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ABSTRACT

We study contracting between a public good provider and users with private valuations of the good. We show that, once the provider extracts the users' private information, she benefits from manipulating the collective information received from all users when communicating with them. We derive conditions under which such manipulation determines the direction of distortions in public good provision. If the provider is non-manipulative, the public good is always underprovided, whereas overprovision occurs with a manipulative provider. With overprovision, not only high-valuation users, but also low-valuation users may obtain positive rents—users may prefer facing a manipulative provider.

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1 Introduction

Since Samuelson's pioneering work (1954), analyzing distortions in the provision of public goods has become a classical topic in economics (e.g. Laffont 1988). The conventional understanding is that the users' incentives result in an "underprovision"—the direction of distortion in the public good provision is downward. For instance, Comes and Sandler (1996) note that "the tendency for public goods to be provided at suboptimal levels is a celebrated result in public economics." Casual observations, however, indicate that, in real life, there are cases where some public goods and services are often "overprovided"—the direction of distortion in the public good provision is upward, instead of downward.

As an example, consider the class-action lawsuits in which a group of victims consolidate their claims into a single lawsuit. A criticism against such collective litigation procedures is that they often lead to an excessive amount of litigation. As pointed out by legal studies, such as Mullenix (2014), in many cases relentlessly pursued by class-action attorneys, some class members do not care much about the outcome of their cases. The studies also report that excessive amount of litigation is often linked to small compensations for class members and large fees for class attorneys.[1] This, in fact, is one of the central reasons that eventually led the United States Congress to pass the Class Action Fairness Act of 2005, removing the class-action lawsuits from the jurisdiction of state courts which are deemed to be over-friendly to attorneys representing plaintiffs.

Industrial lobbying is another instance for over-provision. As pointed out by studies in political science, the amount of lobbying can significantly exceed what would be efficient for the industry.[2] Industrial lobbying expenditure in the United States has reached nearly \$3 billion,[3] and lobbyists are known for inflating the size of their services. For example, Collander (2013) reports that almost all lobbyists representing the companies in the defence industry are devoted to inflate scales of military procurement and acquisition. As pointed out by Hansen (2012), oversized lobbying activities often lead to inefficient use of public resources, such as constructing of a "bridge to nowhere."

The services in the examples above are non-rivalrous. That is, a single service by the provider (a lawyer or a lobbyist) benefits multiple users (clients) who are in the same group—each user may value the service differently, but they do not compete for it. These

[1] See Ulen (2011) and Redish (2014) for example.

[2] See Ainsworth (1993) for examples of trade association lobbying efforts which do not necessarily reflect the demand from their general membership.

[3] See Drutman (2015).

services are, therefore, public goods. Then, from an economic perspective, these excessive public good provisions are rather puzzling, because according to the standard theory in the literature, public goods are expected to be underprovided.

The objective of this paper is to identify a new economic mechanism that results in overprovision of a public good rather than underprovision. We study this mechanism in an agency framework of public good provision with private information. In our model, a provider (the principal) produces a public good for the consumption of multiple users (agents) in exchange for monetary payments from them. Each user's valuation for the public good is his private information, and after all users report their valuations to the provider, she produces the good according to the collective valuation reported by the users.

As in the standard model of screening, a user with a high valuation for the good receives an information rent not to misrepresent his true valuation. In order to reduce this information rent, the provider's second-best contract distorts the size of the public good downward. Except for the case where every user claims that his valuation of the public good is high, the provider lowers provision of the public good from the efficient level in the optimal contract. This is in line with the literature's traditional result in public good provision—the public good is underprovided in equilibrium.

This result, however, is under the assumption that, while the users of the public good are opportunistic, the provider is not. Such an assumption seems to be naive. While each user has private information about his valuation of the public good, at the point of producing the public good, the provider is the only party that has information about all users' *collective valuation* of the good. If possible (and profitable), the public good provider may seize the opportunity to misrepresent the collective information sent by the users, by falsifying the information received from one user when communicating with another user.

In practice, providers of public goods do not all have access to equally effective manipulation opportunities. For some public goods or services provided directly by government organizations, for example, information manipulation may not be easy. With all bureaucratic procedures and "red tapes," such organizations operate in rigid environments, and may not be able to easily manipulate information they collect. On the other hand, operating environments for the public good providers we mentioned earlier may not be as rigid, and thus it may not be as hard for them to engage in manipulation. In the case of class-action lawsuits, attorneys do not make individual class member's information public due to "attorney-client privilege," which may enable them to manipulate collective information. For business lobbying, the lobbyist-client relationship is similar to the attorney-client relationship,[4] and manipulating activities by lobbyists are not entirely unknown. Hansen (2012) reports that lobbyists act mainly based on their "rent-seeking" incentives, noting that they have a large stake in manipulating "lobbying-related information."

We take the public good provider's incentive to manipulate the collective information into account in our model. We identify that, when the provider announces the collective valuations to the users, she has an incentive to exaggerate it—in particular, the provider has an incentive to make a user with a low value for the public good think that the other users' valuations are high. The public good provider's incentive to manipulate information is anticipated by the users when contracting with her. Such an anticipation provides a high-valuation user with a stronger incentive to misrepresent his own valuation. In other words, there is a tension between a user's incentive to misrepresent his private information and the provider's incentive to misrepresent her collective information. To ease this tension, the public good provider must convince the users that she would not manipulate the collective information reported by them.

One way to convince the users that the public good provider will not falsify their reports is designing a *bunching* contract that pools different collective information at the same level of the public good. The provider will not have a reason to manipulate if the public good and the payment levels do not change with her manipulation. More interestingly, the provider can also eliminate her incentive to manipulate by inflating the provision of the public good and leaving a positive rent to users with low valuations. Our result shows that, depending on the likelihood of different user valuations, it is optimal for the provider to implement bunching or overprovision to convince the users that she will not manipulate.

Manipulability of information may have unexpected winners and losers. The provider must convince the users that she will not falsify the reported collective information, and this consideration imposes an additional constraint on the provider's design problem on top of the standard incentive conditions. Modifying the second-best contract to satisfy this new constraint entails a lower payoff for the provider. An examination of how the provider modifies the second-best contract also reveals the effects of the manipulation opportunities on the users' payoffs. Larger public good sizes lead to larger information rents for high-valuation users. In addition, even low-valuation users may end up with positive rent under the optimal manipulation-proof contract. In other words, while the public good provider is worse off for having the opportunity to manipulate the information reported by the users, the users themselves may benefit from the provider's ability to manipulate.

[4] See Armstrong and Mathews (2008).

The rest of the paper is organized as follows. The next section discusses the related studies. Section 3 presents the model. Section 4 outlines the optimal contract without the provider's manipulation opportunities (the second-best contract), and shows that the public good is underprovided in this case. Section 5 demonstrates that the second-best contract may be prone to the provider's manipulation and characterizes the optimal manipulation-proof contract. Section 6 discusses the welfare effects of the provider's manipulation opportunities. Section 7 concludes with some remarks. Proofs are in Appendix.

2 Related Literature

It is a classical result that public goods are underprovided. Under symmetric information and voluntary contributions, this underprovision result obtains when comparing the non-cooperative equilibrium outcome to the cooperative one (e.g. Bergstrom et al. 1986).[5] Under asymmetric information and voluntary participation, the underprovision arises from a trade-off between efficiency and information rents (e.g. Mailath and Postlewaite 1990)[6]

Consequently, the literature views overprovision as an 'anomaly'. The theoretical literature has studied this anomaly mainly under symmetric information. This paper's contribution is to provide a rationale for overprovision that is due to 'endogenous private information'—information manipulation by a public good provider.[7]

Focusing on the preferences of economic agents, Buchanan and Kafoglis (1963), Diamond and Mirrlees (1973) and Sadka (1977) discuss necessary conditions on those preferences for an overprovision to arise. There are studies considering strategic tax policies, demonstrating that overprovision may arise when there is tax exporting (e.g. Gerking and Mutti 1981), when public goods are inputs in production (e.g. Dhillon et al. 2007), or when policy makers have Leviathan tendencies (e.g., Mintz and Tulkens, 1996). All explanations in these studies abstract from private information.

[5] Cheikbossian and Sand-Zantman (2011) show that the underprovision result even persists with repeated interactions that involve imperfect monitoring, while Teoh (1997) shows that information disclosure worsens the free-riding problem that underlies the underprovision.

[6] With forced, involuntary participation, Clarke (1971), and Groves (1973) demonstrate that the efficient level of the public good can be implemented in dominant strategies. Green and Laffont (1977) also study efficiency in public good provisions by characterizing incentive compatible mechanisms in dominant strategies. Under Bayesian incentive compatibility conditions, d'Aspremont and Gerard-Varet (1979) show that, with forced participation, such an outcome can even be achieved with budget-balanced transfers.

