

Uniform Price Auctions with Budget Constrained Bidders: An Experimental Study of Two Budget Rules

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Abstract

Google's initial public offering (IPO) and Korea's emissions trading system auctions, both conducted as uniform price auctions, restrict bidders from submitting bids whose total exceeds their available budget. While simple to enforce, this sum-based rule may distort bidding incentives and reduce auction efficiency and revenue. I propose an alternative rule that applies the budget constraint to each individual bid, preserving overall fiscal discipline while allowing greater flexibility in bidding. Using controlled laboratory experiments with private values under both tight and loose budget conditions, I find that the alternative rule improves both efficiency and revenue, with the gains concentrated under tight budget conditions.

Keyword: Uniform price auction; Multi-unit auctions; Budget constraints; Demand reduction; Auction design

1. Introduction

When individual bidders cannot afford to purchase entire offerings of divisible assets, uniform price auctions enable sellers to fragment assets into multiple units and achieve broader participation. This multi-unit approach often generates higher revenue than single-bidder transactions, making such auctions attractive for a variety of applications.¹ However, accommodating financially constrained bidders introduces a fundamental design challenge: how to prevent participants from committing to payments exceeding their financial capacity while preserving competitive market dynamics.

The conventional approach to this challenge relies on *sum-based budget rules* that restrict the aggregate value of all submitted bids. The most prominent examples include Google's IPO, which explicitly warned bidders: "Do not submit bids that add up to more than the amount of money you want to invest in the IPO. This is a very important point" (Google Inc., 2004, p43) and Korea's emissions trading system, which requires upfront security deposits equal to bidders' total bid commitments. Under such rules, a bidder with budget w cannot submit bids that add up to more than w .

While administratively simple, sum-based rules can distort bidding incentives. In particular, they may induce bidders to shade early bids in order to preserve budget for later units, potentially reducing both allocative efficiency and seller revenue. This paper examines an alternative *individual bid constraint rule*, which constrains the k -th bid to be no greater than w/k . This rule relaxes restrictions on bids while still guaranteeing that a bidder's total payment cannot exceed w .²

Theoretically, it can be shown that individual bid constraints remove the incentive to shade the first-unit bid, making truthful bidding on the first unit a dominant strategy. However, this observation alone does not fully characterize bidding behavior or equilibrium outcomes, nor does it predict the magnitude of performance differences, as uniform price auctions admit multiple equilibria with varying efficiency implications. The experimental analysis therefore plays a central role, providing evidence on whether this theoretical advantage translates into measurable performance

¹ An early recognition of this principle appears in the Phillips' Plan for Outer Continental Shelf oil lease auctions, which proposed allowing bidders to submit bids on fractional working-interest shares to accommodate financially constrained participants. (Office of Minerals Policy and Research Analysis and Anderson, 1979; Wilson, 1979)

² For example, with budget $w=100$ and three shares, the sum-based rule allows only one bid of 100, while the individual constraint rule allows bids of 100, 50, and 33. If the bidder wins all three shares, the uniform price is set by the market-clearing bid and cannot exceed 33 (the bidder's lowest winning bid), ensuring total payment stays within budget.

gains. Using controlled laboratory experiments with private values, three participants competing for five identical units, and a common budget w for each, I compare the conventional sum-based rule (UPA treatment) with the individual bid constraint rule (UPA-I treatment) under both tight ($w=100$) and loose ($w=250$) budget conditions.³

The experimental evidence supports the theoretical intuition that individual bid constraints enhance truthful bidding and improve auction outcomes. Bidders in the UPA-I exhibit significantly higher rates of truthful first-unit bidding, leading to superior efficiency and revenue performance compared to the conventional approach. Importantly, these improvements are most pronounced when budget constraints bind tightly ($w=100$), where sum-based rules generate meaningful strategic distortions. Under loose budget conditions ($w=250$), performance differences become negligible, suggesting that budget rule design matters primarily when financial constraints are prevalent—precisely the settings where auction design choices have the greatest welfare consequences.

The remainder of the paper proceeds as follows. Section 2 reviews related literature on multi-unit auctions and budget constraints. Section 3 presents the theoretical framework and hypotheses. Section 4 describes the experimental procedure, and Section 5 reports the results. Section 6 concludes with a discussion of implications for auction design and regulatory policy.

