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THE REVENUE OPTIMIZATION STRATEGY OF ONLINE ADVERTISING PLATFORM BASED ON PRODUCT QUALITY

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Abstract. *With the continuous expansion of the online advertising market, it has received great attention from the academic and the business community. However, in the current advertising position auction mechanism, the revenue of the platform is maximized without considering the audiences' experience. This is bound to damage the revenue of the advertising platform in the long run. Products quality on the advertising position has very important influence on the audiences' experience. Based on this, this paper builds a revenue optimization model of online advertising platform, in which the product quality is determined endogenously. Through the equilibrium analysis, the product quality strategy is presented to maximize the revenue of the online advertising platform.*

Keywords: Online advertising, Advertising platform, Product quality, Strategy optimization

1. **Introduction.** Online advertising is also known as network advertising. There exists a variety of forms, for example search engine advertising, news page ads, pop-up ads page, desktop pop-up ads, video Trailer advertising, and social network advertising. According to the prediction of the relevant research, the market size of China's online advertising in 2018 will reach 412.5 billion yuan.[1] With the continuous expansion of the online advertising market, it has received great attention from the academic and the business community. It has a profound impact on the advertisers, advertising platforms and audiences: for advertisers, after spending millions of yuan on online advertising, whether the expected marketing effects are achieved or not; for the advertising platform, how to optimize the network advertising in order to find a balance between the platform revenue and the audience experience? This is not only a hard problem for business community, but also a hard issue for the academic community.

In terms of the effect of online advertising, two issues are mostly concerned by advertisers: first, how much money is paid to get the advertising position? Second, when an advertiser bid for the advertising position, how many audiences will browse the advertising and ultimately contribute to the income of the enterprise? The consensus of practice and academic is that advertisers, who want to get the advertising position, should participate in the position auction. The pricing model is mainly divided into 2 categories: based on process and based on output [1]. The formers are CPM (Per Mill Cost), and CPT (Per Time Cost); the latters are CPC (Per Click Cost), and CPS (Cost per Sale). The researches which are about these 2 kinds of pricing model and had been done by scholars at home and abroad show that these models are reasonable but have to be improved [2,3]. However, there are also some problems in the above two pricing models, the former's disadvantages are click fraud and low conversion rate, and the latter's disadvantage is that

[1] iimedia research, "2014-2015 China's DSP Industry Development Research Report"

advertising platform bears the most risk [4]. H. R. Varian built a position auction model based on game theory for the first time. He pointed out that position auction model is similar to matching theory, but the conclusion is more distinct [5]. After that, based on the GSP (Generalized Second-Price) mechanism and VCG (Vickrey-Clarke-Groves) mechanism, a large number of researches has been done [6]. In terms of purpose, the auction is a price discovery mechanism, and it can find out the maximum bid for the advertising position. However, this is not the only aim of the advertising platform, and another question that must be considered is the audiences experience. Therefore, the endogenous value of advertising position has become the core of online advertising pricing [7]. Advertisers' expectation to the endogenous value of advertising position determines their maximum bid, audiences' expectation to the endogenous value of advertising position determines their experience, and the expectations influence each other. The quality of the products has a great influence on the audience experience, which is the reason why Google ads add a quality score system in its auction mechanism. In addition, some researchers point out that the relationship between two advertising products will affect the marketing effect [8]. Quality is a key factor of their relationship, and the relationship of other aspects can be converted into the correlation between the products quality.

Therefore, this paper based on Hotelling model constructs a Bertrand oligopoly model, which consists of three participants: the advertiser, the advertising platform and the audience. Based on equilibrium results, the strategy of the advertising platform to optimize the product quality in the online advertising marketing is analyzed. The paper is organized as follows: the first part is the introduction, the second part is to construct the basic model, the third part shows the main conclusions and propositions, the fourth part shows some numerical examples, and the fifth part makes the conclusion.

2. The Basic Model.

Assume that there are two ad positions i and j on the same web page, the audiences are uniformly distributed in the continuous system of $[0, 1]$, and i and j are located at the two ends of the linear continuous system. n manufacturers sell the vertical difference products at the same price and the quality has no relation with the production cost. n manufacturers determine to bid for the i position or the j position to advertise through the VCG auction mechanism.