[7] Bierbrauer and Winkelmann (2019) study public good overprovision from a mechanism design perspective. They do not, however, consider the public good provider's endogenous private information.

Our modeling of manipulation is similar to Dequiedt and Martimort (2015) and Akbarpour and Li (2020). These papers focus on manipulation in environments with private goods.[8] Considering a principal who can falsify received information in a multi-agent framework with correlated private information, Dequiedt and Martimort (2016) point out that full rent extraction through yardstick competition is no longer possible.[9] As a result, simple sell-out contracts are optimal in a vertical framework of an upstream manufacturer dealing with a retailing network under a wide range of settings.

Akbarpour and Li (2020) study manipulation-proof auction design. They demonstrate that the sealed-bid second-price auction is susceptible to undetectable manipulation, because the auctioneer can overstate the second-highest bid to increase the payment from the winner. In contrast, no such manipulating incentive arises for the first-price auction. They, moreover, develop a general formalization of undetectable manipulation by a mechanism designer, which also provides a micro foundation of the manipulation-proofness constraints that we apply in our framework of public goods. The manipulation opportunities in a public good setting are, however, more limited than under private consumption, because the provided level of a public good is naturally observed and consumed by all users in the group. As we show, this limited form of manipulability has nevertheless an adverse effect on the principal's abilities to extract rents. They are economically significant in that, depending on parameter constellations, they lead to an overprovision of public goods.

Our paper is also related to the studies on informed principal problem following the agent's hidden action. In Demski and Sappington (1993), the agent exerts a costly effort, but the result of the effort is observed only by the principal, who may have an incentive to misrepresent the result. They show that the principal may have to reward the agent for unfavorable result. In a multi-agent setting, Sridhar and Balachandran (1997) show that if result of the internal agent's effort is not observed by the external agent, it can be a source of distortion when the principal contracts with the external agent. In these papers, the principal's manipulation incentive is associated with the agent's hidden action, whereas in ours, the principal's incentive stems from the agents' private information.[10]

[8] See also a paper by Dequiedt and Martimort (2006) which constructs a non-manipulable mechanism for a benevolent public good provider.

[9] Crémer and McLean (1985, 1988) show that, when the agents' types are correlated, a non-manipulative principal could fully extract the agents' information rents by conditioning her transaction with one agent to the information transmitted by another agent.

[10] Lacker and Weinberg (1989) study a case where a costly hidden action can privatize public information. See also Strausz (2006) and Shin (2017) for studies incorporating the principal's incentive in agency problems.

3 Public Good Provision Model

We present a model of public good provision with a provider (the principal) and two users (the agents). The provider's cost of producing size $q \geq 0$ of the public good is given by $c(q)$, where $c(\cdot)$ is a continuously differentiable, strictly increasing, and strictly convex function.[11] We assume that $c(\cdot)$ satisfies the Inada conditions: $c(0) = 0$, $\lim_{q\to 0} c'(q) = 0$, and $\lim_{q\to\infty} c'(q) = \infty$. User $k \in \{1, 2\}$ values q units of the public good by $\theta^k q$. The size of the public good q is verifiable and contractible, whereas each user's valuation parameter θ^k is his private information (his type). The types are independently and identically distributed. Specifically, a user has the high valuation θ_h for the public good with probability $\varphi \in (0, 1)$, and the low valuation $\theta_l > 0$ with probability $1 - \varphi$, where $\Delta\theta \equiv \theta_h - \theta_l > 0$.

In line with the examples in the introduction, we consider the public good provider as a profit maximizer.[12] Accordingly, the provider's and user k's payoffs are respectively

$$\sum_{k=1}^{2} p^k - c(q) \quad \text{and} \quad \theta^k q - p^k,$$

where p^k is the payment from user k to the public good provider.

The collective value of the public good depends on the realized types of the two users. We are either in the *high-value* state (H) where both users have a high valuation for the public good, or in the *low-value* state (L) where both users have a low valuation, or in the *intermediate-value* state (M) where the two users have different valuations. For each of these collective-valuation states, we can find the first-best sizes of the public good that maximizes the sum of the provider's and the users' payoffs. The first-best public good sizes satisfy the *Samuelson condition*—the marginal cost of producing this first-best level is equal to the sum of the marginal values:

$$c'(q_H^*) = 2\theta_h, \quad c'(q_M^*) = \theta_h + \theta_l, \quad c'(q_L^*) = 2\theta_l.$$

If the public good provider could directly observe the users' valuations, she would choose to produce these first-best quantities to maximize the benefits of the public good net of its production costs. However, because these valuations are private information for the users, the provider has to give them the incentive to reveal their valuations truthfully. For this purpose, the provider offers a contract $\mathcal{C}$ that conditions the size of the public good and the

[11] Our public good provision model is similar to the one in Laffont and Martimort (2000).

[12] Our qualitative results remain unchanged if the provider is modeled as a welfare-maximizing government raising distortionary taxes to finance the good's production (as in Laffont and Tirole, 1993).

payments from the users on their reports about valuations. In what follows, we denote by $p_{i\gamma}$ the payment charged to a user of type $i \in \{h, l\}$, when all users' reports indicate the collective value as $\gamma \in \{H, M, L\}$. Similarly, q_γ is the public good size when the collective value is indicated as $\gamma \in \{H, M, L\}$ by the users' reports. Hence, a contract $\mathcal{C}$ is a collection of payments and public good sizes as below:

$$\mathcal{C} \equiv \{(p_{hH}, q_H),\ (p_{lM}, q_M),\ (p_{hM}, q_M),\ (p_{lL}, q_L)\}.$$

Notice that the users are treated symmetrically: $p^k_{i\gamma} = p^{-k}_{i\gamma}$ and $q_\gamma(\theta^k_i, \theta^{-k}_j) = q_\gamma(\theta^k_j, \theta^{-k}_i)$, where $k, -k \in \{1, 2\}$, $i, j \in \{h, l\}$ and $\gamma \in \{H, M, L\}$. We postulate that the public good provider's offer is constrained by "fairness" restrictions. In practice, there are agencies, such as the Federal Trade Commission (FTC), that monitor firms to prevent them from engaging in unfair business practices toward consumers. It is also well-documented in experimental studies that players in the same positions care about being treated symmetrically.[13]

Finally, we assume that each user has an option to *opt out*, after learning the level of the public good and the required payment to the provider. If a user chooses to opt out, then the game ends without any public good provision and payments, so that all parties receive their reservation payoffs of zero. We discuss the importance of the symmetric treatment and opportunity to opt out assumptions in our conclusion.

The timing of the interaction is summarized as follows:

1. The public good provider offers contract $\mathcal{C}$ to the users.

2. Each user reports his valuation $i \in \{h, l\}$ to the provider.

3. The provider reports the collective valuation $\gamma \in \{H, M, L\}$ to the users.

4. Payments are made and the public good is provided, if the users do not opt out.

In the next section, we analyze a non-manipulative public good provider, who would choose the public good and payment levels that would truthfully reflect the reported types of the users in stage 3. This benchmark case leads to the standard result that the public good is underprovided and the high-valuation users get information rents. In the subsequent section, we show that such an underprovision invites the provider's manipulation incentive in stage 3.[14] We then will show that the optimal manipulation-proof contract may exhibit overprovision of the public good and leave a positive rent even for a low-valuation user.

[13] See, for example, Nalbantian and Schotter (1997). Laffont and Martimort (1998) adopt a similar restriction justified by limited communication.

[14] We assume that that it is too costly for the users to directly communicate with each other.

4 Non-Manipulative Public Good Provider

We discuss the benchmark—the public good sizes in the optimal contract when the provider cannot manipulate information reported from the users. Here, the provider's constraints in contracting for the public good provision are the users' participation and truthful reports on their valuation of the public good.

