Power of Bonus in Pricing for Crowdsourcing

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ABSTRACT
We consider a simple form of pricing for a crowdsourcing system, where pricing policy is published a priori, and workers then decide their task acceptance. Such a pricing form is widely adopted in practice for its simplicity, e.g., Amazon Mechanical Turk, although additional sophistication to pricing rule can enhance budget efficiency. With the goal of designing efficient and simple pricing rules, we study the impact of the following two design features in pricing policies: (i) personalization tailoring policy worker-by-worker and (ii) bonus payment to qualified task completion. In the Bayesian setting, where the only prior distribution of workers’ profiles is available, we first study the Price of Agnosticism (PoA) that quantifies the utility gap between personalized and common pricing policies. We show that PoA is bounded within a constant factor under some mild conditions, and the impact of bonus is essential in common pricing. These analytic results imply that complex personalized pricing can be replaced by simple common pricing once it is equipped with a proper bonus payment. To provide insights on efficient common pricing, we then study the efficient mechanisms of bonus payment for several profile distribution regimes which may exist in practice. We provide primitive experiments on Amazon Mechanical Turk, which support our analytical findings. The full paper is provided in [5].

CCS CONCEPTS
• Information systems → Incentive schemes; • Social and professional topics → Pricing and resource allocation; • Theory of computation → Computational pricing and auctions.

KEYWORDS
crowdsourcing; posted price mechanism; price discrimination; quality-based pricing

1 INTRODUCTION
In many microtask crowdsourcing systems, a simple and eidetic pricing mechanism without bidding process is widely adopted due to the volatility of the incoming workers and characteristic of the tasks to be solved. For example in Amazon Mechanical Turk (MTurk), a task requester publishes a pricing rule a priori, based on which each worker decides on the task acceptance. Such workers are finally admitted to the system, if the requester has budget to pay them for their work. The following ideas are natural as possible ways to increase the requester’s utility: (i) personalized pricing that offers different rule to determine price for each individual worker and (ii) giving additional bonus to workers for qualified task completion.

It is clear that personalized pricing is superior to the one with no personalization (which we call common pricing). However, personalized pricing is obviously more complex and even cannot be adopted in some systems such as Mturk. Hence, we analyze the exact benefit from personalization by comparing personalized pricing and common pricing. According to our analysis, common pricing achieves a good approximation to the optimal personalized pricing under some mild assumptions. This implies that common pricing is enough when it is equipped with an appropriate choice of bonus payment, so as to catch two rabbits of simplicity and efficiency simultaneously. We also reveal that the bonus payment is essential to do so as we can construct a worst-case instance which leads to arbitrarily bad performance of any common pricing without bonus payment. Finally, for some canonical scenario, we find the optimal structure of common pricing policies. Our results are also verified through real-world experiments conducted in Mturk.

2 MODEL
We consider a set \( N = \{1, 2, \ldots, n\} \) of workers, where \( n \) is the number of workers who are available for a target task requested by the requester. Each worker \( i \in N \) is associated with a private profile \((s_i, c_i) \in \mathbb{R}^2_{\geq 0}\); she produces the output of quality \( s_i \) at cost \( c_i \) if she decides to perform the task. We adopt a standard Bayesian setting [2]: the requester is aware of the prior distribution \( f(s_i, c_i) \) for each \( i \in N \). We denote \( x_i = 1 \) if worker \( i \) decides to work on the task and \( x_i = 0 \) otherwise. Let \( s := [s_i]_{i \in N} \) and \( c := [c_i]_{i \in N} \). Then, the task requester has utility \( u(s \circ x) \) for some function \( u : \mathbb{R}^n_{\geq 0} \mapsto \mathbb{R}_{\geq 0} \).
where $s \circ x = \{s_i x_i\}_{i \in \mathcal{N}}$, a function of the collection of the qualities of task-accepting workers.

We consider a variant of budget feasible posted pricing framework where a quality-based pricing policy is posted in advance of workers’ arrival. We denote by $p = \{p_i\}$ a pricing policy, where each worker $i \in \mathcal{N}$ is offered $p_i$ consisting of an increasing function $p_i : \mathbb{R}_{\geq 0} \mapsto \mathbb{R}_{\geq 0}$ so that if worker $i$ accepts $p_i$ and submits an output $s_i$, she will be paid $p_i(s_i)$. Then, the requestor’s objective is to find an optimal pricing policy $p$ that maximizes the expected utility for a given prior distribution $[f_i]$ of worker profile.

We assume that each worker is rational so that worker $i$ strategically maximize her quasi-linear payoff $p_i(s_i) - c_i$, i.e. they accept the offer if $p_i(s_i) \geq c_i$ and reject otherwise. We assume that workers arrive in a given but latent ordering model over all possible orderings of $\mathcal{N}$. Given a budget $B = \Theta(n)$, arrival model $\sigma$ and pricing policy $p$, task allocation vector $x$ is determined in the following manner, as in [1]: (1) Worker $i$ arrives with respect to ordering $\sigma$, (2) If the remaining budget is smaller than worker $i$’s maximal possible reward, then discard the worker, and (3) Else, offer her $p_i(s_i)$ and she accepts if her actual reward $r_i(s_i)$ is larger than or equal to her cost $c_i$, and get paid $p_i(s_i)$ and mechanism deducts it from the remaining budget, otherwise discard worker $i$.

