - d_1 P_2 - c_1}{1 - d_1} := V_2 \).

<table>
<thead>
<tr>
<th>Segment</th>
<th>Product sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>REG only</td>
</tr>
<tr>
<td>B</td>
<td>OPQ only</td>
</tr>
<tr>
<td>C</td>
<td>BID, then REG if bid rejected</td>
</tr>
<tr>
<td>D</td>
<td>BID only</td>
</tr>
<tr>
<td>E</td>
<td>BID, then OPQ if bid rejected</td>
</tr>
</tbody>
</table>

Some consumers (Segment C) may bid first and switch to the REG channel if their bid is rejected and their valuations are higher than \( P_1 \). Let \( B_{1c} \) be the bid of consumer \( i \) (a segment C consumer) submitted to BID, where they expect their bid to be accepted with a probability of \( B_{1c} \). If the bid is rejected (with probability of \( 1 - B_{1c} \) in consumers’ belief), the consumer will purchase via REG at \( P_1 \). Given \( v_i \gg P_1 \), the utility for consumer \( i \) is then the sum of the utilities from a possible opaque bidding purchase and in the expected utility from purchasing at regular prices upon bid failure,

\[
U(CS_i) = [d_2(v_i - B_i) - c_2]B_i + (1 - B_i)(v_i - P_1).
\] (2)

As \( U(CS_i) \) is a concave quadratic function of \( B_i \), it is straightforward to show \( U(CS_i) \) is maximized when \( B_i = B_{iC}^*(v_i) \), where

\[
B_{iC}^*(v_i) = \frac{P_1 - (1 - d_2)v_i - c_2}{2d_2}.
\] (3)

As bids must be positive, i.e. \( B_i > 0 \), this results in

\[
B_{iC}^*(v_i) > 0 \Rightarrow v_i < \frac{P_1 - c_2}{1 - d_2} := V_3.
\] (4)

It is easy to show that the optimal bid is less than \( P_1 \) and is decreasing in opacity and buying cost (\( c_2 \)) as the opaque product becomes less valuable (discounted more, and/or higher costs).

However, from the service provider’s perspective, the bid \( B_{iC}^*(v_i) \) will be accepted only if \( B_{iC}^*(v_i) > R \), i.e. \( v_i < \frac{P_1 2d_2 R - c_2}{1 - d_2} := V_4 \). This means that customers with valuations \( v_i \in [V_4, V_3] \) will lose their bid and purchase on REG. Customers with valuation \( v_i \in [P_1, V_4] \) will have accepted bids.

A subset of consumers, Segment E, may choose to bid first and switch to purchase at the OPQ channel upon a failed bid if \( v_i \gg P_2 \). If their bid is rejected, the consumer will go to OPQ and purchase at \( P_2 \) producing,
It is straightforward to show $U(CS_i)$ is maximized when $B_i = B_{iE}^*(v_i)$, where

$$B_{iE}^*(v_i) = \frac{d_1P_2 - (d_1 - d_2)v_i + c_1 - c_2}{2d_2}. \quad (6)$$

One can easily show that $B_{iE}^*(v_i)$ is less than $P_2$, and is decreasing in BID opacity, but increasing in OPQ opacity. It is also easy to see that the optimal bid is increasing with the buying cost on OPQ and decreasing with the buying cost on BID. These results are quite intuitive as the products on the BID channel become less valuable for the customers as the BID channel becomes more opaque and/or the buying cost on BID increases, but become more valuable (relatively) when the OPQ channel becomes more opaque and/or the buying cost on OPQ increases.

However, similar to the segment of BID then purchase at REG after the bid fails, the bid $B_{iE}^*(v_i)$, will be accepted only if $B_{iE}^*(v_i) > R$ i.e. $v_i < \frac{d_1P_2 + c_1 - c_2}{d_1 - d_2} =: V_5$. Thus customers with valuations $v_i \in [V_6, V_5)$ upon losing their bid, purchase at OPQ. Customers with valuations $v_i \in [V_6, V_5)$ have successful bids.