2. Related literature

The uniform price auction (UPA) has been extensively studied in the economics literature, but most analyses abstract away from budget constraints. Without explicit budget limits, a key focus has been the demand reduction incentive—bidders’ tendency to shade their bids for the second and subsequent units to lower the market-clearing price. This idea can be traced back to Wilson (1979). In response to the Phillips Plan for the Outer Continental Shelf (OCS) auction—which proposed selling fractional working-interest shares to attract smaller or more risk-averse firms—Wilson warned that major firms with ample capital could exploit this multi-unit auction format by bidding strategically to reduce the sale price. While Wilson did not use the term “demand reduction,” his analysis foreshadowed the core strategic concern later formalized in the literature. Ausubel et al. (2014) show that in UPAs bidders have a generic incentive to submit bids below their

³ While some applications might be better suited to common value or affiliated value assumptions, the experiment uses private values to simplify the setting and isolate the effects of different budget rules on auction performance.

valuations for the second and later units, which can lead to poor revenue performance, even zero-revenue equilibria. Kagel and Levin (2001) confirm experimentally that bidders exercise demand reduction in laboratory UPAs, and List and Lucking-Reiley (2000) find similar behavior in a field experiment.

The present study contributes by examining budget rules in UPAs where budget constraints bind. Beyond the well-known tendency to reduce demand for second and subsequent units, binding budget limits can also induce bidders to shade their first-unit bids to conserve funds for later units. I show that an appropriately designed budget rule—such as the individual bid constraint—can mitigate this additional distortion and improve both efficiency and revenue.

While uniform price auctions have received extensive theoretical and experimental attention, research on budget-constrained bidding has been more limited and has focused primarily on other auction formats. Pitchik and Schotter (1988) analyze two-stage sequential auctions in which each bidder can strategically deplete the other's budget in the first stage. Kotowski (2011, 2020) theoretically and experimentally studies first-price auctions with private values and budgets. Ausubel et al. (2017) experimentally compare first- and second-price auctions in which budgets are endogenously determined by a financial manager. Anonymous (2022) compare the efficiency and revenue performance of first-price and proportional auctions under budget constraints. This paper contributes to this literature by experimentally examining how an alternative budget rule design affects bidding behavior and outcomes in uniform price auctions.

3. Theoretical framework and experimental design

A seller offers m identical shares without a reserve price to n risk-neutral bidders. Bidder i has a private per-share value v_i . If bidder i wins x shares, her payoff is $v_i x$. Values are independently drawn from $F(v)$. For simplicity, all bidders face a common budget w , the maximum total expenditure across the m shares.

In a uniform price auction (UPA), each bidder can submit up to m bids. The m highest bids each win one share (ties are broken at random), and every winner pays the uniform market price set by the $(m + 1)$ th highest bid, applied per share won.

This paper compares two ways to enforce the budget constraint. The conventional rule requires a bidder's submitted bids to sum to at most w ($\sum_{k=1}^m b_i^k \leq w$). This “pooled-budget” rule

mirrors guidance given in practice (e.g., Google’s IPO advice) and can be implemented via up-front deposits for all submitted bids (as in Korea’s emission-permit auctions). While practical, it is unnecessarily restrictive. I therefore study an alternative individual bid constraint rule that caps the k^{th} bid at w/k . This looser rule still respects the budget but affords more flexibility. I refer to the modified format as UPA-I.

Characterizing an equilibrium in the UPA (and UPA-I) is challenging. Multiple equilibria have been documented in prior studies (Wilson, 1979; Engelbrecht-Wiggans & Kahn, 1998; Ausubel et al., 2014), and closed-form bidding strategies are generally not available (Krishna, 2009). Thus, it is difficult to pin down a unique equilibrium prediction.

Although pinning down a precise equilibrium outcome is not feasible, prior theory identifies several qualitative properties of bidding in these formats. First, overbidding—submitting a bid above one’s valuation—is a dominated strategy in both formats. Second, there is a well-known demand-reduction incentive: bidders have an incentive to shade their bids below value for the second and subsequent units in order to depress the market-clearing price and thereby reduce payments on all winning units (Ausubel et al., 2014), a pattern also documented in laboratory and field experiments (Kagel and Levin, 2001; List and Lucking-Reiley, 2000).