2.1. Expectation of the endogenous value of advertising position and the payment of the advertisers.

Advertisers' expectation of endogenous value of advertising position depends on the following factors: (1) the times of the audiences browsing i advertising position n_i; (2) the times of the audiences browsing j advertising position n_j; (3) the product quality of i advertising position s_i; (4) the product quality of j advertising position s_j; (5) the reservation utility of audiences browsing i advertising position $\bar{v}_i$; (6) the reservation utility of audiences browsing j advertising position $\bar{v}_j$. Because the advertising position is asymmetry, their reservation utilities are different. Without loss of generality, assume that $\bar{v}_i = v_0$, $\bar{v}_j = 0$.

In the perfect common value auction, different advertisers' expectations of the endogenous value of advertising position are consistent. And the expectation of the value of i advertising position is $v_i = \varphi_i(n_i, s_i, v_0)$, and the expectation of the value of j advertising position is $v_j = \varphi_j(n_j, s_j, 0)$, $v_i \geq v_j$. According to the conclusion of the VCG auction mechanism: an advertiser's optimal bid p should be equal to the loss of other participants, which is caused by its involvement. Accordingly, when n advertisers take part in the auction, the bid of the advertiser who wins the i advertising position is $p_i = (v_i - v_j) + (v_j - 0) + \cdots$; the bid of the advertiser who wins the j advertising position is $p_j = (v_j - 0) + (0 - 0) + \cdots$. So, $p_i = v_i$, $p_j = v_j$. That is, in the VCG auction mechanism, the advertiser's bid is equal to its evaluation of the value of the advertising position. If φ_l ($l \in \{i, j\}$) is a linear function, then $v_i = k_1 n_i + k_2 s_i + k_3 v_0$, $v_j = k_1 n_j + k_2 s_j$. k_1, k_2 and k_3 are constants.

2.2. **The audience's opportunity cost of browsing advertising position.** When the audiences browse the advertisement, they enjoy the value-added services that are provided by the advertising platform. The value of those services is $v_s = \phi(p_l) = \theta \cdot v_l$. So, the audience's opportunity cost of browsing i advertising position is the value of the value-added services that the audiences enjoy when they browse the j advertising position. That is $c_i = v_{s-i} = \theta v_j$; for the same reason, $c_j = v_{s-j} = \theta v_i$. Through the above analysis, it can be known that there is a mapping relationship between c_l and v_l.

2.3. **The audience's utility of browsing advertising position.** When the audiences browse i advertising position, his (her) utility is:

$$u_i = v_0 + an_i - c_i - tx \tag{1}$$

When the audiences browse j advertising position, his (her) utility is:

$$u_j = 0 + an_j - c_j - t(1 - x) \tag{2}$$

In addition to the previous notations that have been declared, a is the network effect coefficient, t is the mismatch coefficient, x indicating the distance between an audience and i advertising position; $1 - x$ indicates the distance between an audience and j advertising position.

Because $c_i = \theta v_j$, $c_i = \theta k_1 n_j + \theta k_2 s_j$. For the same reason, $c_j = \theta k_1 n_i + \theta k_2 s_i + \theta k_3 v_0$. Let $\theta = 1$ and $k_1 = k_2 = k_3 = k$, and then $\theta k_1 = \theta k_2 = \theta k_3 = k$, $c_i = kn_j + ks_j$, $c_j = kn_i + ks_i + kv_0$.

2.4. **The profit of advertising position.** Because $v_i = k_1 n_i + k_2 s_i + k_3 v_0$, $v_j = k_1 n_j + k_2 s_j$, $k_1 = k_2 = k_3 = k$, $p_i = v_i = kn_i + ks_i + kv_0$, $p_j = v_j = kn_j + ks_j$.