For consumers with valuations lower than $V_i$ (Segment D) their only choice is to bid. Their utility is $U(CS_i) = [d_2(v_i - B_i) - c_2]B_i$, which is maximized with $B_i = B_{iD}^*(v_i) = \frac{d_2v_i - c_2}{2d_2}$. $B_{iD}^*(v_i) > 0$ implies that $v_i > \frac{c_2}{d_2} =: V_7$. The service provider will only accept the bid when $B_{iD}^*(v_i) > R$ i.e. $v_i > 2R + \frac{c_2}{d_2} =: V_6$. This means that customers with valuations $v_i \in [V_7, V_6)$ will lose their bid and leave empty handed, while customers with valuations $v_i \in [V_7, V_6)$ have winning bids.

We now summarize the consumer self-selected market segmentation when the service provider can list products on all three channels: REG, OPQ, and BID and illustrate it by using critical points $P_1, P_2, P_3, P_4, P_5, P_6$. Based on the relationship between the discount factors $d_1, d_2$, opaque channel costs $c_1, c_2$ and posted prices $P_1, P_2$ there are two sets of consumer segmentation, Case I and Case II.

**Segmentation Case I**

Case exists when: $(d_1 - d_2)P_1 - d_1P_2(1 - d_2) \ll c_1 - c_2 + c_2d_1 - c_1d_2 \leftrightarrow V_5 \gg V_3 \gg V_2$.

The three channels REG, OPQ and BID partition consumers into four potential segments as shown in Table 3 as a function of which interval their valuation $v_i$ lies within. The table indicates the valuation interval, the resulting segment (from Table 2) and the channel (s) used.

Where, REG denotes buying on REG only; BID then REG denotes bidding then purchasing at REG if bid fails; BID then OPQ denotes bidding then purchasing at OPQ if bid fails; BID denotes bidding only. Fig. 3 graphically summarizes these segments and their location along the valuation line.

**Segmentation Case II**

Case II exits when: $(d_1 - d_2)P_1 - d_1P_2(1 - d_2) > c_1 - c_2 + c_2d_1 - c_1d_2 \leftrightarrow V_5 < V_3 < V_2$.

In this situation, the three channels REG, OPQ and BID partition consumers into four potential segments as displayed in Fig. 4 and summarized in Table 4.

**Optimal Service Provider Policies**

In this section, we solve for the optimal prices and threshold set on the channels REG, OPQ and BID respectively and the resulting maximum expected revenue for a service provider under both segmentation cases discussed previously. As mentioned before we assume all revenues are normalized to a market of one, as such expected revenue values are per customer. In this section we allow the firm to optimally set $P_1, P_2$ and $R$, the setting of prices and thresholds then dictates the segmentation of consumers (and the resulting optimal revenue).
As discussed earlier that $B_{iC}^*(v_i)$, $B_{iE}^*(v_i)$, and $B_{iD}^*(v_i)$ are the optimal bids for the consumers in the segments of BID and purchase at REG if the bid fails, BID and purchase at OPQ if the bid fails and BID only respectively. However, from the perspective of the service provider, those bids can be accepted only when they are more than the threshold R, i.e. $B_{iC}^*(v_i) > R$, $B_{iE}^*(v_i) > R$, and $B_{iD}^*(v_i) > R$. As only positive bids are considered, consumers can only have winning bids if their valuations $v_i < V_3$, $v_i < V_6$, and $v_i > V_8$ respectively. Recall that $P_1$, $V_i$, $V_2$, $V_3$, $V_5$, $V_7$ are the critical points for consumer market segmentation and based on the relations among $c_1$, $c_2$, $d_1$, $d_2$, $P_1$, and $P_2$ there are the two segmentation cases. From the perspective of the service provider, We now have several scenarios in each segmentation case as a function of $d_1$, $d_2$, $c_1$, $c_2$, $P_1$, $P_2$, and R, and display the scenarios using critical points $V_i$ through $V_8$ and prices $P_1$ and $P_2$.

