Algorithms for Candidate Control in Sequential Participatory Budgeting Rules

Extended Abstract

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ABSTRACT

We study the problem of candidate control in participatory budgeting elections. Our focus is on two prominent sequential welfare-based rules—GreedyAV and GreedyCost—which are widely used in practice. Candidate control asks whether we can strategically modify the set of available candidates so as to either ensure that a preferred candidate p is selected (constructive control) or prevent p from being selected (destructive control).

Since all variants of candidate control under the two rules we consider are known to be NP-hard, we analyze the problems through the lens of parameterized complexity and approximability. Under the first lens, we provide a comprehensive classification with respect to natural parameters such as the number of voters, the number of controlled candidates, and the number of distinct costs, as well as their combinations. Within the second perspective, we establish a tight approximability bound.

KEYWORDS

Election Control, Participatory Budgeting, Computational Complexity, Fixed-Parameter Tractability, Approximability.

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1 INTRODUCTION

Together with *manipulation* and *bribery* [23], *control* is a classical example of strategic interference in elections, and the study of its computational aspects dates back to the pioneering work of Bartholdi III et al. [4]. The question in control is whether we can change the outcome of an election by changing its structure [4, 27]. More specifically, the prevailing modifications of the election's structure that are studied in the literature include the addition or deletion of candidates or voters. Traditionally, the goal of such attacks is either *constructive* [4]—to make a distinguished candidate win—or *destructive* [29]—to make some initially winning candidate lose.

Although most studies on control focus on single- and multi-winner voting (see, e.g., the recent survey of Chen et al. [15]), we extend this line of research to *participatory budgeting* (PB). PB is a modern democratic innovation, in which a municipality allows its citizens to decide how a certain fraction of its budget will be spent [2, 12, 34]. Participatory budgeting processes usually consist of two phases. In the first phase, significantly less explored in the computer science literature (the only exception we are aware of is the work of Rey et al. [33]), citizens are invited to propose projects they would like to see implemented in their community. In the second phase, all inhabitants vote on the proposed projects.

Citizens commonly vote by casting their *approval ballots*, meaning that each voter submits a set of projects they approve. These ballots are then aggregated using a voting rule. The most widely used rule is the so-called GreedyAV rule [35], which iteratively selects the project with the highest support among the remaining projects that can still be funded within a budget limit. Similarly, under the GreedyCost rule [35], the projects are considered in non-increasing order of their support-to-cost ratio (this value is sometimes referred to as "bang for the buck" ratio). Both of these rules greedily maximize certain notions of social welfare—in the case of GreedyAV, measured as the sum of scores of selected projects, and in the case of GreedyCost, measured as the total voter support weighted by cost efficiency. Unlike the corresponding exact welfare-maximizing rules, both GreedyAV and GreedyCost are computable in polynomial time [35].

The computational study of bribery and control in participatory budgeting has emerged only recently. Boehmer et al. [8] initiated this direction by introducing several bribery-like problems, motivated by the goal of making PB outcomes more explainable. Because most PB rules produce dichotomous results—each project is either funded or not—it can be difficult for organizers to explain to voters and to project proposers why a project succeeded or failed, particularly under more complex rules. Similar questions were addressed by Baumeister and Hogrebe [5], and by Boehmer et al. [7], who analyzed the robustness of PB outcomes via the Flip-Bribery problem [23].

This line of research was further developed by Faliszewski et al. [25], who introduced several performance measures based on *candidate control* and conducted an extensive experimental analysis on real-world PB instances from PabuLib [22]. An example of such a measure is the number of projects one needs to remove from

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Table 1: A basic overview of the parameterized results for GreedyAV and GreedyCost under constructive and destructive control. Algorithmic results marked with ≻ require a specific (but natural) tie-breaking rule to hold. Moreover, it is easy to see that both variants are in FPT when parameterized by the number of projects m.

	n	c	r
n	para-NP-complete [25]	FPT$^{\succ}$	XP and W[1]-hard
c	FPT$^{\succ}$	XP	FPT
r	XP and W[1]-hard	FPT	XP and W[1]-hard

the instance to make some initially losing project win; the lower this number is, the closer the project is to winning. They demonstrated that these measures shed light on the internal structure of real-world PB instances, explaining how projects interact and compete within a given instance. However, they also proved that computing successful control actions in PB elections is NP-hard for all combinations of control goals and operations, even under simple rules such as GreedyAV and GreedyCost. This result highlights the need for algorithms that go beyond brute-force enumeration and scale more effectively with the size of real-world PB elections; a task we thoroughly explore in this paper.