The public good provider's expected payoff can be written as the expected payments that she will receive from the users net of the cost of producing the public good:

$$\begin{aligned}
&\varphi^2 \left[2p_{hH} - c\left(q_H\right)\right] + \varphi\left(1-\varphi\right)\left[p_{hM} + p_{lM} - c\left(q_M\right)\right] \\
&+ \left(1-\varphi\right)\varphi\left[p_{lM} + p_{hM} - c\left(q_M\right)\right] + \left(1-\varphi\right)^2\left[2p_{lL} - c\left(q_L\right)\right]
\end{aligned} \tag{$\mathcal{P}$}$$

$$= \underbrace{\left\{\varphi^2 2p_{hH} + 2\varphi\left(1-\varphi\right)p_{hM} + 2\varphi\left(1-\varphi\right)p_{lM} + \left(1-\varphi\right)^2 2p_{lL}\right\}}_{\text{expected payment from the users}}$$
$$- \underbrace{\left\{\varphi^2 c\left(q_H\right) + 2\varphi\left(1-\varphi\right)c\left(q_M\right) + \left(1-\varphi\right)^2 c\left(q_L\right)\right\}}_{\text{expected cost of production}}$$

As mentioned above, the non-manipulative provider chooses the contract that maximizes her expected payoff subject to two sets of constraints for the users. The source of the first set of constraints is the voluntary participation of the users. The following pairs of *participation constraints* ensure that high and low-valuation users would not opt out of the contract after learning the intended public good and the payment levels:

$$\theta_h q_H - p_{hH} \geq 0, \tag{PC_{hH}}$$
$$\theta_h q_M - p_{hM} \geq 0, \tag{PC_{hM}}$$

for a high-valuation user and

$$\theta_l q_M - p_{lM} \geq 0, \tag{PC_{lM}}$$
$$\theta_l q_L - p_{lL} \geq 0, \tag{PC_{lL}}$$

for a low-valuation user. In addition, to induce the users to reveal their true valuations, the following Bayesian incentive compatibility conditions must be satisfied:

$$\begin{aligned}
&\varphi\left(\theta_h q_H - p_{hH}\right) + \left(1-\varphi\right)\left(\theta_h q_M - p_{hM}\right) \\
\geq\ &\varphi\left(\theta_h q_M - p_{lM}\right) + \left(1-\varphi\right)\left(\theta_h q_L - p_{lL}\right),
\end{aligned} \tag{IC_h}$$

for a high-valuation user and

$$\begin{aligned} & \varphi\left(\theta_l q_M - p_{lM}\right) + (1-\varphi)\left(\theta_l q_L - p_{lL}\right) \qquad (IC_l) \\ \geq \; & \varphi \max\left\{\theta_l q_H - p_{hH}, 0\right\} + (1-\varphi)\max\left\{\theta_l q_M - p_{hM}, 0\right\}, \end{aligned}$$

for a low-valuation user. The 'max' operators on the right hand side (RHS) of IC_l reflect the possibility that a low-valuation user may misrepresent his type as type θ_h, and opt out after being informed of the other user's type (thus after learning the realized size of the public good and the payment level in the contract).[15] As shown by Matthews and Postlewaite (1989) and Forges (1999), quitting rights of the users require such strengthening of the incentive compatibility constraints. Notice that we do not need these 'max' operators on the RHS of IC_h, because PC_{lM} and PC_{lL} imply that opting out would be suboptimal for a high-valuation user after misrepresenting his type as θ_l.

When the public good provider cannot manipulate information from the users, she offers the second-best contract that maximizes her expected payoff ($\mathcal{P}$) subject to the participation and incentive compatibility constraints presented above. We characterize the optimal outcome in the following proposition.

Proposition 1 *The optimal contract $\mathcal{C}^n$ offered by the non-manipulative provider entails the public good levels identified by the following first-order conditions:*

$$\begin{aligned} c'(q_H^n) &= 2\theta_h, \\ c'(q_M^n) &= \max\left\{\theta_h + \theta_l - \frac{\varphi}{1-\varphi}\Delta\theta,\ 0\right\}, \\ c'(q_L^n) &= \max\left\{2\theta_l - 2\frac{\varphi}{1-\varphi}\Delta\theta,\ 0\right\}. \end{aligned}$$

A high-valuation user's expected rent is strictly positive unless $q_M^n = q_L^n = 0$, and a low-valuation user gets zero rent.

Proof. See Appendix A. ■

If both users have high valuations, the optimal size of the public good coincides with the efficient one—conforming to the well-known "no distortion at the top" result of standard screening models. Incentive compatibility is the source of the information rent for the

[15] Alternatively, we can impose a limited liability constraint that a contract-abiding user is assured a positive ex post payoff. In that case, the RHS of (IC_l) is replaced with $\varphi(\theta_l q_H - p_{hH}) + (1-\varphi)\left(\theta_l q_M - p_{hM}\right)$, and our results will not change.

high-valuation user. As in the standard screening model, a user with high-valuation can command information rent by misrepresenting his type as the low-valuation. To prevent this user from misrepresenting his type, the provider must leave an information rent to him. The provider's optimal contract reduces the magnitude of this information rent by distorting the size of the public good downward whenever at least one of the users report a low type, i.e. whenever the collective valuation is low or intermediate. This underprovision of public good can take an extreme form of a *shut down* ($q_L^n = q_M^n = 0$), and a high-valuation user obtains no information rent. This indeed is the case when the likelihood that users are high-valuation type is sufficiently large. When that likelihood is not large enough, the public good levels are strictly positive, although they are distorted downwards.

The binding constraints in the non-manipulative provider's problem are the participation constraints of the low-valuation user, (PC_{lM}) and (PC_{lL}), and the incentive compatibility constraint of the high-valuation user, (IC_h)—see the proof of Proposition 1. The payments from the users are obtained from these binding constraints:

$$p_{lM} = \theta_l q_M, \quad p_{lL} = \theta_l q_L \quad \text{and}$$

$$\varphi p_{hH} + (1-\varphi)\, p_{hM} = \varphi[\theta_h q_H - \Delta\theta q_M] + (1-\varphi)[\theta_h q_M - \Delta\theta q_L].$$

Notice that, in the second-best contract $\mathcal{C}^n$, a high-valuation user's *ex post* payments to the provider, p_{hH} and p_{hM}, have some degree of freedom. We point out this flexibility in allocation of the payment here, because it will be exploited in the next section, where manipulation by the public good provider is an issue.

Our discussion here on the public good size is summarized in the following corollary.

Corollary 1 *If the public good provider is non-manipulative, then the optimal contract entails only under-provision of the public good.*

5 Manipulative Public Good Provider

In the previous section, we derived the public good provider's optimal contract to the users under the assumption that she cannot manipulate the information revealed by the users. We now argue that this assumption is not innocuous—after learning that both users have low valuation, the provider may have an incentive to misrepresent this information in a way that is undetectable by the users.[16]

[16] Using the words in Akbarpour and Li (2020), the second-best contract is "not credible" in our model when the public good provider is manipulative.

Although the users cannot communicate with each other, they can detect certain forms of manipulation by the provider. It is clear that when $\gamma = H$, misrepresenting it as $\gamma = L$ will be detected by all users. Likewise, misrepresenting $\gamma = L$ as $\gamma = H$ will be detected. Also, when $\gamma = M$, the provider cannot misrepresent it as $\gamma = H$ or L. If $\gamma = M$ is misrepresented as $\gamma = H$, then the low-valuation user will detect the provider's false claim. Likewise, the provider cannot misrepresent $\gamma = M$ as $\gamma = L$, because her manipulation then will be detected by the high-valuation user.

In our model, the provider is able to misrepresent the collective valuation as $\gamma = M$ when $\gamma = H$ or L. Neither user will be able to detect the provider's manipulation in such a case. As will be shown below, when $\gamma = H$, the provider has no incentive to misrepresent it as $\gamma = M$. When $\gamma = L$, however, the provider's incentive to misrepresent it as $\gamma = M$ arises. That is, while there are two cases in which the provider is able to manipulate information, it is when the collective valuation is low that her incentive is an issue. The public good provider has an incentive to 'exaggerate' the collective valuation in order to increase the size of the good, while having no incentive to decrease it.[17]

To see the provider's incentive to manipulate, suppose that each user sends a message to the contract indicating that he has a low valuation for the public good. If the provider behaves truthfully and reports the collective valuation as low, the contract would commit her to producing public good level q_L in exchange for receiving payment p_{lL} from each of the users. The provider, however, would have another option if she is able to manipulate the information that she collects from one user when communicating with the other one. If she pretends to each user that the other user had reported to have a high valuation, she would instead commit to producing q_M and would receive p_{lM} from each of the users. For this manipulation not to be profitable, the provider's contract should satisfy the following *incentive compatibility constraint for the provider*:

$$2p_{lL} - c(q_L) \geq 2p_{lM} - c(q_M). \qquad (PIC_L)$$

As shown above, in the second-best contract $\mathcal{C}^n$, the payments p_{lL} and p_{lM} are determined by binding (PC_{lL}) and (PC_{lM}), and $p^n_{lL} = \theta_l q^n_L$ and $p^n_{lM} = \theta_l q^n_M$. Accordingly, when both users' valuations are low $(\gamma = L)$, the public good provider's payoff in $\mathcal{C}^n$ is $2\theta_l q^n - c(q^n)$, where $q^n \in \{q^n_L, q^n_M\}$ depending on whether or not she misrepresents the collective valuation of the public good. If the provider chooses to truthfully announce the collective valuation of the users, then her payoff is:

$$2\theta_l q^n_L - c(q^n_L).$$

[17] This is in line with the examples mentioned in the introduction.

