Omega 63 (2016) 12–22

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Revenue management with minimax regret negotiations ☆

Nur Ayvaz-Cavdaroglu [a,*], Soulaymane Kachani [b], Costis Maglaras [c]

[a] Kadir Has University, Department of Business Administration, Istanbul 34083, Turkey
[b] Columbia University, IE&OR Department, School of Engineering and Applied Sciences Columbia University, 500 West 120th Street, Rm. 313, New York, NY 10027, United States
[c] Columbia Business School, 409 Uris Hall, 3022 Broadway, New York, NY 10027, United States

ARTICLE INFO

Article history:
Received 2 February 2014
Accepted 25 September 2015
Available online 9 October 2015

Keywords:
Allocation
Bidding
Resource management

ABSTRACT

We study the dynamic bilateral price negotiations from the perspective of a monopolist seller. We first study the classical static problem with an added uncertainty feature. Next, we review the dynamic negotiation problem, and propose a simple deterministic "fluid" analog. The main emphasis of the paper is in analyzing the relationship of the dynamic negotiation problem and the classical revenue management problems; and expanding the formulation to the case where both the buyer and seller have limited prior information on their counterparty valuation. Our first result shows that if both the seller and buyer are bidding so as to minimize their maximum regret, then it is optimal for them to bid as if the unknown valuation distributions were uniform. Building on this result and the fluid formulation of the dynamic negotiation problem, we characterize the seller's minimum acceptable price at any given point in time.

1. Introduction

Many transactions between a seller and a buyer follow some form of a negotiation. This is typical in business-to-business settings as well as in transactions that involve end consumers for expensive items such as cars, furniture, and real-estate [5,16,18]. There are also examples in consumer commerce [34,19,15,7,10,30]. The outcome of each such negotiation depends on the reservation values of the seller and buyer, their negotiation skills, and their beliefs on the same parameters of their opponent. This process is known as a "bilateral negotiation", and if the focus of the negotiation process is restricted to prices specifically, as "bilateral price negotiations".

Despite the importance and prevalence of negotiation problems in practice, quantitative dynamic pricing and revenue management, which has "evolved into a mature research area to support a seller's tactical capacity allocation choices and pricing decisions with inventory considerations [24]" has mostly focused on posted price mechanisms [11,35] and auctions [36]. There have been several extensions of the classical revenue management problem, for instance Bodily and Weatherford [4] consider the situations with continuous resources and several pricing classes; Sen [32] develops dynamic pricing heuristics as an extension to the Gallego and Van Ryzin's model that perform substantiall\y better than the fixed price policy. Lan et al. [20,21] provide successful examples of combining the overbooking and seat allocation decisions with the regret models. (Among other interesting line of research lie Kim and Bell's work [17] on the optimal pricing and production decisions in the presence of substitution, Tsai and Hung's paper [33] on the use of integrated real options internet retailing, Zhao et al. [37] regarding dynamic pricing in the presence of customer inertia, and Ghoniem and Maddah [13] optimizing retail assortment, pricing, and inventory decisions with substitutable products.) However, this broad research area has largely ignored the bilateral price negotiation problems perhaps regarding them as being in the scope of game theory. However, as we emphasize in this paper, the two problem types could be very similar and revenue management methods can be readily applicable in bilateral negotiation problems.

In more detail, we hereby focus on the revenue maximization problem of a vendor that has C units of capacity to sell over a time horizon of length T to a market of prospective buyers. These buyers arrive according to a Poisson process with rate Λ, each has a willingness-to-pay that is an independent draw from a distribution F_b, and engage in a bilateral negotiation with the seller for a single unit. The salvage value of the seller is private information, and buyers assume that it follows some distribution F_s and is constant over time. The reservation price of the seller at time t depends on the salvage value and the state of the sales process, i.e., the time-to-go and remaining capacity. The bilateral negotiation is modeled as a one-off negotiation, where the buyer and seller submit bids and where the unit is awarded if the buyer's bid is higher than the seller's bid. When the seller has market power, the transaction price is the seller's posted price (SPP); when the buyer

☆This manuscript was processed by Associate Editor M. Shen.
* Corresponding author.
E-mail address: nur.cavdaroglu@khas.edu.tr (N. Ayvaz-Cavdaroglu).

http://dx.doi.org/10.1016/j.omega.2015.09.009
0305-0483/

has market power, the transaction price is the buyer's posted price (BPP); in other cases the transaction price splits the difference between the two bids according to a fixed ratio that models the relative negotiation power of the two players.[1]

Among the papers that involve revenue management problems in the form of bilateral negotiations, the work of Bhandari and Secomandi [3] is perhaps closest to ours regarding the problem under consideration. However, the authors use a stylized MDP to investigate the negotiation processes and measure the performances of the seller under various negotiation mechanisms via numerical studies, while we resort to fluid approximation and develop an analytical result. Still, our findings in the numerical analysis section has common elements with their work. Our focus is not on the mechanism design, nor does it involve "strategic buyers" who refuse to buy at high prices, which are the main differences of our work from Riley and Zeckhauser [31] and Gallien [12]. Furthermore, Huang et al. [15] and Chen et al. [7] study the two selling mechanisms, namely, "posted price" versus "name-your-own-price" in a retail environment; however, the existence of several competing sellers, the forward-looking customers and other details differentiate their models from the model of our paper.