1.1 Our Contribution

In this paper, we focus on the algorithmic aspects of candidate control in participatory budgeting under two prominent PB rules—GreedyAV and GreedyCost. Our main motivation is to develop efficient algorithms for the control problems that underlie the performance measures proposed by Faliszewski et al. [25]. In view of the hardness results established there, we employ parameterized complexity and approximation frameworks, which equip us with formal tools for a more fine-grained analysis of computationally hard problems.

From the perspective of parameterized complexity, our goal is to identify the sources of computational intractability and to design algorithms that become efficient when certain aspects of the input are restricted. Common restrictions in voting theory include a bounded number of projects (denoted by m) or voters (denoted by n) [14, 16]. Beyond these standard parameters, we also consider the number of projects r that can be controlled, the number of non-controlled projects q, and the number of distinct project costs c. For these parameters and their combinations, we provide a classification of the corresponding problems with respect to the complexity classes FPT, XP, and W[1]-hard. See Table 1 for an overview of our results.

The second perspective we consider is approximability. Here, instead of restricting the input, we seek polynomial-time algorithms that work for all instances, at the cost of allowing solutions whose values approximate the optimum (since the problems are NP-hard). Unfortunately, our results are largely negative, establishing strong inapproximability. In particular, no $m^{1-\epsilon}$-approximation is possible for any $\epsilon > 0$ (unless $\mathrm{P} = \mathrm{NP}$), yet a simple m/c-approximation algorithm exists (for every fixed $c \geq 1$). Hence, the obtained inapproximability ratio is high but essentially tight.

Together, these results provide the first fine-grained computational complexity study of hard control problems in participatory budgeting, offering a detailed understanding of when and how candidate control in PB can be exactly computed or approximated. The most important application of our work is that, in order to compute the performance measures of Faliszewski et al. [25] in practice, one should rely on parameterized algorithms rather than approximation algorithms. Indeed, Faliszewski et al. [25] showed that r tends to be small in real-world settings, so we believe that our algorithmic results are a necessary step toward the adoption of their measures.

1.2 Related Work

From the perspective of classical complexity, deciding whether a successful attack on an election—through manipulation, bribery, or control—has been shown to be computationally intractable for many popular voting rules. This holds across single-winner [3, 4, 17, 20, 23, 27], multi-winner [1, 13, 28, 32], and participatory budgeting [8, 25] elections; see also a recent survey [15].

Following these intractability results, many authors have studied strategic behavior in elections through the lens of parameterized complexity [18]. The most prominent parameters considered are the number of candidates [16, 36] and the number of voters [14]. Other parameters include the number of affected voters, the available budget for an attack, structural properties of the election, and the number of selected candidates in multi-winner settings [9, 28, 31, 37–39]. A survey of parameterized complexity results for single-winner elections is provided by Betzler et al. [6]. The only works studying the parameterized complexity of strategic interference in PB are those of Boehmer et al. [7, 8], who present several parameterized results for bribery-like problems. Importantly, we are not aware of any papers addressing parameterized complexity of control in PB.

Beyond fixed-parameter analysis, another way to address NP-hardness is through approximation algorithms. This approach to attacks on elections has received significantly less attention than the parameterized-complexity viewpoint. The few existing studies focus mainly on bribery and manipulation in single-winner elections, analyzing approximation algorithms and hardness results for various rules [11, 19, 21, 26, 30, 40]. To our knowledge, the only studies that address control problems from an approximation perspective are those of Brelsford [10] and Faliszewski et al. [24]. They showed that, under standard complexity assumptions, no algorithm can achieve an approximation ratio better than $O(\log m)$ for the corresponding single-winner rules. None of these works extend beyond the single-winner framework, and therefore their results do not generalize to PB or other multi-winner environments. Indeed, Faliszewski et al. [25] showed that, for our PB rules, candidate control is polynomial-time solvable in the multi-winner setting.

