Truthful Aggregation of Budget Proposals

RUPERT FREEMAN, Microsoft Research
DAVID M. PENNOCK, Microsoft Research
DOMINIK PETERS, University of Oxford
JENNIFER WORTMAN VAUGHAN, Microsoft Research

CCS Concepts: • **Computing methodologies** → *Multi-agent systems*; • **Applied computing** → *Economics*.

Additional Key Words and Phrases: participatory budgeting, computational social choice, mechanism design

ACM Reference Format:
Rupert Freeman, David M. Pennock, Dominik Peters, and Jennifer Wortman Vaughan. 2019. Truthful Aggregation of Budget Proposals. In *ACM EC '19: ACM Conference on Economics and Computation (EC '19), June 24–28, 2019, Phoenix, AZ, USA.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3328526.3329557

We study a participatory budgeting setting in which a single divisible resource (such as money or time) must be divided among a set of projects. For example, participatory budgeting could be used to decide how to divide a city's tax surplus between its departments of health, education, infrastructure, and parks. A voter might propose a division of the tax surplus among the four departments into the fractions (30%, 40%, 20%, 10%). The city could invite each citizen to submit such a budget proposal, and they could then be aggregated by a suitable mechanism.

In this paper, we seek mechanisms of this form that are resistant to manipulation by the voters. In particular, we require that no voter can, by lying, move the aggregate division toward her preference on one alternative without moving it away from her preference by at least as much on other alternatives. In other words, we seek budget aggregation mechanisms that are incentive compatible when each voter's disutility for a budget division is equal to the ℓ_1 distance between that division and the division she prefers most.

Goel et al. [4] showed that choosing an aggregate budget division that maximizes the welfare of the voters—that is, a division that minimizes the total ℓ_1 distance from each voter's report—is both incentive compatible and Pareto-optimal under this voter utility model. However, this utilitarian aggregate has a tendency to overweight majority preferences, creeping back towards all-or-nothing allocations. For example, imagine that a hundred voters prefer (100%, 0%) while ninety-nine prefer (0%, 100%). The utilitarian aggregate is (100%, 0%) even though the mean is close to (50%, 50%). In many participatory budgeting scenarios, the latter solution is more in the spirit of consensus. To capture this idea of fairness, we define a notion of *proportionality*, requiring that when voters are single-minded (as in this example), the fraction of the budget assigned to each alternative is equal to the proportion of voters who favor that alternative. Do there exist aggregators that are both incentive compatible and proportional?

For the special case of two alternatives, ℓ_1 preferences are a special-case of *single-peaked* preferences, well studied in the voting literature. The seminal results of Moulin [5] imply that, in this setting, all incentive compatible voting schemes correspond to inserting $n + 1$ phantom proposals,

EC '19, June 24–28, 2019, Phoenix, AZ, USA

ACM ISBN 978-1-4503-6792-9/19/06.
https://doi.org/10.1145/3328526.3329557

where n is the number of voters, and returning the median of the n true proposals and the $n + 1$ phantoms. We show that there exists a way of placing the phantoms that results in a proportional mechanism for two alternatives.

We generalize Moulin's phantom median mechanisms to allow for more than two alternatives. Existing proposals for such generalizations take a median in each dimension independently [1, 2, 6], but this strategy fails in our application with normalization constraints; unlike the mean, taking a coordinate-wise median will generally fail to normalize. We address this problem by allowing the set of phantoms to continuously shift upwards, increasing the sum of the generalized medians until the aggregate becomes normalized. This idea allows us to define a very general class of *moving phantom* mechanisms. Although one might think that allowing the final phantom locations to depend on voters' reports might give voters an incentive to misreport, we prove that every moving phantom mechanism is incentive compatible under ℓ_1 preferences.

Among this large family of incentive compatible mechanisms, we find one that satisfies our proportionality requirement. This moving phantom mechanism is obtained when phantoms are placed uniformly between 0 and a value $x \geq 0$ which increases until the coordinate-wise medians sum to one. To analyze this mechanism, we prove that the aggregate found by this mechanism can be interpreted as the clearing prices in a market system, and hence call it the *independent markets* mechanism. This reveals an unexpected connection between market prices and generalized medians that may be of broader interest. The independent markets mechanism can also be justified from a game-theoretic perspective as the unique Nash equilibrium of a natural voting game. By analyzing the market and Nash equilibria of these systems, we can show that our mechanism satisfies several important social choice properties.

In contrast, the independent markets mechanism unfortunately fails to satisfy Pareto optimality. We show that this is unavoidable, as no proportional moving phantom mechanism is Pareto-optimal. In fact, we prove that there is a *unique* moving phantom mechanism that is. In this mechanism, all phantoms start at 0 and then, one by one, transition to 1, with no two phantoms moving at the same time. This mechanism turns out to also have a phantom-free interpretation: it is equivalent to selecting the maximum-entropy budget division out of all those that maximize social welfare—the same mechanism studied by Goel et al. [4] up to the choice of tie-breaking rules.

For more details, we refer the reader to the full version of the paper [3].

REFERENCES

[1] S. Barberà and M. Jackson. 1994. A characterization of strategy-proof social choice functions for economies with pure public goods. *Social Choice and Welfare* 11, 3 (1994), 241–252.

[2] K. C. Border and J. S. Jordan. 1983. Straightforward elections, unanimity and phantom voters. *Review of Economic Studies* 50, 1 (1983), 153–170.

[3] R. Freeman, D. M. Pennock, D. Peters, and J. W. Vaughan. 2019. Truthful Aggregation of Budget Proposals. arXiv:1905.00457.

[4] A. Goel, A. K. Krishnaswamy, S. Sakshuwong, and T. Aitamurto. 2016. Knapsack Voting: Voting mechanisms for Participatory Budgeting. Manuscript.

[5] H. Moulin. 1980. On strategy-proofness and single-peakedness. *Public Choice* 35 (1980), 437–455.

[6] H. Peters, H. van der Stel, and T. Storcken. 1992. Pareto optimality, anonymity, and strategy-proofness in location problems. *International Journal of Game Theory* 21, 3 (1992), 221–235.