Research on Information Structure of Programmatic Advertising Markets

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Abstract: With the abundance of online big data and computing resources, as well as the rapid development and diversification of business models, programmatic advertising (PA) has emerged and become the mainstream and one of the most promising advertising channels in recent years. As an effective way to precision marketing, PA relies heavily on the information elicited from analyzing Web users and pages, which can help advertisers precisely identify their best-matched audiences and evaluate the ad impressions in a real-time fashion. In PA markets, publishers serve as the supplier of ad impressions, and have control on whether, what and how to reveal such key information to advertisers. These decisions play a central role in the information structure of data-driven PA markets, and attract intensive research interests. In this paper, we strive to investigate publishers’ rational preference over the symmetric and asymmetric information structures, with the aim of maximizing their revenues. Our model views publishers’ revenue as a function of the information structure among advertisers, and we hereby proved its convexity under an incentive compatible mechanism. This conclusion indicates that publishers prefer an asymmetric information structure rather than a symmetric one. Our research findings can help improve publishers’ revenue, and also can explain the underlying rationale for the hybrid PA markets mixed by public real-time bidding and private marketplaces.

Keywords: programmatic advertising, real-time bidding, private marketplace, information structure

1. INTRODUCTION

Programmatic advertising (PA), widely recognized as a novel technique and big data-driven online advertising format in recent years, has sparked a new wave of rapid growth in revitalizing display advertising markets. Compared with traditional sale models of media-buying or ad-slot-buying, PA has evolved to a more fine-grained ad-impression-buying model, which can help realize precise audience targeting and dynamic allocation of ad resources in a real-time fashion. As such, PA has the potential to guarantee that the right audience goes to the best-matched advertisers, and also to improve advertisers’ promotion performance and market efficiency.

In current PA markets, there are typically two forms of the ad-delivery process, i.e., public deals and private deals. The former is usually realized via real-time bidding (RTB) auctions, while the latter has diversified forms including private marketplace (PMP), programmatic guaranteed buying, and preferred deals. This paper mainly discusses RTB and PMP, which are the mainstream and most representative advertising formats in their corresponding categories. More specifically, both RTB and PMP sell ad impressions using real-time auctions, and their difference lies in that: RTB advertising adopts auctions open to all advertisers and sells ad impressions with different qualities; in contrast, PMP uses invitation-only private auctions to sell high-quality ad impressions to premium or VIP advertisers. As the supplier of ad impressions, publishers will make the decision to which channel, i.e., RTB or PMP, should each ad impression be forwarded. This decision will lead to different mechanisms for the information disclosure in ad auctions, and also different information structures for all advertisers.

Information plays a critical role for both advertisers and publishers. On one hand, it is an important ingredient for advertisers in evaluating the quality of user behind each ad impression, so as to derive the best user-ad matching. On the other hand, it also helps publishers evaluate and thus price ad impressions. In literature, it has been theoretically proved that information advantages can lead to more equilibrium profit in sealed-bid auctions (Milgrom & Weber, 1982), and this is also the case for programmatic instantaneous auctions in PA markets. Specially, due to the externality and lack of control in the real-time ad delivery process, PA advertisers typically pay more attention to where their ads are displayed. An ad impression triggered in a Web page with higher-quality Web context will certainly be more profitable for advertisers than that in the lower-quality one. This can be easily justified by the fact that ad slots in premium Web pages usually can attract more advertisers and get a higher price. Thus, information about users and especially also the quality of ad impressions are of significant research and practice importance.