**Table 3**

<table>
<thead>
<tr>
<th>Critical valuation intervals</th>
<th>Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[V_3, 1]$</td>
<td>A (REG)</td>
</tr>
<tr>
<td>$[V_2, \min(V_3, 1)]$</td>
<td>C (BID then REG)</td>
</tr>
<tr>
<td>$[V_1, \min(V_2, 1)]$</td>
<td>E (BID then OPQ)</td>
</tr>
<tr>
<td>$[V_7, V_1)$</td>
<td>D (BID)</td>
</tr>
</tbody>
</table>

![Fig. 3. Market segmentation - Case I.](image)

**Table 4**

<table>
<thead>
<tr>
<th>Critical valuation intervals</th>
<th>Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[V_2, 1]$</td>
<td>A (REG)</td>
</tr>
<tr>
<td>$[V_5, \min(V_2, 1)]$</td>
<td>B (OPQ)</td>
</tr>
<tr>
<td>$[V_1, \min(V_5, 1)]$</td>
<td>E (BID then OPQ)</td>
</tr>
<tr>
<td>$[V_7, V_1)$</td>
<td>D (BID)</td>
</tr>
</tbody>
</table>

![Fig. 4. Market segmentation - Case II.](image)
The Case I condition \((d_1 - d_2)P_1 - d_1P_2(1 - d_2) < c_1 - c_2 + c_1d_1 - c_1d_2 \leftrightarrow V_5 \gg V_3 \gg V_2\). Leads to segmentation as summarized in Table 3. Under optimal pricing policies three revenue generating scenarios are created.

**Case I - Scenario I.** \((d_1 - d_2)P_1 - d_1P_2(1 - d_2) < -2d_2R(1-d_1) + c_1 - c_2 + c_2d_1, c_1 < (P_1 - P_2)d_1\) and \(d_1d_2(P_2 - 2R) + c_1d_2 - c_2d_1 > 0\).

Consumers in the first segment \([V_5, 1]\) if \(V_5 < 1\) buy on REG directly. It is straightforward to check that \(d_1-d_2)P_1 - d_1P_2(1 - d_2) < -2d_2R(1-d_1) + c_1 - c_2 + c_2d_1\) is equivalent to

\[
\frac{P_1 - 2d_2R - c_2}{1 - d_2} \geq \frac{P_1 - d_1P_2 - c_1}{1 - d_1}, \text{ i.e. } V_4 \gg V_2.
\]

Thus the segment \(BID\) then \(REG\) (\([V_2 \min(V_3, 1)]\)) is divided into two groups of customers where the first group \(v \in [\min(V_4, 1), \min(V_3, 1)]\) purchases on REG and the second group \(v \in [V_2, \min(V_4, 1)]\) have winning bids.

One can also easily show that \(V_4 < V_2\) if \(V_4 < V_2\), and if \(c_1 < (P_1 - P_2)d_1\), i.e. \(V_7 < V_8\), then in the segment of \(BID\) then \(OPQ\) \((V_2, \min(V_7, r))\), all consumers have winning bids since their optimal bids are above the threshold \(R\) as long as their valuation \(v \ll V_6\).

\(d_1d_2(P_2 - 2R) + c_1d_2 - c_2d_1 > 0 \Rightarrow V_1 > V_6\), then in the segment of bidding only, consumers with valuations \(v \in [V_6, V_1]\) win their bid and consumers with valuations \(v \in [V_7, V_8]\) lose. Table 5 summarizes the valuation interval, which consumer segment is present in this interval and which channel generates the revenue.

**Case I - Scenario II.** \(c_1 - c_2 + c_2d_1 - c_1d_2 \Rightarrow (d_1 - d_2)P_1 - d_1P_2(1 - d_2) < -2d_2R(1-d_1) + c_1 - c_2 + c_2d_1, P_1 - d_1P_2 - c_1 < 1 - d_1\) and \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) \gg 0\).