The third property, which motivates the experimental design, concerns how the two budget rules shape bidding incentives across units. In the conventional UPA, the pooled budget constraint applies to the sum of all bids. This creates an incentive to conserve budget from the outset: even on the first unit, bidders may shade their bids below value to preserve funds for later units. In contrast, under the second rule (UPA-I), each k^{th} bid is capped at w/k , so lowering the first bid does not increase the allowable size of later bids. This difference has a clear theoretical implication: truthful bidding on the first unit is (weakly) dominant in UPA-I but not in UPA.

Proposition 1. In the UPA-I, bidding v_i on the first share is a dominant strategy. In the UPA, however, it is not a dominant strategy.

Proof. See Appendix A1

Beyond the first unit, demand-reduction incentives remain in both formats, but they operate differently. In UPA, the pooled budget rule makes early shading more attractive because budget savings from any unit can be reallocated to later bids. UPA-I lacks this channel, so while bidders

may still shade later bids to reduce the clearing price, they have no budgetary reason to do so on earlier units. Thus, overall, UPA provides stronger and more pervasive incentives to withhold bids early in the sequence.

To examine how these incentive differences translate into actual bidding behavior and outcomes, I implement a 2×2 experimental design that varies both the auction format (UPA vs. UPA-I) and the tightness of the budget constraint ($w=250$, “loose” vs. $w=100$, “tight”). In each auction, three bidders ($n=3$) compete for five shares ($m=5$), and each bidder may submit up to five bids. Values are independently drawn from a discrete uniform distribution on $\{1, 2, \dots, 100\}$.

The experiment tests the following hypotheses, with the expectation that differences between UPA and UPA-I will be more pronounced under the tight budget:

1. **First-unit bidding incentives.** In UPA, first-unit bids are expected to be shaded more often than in UPA-I. This is because bidding the full value on the first unit is not a dominant strategy in UPA, whereas in UPA-I it is (weakly) dominant, leading first-unit bids to more frequently match the bidder’s value.
2. **Budget binding.** The pooled budget rule in UPA is more restrictive, so bidders will more often be budget-capped than in UPA-I, which may reduce overall bidding levels.
3. **Efficiency and revenue.** If the first two hypotheses hold, UPA-I should yield higher allocative efficiency and higher seller revenue.

4. Experimental procedures

A total of six experimental sessions were conducted, three for each auction format. Between 15 and 21 subjects participated in each session.⁴ In every session, subjects first completed ten auctions under the tight budget $w=100$ and then ten auctions under the loose budget $w=250$.⁵ Each auction offered five identical shares. Subjects were assigned integer values randomly drawn from $\{1, 2, \dots, 100\}$ and were randomly re-matched into new groups for each auction. Participants

⁴ The UPA sessions had 21, 15, 21 subjects in each session, and the UPA-I sessions had 21, 18, 18 subjects in each session. A different set of subjects participated in each experimental session.

⁵ Participants were not informed in advance about the change in the budget level; it was announced only at the end of round 10. As is well known in within-subject designs, earlier conditions may influence later behavior. The tight-to-loose ordering appeared less likely to generate such carryover, since moving to a looser budget merely enlarged the feasible bid set, whereas the reverse ordering would have required subjects to unlearn bidding habits formed under a relatively slack constraint. In any case, the main objective is to compare bidding behavior under UPA and UPA-I; variation in w is included to examine how this format comparison depends on budget tightness, rather than to identify a standalone treatment effect of w itself.

could submit up to five integer bids (including zero) but were not required to submit bids for all five shares.

In the UPA, the sum of a subject's bids could not exceed the budget constraint. In the UPA-I, the cap applied to each bid individually: under $w=100$, the maximum bids were (100, 50, 33, 25, 20) for the first through fifth shares, respectively; under $w=250$, the limits were (250, 125, 83, 62, 50).

All sessions began with three practice rounds in which every subject was assigned the same values and bid against two computerized bidders programmed with fixed bidding strategies. Using computerized bidders ensured that all participants faced an identical bidding environment and thus received a uniform initial experience. By the start of the main auctions, subjects had familiarized themselves with the interface, budget rules, and feedback structure.

Bidders were given one minute to submit bids in each auction. Each subject received an initial balance of 500 experimental currency units (ECUs). Earnings were added to, and losses deducted from, this balance. The instructions informed participants that losses were possible; however, the instructions did not provide specific guidance on how they could be avoided, and no bidding restrictions were imposed to prevent them. Participants who went bankrupt would be dismissed and receive only the show-up fee, but no bankruptcies occurred.