Publishers, such as CNN.com, are the closest entities in PA ecosystems to Web users, and thus have full information on
both the users and their own landing pages (Esö & Szentes, 2007). Once ad impressions arrive, publishers will elicit the useful information and make decisions on how much information will be revealed to individual advertisers when choosing the advertising channel, i.e., RTB or PMP, resulting in the corresponding information structures that describe how accurately advertisers formulate their private valuations by observing a signal (Hagedorn, 2009). As such, information structure can determine advertisers’ evaluation of ad impressions, their bidding strategies, and in turn publishers’ revenues (Hagedorn, 2009, and Bergemann & Pesendorfer, 2007). If publishers choose a single advertising channel of either RTB or PMP to sell the ad impressions, a symmetric information structure will be formed and the same information will be passed to all advertisers. On the contrary, if publishers use a hybrid advertising channel with both RTB and PMP, an asymmetric information structure occurs with different granularity of information passed to all advertisers. From the viewpoint of publishers, they prefer to allocate sufficient information to identify the advertiser with the highest valuation (Bergemann & Wambach, 2015), and their objective is to maximize revenue which is a function of advertisers’ information structures. As such, information structure is considered as a critical and challenging decision for publishers.

After publishers make their decision on the information structure, advertisers will submit their bids according to a specific auction mechanism, which determines advertisers’ probability of winning the ad impression and their monetary transfer to publishers. In the optimal mechanism of information revelation, each losing bidder will know his true valuation, while the winner only knows that his/her valuation is sufficiently high to win the auction. From a research perspective, many research efforts have been done to study the bidders’ instead of the auctioneers’ preferences over information in contractual relationships or auctions (Cremer & Khalil, F, 1998; Persico, 2000; Athey & Levin, 2001). Generally speaking, an advertiser’s bid is affected by his/her valuation based on privately received information, and meanwhile, the bid of an ad impression is also a signal of its value (Ghosh et al., 2009). Advertisers can also adjust the bids based on the performance distribution in previous auctions (Lee et al., 2013) besides the received information. Cui et al. (2011) investigated the real-time prediction of the bid distribution for the RTB advertising campaign, since there is no accurate prior information for advertisers’ reference.

In PA markets, information-related topic is mainly studied as an important underlying problem in such research branches as auction mechanism design and bidding strategy optimization. Specially, in literature, research efforts on information structure are still far from enough. Gomes & Mirroknii (2014) studied the optimal mechanism design in settings plagued by competition and two-sided asymmetric information regarding the valuations of buyers, as well as the seller’s opportunity cost for the Ad Exchange. In the research of Liu & Viswanathan (2014), they highlighted the role of pricing schemes as a means of leveraging private information available to providers and advertisers.

Most of the above research efforts formulate the environment in PA markets with a single advertising channel or a specific information structure. However, the bidding scheme and revenue optimization under different information structures are essentially different in PA practice, which poses great challenges for publishers to assign information structure to individual advertisers. For instance, symmetric information structure gives equal information to all advertisers, and may result in averaged bids of both high-quality and low-quality ad impressions from advertisers, and in turn averaged revenues for publishers; On the contrary, an asymmetric information structure makes some advertiser more perfectly informed and others only roughly informed, which may lead to more revenues from high-quality ad impressions and less from low-quality ones. From the perspective of PA market practice, the information structure will not only affect the publishers’ revenues, but also in a system level plays a key role in improving the accuracy and performance of the PA advertising ecosystems. Therefore, there is a critical need to study the information structure problem emerged in PA markets.

Our research is targeted at studying publisher’s optimal decision on information structure to maximize their revenues. We establish a model to investigate the information structure related to quality information of the ad impression in PA market, explicitly considering that the information of target audiences is symmetric for all advertisers due to the attribute of precision targeting. We consider the publisher’s payment transferred from advertisers is maximized under the advertisers’ information structures. Then, we identify several important properties of the model and draw useful conclusions to support the publisher’s decision on information structures.

The remainder of this paper is organized as follows. In Section 2, we briefly state our research problem related to information structure in PA markets, establish a model under a direct revelation mechanism, and prove the important properties. Section 3 discusses the management insights of our research. Section 4 concludes.