Let $P(p, B, \sigma)$ be the (random) process generating a task allocation vector $x$ under pricing policy $p$ and budget constraint $B$, where we denote $x \sim P(p, B, \sigma)$. Under process $P(p, B, \sigma)$, after the entire budget is exhausted, any incoming worker is naturally discarded and has $s_i = 0$ even if she wants to participate in the task, i.e., $\phi_i(p_i) = 1$. Hence, any realization $x$ verifies the ex-post budget constraint [1], i.e., $\sum_{i \in \mathcal{N}} p_i(s_i) x_i \leq B$. The expected utility of the task requestor is defined as the following:

$$U(B, p) := \mathbb{E}_{x \sim P(p, B, \sigma)}[u(s \circ x)].$$

(1)

Our objective is to find a pricing policy that maximizes the expected utility, and we call this problem OPP($B$). Additionally, we assume that the utility function is additive, i.e. $u(s \circ x) = \sum_{i \in \mathcal{N}} s_i x_i$, and the workers possess reasonable private values so that the maximal value of the support of the random variable $s_i / c_i$ is constant, i.e. for every $i \in \mathcal{N}$, $P[s_i / c_i < C] = 1$ for some constant $C$.

3 RESULTS

To formally discuss, we define a notion of approximate solution given by a common pricing to OPP($B$):

**Definition 3.1.** Let $p^{*}(B)$ be an optimal personalized pricing of OPP($B$). For $0 \leq \delta \leq 1$, and $1 \leq \gamma$, a common pricing $p_c \in (\delta, \gamma)$-APX to OPP($B$) if $U(\gamma B, p_c) \geq \delta \times U(B, p^{*}(B)).$.

We first study Price-of-Agnosticism (PoA) that quantitatively compares personalized and common pricing policies, revealing how good a simple common pricing with bonus payment is, compared to the best personalized one. The following theorem states that PoA is bounded within a constant factor as the number of workers $n$ grows.

**Theorem 3.2 (Price-of-Agnosticism).** There exists a common pricing $p_c$ that is $(1 - O(e^{-n^{\Omega(\epsilon)}}), O(1))$-APX to OPP($B$).

To justify the necessity of bonus structure in common pricing, we present the following theorem which demonstrates that any common pricing without bonus payment is vulnerable to cherry picking of low quality workers.

**Theorem 3.3 (Power of Bonus).** There exists a worker profile distribution $[f_i]$ and worker arrival $\sigma$ such that no common pricing without bonus is $(\delta, o(n))$-APX to OPP($B$) for any $\delta \in (0, 1]$.

Now, consider tedious tasks such as filtering out the spam mails or correcting the typos on some elementary-level articles. In this case, the worker quality would be linearly proportional to her effort and time. We define such a case to be ratio-equivalent regime where $P[c_i = k s_i] = 1$ for every $i \in \mathcal{N}$ and for proportional constant $k \in \mathbb{R}_{\geq 2}$, and the following proposition shows the existence of optimal common pricing in this regime:

**Proposition 3.4.** There exists a common pricing that is asymptotically optimal under ratio-equivalent regime, i.e. achieves $(1, 1)$-APX to OPP($B$) asymptotically.

In next, SETI [4] crowdsources computation resource, where the only thing participant needs to do is just setting a specific screen saver on computer, and thus the effort to participate is almost identical across the entire workers while each worker’s contribution is different depending on the specification of computers. This motivates us to define cost-equivalent regime such that $P[c_i = c_0] = 1$ for every $i \in \mathcal{N}$ and for some $c_0 \in \mathbb{R}_+$. The following proposition claims that bonus is useless in this case.

**Proposition 3.5.** There exists a common pricing that is asymptotically optimal under cost-equivalent regime.

We highlight that the above two propositions are shown in constructive manner, i.e. one can find the corresponding closed-form expression of the optimal common pricing.

Finally, we define quality-equivalent regime such that $P[s_i = s_0] = 1$ for every $i \in \mathcal{N}$ and for some $s_0 \in \mathbb{R}_{\geq 2}$. As an example corresponding to this regime, one can consider survey asking non-trivial question, e.g., Moral Machine [3] collecting people’s decision on a moral dilemma, where each individual’s contribution is counted as just a single answer regardless of the depth of thinking. The following proposition claims that bonus is useless in this case.

**Proposition 3.6.** Under quality-equivalent regime, for any common pricing $p(s_i)$, there exists a common pricing without bonus $(p'(s_i))$ such that $p'(s_i) = v$ for all $v \in \mathbb{R}_{\geq 2}$ and $U(B, p) = U(B, p')$.

To sum up, we analytically studied the impact of personalization and bonus payment in quality-based posted pricing. We also verify our results and provide further insights through extensive real-world experiments conducted in Mturk, please see [5] for the experimental results as well as the detailed explanation on the theoretical results. We believe that our findings shed light upon the understanding of efficient pricing with respect to various types of crowdsourcing tasks.

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