Finally, Kuo et al. [19] study a very similar problem to ours in the sense that they focus on retailers for whom take-it-or-leave-it price is the main mode of operation, but who nonetheless allow price negotiation when they encounter "bargainers". The retailer, as in the dynamic setting of our paper, encounters a series of bargainers over time, and the outcome of the negotiation with each bargainer will depend on the retailer's inventory and the remaining time until the end of the selling season. Their formulation differs from ours in how the outcome of each negotiation is characterized: in their work, the retailer sets a posted price, which acts as a ceiling on the revenue obtained from buyers, and a cutoff price which affects the final price according to the general Nash bargaining solution (GNBS); while we adopt the Chatterjee and Samuelson's model in which the seller sets a single bid value. Therefore, each party's lack of information about each other's valuation does not create a problem in their setting in terms of reaching a bargaining outcome, while the assumption in the classical one-to-one negotiation problem we consider is both parties having perfect information about each other's valuation distribution, which we happen to relax in the course of the paper. Moreover, the main focus of Kuo et al. is to study the effects of negotiation on the retailer's dynamic prices and revenues and the payments of both bargainers and price-takers in a variety of settings; while the ultimate focus of our paper is to study the classical and the dynamic bilateral negotiation problem with various extensions and to create a link between the economics and revenue management literatures by establishing its connection with the classical revenue management problems.

The first modeling and methodological contribution of our paper is in formulating the classical bilateral negotiation problem in an uncertain environment, where buyers and the seller do not have information about F_s, F_b, respectively. There are three natural ways to specify this type of model uncertainty. The first one is stochastic, wherein the unknown distributions are assumed to be drawn from a given set of possible distributions according to some known probability law, and where the firm's goal is to optimize its expected revenues over all possible market model realizations. Its main shortcoming is that it requires detailed information on the distribution of the model uncertainty. As a second formulation, both the seller and the buyer adopt a max-min criterion where they aim to optimize their respective worst-case revenues. This criterion may yield overly pessimistic results. Finally, a third approach that reduces the conservatism of max-min formulations while maintaining their appealing low informational requirements is through the use of the competitive ratio or maximum regret criteria, which measure the performance relative to that of a fully-informed decision maker. They have been used extensively in the computer science literature, and have recently been applied in pricing and operations management problems. Specifically, Ball and Queyranne [1], Eren and Maglaras [8], Perakis and Roels [29], Lan et al. [22] and Eren and Van Ryzin [9] adopt different versions of this idea. Adopting the maximum regret criterion, we formulate jointly the buyer and seller bidding problems in the setting where the underlying distribution functions F_s, F_b are unknown to the respective counterparties, and show that the optimal strategies are to bid as if these distributions were uniform. This result, to our knowledge, is novel in the literature; although there are several papers that accept that the players will *de facto* believe that the other party has uniform distribution and act on it.

Secondly, we turn our attention to the dynamic setting. The key finding is to recognize that in the buyer's market (i.e. BPP setting) where the seller is simply making accept or reject decisions of the buyer bids, the problem can be reduced to a single resource capacity control problem in the form analyzed by Lee and Hersh [23]. Specifically, the distribution of buyer bids is analogous to a continuous distribution of fare classes. This observation allows us to completely characterize the structure of the optimal policy. We note in passing that the problem in the seller's market is similarly analogous to the well-studied dynamic pricing problem in Gallego and van Ryzin [11].

Next, motivated by the goal of studying the dynamic settings, we start with a simpler approximated problem where the buyer arrival process is replaced by a deterministic and continuous process. This model can be justified as a limit as the capacity and market potential grow large and the sales horizon and distributional assumptions stay unchanged. This is often referred to as a "fluid" model and admits a static solution. Furthermore, extending the findings of the one-to-one problem with the added uncertainty feature, it becomes possible to study a setting where the distributional assumptions are not known.

The main contributions of the paper are as follows: first, the maximum regret formulation and associated results are novel, and important on their own right as they offer a robust analog of the one-to-one bilateral negotiations problem. Parenthetically, we find that the uniform distribution appears as the natural assumption under incomplete information, which is consistent with results derived in the robust optimization literature. Secondly, we draw attention to the analogy between the dynamic bilateral negotiation problems and the classical revenue management problems; which is a first in the literature. Third, the formulation of the seller's dynamic problem with uncertain F_s, F_b distributions assumed as being uniform, as motivated by the result in the one-to-one setting, is novel. The numerical analysis section complements the analytical findings from other interesting perspectives, namely investigating the effect of the negotiation power and the effect of the uniform distribution assumption on the revenues of the seller and the bids of the two parties.

1.1. The remainder of the paper

In Section 2, we analyze a variant of the classical one-to-one negotiation problem with an added uncertainty element. In Section 3, the analysis is carried to a dynamic setting. Section 3.1 sheds light on the analogy of the negotiation and the revenue management problems. Section 3.2 presents the dynamic pricing model that extends the results of the static negotiation problem to

[1] A detailed definition of each negotiation mechanism can be found in Bhandari and Secomandi [3].