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Optimal contract-sizing in online display advertising for publishers with regret considerations

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ABSTRACT

In this paper, we study optimal contract problems for online display advertisements with pay-per-view pricing scheme. We first provide and analyze a single contract model, which is shown to be equivalent to the newsvendor problem. We then consider a stochastic optimization problem with two different advertisements and show that a contract to display both of them is not optimal. However, we show that a contract to display of both advertisements may be optimal when we consider the publisher's regret. We consider a chance constraint for the publisher's regret and provide numerical experiments that illustrate the change of optimal strategy for different probability levels.

1. Introduction

Online advertising has already become a dominant ad-medium and is continuously gaining market share. In the United States, with 2011 revenue of $31.74 billion, online advertising is now marking increasing significance to marketers and consumers [14]. Online advertising in the US is expected to grow eight times faster than the overall market and is already the second largest behind direct marketing with a $9.3 billion revenue in the third quarter of 2012 [15]. According to Interactive Advertising Bureau [14], search and display are the major formats of online advertising having 81.3% market share in 2011. Search advertisement appears as a search result in a web page loaded in response to a user keyword(s) search request. Display advertisement, on the other hand, is displayed in web pages that are requested for different purposes. Rather than instantaneous response, display advertising, in general, focuses in achieving memory. Even though both search and display format will exist, reports suggest that marketeers are becoming more interested in display advertising. Instead of making a keyword search, more users are making online purchases in response to display advertising [9]. Such gain in market share is attributed to the use of vast potential for technological innovation and creativity in providing display advertisement [13]. From 2009 to 2010, the market share for display increased for 34–36% resulting about 5% relative gain while the market for search remains the same [13]. As a result, display will remain as one of the leading modes of online advertising.

There are several pricing methods for online advertising services. Among those, pay-per-view (PPV) and pay-per-click (PPC) are dominant in the market. In particular, PPV is popular in display advertising and PPC is popular in search-based keyword advertising. For example, most news websites like BBC use PPV schemes [4] for displaying ad banners, while search engines like Google mainly use PPC schemes [12] for search keywords. In this paper, we focus on PPV schemes for display advertising.

There are two major sources of uncertainty in online advertising. First, the publisher does not have any prior information about the number page-views, i.e., how many times the publisher's page will be accessed by users. The second uncertainty is the number of clicks that is the total number of clicks on the advertising. In this study, we consider the case that the publisher has decided to host display advertisements only, which use pay-per-view pricing schemes, or the nature of the problem suggests so. We will examine how to make contracts optimally while the number of page-views is uncertain. With this end in view, we first consider that there is only one type of PPV advertisement available and the publisher needs to determine contract size. Next, we consider the case where there are two types of PPV advertisement available. Here, the publisher needs to determine whether she should go for both advertisements (multiple contracts), and what should be the optimal contract size. In particular, we study the optimal contract problem for single as well as two PPV advertisements. We also make a similar study of optimal contract decision problem when the publisher considers regret. In particular, we model the regret of the publisher with the probability that the revenue is less than a certain number.

In a perfect competitive market, everyone generally accepts the market price so that it would generate reasonable demand for

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one's product. Similarly, the publisher is considered a price-taker in this study. Therefore, she needs to determine the size of the contract that maximizes the revenue. The optimal contract size should be the upper limit on the promise she should be making. In case the demand at any pricing structure is less than the revenue-maximizing contract, the publisher should make the contract equal to the demand and then try to decide on contract size of the next best option. The effect of price on demand and optimizing the contract size as well as price can be considered in an oligopoly. In online advertising, Ahmed and Kwon [2] have studied this problem where each publisher needs to optimize the price and contract size considering the effect of price on demand. In this study, we assumed that the publisher, in a perfect competition, has unlimited number of display advertising available. Therefore, there is no limit on the size of contract the publisher can make.

Regarding online advertising, there are limited studies reported in the literature of operations research. Mangani [22] addressed optimal decision making between cost-per-impression (CPM) and cost-per-click (CPC) advertisements when the publishers are price-takers in the display advertisement market and later Fjell [10] revisited the same problem. Both Mangani [22] and Fjell [10] used the concept of elasticity to reach the conclusions. Kwon [19] also studied a capacity allocation problem between CPM and CPC advertisements with stochastic page-view and click-through rate (CTR) and provided a stochastic optimization formulation. Kumar and Sethi [18] considered a dynamic pricing problem considering subscription and advertising. Roels and Fridgeirsdottir [26] studied a dynamic optimal customer selection and display scheduling problem considering only CPM contracts. Fjell [11] first considered the problem for a publisher who has the market power to set the price. However, to the knowledge of the authors, no study on optimal contract problems considering risk/regret has been reported. Deane and Agarwal [8] study a display scheduling problem for display advertisements.