After each auction, participants received feedback showing all values, bids, allocations, payments, and earnings. All amounts were denominated in ECUs, with final earnings converted to U.S. dollars at a rate of 100 ECUs = \$1. In addition to their experimental earnings, each subject received a \$4 show-up fee. Average total earnings were \$17.75 per subject in the UPA and \$17.36 in the UPA-I. Each session lasted about 1.5 hours.

The experiment was conducted at the Ohio State University Experimental Economics Laboratory. Subjects were recruited through ORSEE (Greiner, 2004) and were generally undergraduate students from a range of disciplines. No participant took part in more than one session. The experiment was computerized and implemented in z-Tree (Fischbacher, 2007).

5. Experimental results

5.1 First-Unit Bidding: Truthful Bidding versus Strategic Shading

The key theoretical distinction between UPA and UPA-I concerns the incentive to shade first-unit bids. In the UPA, a bidder can free up budget for later units by reducing the first bid,

making truthful bidding non-dominant. In the UPA-I, each bid's cap is independent, so lowering the first bid confers no budgetary advantage. Proposition 1 establishes that truthful bidding on the first unit is a dominant strategy in the UPA-I but not in the UPA. The data are broadly consistent with this prediction: first-unit truthful bidding is more frequent in the UPA-I, with the difference more pronounced under $w=100$. More generally, the underlying intuition applies under both budget levels, as the incentive to shade the first bid below value remains stronger in the UPA.

Figure 1 shows the distribution of overbids, truthful bids, and underbids across all five shares for each format and budget level. Under $w=100$, bidders submitted their true value on the first share 19.5% of the time in the UPA, compared to 24.6% in the UPA-I. The raw difference in truthful bidding rates is modest, but it understates the behavioral divergence. In the UPA, the majority of the remaining first-unit bids are underbids: 55.1% of first bids fall below value, consistent with bidders strategically conserving budget for later shares. In the UPA-I, by contrast, underbidding on the first unit is far less prevalent (21.4%), and the main deviation from truthful bidding takes the form of overbidding (54.0%), suggesting a markedly different response pattern under UPA-I—a pattern examined in detail in Section 5.4.⁶

⁶ Overbidding is theoretically irrational and is not a central prediction of our model. As it is more naturally attributed to behavioral factors, we defer its discussion to Section 5.4, where we also present bid plots that illustrate the full distribution of submitted bids.

