Budget Pacing in Repeated Auctions: Regret and Efficiency Without Convergence

Jason Gaitonde ⊠☆

Department of Computer Science, Cornell University, Ithaca, NY, USA

Yingkai Li ☑�

Cowles Foundation, Yale University, New Haven, CT, USA

Bar Light ⊠

Microsoft Research New York City, NY, USA

Brendan Lucier ☑

Microsoft Research New England, Cambridge, MA, USA

Microsoft Research New York City, NY, USA

Abstract

Online advertising via auctions increasingly dominates the marketing landscape. A typical advertiser may participate in thousands of auctions each day with bids tailored to a variety of signals about user demographics and intent. These auctions are strategically linked through a global budget constraint. To help address the difficulty of bidding, many major online platforms now provide automated budget management via a flexible approach called budget pacing: rather than bidding directly, an advertiser specifies a global budget target and a maximum willingness-to-pay for different types of advertising opportunities. The specified maximums are then scaled down (or "paced") by a multiplier so that the realized total spend matches the target budget.

These automated bidders are now near-universally adopted across all mature advertising platforms, raising pressing questions about market outcomes that arise when advertisers use budget pacing simultaneously. In this paper we study the aggregate welfare and individual regret guarantees of dynamic pacing algorithms in repeated auctions with budgets. We show that when agents simultaneously use a natural form of gradient-based pacing, the liquid welfare obtained over the course of the dynamics is at least half the optimal liquid welfare obtainable by any allocation rule, matching the best possible bound for static auctions even in pure Nash equilibria [Aggarwal et al., WINE 2019; Babaioff et al., ITCS 2021]. In contrast to prior work, these results hold without requiring convergence of the dynamics, circumventing known computational obstacles of finding equilibria [Chen et al., EC 2021]. Our result is robust to the correlation structure among agents' valuations and holds for any core auction, a broad class that includes first-price, second-price, and GSP auctions. We complement the aggregate guarantees by showing that an agent using such pacing algorithms achieves an $O(T^{3/4})$ regret relative to the value obtained by the best fixed pacing multiplier in hindsight in stochastic bidding environments. Compared to past work, this result applies to more general auctions and extends to adversarial settings with respect to dynamic regret.

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