If, however, the provider misrepresents the collective valuation as $\gamma = M$, then her payoff is:

$$2\theta_l q_M^n - c\left(q_M^n\right).$$

Notice that $2\theta_l q - c(q)$ is concave in q and it is maximized at the first-best level of the pubic good q_L^*. In the second best contract $\mathcal{C}^n$, q_L^n is set smaller than q_L^*. Notice, however, from Proposition 1 that, when the high and low valuations are equally likely ($\varphi = 1/2$), the second best level of q_M coincides with q_L^*, and thus:

$$2\theta_l q_M^n - c\left(q_M^n\right) = 2\theta_l q_L^* - c\left(q_L^*\right) > 2\theta_l q_L^n - c\left(q_L^n\right).$$

It follows from the continuity of the second-best contract that, as long as φ is sufficiently close to 1/2, the provider would prefer misrepresenting $\gamma = L$ as $\gamma = M$ under the second-best mechanism. We formalize this discussion with the following lemma.

Lemma 1 *The second-best contract $\mathcal{C}^n$ violates (PIC_L) if and only if $\varphi \in (\underline{\varphi}, \overline{\varphi})$, where $\overline{\varphi} \equiv (\theta_l + \theta_h)/(2\theta_h) > 1/2$ and $\underline{\varphi} \in (0, 1/2)$.*

Proof. See Appendix B. ■

Again, the second best contract $\mathcal{C}^n$ is prone to the public good provider's misrepresentation of the users' collective valuation—when both users report that their valuations are low to the provider, the provider has an incentive to claim to each user that the other user's valuation is high. According to Lemma 1, such an incentive of the provider is an issue for intermediate values of the likelihood that a user's valuation is high: $\varphi \in (\underline{\varphi}, \overline{\varphi})$. Within this interval, the public good level q_M is close enough to q_L^* and thus the provider has an incentive to misrepresent $\gamma = L$ as $\gamma = M$ after she receives each user's information.

More intuitively, for extreme values of φ the provider has no incentive to manipulate the collective valuation in $\mathcal{C}^n$. When $\varphi \leq \underline{\varphi}$, it is unlikely that the collective value is high ($\gamma = H$), and thus distortion in q_L to reduce a high-valuation users' information rent in $\mathcal{C}^n$ is small—as a result, the provider's manipulation incentive to misrepresent $\gamma = L$ as $\gamma = M$ does not arise in $\mathcal{C}^n$. Likewise, when $\varphi \geq \overline{\varphi}$, it is likely that the collective value is high. Therefore, to reduce the high-valuation users' rents, not only q_L, but also q_M is distorted significantly downward in $\mathcal{C}^n$—as a result, the provider has no incentive to misrepresent $\gamma = L$ as $\gamma = M$ in $\mathcal{C}^n$. When $\varphi \in (\underline{\varphi}, \overline{\varphi})$, the provider's incentive to manipulate arises because q_L is distorted relatively more severely than q_M.

Figure 1 below illustrates the range of q_M within which the manipulation incentive of the public good provider arises.

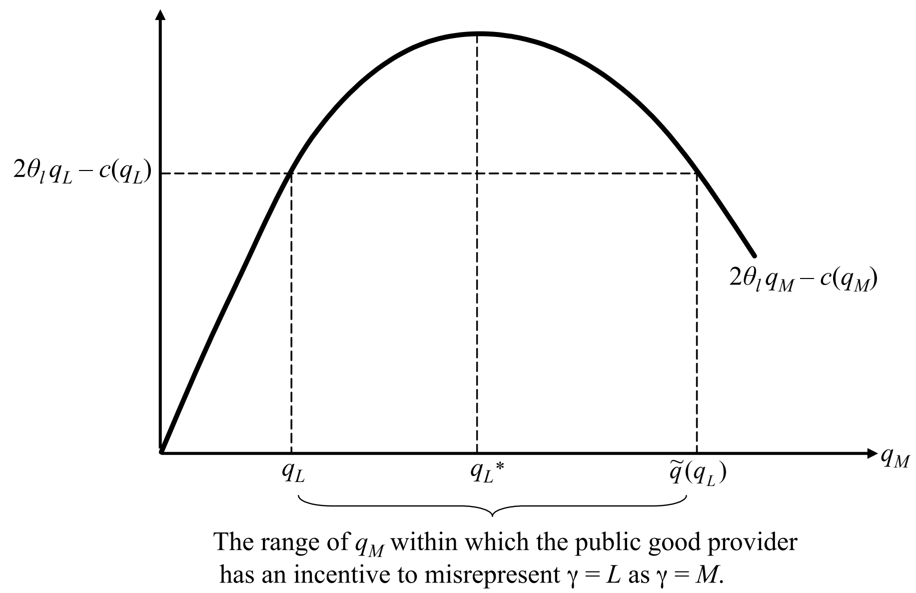

Fig 1. The public good sizes and the provider's incentive.

It is noteworthy what would go wrong for the second-best contract $\mathcal{C}^n$ when (PIC_L) constraint is violated and the public good provider indeed manipulates the information that she receives from the low-valuation users. In that case, a user would end up with a higher level of the public good (q_M^n instead of q_L^n) and make a higher payment ($p_{lM} = \theta_l q_M^n$ instead of $p_{lL} = \theta_l q_L^n$) to the provider. Notice that a low-valuation user would be indifferent to this manipulation, because the binding participation constraints guarantee that he receives no rent whether the provider manipulates or not. Thus, the provider's misrepresentation is Pareto-improving *ex post*. The provider's manipulation incentive, however, is anticipated by the users, and as a result, $\mathcal{C}^n$ becomes no longer incentive compatible for a high-valuation user. To see this, consider the following binding (IC_h) in $\mathcal{C}^n$:

$$\varphi\left(\theta_h q_H^n - p_{hH}^n\right) + (1-\varphi)\left(\theta_h q_M^n - p_{hM}^n\right) = \varphi\left(\theta_h q_M^n - p_{lM}^n\right) + (1-\varphi)\left(\theta_h q_L^n - p_{lL}^n\right).$$

With the provider's misrepresentation, however, the RHS of the above equation becomes $\theta_h q_M^n - p_{lM}^n$, and after substituting for the payments we have:

$$\underbrace{\varphi\left(\theta_h q_H^n - p_{hH}^n\right) + (1-\varphi)\left(\theta_h q_M^n - p_{hM}^n\right)}_{=\varphi\Delta\theta q_M^n + (1-\varphi)\Delta\theta q_L^n} < \underbrace{\theta_h q_M^n - p_{lM}^n}_{=\Delta\theta q_M^n}.$$

The strict inequality above implies that (IC_h) will be violated—the real cost of the provider's manipulation is due to the violation of the incentive compatibility for a high-valuation user. Hence a high-valuation user, anticipating the provider's misrepresentation of the collective value, will require a larger information rent to reveal his private information truthfully.

In addition to the manipulation opportunity that we identified above for the low-value state, there is one more undetectable way for the provider to manipulate information. When both users report that they have high valuations, the provider can claim to each user that the other user reported his valuation as low. To ensure that the provider will not pursue this manipulation, the following incentive compatibility constraint should be satisfied in addition to (PIC_L):

$$2p_{hH} - c\left(q_H\right) \geq 2p_{hM} - c\left(q_M\right). \tag{PIC_H}$$

It is easier to curtail the provider's manipulation incentive in the high-value state in comparison to her manipulation incentives in the low-value state. In other words, (PIC_H) is a less demanding constraint than (PIC_L). As mentioned in the previous section, when the incentive compatibility constraint (IC_h) pins down the expected payment $\varphi p_{hH} + (1-\varphi)\, p_{hM}$ from a high-valuation user, it still leaves some degree of freedom in determining individual payment levels of p_{hH} and p_{hM}. In Lemma 2 below, we show that the manipulative provider's contract can make use of this freedom to satisfy (PIC_H) without violating the users' incentive compatibility or participation constraints, for the relevant levels of the public good.

Lemma 2 *Consider public good levels such that $q_L \leq q_M \leq q_H \leq q_H^*$, payments p_{lL} and p_{lM} satisfying (PC_{lL}) and (PC_{lM}), and $\varphi p_{hH} + (1-\varphi)\, p_{hM}$ given by binding (IC_h). There exist p_{hH} and p_{hM} that satisfy (PC_{hH}), (PC_{hM}), (IC_l) and (PIC_H).*

Proof. See Appendix C. ■

According to Lemma 2, the public good provider's manipulation incentive is toward one direction—while having an incentive to exaggerate the collective valuation, she has no incentive to understate it. Again, inducing high-valuation users' truthful reports requires downward distortions in the public good sizes for low-valuation users, which in turn give the provider the incentive to exaggerate the collective valuation of the users. Although the provider is able to misrepresent $\gamma = H$ as $\gamma = M$, she has no incentive to do so in $\mathcal{C}^n$.