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REFERENCES

[1] Haris Aziz, Serge Gaspers, Joachim Gudmundsson, Simon Mackenzie, Nicholas Mattei, and Toby Walsh. 2015. Computational Aspects of Multi-Winner Approval Voting. In *Proceedings of the 14th International Conference on Autonomous Agents and Multiagent Systems, AAMAS '15*. IFAAMAS, 107–115.

[2] Haris Aziz and Nisarg Shah. 2021. Participatory Budgeting: Models and Approaches. In *Pathways Between Social Science and Computational Social Science*. Springer, 215–236. https://doi.org/10.1007/978-3-030-54936-7_10

[3] John J. Bartholdi III, Craig A. Tovey, and Michael A. Trick. 1989. The Computational Difficulty of Manipulating an Election. *Social Choice and Welfare* 6, 3 (1989), 227–241. https://doi.org/10.1007/BF00295861

[4] John J. Bartholdi III, Craig A. Tovey, and Michael A. Trick. 1992. How Hard Is It to Control an Election? *Mathematical and Computer Modelling* 16, 8-9 (1992), 27–40. https://doi.org/10.1016/0895-7177(92)90085-Y

[5] Dorothea Baumeister and Tobias Hogrebe. 2023. On the Complexity of Predicting Election Outcomes and Estimating Their Robustness. *SN Computer Science* 4, 4 (2023), 362. https://doi.org/10.1007/s42979-023-01725-0

[6] Nadja Betzler, Robert Bredereck, Jiehua Chen, and Rolf Niedermeier. 2012. Studies in Computational Aspects of Voting - A Parameterized Complexity Perspective. In *The Multivariate Algorithmic Revolution and Beyond (LNCS, Vol. 7370)*. Springer, 318–363. https://doi.org/10.1007/978-3-642-30891-8_16

[7] Niclas Boehmer, Piotr Faliszewski, Łukasz Janeczko, and Andrzej Kaczmarczyk. 2023. Robustness of Participatory Budgeting Outcomes: Complexity and Experiments. In *Proceedings of the 16th International Symposium on Algorithmic Game Theory, SAGT '23 (LNCS, Vol. 14238)*. Springer, 161–178. https://doi.org/10.1007/978-3-031-43254-5_10

[8] Niclas Boehmer, Piotr Faliszewski, Łukasz Janeczko, Dominik Peters, Grzegorz Pierczyński, Šimon Schierreich, Piotr Skowron, and Stanisław Szufa. 2024. Evaluation of Project Performance in Participatory Budgeting. In *Proceedings of the 33rd International Joint Conference on Artificial Intelligence, IJCAI '24*. ijcai.org, 2678–2686. https://doi.org/10.24963/ijcai.2024/296

[9] Robert Bredereck, Jiehua Chen, Piotr Faliszewski, André Nichterlein, and Rolf Niedermeier. 2016. Prices Matter for the Parameterized Complexity of Shift Bribery. *Information and Computation* 251 (2016), 140–164. https://doi.org/10.1016/j.ic.2016.08.003

[10] Eric Brelsford. 2007. *Approximation and Elections*. Master's thesis. Rochester Institute of Technology.

[11] Eric Brelsford, Piotr Faliszewski, Edith Hemaspaandra, Henning Schnoor, and Ilka Schnoor. 2008. Approximability of Manipulating Elections. In *Proceedings of the 23rd AAAI Conference on Artificial Intelligence, AAAI '08*. AAAI Press, 44–49.