As in the previous scenario, the consumers in the first segment \([V_3, r]\) if \(V_3 < r\) buy on REG directly. It is easy to see that \((d_1 - d_2)P_1 - d_1P_2(1 - d_2) < -2d_2R(1-d_1) + c_1 - c_2 + c_2d_1 - c_1d_2\) is equivalent to

\[
\frac{P_1 - 2d_2R - c_2}{1 - d_2} < \frac{P_1 - d_1P_2 - c_1}{1 - d_1}, \text{ i.e. } V_4 < V_2.
\]

Thus, all the consumers in the segment of \(BID\) then \(REG\) (\([V_2, \min(V_3, 1)]\)) lose their bids and purchase at \(REG\) as their bids are below the threshold \(R\) if \(v_5 > V_4\).

One can easily show that \(V_4 < V_2\) implies \(V_6 < V_2\) and also if \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) \gg 0\), then \(V_1 \ll V_6\), so the segment of \(BID\) then \(OPQ\) \((V_2, \min(V_7, r))\) purchase on \(OPQ\) and second group \(v \in [V_6, \min(V_4, 1)]\) win their bids.

\(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) \gg 0\) indicates \(V_3 \gg V_6\), then in the segment of bidding only, consumers with valuations \(v \in [V_6, V_1]\) win their bid and consumers with valuations \(v \in [V_7, V_8]\) lose. The revenue generating scenarios the service provider are summarized in Table 6.

**Case I - Scenario III.** \(c_1 - c_2 + c_2d_1 - c_1d_2 \Rightarrow (d_1 - d_2)P_1 - d_1P_2 (1 - d_2) > -2d_2R(1-d_1) + c_1 - c_2 + c_2d_1 - c_1d_2, P_1 - d_1P_2 - c_1 < 1 - d_1, c_1 < (P_1 - P_2)d_1\) and \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) < 0\).

As in previous scenarios, consumers in the first segment \([V_3, 1]\) if \(V_3 < 1\) buy on REG directly. And \((d_1 - d_2)P_1 - d_1P_2(1 - d_2) > -2d_2R(1-d_1) + c_1 - c_2 + c_2d_1 - c_1d_2\) implies

\[
\frac{P_1 - 2d_2R}{1 - d_2} < \frac{P_1 - d_1P_2}{1 - d_1}, \text{ i.e. } V_4 < V_2.
\]

Hence, all the consumers in the segment \(BID\) then \(REG\) (\([V_2, \min(V_3, 1)]\)) lose their bids and purchase at the \(REG\) channel as their bids are below the threshold \(R\) if their valuation is more than \(V_4\).

If \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) < 0\), then \(V_6 < V_1\), so all consumers in the segment of \(BID\) then \(OPQ\) lose their bids and switch to the \(OPQ\) channel to buy as their bids are less than the threshold \(R\) as \(v_1 > V_6\).

If \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) < 0\) also indicates \(V_1 < V_8\), then in the segment of bidding only, all consumers will lose their bid as \(B_1 < R\) if \(v_1 < V_8\). Table 7 summarizes these revenue scenarios.
Case II

The Case II condition \((d_1 - d_2)P_1 - d_1P_2(r - d_2) > c_1 - c_2 + c_2d_1 - c_1d_2 \leftrightarrow V_5 < V_3 < V_2\) results in two revenue generating scenarios.

Case II - Scenario I. \((d_1 - d_2)P_1 - d_1P_2(1 - d_2) > c_1 - c_2 + c_2d_1 - c_1d_2 = P_1 - d_1P_2 - c_1 < 1 - d_1\), and \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) > 0\).

Recall that the segment \([V_2, 1]\) (if \(V_2 < 1\)) and \([V_5, \min(V_2, 1)]\) are the segments of REG only and OPQ only respectively. If \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) > 0\), then \(V_6 > V_1 \geq V_8\) and easy to check that \(V_5 < V_6\), and so the segment of BID then OPQ \((v_1 \in [V_1, \min(V_5, 1)]\) consists of two groups of consumers. The first group of consumers with valuation \(v_1 \in [V_6, \min(V_5, 1)]\) purchase OPQ and second group \(v_1 \in [V_7, \min(V_6, 1)]\) have winning bids. And in the segment of bidding only, consumers with valuation \(v_1 \in [V_8, V_1]\) win their bid and consumers with valuation \(v_1 \in [V_7, V_8]\) lose. Table 8 summarizes the resulting revenue scenarios.