According to this, we can get the profit of l advertising position:

$$\pi_i = k \int_0^{n_i} (n_i + s_i + v_0) dn_i = k\frac{1}{2} n_i^2 + ks_i n_i + kv_i n_i \tag{3}$$

$$\pi_j = k \int_0^{n_j} (n_j + s_j) dn_j = k\frac{1}{2} n_j^2 + ks_j n_j \tag{4}$$

2.5. **Equilibrium analysis.** Let $x = n_i$ be an indifference point of the audience to browse the advertising position, so, $u_i = u_j$. That is, let Formula (1) equal Formula (2), so n_i and n_j are respectively:

$$n_i = \frac{1}{2} + \frac{k(s_i - s_j)}{2(t - a - k)} + \frac{(1 + k)v_0}{2(t - a - k)} \tag{5}$$

$$n_j = \frac{1}{2} - \frac{k(s_i - s_j)}{2(t - a - k)} - \frac{(1 + k)v_0}{2(t - a - k)} \tag{6}$$

From Formula (5) and Formula (6), we can know that: when v_0 is increasing, the difference of n_i and n_j has a trend of increasing; while the quality difference $(s_i - s_j)$ decreases, the difference of n_i and n_j has a trend of decreasing.

When n_i and n_j are substituted into Formula (3) and Formula (4), π_i and π_j are respectively:

$$\begin{aligned} \pi_i = {} & k \left[\frac{1}{8} + \frac{(1 + k)v_0}{4(t - a - k)} + \frac{(1 + k)^2 v_0^2}{8(t - a - k)^2} + \frac{v_0}{2} + \frac{(1 + k)v_0^2}{2(t - a - k)} \right] \\ & + k \left[\frac{k}{4(t - a - k)} + \frac{(1 + k)kv_0}{4(t - a - k)^2} + \frac{kv_0}{2(t - a - k)} \right] (s_i - s_j) \end{aligned}$$

$$+k\frac{k^2(s_i-s_j)^2}{8(t-a-k)^2}+k\left[\frac{1}{2}+\frac{(1+k)v_0}{2(t-a-k)}\right]s_i+\frac{k^2s_i^2}{2(t-a-k)}-\frac{k^2s_is_j}{2(t-a-k)}$$

$$\pi_j=k\left[\frac{1}{8}-\frac{(1+k)v_0}{4(t-a-k)}+\frac{(1+k)^2v_0^2}{8(t-a-k)}\right]+k\left[\frac{(1+k)kv_0}{4(t-a-k)^2}-\frac{k}{4(t-a-k)}\right](s_i-s_j)$$
$$+k\frac{k^2(s_i-s_j)^2}{8(t-a-k)^2}+k\left[\frac{1}{2}-\frac{(1+k)v_0}{2(t-a-k)}\right]s_j-\frac{k^2s_is_j}{2(t-a-k)}+\frac{k^2s_j^2}{2(t-a-k)}$$

During the auction of the advertising position, the advertising platform can require the advertisers to provide the quality information of their product, so the advertising platform can determine the product quality of each advertising position. So, s_i and s_j are decision variables. The reaction function of i advertising position is:

$$s_i=-\frac{[(t-a-k)k+(1+k)kv_0+2(t-a-k)kv_0+2(t-a-k)^2+2(t-a-k)(1+k)v_0]}{k^2+4(t-a-k)k}$$
$$+\frac{[k^2+2(t-a-k)k]\,s_j}{k^2+4(t-a-k)k} \tag{7}$$

The reaction function of j advertising position is:

$$s_j=-\frac{[(t-a-k)k-(1+k)v_0k+2(t-a-k)^2-2(t-a-k)(1+k)v_0]}{k^2+4(t-a-k)k}$$
$$+\frac{[k^2+2(t-a-k)k]\,s_i}{k^2+4(t-a-k)k} \tag{8}$$

Solving the simultaneous Equations (7) and (8), we can get s_i and s_j respectively:

$$s_i=\frac{-k^2-5(t-a-k)k-6(t-a-k)^2-kv_0-2k^2v_0-2(t-a-k)v_0-6(t-a-k)kv_0}{2k^2+6(t-a-k)k}$$

$$s_j=\frac{-k^2-5(t-a-k)k-6(t-a-k)^2-kv_0+2(t-a-k)v_0}{2k^2+6(t-a-k)k}$$

s_i and s_j are respectively the product quality of i advertising position and j advertising position, which makes the maximum profit for the advertising platform. Since this article focuses on the quality strategy of the network advertising, the relaxed maximum condition s_i-s_j is meaningful to the analysis.