[12] Yves Cabannes. 2004. Participatory Budgeting: A Significant Contribution to Participatory Democracy. *Environment and Urbanization* 16, 1 (April 2004), 27–46. https://doi.org/10.1177/095624780401600104

[13] Ioannis Caragiannis, Dimitris Kalaitzis, and Evangelos Markakis. 2010. Approximation Algorithms and Mechanism Design for Minimax Approval Voting. In *Proceedings of the 24th AAAI Conference on Artificial Intelligence, AAAI '10*. AAAI Press, 737–742. https://doi.org/10.1609/aaai.v24i1.7615

[14] Jiehua Chen, Piotr Faliszewski, Rolf Niedermeier, and Nimrod Talmon. 2017. Elections With Few Voters: Candidate Control Can Be Easy. *Journal of Artificial Intelligence Research* 60 (2017), 937–1002. https://doi.org/10.1613/jair.5515

[15] Jiehua Chen, Joanna Kaczmarek, Paul Nüsken, Jörg Rothe, Ildikó Schlotter, and Tessa Seeger. 2025. Control in Computational Social Choice. In *Proceedings of the 34th International Joint Conference on Artificial Intelligence, IJCAI '25*. ijcai.org, 10391–10399. https://doi.org/10.24963/ijcai.2025/1154

[16] Vincent Conitzer, Tuomas Sandholm, and Jérôme Lang. 2007. When Are Elections With Few Candidates Hard to Manipulate? *Journal of the ACM* 54, 3, Article 14 (2007), 33 pages. https://doi.org/10.1145/1236457.1236461

[17] Vincent Conitzer and Toby Walsh. 2016. Barriers to Manipulation in Voting. In *Handbook of Computational Social Choice*. Cambridge University Press, 127–145.

[18] Marek Cygan, Fedor V. Fomin, Łukasz Kowalik, Daniel Lokshtanov, Dániel Marx, Marcin Pilipczuk, Michał Pilipczuk, and Saket Saurabh. 2015. *Parameterized Algorithms*. Springer, Cham. https://doi.org/10.1007/978-3-319-21275-3

[19] Edith Elkind and Piotr Faliszewski. 2010. Approximation Algorithms for Campaign Management. In *Proceedings of the 6th International Workshop on Internet and Network Economics, WINE '10 (LNCS, Vol. 6484)*. Springer, 473–482. https://doi.org/10.1007/978-3-642-17572-5_40

[20] Gábor Erdélyi, Marc Neveling, Christian Reger, Jörg Rothe, Yongjie Yang, and Roman Zorn. 2021. Towards Completing the Puzzle: Complexity of Control by Replacing, Adding, and Deleting Candidates or Voters. *Autonomous Agents and Multiagent Systems* 35, 2 (2021), 41. https://doi.org/10.1007/s10458-021-09523-9

[21] Piotr Faliszewski. 2008. Nonuniform Bribery. In *Proceedings of the 7th International Joint Conference on Autonomous Agents and Multiagent Systems, AAMAS '08*. IFAAMAS, 1569–1572.

[22] Piotr Faliszewski, Jarosław Flis, Dominik Peters, Grzegorz Pierczyński, Piotr Skowron, Dariusz Stolicki, Stanisław Szufa, and Nimrod Talmon. 2023. Participatory Budgeting: Data, Tools and Analysis. In *Proceedings of the 32nd International Joint Conference on Artificial Intelligence, IJCAI '23*. ijcai.org, 2667–2674. https://doi.org/10.24963/ijcai.2023/297

[23] Piotr Faliszewski, Edith Hemaspaandra, and Lane A. Hemaspaandra. 2009. How Hard Is Bribery in Elections? *Journal of Artificial Intelligence Research* 35 (2009), 485–532. https://doi.org/10.1613/jair.2676

[24] Piotr Faliszewski, Edith Hemaspaandra, and Lane A. Hemaspaandra. 2015. Weighted Electoral Control. *Journal of Artificial Intelligence Research* 52 (2015), 507–542. https://doi.org/10.1613/jair.4621

[25] Piotr Faliszewski, Łukasz Janeczko, Dušan Knop, Jan Pokorný, Šimon Schierreich, Mateusz Słuszniak, and Krzysztof Sornat. 2025. Participatory Budgeting Project Strength via Candidate Control. In *Proceedings of the 34th International Joint Conference on Artificial Intelligence, IJCAI '25*. ijcai.org, 3821–3829. https://doi.org/10.24963/ijcai.2025/425

[26] Piotr Faliszewski, Pasin Manurangsi, and Krzysztof Sornat. 2021. Approximation and Hardness of Shift-Bribery. *Artificial Intelligence* 298 (2021), 103520. https://doi.org/10.1016/j.artint.2021.103520

[27] Piotr Faliszewski and Jörg Rothe. 2016. Control and Bribery in Voting. In *Handbook of Computational Social Choice*. Cambridge University Press, 146–168.