In light of the previous two lemmas, we can conclude that the optimal manipulation-proof contract is the second-best one, $\mathcal{C}^n$, if the value of φ is small or large ($\varphi \leq \underline{\varphi}$ or

$\varphi \geq \overline{\varphi}$). The remaining task is identifying the optimal contract for an intermediate range of φ, where the public good provider's manipulation incentive is an issue. This contract should maximize the provider's expected payoff in $(\mathcal{P})$ subject to the provider's incentive compatibility constraints, as well as the users' participation constraints and the users' incentive compatibility constraints.

Since the second-best contract $\mathcal{C}^n$ violates (PIC_L) for $\varphi \in (\underline{\varphi}, \overline{\varphi})$, within this range of φ, perhaps the most natural contract that would eliminate the provider's incentive to manipulate is a *bunching* contract that does not distinguish between the case where both users report low valuation for the public good and the case where only one of them reports low valuation, i.e., $q_L = q_M$. In this way, a low-valuation user and the provider end up with the same public good and payment levels for both $\gamma = L$ and $\gamma = M$—with this bunching, there is no reason for the provider to misrepresent $\gamma = L$ as $\gamma = M$. With our next proposition, we show that this is indeed the optimal contract for the provider when a user is more likely to be the high-valuation type.

Proposition 2 *For $\varphi \in (1/2, \overline{\varphi})$, the optimal contract $\mathcal{C}^m$ offered by the manipulative provider entails a bunching outcome with under-provision of the public good:*

$$\begin{aligned} c'(q_H^m) &= 2\theta_h, \\ c'(q_M^m) &= c'(q_L^m) = \max\left\{2\theta_l - 2\frac{\varphi^2}{1-\varphi^2}\Delta\theta,\ 0\right\}. \end{aligned}$$

A high-valuation user's expected rent is strictly positive unless $q_M^m = q_L^m = 0$, and a low-valuation user gets zero rent.

Proof. See Appendix D. ■

When all users have low-valuation, the provider produces $q_L^m = q_M^m$ and receives $p_{lL}^m = p_{lM}^m$ $(= \theta_l q_L^m = \theta_l q_M^m)$ from each user regardless of whether she manipulates the reported information or not. It is straightforward to see that this arrangement sets the LHS and the RHS of PIC_L constraint equal to each other, thus eliminating the provider's incentive to manipulate information. Notice that the public good is under-provided in $\mathcal{C}^m$ ($q_M^m < q_M^*$ and $q_L^m < q_L^*$) for $\varphi \in (1/2, \overline{\varphi})$. When it is more likely that a user is the high-valuation type (the type receiving information rent), it is optimal for the provider to reduce the source of the users' information rents when removing her own manipulation incentive.

In addition to the bunching presented in Proposition 2 above, there are other ways to keep the public good provider from manipulating information. To see this, consider the binding (PIC_L) presented below:

$$2p_{lL} - c(q_L) = 2p_{lM} - c(q_M).$$

From this equation, instead of bunching the two outcomes for $\gamma = L$ and $\gamma = M$, the provider can reduce the payment p_{lM} in the RHS to discourage herself from information manipulation. Notice that, although lowering this payment relaxes the constraint, it comes at the cost of providing a low-valuation user with a strictly positive rent when he is paired with a high-valuation user. Another way to discourage the provider from manipulating information would be to inflate the level of public good q_M in the RHS, so that the value generated by it for low-valuation users would not justify the cost of producing it. As will be shown below, when a user is more likely to be the low-valuation type, the provider finds it optimal to use a combination of these two approaches to deal with her own incentive to manipulate information.

In order to present our results for $\varphi \in (\underline{\varphi}, 1/2)$, we first introduce the following condition.

Condition 1 $2\theta_l \hat{q}_L - c(\hat{q}_L) \leq 2\theta_l q_H^* - c(q_H^*)$, *where* $\hat{q}_L$ *is defined by:*

$$c'(\hat{q}_L) = \max\left\{2\theta_l - 2\frac{\varphi(1-\varphi)}{1-\varphi(1-\varphi)}\Delta\theta, 0\right\}.$$

When Condition 1 holds, the principal's gain from misrepresenting the users' collective valuation is significantly large when the reports from the users indicate $\gamma = L$. That is, it becomes tremendously costly for the provider to keep herself from manipulating information. As a result, she will make a drastic choice in the optimal contract as we show below.[18] The next proposition presents the optimal outcome when the condition holds.

Proposition 3 *Suppose Condition 1 holds. For* $\varphi \in (\underline{\varphi}, 1/2)$*, the optimal contract* $\mathcal{C}^m$ *offered by the manipulative provider entails a bunching outcome with overprovision of the public good:*

$$q_H^m = q_H^* = q_M^m > q_M^* \text{ and } q_L^m = \hat{q}_L < q_L^*.$$

A high-valuation user receives a rent, and a low-valuation user receives a rent when paired with a high-valuation user.

Proof. See Appendix E. ■

[18] Whether or not Condition 1 holds depends on the parameter values and the cost function's curvature. In the working paper version, we provide a numerical example that satisfies the condition.

As mentioned above, the manipulative public good provider can prevent herself from misrepresenting the users' collective valuation by distorting the size of public good and/or decreasing the payment from the low-valuation user when he is paired with a high-valuation user. Recall from Proposition 2 that, when it is more likely that a user is the high-valuation type ($\varphi > 1/2$), the optimal way to prevent the provider's manipulation is pooling the outcome for $\gamma = M$ with the outcome for $\gamma = L$. The bunching with public good under-provision effectively prevents the provider's manipulation, and at the same time, limiting her rent provision to a high-valuation user.

When it is more likely that a user is the low-valuation type ($\varphi < 1/2$), the optimal way to prevent the provider's manipulation entails increasing q_M, thus increasing the cost of production for $\gamma = M$, which in turn prevents the provider from misrepresenting $\gamma = L$ as $\gamma = M$ (a larger q_M implies a larger rent provision to a high-valuation user, but it is more likely that a user is the low-valuation type). Proposition 3 exhibits an extreme case. When it becomes significantly hard for the provider to incentivize herself for a truthful behavior, the provider must distort q_M^m upward all the way to q_H^m $(= q_H^*)$, and also give a strictly positive rent to a low-valuation user paired with a high-valuation user in the optimal contract. This implies an overproduction of the public good when the users have different valuations ($q_M^m > q_M^*$)—when a user is more likely to be the high-valuation type, as long as at least one of the users has a high valuation for the public good, the provider may prefer to set the production at the first-best level corresponding to all users having high valuation.

Comparison of $q_L^m (= \hat{q}_L)$ with the conditions defining the first-best and the second-best outcomes reveals that $\hat{q}_L$ is in between q_L^n and q_L^* for $\varphi \in (\underline{\varphi}, 1/2)$ and exactly equal to q_L^n for $\varphi = \underline{\varphi}$. This implies that Condition 1 is violated at $\varphi = \underline{\varphi}$.[19] When Condition 1 does not hold, the participation constraint (PC_{lM}) of the low-valuation user becomes binding in the optimal contract. As we have seen in Proposition 2, one way to satisfy constraints (PC_{lM}) and (PIC_L) simultaneously is setting the public good level q_M of the intermediate-value state equal to the public good level q_L of the low-value state. As illustrated in Figure 1, concavity of function $2\theta_l q - c(q)$ (together with the Inada condition that $\lim_{q\to\infty} c'(q) = \infty$) implies the existence of another level for q_M which achieves this objective but higher than the first-best public good level q_L^*. We define $\tilde{q}(q_L)$ as this higher level of q_M $(> q_L^*)$ that would satisfy the (PIC_L) constraint as an equality:

$$\tilde{q}(q_L) = \max\{q_M : 2\theta_l q_M - c(q_M) = 2\theta_l q_L - c(q_L)\}.$$

[19] When $\varphi = \underline{\varphi}$, the second-best outcome satisfies the (PIC_L) constraint as an equality. Accordingly, $2\theta_l \hat{q}_L - c(\hat{q}_L) > 2\theta_l q_L^n - c(q_L^n) = 2\theta_l q_M^n - c(q_M^n) > 2\theta_l q_H^* - c(q_H^*)$.

The following proposition presents the outcome in the optimal contract offered by the manipulative provider when Condition 1 is violated.

Proposition 4 *Suppose Condition 1 does not hold. For $\varphi \in (\underline{\varphi}, 1/2)$, the optimal contract $\mathcal{C}^m$ offered by the manipulative provider entails the following public good sizes:*

$$q_H^m = q_H^*,\ q_M^m = \tilde{q}\left(q_L^m\right) > q_L^*,\ \text{where } q_M^m \gtrless q_M^* \text{ and } q_L^m < q_L^*.$$

A high-valuation user receives a rent, and a low-valuation users receives no rent.