Case II - Scenario II. \((d_1 - d_2)P_1 - d_1P_2(1 - d_2) > c_1 - c_2 + c_2d_1 - c_1d_2, P_1 - d_1P_2 - c_1 < 1 - d_1, c_2 < (P_1 - P_2)d_1\) and \(c_1d_2 = c_2d_1 + d_1d_2(P_2 - 2R) < 0\).

Consumers in the segment of \([V_2, 1]\) (if \(V_2 < 1\)) and \([V_5, \min(V_2, 1)]\) buy at REG only and OPQ only respectively. If \(c_1d_2 - c_2d_1 + d_1d_2(P_2 - 2R) < 0\), then \(V_6 < V_1 < V_8\), for both the segments of BID (OPQ) \((v_1 \in [V_1, \min(V_5, 1)]\) if \(V_1 < V_5\) and BID only \((v_1 \in [V_7, V_1]\), there are no consumers with winning bids (Table 9).

### Table 5

<table>
<thead>
<tr>
<th>Revenue scenario, Case I – Scenario I</th>
<th>Revenue generating segment and resulting (revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>([V_5, 1])</td>
<td>A – REG ((P_1))</td>
</tr>
<tr>
<td>([V_2, \min(V_4, 1)])</td>
<td>B = BID then REG ((B'_{IC}(v_1)))</td>
</tr>
<tr>
<td>([V_1, \min(V_2, 1)])</td>
<td>C = BID then REG ((B'_{IC}(v_1)))</td>
</tr>
<tr>
<td>([V_8, V_1])</td>
<td>D = BID only ((B'_{ID}(v_1)))</td>
</tr>
</tbody>
</table>

Please see Appendix A for the details of solving for the optimal price, threshold solutions and the resulting maximum expected total revenue in each of the above revenue scenarios.

**Special case with zero channel costs**

In this section we illustrate the impacts upon optimal policies under the setting of zero channel costs \(c_2 = 0\). By substituting \(c_1 = c_2 = 0\) into the results in previous section (summarized in Appendix A) we can obtain the corresponding optimal prices and threshold as well as the conditions that parameters need to satisfy.

Furthermore, for each scenario, under their parameter conditions one can show that both the optimal full information price and the maximum expected revenue are more than those values in the situation where there is only the REG channel, which are 1/2 and 1/4 respectively. Please see Appendix B for the detailed derivation. This implies adding opaque channels will allow the service provider to increase the posted price on the fill information channel and also improve the revenue comparing to the case with only REG channel. We will see in later sections that this property will also occur in the case with nonzero costs and even the one with limited capacity constraint.

We summarize the resulting five scenarios of revenue generation under the setting of zero channel costs \((c_1 = c_2 = 0)\) in Table 10, where conditions (8)-(12) are given as the follows:
Illustration of the optimal policies

In this section we illustrate optimal policies and the resulting segmentation by substituting sample values of \(d_1, d_2, c_1\) and \(c_2\) into the closed-form solutions discussed previously and plot them to illustrate the impact of channel costs and opacity on revenues, prices, and thresholds. For ease of presentation we set channel costs \((c's)\) equal to zero and illustrate optimal policies as a function of channel opacities \((d's)\). Fig. 5 plots optimal expected

\[
\begin{align*}
\frac{d_1^3}{d_2^2} - d_1^2(2 + d_2) + d_1d_2 - 4d_2^2 &\geq 0, \\
\frac{d_2}{d_1} &\leq \frac{d_1}{2}, \\
4d_1^2 + d_2^2(-2d_1 + 2d_2) + d_1(d_1 - 6d_2^2) &< 0, \\
4d_1^2 - 4d_2^2 + d_3^2(-1 + 2d_2) + d_1^2(d_2 - 2d_2^2) &\geq 0, \\
4d_1^2 - 4d_2^2 + d_3^2(-1 + 2d_2) + d_1^2(d_2 - 2d_2^2) &< 0.
\end{align*}
\]