### 2. THE MODEL

#### 2.1 Problem Statement

Once a user visits a publisher’s Webpage, an ad impression is triggered, and the publisher will then forward the information behind the impression (especially information of the user and Webpage) to competing advertisers via intermediating platforms including an ad exchange (AdX) and multiple demand-side platforms (DSP). We consider two kinds of information, i.e., user (or audience) information denoted by $u$ and quality information of ad impression in the Web pages denoted by $q$. The former typically refers to user profiles (e.g., age, gender, intention, etc) elicited from the Web cookie data, while the latter includes URLs, Web context, ad slots, ad sizes and so on. In PA markets, advertisers rely on audience information to identify the best-matched audience and its corresponding ad impressions. As such, audience information can serve as the basis of the more fine-grained “impression-level buying” sale model in PA. On the contrary, quality information does not influence the audience-advertiser matching, but has a significant impact on advertisers’ valuations, and thus their bids of the ad impressions.
The publisher can choose a symmetric or asymmetric information structure to sell ad inventory for maximized revenues. In PA markets, the second-price auction scheme is generally used (Yuan et al., 2014), and all advertisers can only obtain noisy signals about ad impressions. Due to the characteristics of precision marketing of PA, it is rational for publishers to use the symmetric information structure on the audience part, under which all advertisers can receive the same signals $s(u)$ about the audience behind ad impressions. Consequently, in this paper, we mainly focus on the quality information of ad impressions.

Suppose the publisher and the advertisers in the PA markets are all risk-neutral. When a user’s visit on the Webpage triggers an ad impression, the publisher will try to sell it to one of the potential advertisers through the second-price auction. Typically, not all $n$ advertisers will participate in the auction. In practice, only those advertisers who view the user as their target audience will bid and compete for the ad impression. If the advertiser wins the auction, he/she will gain the opportunity of displaying their ads, and has to transfer a certain payment to the publisher. Then, the payoff of advertiser $i$ is given as

$$u_i(v_i, \alpha_i) = \alpha_i v_i(u_i, q_i) - p_i,$$

which is quasi-linear. Here, $v_i$ is the advertiser’s individual valuation of the ad impression, and $\alpha_i$ is the probability of winning in the ad impression auction, where $0 \leq \alpha_i \leq 1$ and $\sum_i \alpha_i \leq 1$. $p_i$ is a monetary transfer to the publisher, and $p_i \geq 0$. Every advertiser has individual rationality, thus we have $u_i(v_i, \alpha_i) \geq 0, \forall i \in N = \{1, 2, \ldots, n\}$. If the advertiser fails to get the ad impression, he/she will not pay for the auction, which means when $\alpha_i v_i(u_i, q_i) = 0$, there is $p_i = 0$.

Generally, ads exposed to different users bring different values to the advertiser; and ads exposed to the same user on different Web pages also have different values to the advertiser. Only under the condition that advertisers decide to bid for the ad impression according to the audience information, the quality information can influence their valuations. Otherwise, even the top quality cannot attract advertisers to bid for the untargeted audience. Consequently, we split the advertiser’s valuation into two parts: the valuation of audience part generated by the specific audience, and the valuation of quality part caused by the ad showing on the Web pages of different qualities. Accordingly, the valuation of the advertiser can be formulated as

$$v_i(u_i, q_i) = v_i^a(u_i) v_i^q(q_i),$$

where $v_i^a(u_i)$ defines the valuation of audience part, and $v_i^q(q_i)$ represents the valuation of quality part. As mentioned above, for the characteristic of precision marketing of PA market, it is rational to assume that the audience information is perfectly and symmetrically delivered to all advertisers in the market, that is $v_i^a(u_i) = v_i^a(u)$. Therefore, we make some further transformation to formulate the advertiser $i$’s payoff function as

$$u_i(v_i, \beta_i) = \beta_i g_i(q_i) - p_i.$$

Here, $\beta_i = \alpha_i v_i^a(u_i)$, and $g_i(q_i) = v_i^q(q_i)$. The uncertainty is described by quality $q$, and it is independently distributed with the prior distribution as common knowledge for all advertisers and the publisher.