Proof. See Appendix F. ■

Again, when a user is more likely to have low valuation ($\varphi < 1/2$), it may be optimal for the provider to prevent her own manipulation incentive by increasing q_M beyond the first-best level q_M^*. Proposition 4 exhibits cases where inducing the provider's truthful behavior is not as costly as in Proposition 3. Here, the provider leaves no rent to a low-valuation user by setting the payment from him as large as the value that this user gets from the public good. At the same time, to prevent the provider from manipulating collective information from the users, the optimal contract inflates the size of the public good large enough in the intermediate-value state. As a result, the optimal contract can still lead to an overprovision of the public good for $\gamma = M$.

The propositions in this section characterized the optimal contract offered by the manipulative provider for the entire range of φ.[20] For the extreme values of φ, the provider's manipulation is not an issue and the optimal contract is the same as the second-best contract given in Proposition 1. If φ is larger than but close enough to 1/2, Proposition 2 yields the optimal contract, which bunches the low and intermediate collective valuations at the same public good level. If φ is smaller than but close enough to 1/2, the optimal contract is given either by Proposition 3 or by Proposition 4, depending on whether or not Condition 1 holds. For these latter values of φ, the public good can be overprovided and even the low-valuation users may receive a positive rent.[21]

In short, the provider's manipulation incentive and hence the direction of distortion in the public good size is determined by the likelihood of high valuation by the users. For

[20] For completeness, we note that when $\varphi = 1/2$, there is a continuum of contracts maximizing the provider's expected payoff. The optimal public good and payment levels are given as in Proposition 3 for these contracts, except for the level of q_M which can take any value within the set $[\hat{q}_L, \min\{\tilde{q}(\hat{q}_L), q_H^*\}]$.

[21] In a single-agent setting, Beaudry (1994) shows that the privately informed principal may leave a rent to the agent without private information.

extreme ranges of the likelihood, the provider has no incentive to manipulate. For an intermediate range, her manipulation incentive becomes an issue. Within that range, when it is more likely that the users have high valuation, the public good is still underprovided. When it is less likely that the users have high valuation, however, the provider's manipulation incentive may lead to overprovision of the public good.

The central message in this section is summarized in the following corollary.

Corollary 2 *If the public good provider is manipulative, then the optimal contract may entail over-provision of the public good.*

6 Welfare Effects

Having characterized the optimal manipulation-proof contract for all the parameter constellations, we now provide a discussion of the welfare effects of the manipulability of collective information. Our analysis indicates that the provider's opportunity to manipulate comes at a cost. When designing the contract, the provider has to persuade the users that she will not falsify the information that they will report to her. This consideration imposes a new incentive constraint for the public good provision contract, on top of the standard conditions securing the users' participation and their truthful reporting. It follows from Lemma 1 that, as long as there is a sufficient level of uncertainty about the users' valuations for the public good (as long as $\varphi \in (\underline{\varphi}, \overline{\varphi})$), this new constraint is violated by the second-best contract. In this case, the optimal manipulation-proof contract brings in a lower payoff for the provider relative to the second best.

The source of the users' payoffs in the second-best contract is their private information. A high-valuation user should be given an information rent, so that he would not choose to misreport his valuation. This information rent is increasing in q_L and q_M, the public good levels supplied for the low-valuation user. When high valuations are more likely than low valuations ($\varphi \in (1/2, \overline{\varphi})$), Proposition 2 tells us that the manipulation-proofness constraint would have different effects on these two public good levels: The optimal q_L is weakly higher and the optimal q_M is lower than their second-best values. Hence the effect of manipulability on the users' payoffs is ambiguous. By contrast, when low valuations are more likely ($\varphi \in (\underline{\varphi}, 1/2)$), we know from Propositions 3 and 4 that the optimal levels of both q_L and q_M are higher than in the second best. Therefore the high-valuation user is better off in this case, with the introduction of the provider's manipulation opportunities. Proposition 3 also points to the possibility that even the low-valuation user may receive a strictly positive payoff in the intermediate-value state. The provider tolerates leaving a rent to this user in order to strengthen her commitment not to misrepresent the low-value state as the intermediate-value one.

In sum, the provider's ability to manipulate lowers her own expected payoff, but the users may strictly prefer to interact with a provider who is known to be capable of manipulation. Examination of the change in the optimal levels of q_L and q_M would also give an idea on whether the increase in the users' payoffs compensate for the loss in the provider's. If $\varphi \in (\underline{\varphi}, 1/2)$ and there is no overprovision of the public good (if the optimal manipulation-proof level of q_M is lower than its first-best value q_M^*), then the provider's manipulability improves the sum of the provider's and the users' expected payoffs, because both q_L and q_M get closer to their first-best values under the optimal manipulation-proof contract.

The next corollary follows directly from the discussion here.

Corollary 3 *Suppose $\varphi \in (\underline{\varphi}, 1/2)$.*

- *If Condition 1 holds, then the users, regardless of their valuation of the public good, strictly prefer to deal with a manipulative provider.*
- *If Condition 1 does not hold and $q_M^m < q_M^*$, then the sum of all parties' expected payoff is higher with a manipulative provider.*

The corollary above identifies conditions under which we can interpret the provider's ability to manipulate as a countervailing force that reduces her power to extract the users' rents. It suggests, at first sight, the counter intuitive result that the users would prefer a setting in which the provider could manipulate. Yet, this statement requires a careful interpretation—if the users can affect the institutional environment, they would be better served with more direct ways to limit the provider's rent extraction than doing so indirectly by taking the environment to where the provider's manipulation is easier. It is, however, worthwhile to point out that the result is supportive of privacy concerns that reduce transparency and thereby increase the provider's ability to manipulate.

7 Conclusion

In this paper, we have provided a rationale for an overprovision of public goods that is based on the presence of private information. In doing so, we analyzed contracting for a public good between a provider and users with private valuations for the public good. The users' private information causes a distortion in the size of the public good offered to them and such distortions may lead to the provider's incentive to manipulate. We have shown that, once the public good provider extracts the users' private information, she may have an incentive to misrepresent the collective information from the users.[22] Our results suggest that the provider's manipulation ability determines the direction of distortion in public good provision. If the provider is non-manipulative, her optimal contract underprovides the public good. If she is manipulative, however, public goods can be overprovided. In such cases, not only the high-valuation users of the public good, but also the low-valuation ones may obtain positive rents. Lastly, we have shown that all users, regardless of their valuations, can receive higher rents when the provider is manipulative, thus suggesting that, for strategic reasons, the users may want to contract with a provider who is capable of manipulating information.

For simplicity, we assumed two users in our model, but our qualitative results hold for more than two users. In fact, with more users, the provider's manipulation opportunities increase. To see this, suppose there are three users. Then the collective value of the users can be one of the four values: $\gamma \in \{H, \overline{M}, \underline{M}, L\}$, where $\overline{M}$ and $\underline{M}$ represent the case with two high-valuation users and the case with one such user respectively. The output schedule when the provider is non-manipulative will be $q^n_H > q^n_{\overline{M}} > q^n_{\underline{M}} > q^n_L$, where $q^n_H = q^*_H$, $q^n_{\overline{M}} < q^*_{\overline{M}}$, $q^n_{\underline{M}} < q^*_{\underline{M}}$ and $q^n_L < q^*_L$. Thus, when the provider is manipulative, her incentive to manipulate the collective valuation arises. Depending on φ, the provider may have an incentive to misrepresent $\gamma = L$ as $\gamma = \overline{M}$ or $\underline{M}$ (if $q^n_{\underline{M}}$ is closer to q^*_L, then she will misrepresent $\gamma = L$ as $\gamma = \underline{M}$ and vice versa), and also $\gamma = \underline{M}$ as $\gamma = \overline{M}$.[23]

Again, to make our point in a simple setup, we allowed each user to have two possible valuations for the public good. Our qualitative results continue to hold with an enlarged set of types. Suppose that a user's type can be $i \in \{h, m, l\}$. With these three types, in our two-user model, the collective valuation γ can have six potential values, giving the provider more opportunities to manipulate.

One of the key assumptions in our model is that a user can opt out, if he anticipates a strictly negative payoff after receiving the provider's report about collective valuation of

[22] See Celik et al. (2019) for a study on the linkage between the principal's incentive to manipulate the information from the agents and the optimal structures of the organization. In that paper, the transfers are restricted to be equal even when the agents' types are different, resulting in no over-production in the optimal contract.