**Table 6**

<table>
<thead>
<tr>
<th>Critical valuation interval</th>
<th>Revenue generating segment and resulting (revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[(V_2, 1)]</td>
<td>A – REG (P_1)</td>
</tr>
<tr>
<td>[(V_b, \min(V_2, 1))]</td>
<td>B – OPQ (P_2)</td>
</tr>
<tr>
<td>[(V_1, \min(V_b, 1))]</td>
<td>E – BID then OPQ (F_1^e(v_1))</td>
</tr>
<tr>
<td>[(V_b, V_1)]</td>
<td>D – BID (F_1^d(v_1))</td>
</tr>
</tbody>
</table>

**Table 7**

<table>
<thead>
<tr>
<th>Critical valuation interval</th>
<th>Revenue generating segment and resulting (revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[(V_2, 1)]</td>
<td>A – REG (P_1)</td>
</tr>
<tr>
<td>[(V_1, \min(V_2, 1))]</td>
<td>B – OPQ (P_2)</td>
</tr>
</tbody>
</table>

**Table 8**

<table>
<thead>
<tr>
<th>Critical valuation interval</th>
<th>Revenue generating segment and resulting (revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[(V_2, 1)]</td>
<td>A – REG (P_1)</td>
</tr>
<tr>
<td>[(V_b, \min(V_2, 1))]</td>
<td>B – OPQ (P_2)</td>
</tr>
<tr>
<td>[(V_1, \min(V_b, 1))]</td>
<td>E – BID then OPQ (F_1^e(v_1))</td>
</tr>
<tr>
<td>[(V_b, V_1)]</td>
<td>D – BID (F_1^d(v_1))</td>
</tr>
</tbody>
</table>

revenues resulting from the service provider setting the corresponding optimal prices and threshold set on those
As shown in Fig. 5 prices on REG decrease as BID and OPQ become less opaque, conversely OPQ prices increase (and converge to REG prices) as opacity on OPQ decreases, but decreases as opacity on BID decreases. BID thresholds increase as opacity on BID decreases, but decreases as opacity on OPQ decreases. The impacts of channel opacity on optimal prices and threshold indicate that when the products on the opaque channels (OPQ and BID) become more valuable (less opaque), the price on the full information channel (REG) decrease and approach $1/2$, i.e. optimal prices in the absence of opaque selling. Similarly, if the BID channel becomes less opaque, some consumers on OPQ may switch to bid on the BID channel due to a potential chance of getting a better value with less price. Optimal expected revenue decreases when either OPQ or BID channel opacity decreases ($d$'s increase). This implies that increasing opacity results in more consumer segments actively participating in the market; as a result the service provider can capture more consumers owing to their heterogenous valuations.

Fig. 6 shows the impact of channel opacity upon customer segmentation (right) and the resulting revenue generating channels (left). Together these figures illustrate the impacts of opaque selling and under what conditions it appears fruitful to consumers and service providers. Firms should always adopt at least two channels, selling via opaque posted prices in addition to regular full information prices. The opaque posted prices simply approach regular full information prices as the opaque channel becomes less opaque or more costly. Similarly firms should employ opaque bidding but only when opacity of this channel is significant. It is important to realize that the firm should always be using all three channels, with posted opaque prices/thresholds set higher such that fewer transactions occur under conditions of decreased opacity.