In this paper, we provide formulations for contract-sizing problems of online display ad publishers. The modeling framework is similar to that of Ahmed and Kwon [2] for which price is the main decision variable, while in this paper the size of contract is the primary decision. Our models also inherit modeling components of Roels and Fridgeirsdottir [26], in the sense that we consider revenue opportunities from third-party risk-free ad networks and lost revenue opportunities from a revenue optimization perspective. This paper further extends the previous modeling frameworks to consider regrets of ad publishers. We find that a regret-averse ad publisher may consider two different contract types under PPV pricing schemes, while a neutral ad publisher would not consider two different contract types.

Our study of regret-averse ad publishers is closely related to risk management in stochastic inventory problems. The main difference is that *supply* is stochastic in our online advertising problem, while *demand* is stochastic in most inventory problems. A good number of studies in stochastic inventory management consider Value-at-Risk (VaR) as the measure of risk. Özler et al. [24] studied single, two and multi-product newsvendor problems incorporating VaR risk measure. The exact formulation of the problem for single and two products case has been studied. They also found the results for two products for the case of correlated demand. An approximation method has been proposed to obtain the results for a multi-products case. Luciano et al. [21] also studied multi-period static inventory models with VaR being the risk measure. Zhou et al. [33] proposed an optimal-order model to consider multi-product inventory problem with Conditional Value-at-Risk (CVaR) constraints. The model is simulated for the case of a newsvendor problem and they find the solution bound is fully consistent with the decision maker's intuition on return-risk decision-making. The return-CVaR model is found to be more flexible than the classical model. Yang et al. [32] considered the risk of a newsvendor with limited capacity. Both the downside risk measure and CVaR risk measure have been used here to optimize the model. Tapiero [28] also addressed stochastic inventory control problem with VaR approach, and showed that VaR approach is justified by a disappointment criterion and provides its applications to inventory management. Agrawal and Seshadri [1] studied how price and order quantity is impacted by uncertainty and risk aversion. They found that risk-averse retailers distort their pricing decision in different ways depending on the impact of price on the distribution of demand. Other examples for newsvendor problems with risk considerations include the studies of Keren and Pliskin [17], Van Mieghem [30], Choi and Ruszczynski [7], Chen et al. [6] and Wang and Webster [31], Arcelus et al. [3], and Jörnsten et al. [16].

In this work, *display* of an advertisement refers to loading a web-page containing the advertisement in response to an online user request to load that page. When a page containing an advertisement is displayed, we count that as a single *impression*. The number of *page-views* is a random variable specifying how many times a publisher's web-page containing an advertisement is requested by visitors. The term *capacity* is used synonymously with the number of page-views, in the perspective of web publishers for online advertising services. After the period of consideration is over, the total number of display of an advertisement is termed as *realized display* of that advertisement. For displaying only one advertisement, realized display and realized number of page-views are same. If the publisher displays more than one advertisement, she needs to decide on allocation and *display rule*. The publisher may display an advertisement first until the contracted number of displays, and then start displaying another advertisement. We call this display rule a sequential display rule. On the other hand, the publisher may display advertisements proportionally. That is, the publisher displays advertisements in a mixed sequence of various advertisements. We call this display rule a proportional display rule. In this study, we consider proportional display rule only.

The paper is organized as follows. Section 2 provides the optimal contract problem for a single contract, and provides the equivalence of the optimal contract problem to the well-known newsvendor problem. Then, Section 3 considers an optimal contract problem with two display advertisements contracts and shows that making multiple contracts is not optimal. Section 4 formulates the problems for single and two PPV advertisements considering a chance constraint for regret, which is followed by numerical examples in Section 5. The numerical results show that making a contract to display both advertisements may be optimal when publisher is willing to take a high chance of paying large penalty to generate more revenue. Finally, Section 6 concludes the study.

2. Optimal contract sizing problem: single PPV advertisement

In this section, we will develop a model for the optimal contract-sizing problem in online advertising. In particular, we will consider a contract-sizing problem for displaying online advertisements with pay-per-view (PPV) pricing scheme. Payment for PPV is dependent on cost-per-impression (CPM), hence the revenue of a publisher depends on how many impressions she can be able to display.

When we consider a publisher's optimal contract sizing problem, two types of advertisements have PPV pricing scheme: one is advertisements by direct contract with the publisher, and the other is so-called network advertisements [26]. The former type, henceforth termed as PPV advertisements, involves a contract that specifies how many times the advertisements will be displayed within a certain time-frame. Network advertisements are sourced