[23] Also, in our two-user model, the optimal contract allows the users to indirectly learn each other's valuations, but that is not the case when there are more than two users.

the public good. Without such a limited liability of the users, the manipulative provider can still achieve the second-best outcome by trading off payments from low-valuation users. The binding participation constraint for a low-valuation user, with no limited liability, is:

$$\varphi\left(\theta_l q_M - p_{lM}\right) + (1-\varphi)\left(\theta_l q_L - p_{lL}\right) = 0.$$

As can be seen from the equation, the provider has an extra degree of freedom—she can make a low-valuation user's ex post payoff positive for $\gamma = M$ by decreasing p_{lM}, and negative for $\gamma = L$ by increasing p_{lL} without altering the public good sizes from the second-best level in each state. This allows the manipulative provider to achieve the second best, but with the drawback that it violates the user's ex post participation constraint. In practice, such a violation may be feasible in some situations, but not in others. For example, for a public good provision such as a local government's highway construction, financed by tax revenue, a user is not able to opt out. For a public good such as a class-action lawsuit, on the other hand, one can choose to opt out of a class action, and not be able to claim part of any settlement funds or court award that results from the case.[24]

Another important assumption in our model is that the public good provider's mechanism treats the users symmetrically when determining the size of the public good and the payments from the users. If the provider could condition the public good level for intermediate collective value, q_M, on which user has the high valuation and which user has the low valuation, then any manipulation attempt by the provider would have been detectable by observing the size of the provision. In many applications, the symmetric treatment assumption is justified by a fairness consideration imposed on the provider. In addition, when the number of the users is large, it may be too costly for the provider to arrange an asymmetric treatment of the users in practice.

Appendix

A. Proof of Proposition 1

The non-manipulative provider's optimal contract $\mathcal{C}^n$ maximizes $(\mathcal{P})$ subject to (PC_{lM}), (PC_{lL}), (PC_{hH}), (PC_{hM}), (IC_h) and (IC_l). We follow the usual procedure of considering a relaxed problem with only the constraints (PC_{lM}), (PC_{lL}) and (IC_h), and ignoring the remaining three. Since the provider's payoff is increasing in p_{lM} and p_{lL} from low-valuation users and the expected payment $\varphi p_{hH} + (1-\varphi)\, p_{hM}$ from high-valuation users, (PC_{lM}),

[24] See Klonoff (2017).

(PC_{lL}) and (IC_h) are binding. These binding constraints give the following expressions:

$$\begin{aligned} p_{lL} &= \theta_l q_L, \\ p_{lM} &= \theta_l q_M, \\ \varphi p_{hH} + (1-\varphi)\, p_{hM} &= \varphi[\theta_h q_H - \Delta\theta q_M] + (1-\varphi)[\theta_h q_M - \Delta\theta q_L]. \end{aligned}$$

Maximizing the objective function in $\mathcal{P}$ after substituting out these payments yields q_L^n, q_M^n and q_H^n. From the expressions of the payments from the users, it follows that a high-valuation user's expected rent is strictly positive unless $q_M = q_L = 0$, and a low-valuation user's rent is always zero. What remains is showing that we can find individual levels of payments p_{hH} and p_{hM} that would satisfy the ignored constraints of (PC_{hH}), (PC_{hM}) and (IC_l). First, from the first order conditions for the optimal public good levels in the proposition, notice that $q_M^n = 0$ for $\varphi \geq (\theta_h + \theta_l)/2\theta_h$ and $q_L^n = 0$ for $\varphi \geq \theta_l/\theta_h$. Since $(\theta_h + \theta_l)/2\theta_h > \theta_l/\theta_h$, if $q_M^n = 0$ then $q_L^n = 0$. Also, for strictly positive public good levels, $q_H^n > q_M^n > q_L^n$. Thus, $q_H^n > q_M^n \geq q_L^n$ in any case. Consider now the levels of these payments which would satisfy (IC_h) in the ex-post sense:

$$\begin{aligned} p_{hH} &= p_{lM} + \theta_h\,(q_H - q_M)\,, \\ p_{hM} &= p_{lL} + \theta_h\,(q_M - q_L)\,. \end{aligned}$$

It follows from the monotonicity of the public good levels ($q_H^n > q_M^n \geq q_L^n$) that (PC_{hH}) and (PC_{hM}) are satisfied with these payments. Also, (IC_l) holds with zero on either side of the weak inequality. ■

B. Proof of Lemma 1

With the outcome in $\mathcal{C}^n$, we can re-write (PIC_L) by using the binding (PC_{lM}) and (PC_{lL}):

$$2\theta_l q_L^n - c\,(q_L^n) \geq 2\theta_l q_M^n - c\,(q_M^n)\,.$$

Function $2\theta_l q - c\,(q)$ is concave in q and maximized at q_L^*. It follows from the first-order conditions in Proposition 1 that $\bar{\varphi} \equiv (\theta_h + \theta_l)/2\theta_h$ is the lowest level of φ under which the provider chooses to shut down unless both users report high values. If $\varphi \geq \bar{\varphi}$, then $q_L^n = q_M^n = 0$ and (PIC_L) holds as an equality. For $\varphi \in [1/2,\ \bar{\varphi})$, the first order conditions of the optimal outcome in $\mathcal{C}^n$ implies $q_L^n < q_M^n \leq q_L^*$ and therefore (PIC_L) is violated. Similarly, when φ approaches to 0, q_L^n approaches to $q_L^*\,(< q_M^n)$ and (PIC_L) is satisfied. Existence of the threshold value $\underline{\varphi}$ follows from the fact that the left hand side of (PIC_L) decreases and its right hand side increases in φ on the interval $[0, 1/2]$. ■

C. Proof of Lemma 2

We first try setting payments p_{hM} and p_{hH} equal to the values that would satisfy a high-valuation user's incentive compatibility conditions in the ex-post sense: $p_{hH} = p_{lM} + \theta_h (q_H - q_M)$ and $p_{hM} = p_{lL} + \theta_h (q_M - q_L)$. The participation constraints for a low-valuation user, (PC_{lM}) and (PC_{lL}), imply that these payments also satisfy (PC_{hH}) and (PC_{hM}). Constraint (IC_l) holds provided that (IC_h) is binding and the public good levels are monotonic ($q_L \leq q_M \leq q_H$): Pretending to have high valuation would bring a lower payoff than the equilibrium payoff to a low-valuation user, regardless of the other user's type. So, if (PIC_H) is satisfied as well, then the proof is complete.

Suppose (PIC_H) is violated with the above values of p_{hM} and p_{hH}. In such a case, we increase p_{hH} and reduce p_{hM} such that both (IC_h) and (PIC_H) hold as equalities:

$$
\begin{aligned}
p_{hH} &= \varphi p_{lM} + \varphi\theta_h (q_H - q_M) + (1-\varphi) p_{lL} + (1-\varphi)\theta_h (q_M - q_L) + (1-\varphi)\frac{c(q_H) - c(q_M)}{2}, \\
p_{hM} &= \varphi p_{lM} + \varphi\theta_h (q_H - q_M) + (1-\varphi) p_{lL} + (1-\varphi)\theta_h (q_M - q_L) - \varphi\frac{c(q_H) - c(q_M)}{2}.
\end{aligned}
$$

Constraint (PC_{hM}) still holds, because we are reducing the payment p_{hM} that the user makes in this state of nature. Constraint (PC_{hH}) is satisfied as well, because $c(q_H) - c(q_M) \leq 2\theta_h (q_H - q_M)$ under convexity of $c(\cdot)$, and therefore:

$$
\begin{aligned}
p_{hH} &\leq \varphi\theta_l q_M + \theta_h (q_H - q_M) + (1-\varphi)\theta_l q_L + (1-\varphi)\theta_h (q_M - q_L) \\
&= \theta_h q_H - \varphi(\theta_h - \theta_l) q_M - (1-\varphi)(\theta_h - \theta_l) q_L \leq \theta_h q_H.
\end{aligned}
$$

Showing (IC_l) holds is more involved for this case because of the 'max' operators representing the user's opportunity to opt out of the contract. First notice that the expected equilibrium payoff of the low-valuation user is higher than the expected payoff of pretending to be high-valuation and opting in the contract regardless of the other user's type. This is due the fact that (IC_h) is binding and the public good levels are monotonic ($q_L \leq q_M \leq q_H$). What remains to show is the suboptimality of imitating a high-valuation user and then opting out depending on the type of the other user. This imitation is not profitable when the other user has high valuation, because p_{hH} is now higher than $p_{lM} + \theta_h (q_H - q_M)$. On the other hand, in the case that the other user has low valuation, the imitation payoff is:

$$
\begin{aligned}
& \theta_l q_M - p_{hM} \\
=\ & \theta_l q_M - \varphi p_{lM} - \varphi\theta_h (q_H - q_M) - (1-\varphi) p_{lL} - (1-\varphi)\theta_h (q_M - q_L) + \varphi\frac{c(q_H) - c(q_M)}{2} \\
\leq\ & \theta_l q_M - \varphi p_{lM} - (1-\varphi) p_{lL} - (1-\varphi)\theta_h (q_M - q_L) \\
=\ & \varphi(\theta_l q_M - p_{lM}) + (1-\varphi)(\theta_l q_L - p_{lL}) - (1-\varphi)(\theta_h - \theta_l)(q_M - q_L),
\end{aligned}
$$

where the inequality follows from the convexity of $c(\cdot)$ again. Because this payoff is smaller than the expected equilibrium payoff of $\varphi(\theta_l q_M - p_{lM}) + (1-\varphi)(\theta_l q_L - p_{lL})$ for a low-valuation user, constraint (IC_l) is satisfied. ■

D. Proof of Proposition 2

For proof of the proposition, we first consider a relaxed problem in Lemma 3 below where we look for the outcome that maximizes the provider's objective function in $(\mathcal{P})$ subject to (IC_h), (PC_{lM}), (PC_{lL}) and (PIC_L) constraints, ignoring (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints—we will also refer to this lemma for proofs of all remaining propositions.