Each advertiser privately gets a noisy signal $S_i$ with generic element $s_i$ about the true state of quality $q$. Here, $S_i \subseteq Q$. Signal $s_i$ is assumed to be independently distributed. Then
the information structure is a joint distribution over the signal and the quality,

\[ F_i : Q \times S_i. \]

The marginal distribution of the signal and the quality are \( F_i(s_i) \) and \( F_i(q_i) \), respectively. The corresponding densities are strictly positive. The publisher can apply any information structure to the ad impression auction under the condition that the posterior distributions should equals to the prior distributions according to Bayes’ rule.

In the auction, signal \( s_i \) represents the type of the advertiser, which is private. However, the distribution of information structure is common knowledge for all advertisers. The true state of the quality \( q_i \) cannot be observed by the advertisers. Given the signal and the information structure, each advertiser can formulate estimation about his/her true valuation.

Based on the observed signal \( s_i \) and the information structure \( F_i \), the expectation of \( g_i \) can be formulated as

\[ \mathbb{E}[g_i] = w_i(F, s) = \int g(q) dF(q | s_i). \]

The utility function is additively separable if it can be represented as

\[ w_i(F, s) = \sum_s w_i^s(F^s, s^i). \]

Under the second-price auction mechanism of PA markets, all advertisers will be willing to bid on their valuations in pursuit of the optimal revenues, if they do not consider the competitors’ valuations. They submit their true valuations to DSP/AdX, and be returned with the auction results and corresponding payments. As such, we consider the ad impression auction mechanism in PA markets as a direct revelation mechanism. When the publisher decides the information structure, the payoff of advertiser \( i \) will be defined as the function of the expectation of his/her valuation,

\[ w_i(F, s) \beta_i^F (s) - p_i^F (s). \]

Here, we make a transformation to set \( Z_i = F_i(s_i) \) on \([0, 1]\) for the convenience of the following analysis. Obviously, \( Z_i \) has the same information content with \( S_i \). Then, a new joint distribution of \( Q_i \) and \( Z_i \) is generated as \( F_i' : Q \times Z \). Assume that the marginal distributions \( F_i'(z) \) are uniform and with strictly positive densities. Then, given the information structure \( F' \) and signals \( z \), the payoff for the advertiser is equal to

\[ w_i(F', z) \beta_i^{F'} (z) - p_i^{F'} (z), \]

where \( w_i(F', z) = \int g(q) dF'(q | z). \)

In the single item auction of ad impression in PA markets, the publisher aims at maximizing the revenues after choosing a specific information structure.

Next, we will figure out the marginal revenue for the publisher gained from the advertiser \( i \) under the information structure \( F' \), which is noted as \( R_i'(F', z) \). Then, the following equality is gained,

\[ R_i(F', z) = w_i(F', z) - (1 - z)\hat{d}w_i(F', (z, z_\sim))\hat{d}z_i. \]

\(-i = (i, i-1, i+1...N)\) is defined as the competitors of advertiser \( i \), who have the information space \( Z_\sim \) with the generic element \( z_\sim \).

Furthermore, the total revenues gained from all advertisers by the publisher applying the information structure \( F' \) under a direct auction mechanism can be figured out. Since \( w_i(F', z) \) is additive, \( R_i(F', z) \) is also additive. Then, the total revenues for the publisher is equal to

\[ R(F') = \int_z [\sum_i R_i(F', z) \beta_i^{F'} (z)] dz. \]

Under each information structure \( F' \), the publisher can win a corresponding maximal revenues \( R'(F') \).

2.3 Analysis

2.3.1 Convexity of the Publisher’s Revenue

Although PA usually adopts the second-price scheme for ad impression auction, some leading AdXs (e.g. Google, Facebook, etc) still claim that their mechanisms can encourage advertisers to bid with their true valuations and also realize the maximization of social efficiency or social revenues. Therefore, it is rational for us to assume that the auction mechanism in PA markets is incentive compatible (Hurwicz, 1973; Nisan et al. 2007).