[28] Piotr Faliszewski, Piotr Skowron, and Nimrod Talmon. 2017. Bribery as a Measure of Candidate Success: Complexity Results For Approval-Based Multiwinner Rules. In *Proceedings of the 16th Conference on Autonomous Agents and MultiAgent Systems, AAMAS '17*. IFAAMAS, 6–14.

[29] Edith Hemaspaandra, Lane A. Hemaspaandra, and Jörg Rothe. 2007. Anyone but Him: The Complexity of Precluding an Alternative. *Artificial Intelligence* 171, 5-6 (2007), 255–285. https://doi.org/10.1016/j.artint.2007.01.005

[30] Orgad Keller, Avinatan Hassidim, and Noam Hazon. 2019. Approximating Weighted and Priced Bribery in Scoring Rules. *Journal of Artificial Intelligence Research* 66 (2019), 1057–1098. https://doi.org/10.1613/jair.1.11538

[31] Bartosz Kusek, Robert Bredereck, Piotr Faliszewski, Andrzej Kaczmarczyk, and Dušan Knop. 2023. Bribery Can Get Harder in Structured Multiwinner Approval Election. In *Proceedings of the 22nd International Conference on Autonomous Agents and Multiagent Systems, AAMAS '23*. IFAAMAS, 1725–1733.

[32] Reshef Meir, Ariel D. Procaccia, Jeffrey S. Rosenschein, and Aviv Zohar. 2008. Complexity of Strategic Behavior in Multi-Winner Elections. *Journal of Artificial Intelligence Research* 33 (2008), 149–178. https://doi.org/10.1613/jair.2566

[33] Simon Rey, Ulle Endriss, and Ronald de Haan. 2021. Shortlisting Rules and Incentives in an End-to-End Model for Participatory Budgeting. In *Proceedings of the 30th International Joint Conference on Artificial Intelligence, IJCAI '21*. ijcai.org, 370–376. https://doi.org/10.24963/ijcai.2021/52

[34] Simon Rey, Felicia Schmidt, and Jan Maly. 2025. The (Computational) Social Choice Take on Indivisible Participatory Budgeting. arXiv:2303.00621 [cs.GT]

[35] Nimrod Talmon and Piotr Faliszewski. 2019. A Framework for Approval-Based Budgeting Methods. In *Proceedings of the 33rd AAAI Conference on Artificial Intelligence, AAAI '19*. AAAI Press, 2181–2188. https://doi.org/10.1609/aaai.v33i01.33012181

[36] Yongjie Yang. 2014. Election Attacks With Few Candidates. In *Proceedings of the 21st European Conference on Artificial Intelligence, ECAI '14 (FAIA, Vol. 263)*. IOS Press, 1131–1132. https://doi.org/10.3233/978-1-61499-419-0-1131

[37] Yongjie Yang. 2019. Complexity of Manipulating and Controlling Approval-Based Multiwinner Voting. In *Proceedings of the 28th International Joint Conference on Artificial Intelligence, IJCAI '19*. ijcai.org, 637–643.

[38] Yongjie Yang. 2025. On the Complexity of Destructive Bribery in Approval-Based Multiwinner Voting. *ACM Transactions on Computation Theory* 17, 4, Article 25 (2025), 39 pages. https://doi.org/10.1145/3749377

[39] Yongjie Yang and Jiong Guo. 2015. How Hard Is Control in Multi-Peaked Elections: A Parameterized Study. In *Proceedings of the 14th International Conference on Autonomous Agents and Multiagent Systems, AAMAS '15*. IFAAMAS, 1729–1730.

[40] Michael Zuckerman, Ariel D. Procaccia, and Jeffrey S. Rosenschein. 2009. Algorithms for the Coalitional Manipulation Problem. *Artificial Intelligence* 173, 2 (2009), 392–412. https://doi.org/10.1016/j.artint.2008.11.005