Lemma 3 *Suppose $\varphi \in (\underline{\varphi}, \overline{\varphi})$. At the solution to the relaxed problem, payment levels are given by the binding (IC_h), (PC_{lL}) and (PIC_L) constraints. The public good levels q_H, q_M and q_L are chosen to maximize:*

$$\begin{aligned}\varphi^2\left[2\theta_h q_H - c(q_H)\right] + \varphi(1-2\varphi)\left[2\theta_l q_M - c(q_M)\right] + (1-\varphi(1-\varphi))\left[2\theta_l q_L - c(q_L)\right] \\ +2\varphi(1-2\varphi)(\theta_h-\theta_l)q_M - 2\varphi(1-\varphi)(\theta_h-\theta_l)q_L,\end{aligned} \qquad (\widetilde{\mathcal{P}})$$

subject to

$$2\theta_l q_M - c(q_M) \geq 2\theta_l q_L - c(q_L). \qquad (\widetilde{PC}_{lM})$$

Proof. Because the objective function is decreasing in p_{hH}, p_{hM}, p_{lL} and constraint (PIC_L) is relaxed with a lower value of p_{lL}, constraints (IC_h) and (PC_{lL}) are binding for the outcome solving the relaxed problem. It follows from Lemma 1 that (PIC_L) is binding for $\varphi \in (\underline{\varphi}, \overline{\varphi})$. We can rewrite the expected payment to the provider by substituting in these constraints:

$$\begin{aligned}&\varphi^2 2p_{hH} + 2\varphi(1-\varphi)p_{hM} + 2\varphi(1-\varphi)p_{lM} + (1-\varphi)^2 2p_{lL} \\ =\;& 2\theta_l q_L + \varphi^2 2\theta_h q_H + \varphi(1-2\varphi)2\theta_h q_M - \varphi(1-\varphi)2\theta_h q_L + \varphi c(q_M) - \varphi c(q_L).\end{aligned}$$

Once the expected cost of public good provision is taken into account, the provider's objective function reduces to the objective in $(\widetilde{\mathcal{P}})$. Similarly, constraint (PC_{lM}) can be rewritten as $(\widetilde{PC}_{lM})$ after substituting in the binding constraints of (PIC_L) and (PC_{lL}). ■

We now move on to the proof of Proposition 2. We will start with ignoring (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints and maximizing the provider's objective function subject to (IC_h), (PC_{lM}), (PC_{lL}) and (PIC_L) constraints only, as in Lemma 3. The solution to the relaxed problem will be the one identified by the proposition. Since the solution in the proposition satisfies the hypothesis of Lemma 2, there exists an outcome that solves the relaxed problem and that satisfies the ignored constraints.

For $\varphi > 1/2$, the objective function $(\widetilde{\mathcal{P}})$ is convex in q_M. Therefore $(\widetilde{PC_{lM}})$ constraint is satisfied as an equality at the solution to this maximization. This equality holds when $q_M = q_L$. Given concavity of function $2\theta_l q - c(q)$, the equality may also be satisfied when one variable is strictly higher than the other. This will not be the case for the outcome solving the maximization problem: Holding $2\theta_l q_M - c(q_M)$ and $2\theta_l q_L - c(q_L)$ constant, the objective function is decreasing in both q_L and q_M (when $\varphi > 1/2$). This proves that the optimal outcome is a bunching outcome ($q_M = q_L$). The first order condition yields:

$$c'(q_M) = c'(q_L) \geq 2\theta_l - 2\frac{\varphi^2}{1-\varphi^2}\Delta\theta,$$

where the weak inequality holds as equality if $q_M = q_L > 0$.

Finally, Lemma 2 implies that we can find individual levels of p_{hM} and p_{hH} (for instance, $p_{hM} = \theta_l q_L$ and $p_{hH} = \theta_l q_L + \theta_h (q_H - q_L)$) that satisfy the ignored (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints. ■

E. Proof of Proposition 3

Ignoring (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints, it follows from Lemma 3 that the provider's problem turns into maximization of $(\widetilde{\mathcal{P}})$ by choosing q_H, q_M and q_L subject to $(\widetilde{PC_{lM}})$. When we ignore $(\widetilde{PC_{lM}})$ constraint as well, the problem is an unconstrained optimization problem and the first order conditions yield the values of outputs q_H, q_M, and q_L as stated in the proposition. The payments p_{lL}, p_{lM}, and $\varphi p_{hH} + (1-\varphi) p_{hM}$ are given by the binding (PC_{lL}), (PIC_L) and (IC_h) constraints:

$$\begin{aligned}
p_{lL}^m &= \theta_l q_L^m, \\
p_{lM}^m &= \theta_l q_L^m + \frac{c(q_H^m) - c(q_L^m)}{2}, \\
\varphi p_{hH}^m + (1-\varphi) p_{hM}^m &= \theta_l q_L^m + \varphi \frac{c(q_H^m) - c(q_L^m)}{2} + (1-\varphi)\theta_h (q_H^m - q_L^m).
\end{aligned}$$

The solution satisfies the ignored $(\widetilde{PC_{lM}})$ constraint because:

$$2\theta_l q_M - c(q_M) = 2\theta_l q_H^* - c(q_H^*) \geq 2\theta_l \hat{q}_L - c(\hat{q}_L).$$

The existence of the individual values of p_{hH} and p_{hM} satisfying the ignored (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints follow from Lemma 2. For instance, setting these payments equal to each other would work:

$$p_{hH} = p_{hM} = \theta_l q_L + \varphi \frac{c(q_H) - c(q_L)}{2} + (1 - \varphi)\theta_h (q_H - q_L). \blacksquare$$

F. Proof of Proposition 4

Following the proof of the previous propositions, we maximize the provider's objective function, ignoring (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints. The payments p_{lL}, p_{lM}, and $\varphi p_{hH} + (1-\varphi) p_{hM}$ are given by the binding (PC_{lL}), (PC_{lM}), (PIC_L) and (IC_h) constraints:

$$\begin{aligned} p^m_{lL} &= \theta_l q_L, \\ p^m_{lM} &= \theta_l q^m_M, \\ \varphi p^m_{hH} + (1-\varphi) p^m_{hM} &= \theta_l q^m_L + \varphi\theta_l (q^m_M - q^m_L) + (1-\varphi)\theta_h (q^m_M - q^m_L) + \varphi\theta_h (q^m_H - q^m_M) \end{aligned}$$

From Lemma 3, this problem turns into maximization of $(\widetilde{\mathcal{P}})$ by choosing q_H, q_M and q_L subject to $(\widetilde{PC}_{lM})$. The constraint is binding—otherwise, the first order conditions yield that $q_M = q^*_H$ and $q_L = \hat{q}_L$, violating $(\widetilde{PC}_{lM})$ since:

$$2\theta_l q_M - c(q_M) = 2\theta_l q^*_H - c(q^*_H) < 2\theta_l \hat{q}_L - c(\hat{q}_L).$$

Holding $2\theta_l q_L - c(q_L)$ and $2\theta_l q_M - c(q_M)$ constant, the objective function is decreasing in q_L but increasing in q_M (for $\varphi < 1/2$). This proves that $q_L < q^*_L$ and $q_M = \tilde{q}(q_L)$, where $\tilde{q}(q_L) = \max\{q_M : 2\theta_l q_M - c(q_M) = 2\theta_l q_L - c(q_L)\}$. Since q^*_M is the the maximizer of $(\theta_h + \theta_l) q_M - c(q_M)$, if the gap between θ_h and θ_l is small enough, q^*_M will be in between q^*_L and $\tilde{q}(q_L)$, implying that $q_M = \tilde{q}(q_L) > q^*_M$. If the gap between θ_h and θ_l is not small enough, then $q_M = \tilde{q}(q_L) < q^*_M$.

Lemma 2 implies that we can find individual levels of p_{hM} and p_{hH} that satisfy the ignored (IC_l), (PC_{hH}), (PC_{hM}) and (PIC_H) constraints. $\blacksquare$

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