### Table 9
Revenue segmentation, Case II – Scenario II.

<table>
<thead>
<tr>
<th>Critical valuation interval</th>
<th>Revenue generating segment and resulting (revenue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[V_2, 1]$</td>
<td>A – REG ($P_1$)</td>
</tr>
<tr>
<td>$[V_1, \min(V_2, 1)]$</td>
<td>B – OPQ ($P_2$)</td>
</tr>
</tbody>
</table>

### Table 10
Revenues, prices and bidding threshold summaries.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Optimal price on REG ($P_1^*$)</th>
<th>Optimal price on OPQ ($P_2^*$)</th>
<th>Optimal threshold on BID ($R^*$)</th>
<th>Maximum expected revenue ($r^*$)</th>
<th>Parameter conditions ($d_1, d_2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case I–I</td>
<td>$\frac{2(1-d_1)}{3}$</td>
<td>$\frac{2(1-d_1)}{3}$</td>
<td>$\frac{2d_1(1-d_1)}{3}$</td>
<td>$\frac{1-d_1}{3}$</td>
<td>$0 &lt; d_2 &lt; \frac{1}{2}$</td>
</tr>
<tr>
<td>Case I–II</td>
<td>$\frac{2(1-d_1)}{3}$</td>
<td>$\frac{2(1-d_1)}{3}$</td>
<td>$\frac{2d_1(1-d_1)}{3}$</td>
<td>$\frac{1-d_1}{3}$</td>
<td>(8) and (9)</td>
</tr>
<tr>
<td>Case I–III</td>
<td>$\frac{1+d_2}{3}$</td>
<td>$\min\left(\frac{1+d_2}{2(1+d_2)} - \frac{2d_1(1-d_1)}{3}, 1\right)$</td>
<td>$\frac{1}{3}$</td>
<td>$0 &lt; d_1 &lt; 1$</td>
<td></td>
</tr>
<tr>
<td>Case II–I</td>
<td>Same as Case I–II</td>
<td></td>
<td></td>
<td></td>
<td>(8) and (9)</td>
</tr>
<tr>
<td>Case II–II</td>
<td>Same as Case I–III</td>
<td></td>
<td></td>
<td></td>
<td>(10) and (12)</td>
</tr>
</tbody>
</table>
Fig. 5. Optimal revenues and channel policies.

Fig. 6. Revenue generating channels (left) and consumer segmentation (right).
Optimal service provider policies with limited capacity

In this section, we consider a service provider with limited capacity. One would assume under limited capacity the firm would logically limit sales at lower prices. We assume that the service provider has a limited inventory of capacity \( C < 1 \). Although we have the capacity constraint in this case, the consumer segmentation and the revenue segmentation remain the same as the case with abundant capacity discussed in earlier sections. However, the effective segments (those which generate sales), the optimal pricing policies and the maximum expected revenue that the service provider can achieve will depend on capacity. For ease of exposition here we assume that channel costs are zero (\( c_1 = c_2 = 0 \)), as illustrated in the prior section the results will be consistent if channel costs were positive, with the opaque channels decreasing in their overall impact as these costs are increased.

As the firm is simultaneously using all three channels we assume the customer segments arrive in a random order, i.e. first come first serve. Thus, the capacity \( C \) will be allocated to each segment of the market proportional to its size relative to the total demand in the market, otherwise referred to as random or proportionate splitting.

As an illustration on how the limited capacity influences the service provider’s pricing policy and maximum revenue that can be achieved, we assume that the service provider sells the products only on the REG channel and set its price as \( P_1 \).

Similar to the situation with no capacity constraint, consumers with valuation higher than the price \( P_1 \) will purchase through this channel. However, demand can be met only up to \( C \). In other words, when the total demand \( 1 - P_1 \ll C \), the situation is exactly the same as the case with no capacity constraint discussed previously, and so the revenue is \( \pi_C = (1 - P_1)P_1 \), which reaches the maximum value \( \pi_C^* = \frac{1}{4} \) at \( P_1^* = \frac{1}{2} \). But when \( 1 - P_1 > C \), the revenue is \( \pi_C = CP_1 \). Thus, the price \( P_1 \) increases until it reaches the upper bound \( 1 - C \) and the maximum revenue \( \pi_C^* = C(1 - C) \) is achieved.