In PA markets, if the advertiser can get more accurate signals about the ad impression’s quality than that of his/her competitors, he/she will formulate a more reliable valuation, and consequently has a higher probability to win the auction and gain a better payoff, thus return more revenues for the publisher than others. Therefore, a higher \( z_i \) will result in a higher \( R_i(F', z) - R_j(F', z) \) for all \( i \) and \( j \), and \( i \neq j \). Then, it can be concluded that if \( R_i(F', z) - R_j(F', z) \) is increasing in \( z_i \), the marginal revenues of the publisher are strictly increasing for the information structure \( F' \).

Suppose there are three convex information structures \( F, F' \) and \( H = AF + (1 - A)F' \) with \( \lambda \in (0, 1) \). Since the marginal revenue is a linear function of information structure, then it can be written as:

\[ R(H, z) = \lambda R_i(F, z) + (1 - \lambda)R_i(F', z). \]

Furthermore, if advertiser’s expectation of valuation is additive, we can get

\[ R'(H) = \int_z [\lambda R_i(F, z) + (1 - \lambda)\lambda R_i(F', z)] \beta_i^{H} (z) dz. \]

Under the condition of incentive compatibility in the ad impression auction of PA markets mentioned above, we can prove that:

\[ \lambda[R(H, z) + (1 - \lambda)\lambda R_i(F', z)]dz \leq \lambda[\int_z [\sum_i R_i(F, z) \beta_i^{F'} (z)] dz + (1 - \lambda)\lambda R_i(F', z) \beta_i^{H} (z)] dz, \]

\[ = \lambda R'(F) + (1 - \lambda)R'(F') \]
which means,
\[ \lambda R'(F) + (1 - \lambda)R'(F') \geq R'(H) \]

Therefore, under an incentive-compatible mechanism, the convexity of the publisher's revenue in the advertisers’ information structures has been proved.

2.3.2 Asymmetric Information Structure

As follows, we will make further analysis of the revenue maximization for the publisher under both symmetric and asymmetric information structure, and try to give a convincing support for the publisher’s choice between these two forms of information structures.

At first, we analyze a special case to suppose two ad impressions triggered by the same user’s visiting on different Web pages of the publisher, where \( a \) is with high quality \( q^a \) and \( b \) is with low quality \( q^b \).

If the publisher chooses the hybrid channels to allocate \( a \) to PMP and \( b \) to RTB market, he/she adopts the asymmetric information structure \( G = (G^a, G^b) \). For premium advertisers in private marketplace, they know their quality for the ad impression with high quality \( q^a \) from assigned signals; and for the generic advertisers knowing the existence of private marketplace, they will judge the ad impression with low quality \( q^b \) according to received signals. Under the asymmetric information structure, the publisher can gain revenues as

\[ R(G^a) + R(G^b) \]

If the publisher chooses the single channel to allocate both \( a \) and \( b \) to RTB advertising market, he/she determines the symmetric information structure \( G' = (G', G') \) and delivers just the same signals to all advertisers. Then, the advertisers will evaluate the qualities of ad impressions based on noisy signals to formulate expectations:

\[ E(q^a) = \omega q^a + (1 - \omega)q^b \]
\[ E(q^b) = (1 - \omega)q^b + \omega q^1 \]

where \( \omega \in [0, 1] \). Under the symmetric information structure, the publisher can gain revenues as \( R(G') + R(G') \).

Then, according to the convexity of the publisher’s revenue in advertisers’ information structures proved above, we can get

\[ \omega R'(G') + (1 - \omega)R'(G') \geq R'(G') \]
\[ (1 - \omega)R'(G') + \omega R'(G') \geq R'(G') \]

Therefore, \( R(G^a) + R(G^b) \geq R(G') + R(G') \), which means applying asymmetric information structure in PA markets will result in more revenues for the publisher than applying symmetric information structure. From analysis of the special case, we can also get the conclusion that selling ad inventory through hybrid channels is more profitable for the publisher in PA markets.