$$s_i-s_j=\left[\frac{2(a+k-t)-k}{k^2+3(t-a-k)k}-1\right]v_0 \tag{9}$$

Lemma 2.1. *When the revenue of the advertising platform is maximized, the quality difference between the product which is shown on the i position and the product which is shown on the j position depends on the reservation utility v_0, the network effect coefficient a, the mismatch coefficient t and the conversion rate k.*

This means that when the reservation utility v_0, the network effect coefficient a, the mismatch coefficient t and the conversion rate k are set, only make the quality difference between the product which is shown on the i position and the product which is shown on the j position equal to (9), and the revenue of the advertising platform is maximized.

3. **Main Conclusions and Propositions.** The main conclusions and propositions of this thesis can be obtained through discussing s_i-s_j.

When the two advertising positions are symmetric, and the product qualities of the two positions are different, this will centralize the audiences on the high product quality position. The network effect has exacerbated this trend. Excessive concentration of audiences will decrease the advertisers' evaluation on the advertising position, because the advertisers' marginal utility on the number of audiences is decreasing. This will lead to the decreasing of the revenue of the advertising platform.

Proposition 3.1. *When the two advertising positions are symmetric, the advertising platform's optimal strategy is to equal the product quality of the two advertising positions.*

Proof: Because of the symmetry of the advertising position, $v_0 = 0$. According to Formula (9), then, $s_i = s_j$. □

When the conversion rate is high, the competition for the first advertising position is becoming fiercer. For the higher product quality advertiser the revenue obtained from the prominent advertising position which is gotten by price competition is less than the revenue that is obtained from price-off promotion. So, the higher product quality advertiser may choose the second advertising position.

Proposition 3.2. *When* $(t–a) \in (0, 0.6]$, *and* $k \in \left(0, \frac{[3(t–a)–1]+\sqrt{[1–3(t–a)]^2+16(t–a)}}{4}\right]$, *the product quality of the prominent advertising position is better than the disadvantaged advertising position. Increasing of the asymmetry of the advertising positions (increasing of* v_0*) will lead to the expansion of the gap between the product qualities of the two advertising positions. When* $k \in \left(\frac{[3(t-a)-1]+\sqrt{[1-3(t-a)]^2+16(t-a)}}{4}, 1\right]$, *the product quality of the prominent advertising position is poorer than the disadvantaged advertising position. Increasing of the asymmetry of the advertising positions (increasing of* v_0*) will lead to the expansion of the gap between the product qualities of the two advertising positions.*

Proof: $\frac{\partial(s_i - s_j)}{\partial v_0} = \frac{2(a+k-t)-k}{k^2+3(t-a-k)k} - 1$.

Let $\frac{2(a+k-t)-k}{k^2+3(t-a-k)k} - 1 = 0$, and trim this formula:

$$2k^2 + [1-3(t-a)]k - 2(t-a) = 0$$

Solve it:

$$k_a = \frac{-[1-3(t-a)] - \sqrt{[1-3(t-a)]^2+16(t-a)}}{4} \quad \text{(abandon)},$$
$$k_b = \frac{-[1-3(t-a)] + \sqrt{[1-3(t-a)]^2+16(t-a)}}{4}.$$

Because: $0 < k_b \le 1$, $0 < t-a \le 0.6$, that is, $(t-a) \in (0, 0.6]$.

Because when $k \in \left(0, \frac{[3(t-a)-1]+\sqrt{[1-3(t-a)]^2+16(t-a)}}{4}\right]$, $\frac{\partial(s_i-s_j)}{\partial v_0} \ge 0$; when $k \in \left(\frac{[3(t-a)-1]+\sqrt{[1-3(t-a)]^2+16(t-a)}}{4}, 1\right]$, $\frac{\partial(s_i-s_j)}{\partial v_0} \le 0$, the proposition is proved. □

When t is fixed, the increase of the network effect coefficient a will attract more audiences to browse the advertising position, and this makes the low product quality advertiser competing for the prominent advertising position profitable. When a is fixed, the increase of the mismatch cost t will block the audiences to browse the advertising position, and this makes the low product quality advertiser competing for the prominent advertising position unprofitable.