We summarize the results as the following:

- If \( 1 - C \ll \frac{1}{2} \) i.e. \( C \gg \frac{1}{2} \), then \( \pi_C^* = \frac{1}{4} \) and \( P_1^* = \frac{1}{2} \).
- If \( 1 - C > \frac{1}{2} \) i.e. \( C < \frac{1}{2} \), then \( \pi_C^* = C(1 - C) \) and \( P_1^* = 1 - C \).

One can easily show that when \( C < \frac{1}{2} \), \( \pi_C^* = C(1 - C) \) is an increasing function in the capacity \( C \), and \( P_1^* \) is decreasing in \( C \). These are quite intuitive as when we can not meet all demand we receive less revenue but through higher prices.

The service provider now lists the products on the REG, OPQ and BID simultaneously. They set price \( P_1 \) on REG, \( P_2 \) on OPQ a bidding threshold \( R \) on BID. The derivation of expected revenue is similar to the situation where there is no limited capacity discussed above, see Appendix C for detailed derivations. Fig. 7 illustrates optimal revenues, prices and thresholds under constrained capacity (capacity = 0.55 of demand).

Comparison of Fig. 5 with Fig. 7 illustrates how firms increase prices and thresholds as capacity decreases. Similarly comparison of Fig. 6 with Fig. 8 shows the impact of constrained capacity upon consumer segmentation and the resulting revenue generating channels. As one would expect, as capacity becomes tighter, the required degree of opacity increases (for continued use of opaque channels) as do prices and thresholds.

Summary

Opaque selling continues to grow in popularity as numerous variants of opaque selling are being created on a regular basis - Expedia (its Unpublished Rates product) and Travelocity (TopSecret listings) have recently launched opaque posted price models in concert with their full information listings. New variants of opaque like selling are also evolving in the travel space with products like HotelTonight and GuestMob offering a little more information (than Hotwire and Priceline) at slightly higher prices. Similarly, new firms like PriceWhispers and ScoreBig are bringing opaque selling to retail, arts, entertainment and sports. The growth and evolution of opaque selling reinforces the need to understand the role and impact of this increasingly popular selling method. Here we illustrate the role of opaque selling as it increases revenues through the natural segmentation of customers.
We illustrate that as opacity increases, increased consumer segmentation is created as suppliers can capitalize on heterogenous valuations of the product. This is consistent with what we see in practice as opaque channels tend to separate themselves along

![Graphs](image)

Fig. 7. Optimal revenues and channel policies with constrained supply.
degrees of opacity, for example Hotwire.com provides information of hotel amenities as well as feedback from recent guests whereas Priceline.com provides neither on its NYOP bidding channel indicating Hotwire is probably less opaque than Priceline. As a result of this, prices on Hotwire and less than those on full information channels but higher than bids typically accepted at Priceline. The introduction of opaque products allows firms to reach a wider array of consumers, as low valuation consumers previously priced out of the market can now get access to (opaque) inventory at lower prices.

Our illustration of consumer segmentation from opaque selling indicates that the use of opaque selling grows overall demand for the firm. The firm must be conscious though in how it sets prices (given the degree of opacity) as some consumers with valuations above full information prices may now purchase opaque products creating a dilution of revenue. We illustrate how the firm’s optimal prices change as a function of opacity as it manages the tradeoff between demand growth and revenue dilution.

Our modeling efforts indicate when and how to deploy an opaque selling strategy in concert with regular full information pricing. Unlike previous research which usually assumes an exogenous consumer separation into regular consumers and opaque consumers we endogenously model this channel selection process as a function of prices and channel characteristics (opacity). We have shown that even in the face of capacity constraints firms should be simultaneously using opaque channels in concert with regular channels whereas previous research has focussed only on using opaque channels to sell distressed inventory (surplus capacity). The simultaneous use of opaque selling with regular full information selling effectively segments consumers - allowing firms to sell at higher prices to higher valuation/brand loyal consumers and at lower prices to lower valuation/brand agnostic shoppers via opaque channels and increase firm revenues.
References


exploration. Management Science, 55(6), 968-979.