As for the general case, there are a number of ad impressions generated by various users. If the publisher chooses the symmetric information structure \( G = (G, ..., G) \), then there is \( G_i(s, q) = G(s, q) \) for all advertisers. If the publisher chooses the asymmetric information structure, consider that \( G = (G^i, ..., G^i) \) and \( G^* = (G^i, ..., G^i) \) represent two different asymmetric information structures respectively, which satisfy the condition that \( G = aG' + (1 - \varepsilon)G^* \), where \( \varepsilon \in (0,1) \). Then, according to the property of the publisher’s revenue convexity in advertisers’ information structures, we can get that \( \varepsilon R'(G') + (1 - \varepsilon)R'(G^*) \geq R'(G) \). Since the marginal revenue is strictly increasing for information structure, then choosing the asymmetric information structure \( G' \) or \( G^* \) will improve the publisher’s revenue based on the revenues achieved by adopting symmetric information structure.

Therefore, we have proved that under the condition of the convexity of the publisher's revenue, he/she prefers the asymmetric information structure, and adopting an asymmetric information structure will result in more optimal revenues for him/her than that from the symmetric information structure.

The above analysis also provides a good explanation of the existence and the prevalence of RTB publishers adopting PMP scheme to sell part of their ad inventories in PA markets.

3. MANAGEMENT INSIGHTS

Our research findings can offer useful managerial insights for publishers’ decisions of information structure in PA markets. In practice, it is very challenging for the publisher to determine whether to choose a symmetric information structure for an averaged revenue from all advertisers, or an asymmetric information structure for higher revenues from premium advertisers and lower revenues from generic advertisers, since a symmetric information structure may result in a good price for some low-quality ad impressions, and an asymmetric information structure can help high-quality ad impressions win higher bids. We consider the publisher’s revenue as a function of advertisers’ information structure to study the problem, and provide a straight-forward support for the asymmetric information structure under the incentive-compatible mechanism. Although we consider the audience information should be symmetric for all advertisers because of the characteristics of precision marketing of PA, publishers still can control the quality information delivered to advertisers for the purpose of revenue maximization through encouraging them to distinguish high-quality ad impressions and formulate more reasonable valuations and bids.

Also, our research provides a feasible solution for publishers to decide information structure from the perspective of global-level for all advertisers other than local-level for each advertiser, which helps maximize the publisher’s total revenues. From the angle of the publisher’s choice on ad inventory selling channels, our research can also support the publisher to adopt the hybrid-channel strategy.

The marketing practices in China have also validated our analysis and conclusions: publishers prefer to choose an asymmetric information structure in the ad impression auc-
tions. More and more PA publishers choose the hybrid channels to sell ad inventory through both RTB and PMP. More than 40% leading publishers-supply-side platforms (SSP) who take more than 90% market share of PA markets in China both plug into public RTB ad exchange and build their own private ad exchange, according to Analysys. Also, iPinYou, the largest programmatic buying platform in China has provides both RTB and PMP scheme for ad impression deals. Figure 2 describes and predicts the market shares of PMP and RTB in PA markets in China according to iResearch, which means PMP is a good alternative way of ad inventory selling for publishers in RTB market practice, with the aim to encourage their advertisers to increase ad budgets for a premium segment of ad inventory.

Fig. 2. Market shares of PMP and RTB in Chinese PA markets

4. CONCLUSIONS AND FUTURE WORK

Information is the essential basis for the ad impression auctions, which not only plays a key role for advertisers to formulate valuations, but also influences revenue maximization of publishers. Therefore, information structure is a significant decision for the publisher. We establish a model to consider the publisher’s revenue as a function of advertisers’ information structures in PA markets. On account of the characteristics of precision audience targeting of PA, we consider the symmetric audience information for all advertisers, and information structure research in this paper mainly refers to quality information. We prove the convexity of the publisher’s revenue in advertisers’ information structure in incentive compatible mechanisms and further find out that the publisher will prefer an asymmetric information structure to a symmetric information structure for the purpose of revenue maximization.

In the future, we are planning to extend this paper to take the cost of adopting asymmetric information structure into consideration. Also, we plan to probe information asymmetry in both audience information and quality information, e.g. the publisher applies different audience information granularity and meanwhile disclosure different quality information for generic advertisers in RTB markets and premium advertisers in PMP markets.

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