Proposition 3.3. *When the advertisers' expectation of the conversion rate is uniformly distributed in* $[0, 1]$, *and* t *is a constant, the increase of the network effect coefficient* a *will* *raise the probability that the product quality of the prominent advertising position is poorer than the disadvantaged advertising position. When a is fixed, the increase of the mismatch cost t will decrease the probability that the product quality of the prominent advertising position is poorer than the disadvantaged advertising position.*

Proof: For $k_b = \dfrac{-[1-3(t-a)] + \sqrt{[1-3(t-a)]^2 + 16(t-a)}}{4}$, when t is fixed, the increase of the network effect coefficient a will reduce k_b, assuming that k_b^1 and k_b^2 are respectively the value before its change and after its change, and $k_b^2 < k_b^1$. When a is fixed, the increase of the mismatch cost t will increase k_b, assuming that k_b^2 and k_b^1 are respectively the value before its change and after its change, and $k_b^2 < k_b^1$. See Figure 1.

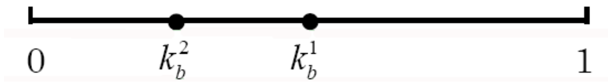

FIGURE 1. Conversion rate of different network effects and mismatch costs

Because the advertisers' expectation of the conversion rate is uniformly distributed in $[0, 1]$, when $k_b = k_b^2$, the probability that the high product quality advertiser wins the position is k_b^2; when $k_b = k_b^1$, the probability that the high product quality advertiser wins the position is k_b^1. □

4. **Numerical Example.** Suppose there are 4 advertising pages, and the parameters of each advertising page are shown in Table 1. Substitute the above parameters into the Formulae (7)-(9), and π_i, π_j and $s_i - s_j$ are also shown in Table 1.

TABLE 1. Parameter setting

Example	Settings				Results		
Parameter	k	t	a	v_0	π_i	π_j	$s_i - s_j$
Case1	0.18	0.95	0.85	0.05	0.00047	0.04560	0.0426
Case2	0.19	0.95	0.85	0.05	0.00299	0.04480	−0.0171
Case3	0.18	0.95	0.85	0.00	0.01750	0.01750	0.0000
Case4	0.19	0.95	0.85	0.00	0.02125	0.02125	0.0000

The results of the cases are analyzed as follows. First of all, it is easy to prove that when s_i and s_j deviate in Formula (9), the profit of the platform will reduce in each case, which proves Lemma 2.1. Second, when $v_0 = 0$, the qualities of the two advertising positions as well as profits are equal, which confirms Proposition 3.1. Third, when $k = 0.18$, the quality of the priority position is higher than the second position; when $k = 0.19$, the quality of the second position is higher than the priority position. This confirms Proposition 3.2. Fourth, when $t = 0.95$, $a = 0.85$, then $k_b = 0.1864$; if the conversion rate is evenly distributed, its probability to fall into the interval $[0.1864, 1]$ is greater than the probability to fall into the interval $[0, 0.1864]$, so the probability that the quality of the second position is higher than the priority position is higher, which confirmed Proposition 3.3.

5. **Conclusions.** Through the analysis of the model, this paper draws the following conclusions.

(1) When the two advertising positions are symmetric, the advertising platform's optimal strategy is to equal the product quality of the two advertising positions.
(2) Even when the two advertising positions are asymmetric, the product quality of the prominent advertising position is not necessarily better than the disadvantaged position.

(3) The existence of the network effect increases the probability that the product quality of the prominent advertising position is poorer than the disadvantaged advertising position, while the mismatch cost reduces that probability.

The prospects of the research are: this study assumes the audiences are advertising position single homing, advertising platform has sufficient control to the advertisers and the audiences and the control measures are exogenous and so on. Further research can consider relaxing these assumptions, for example optimizing the advertising platform revenue based on the audiences multi homing and endogenous management strategy.

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