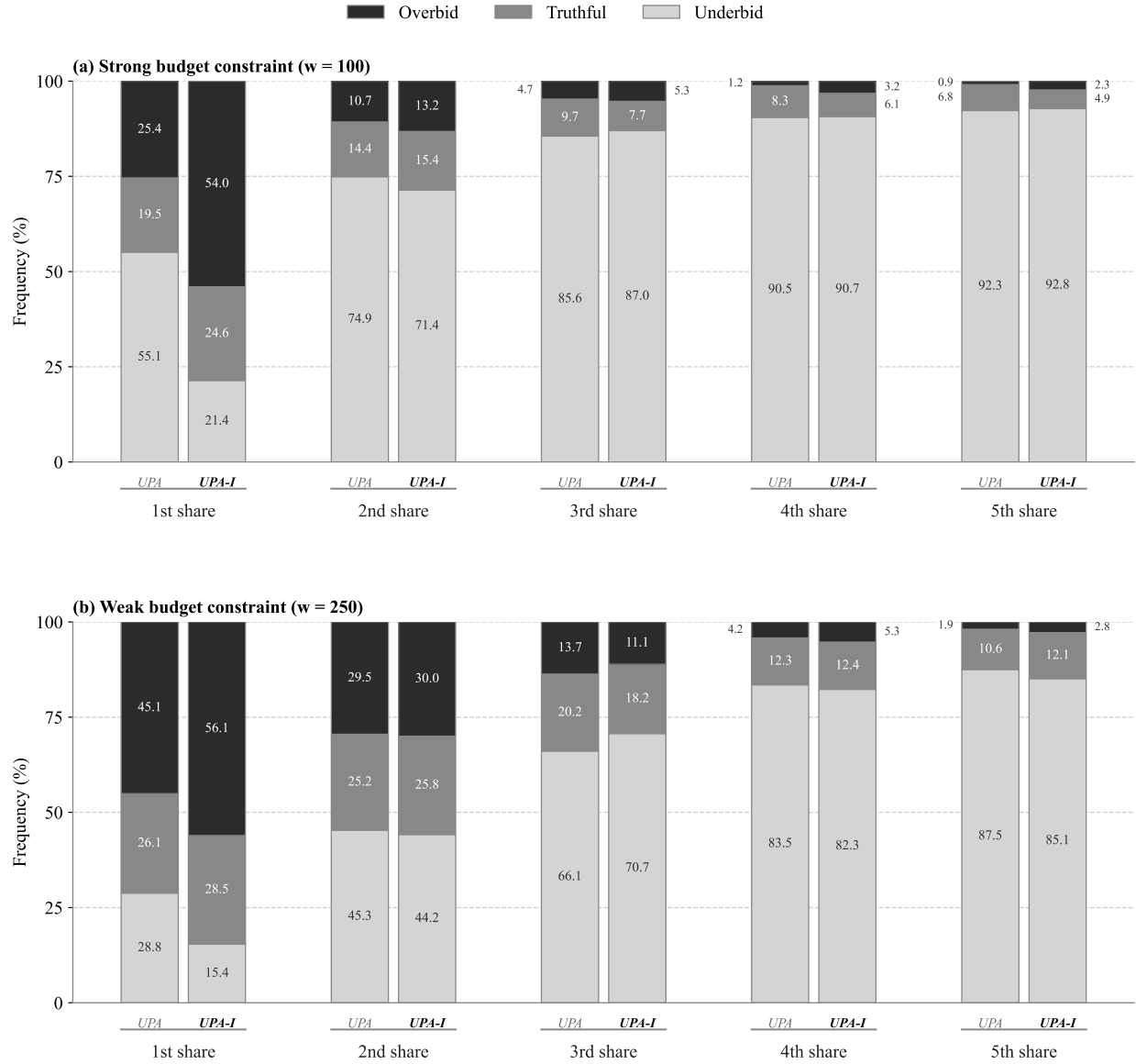


Figure 1. Truthful bidding and deviations by share and auction format

Notes: Overbids are defined as bids exceeding the bidder's value by more than 2 ECU. Truthful bids are those within ± 2 ECU of value and underbids are bids below value by more than 2 ECU. Values inside bars denote frequency in percentage.

Figure 2 provides a closer look at first-unit truthful bidding as a function of the bidder's value under $w=100$. In the UPA, high-value bidders (value above 60) almost never bid their true value on the first share: the budget-conservation incentive is strongest for precisely these bidders, since their true value would exhaust a large fraction of the total budget if submitted. In the UPA-I, high-value bidders bid truthfully at rates broadly comparable to low-value bidders, consistent with the absence of a budget-conservation incentive.

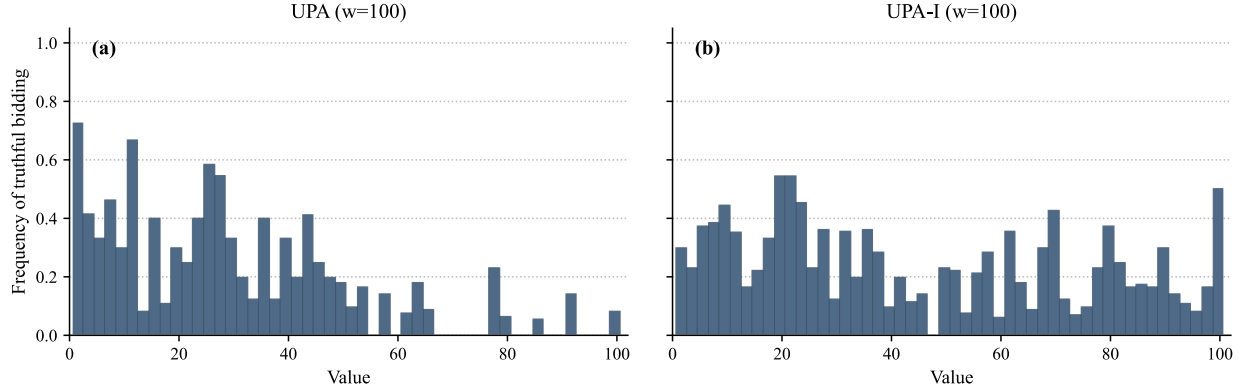


Figure 2. Frequencies of truthful bid on the first share by bidder's value

Under $w=250$, the budget-conservation motive that differentiates UPA from UPA-I in first-unit bidding becomes weaker, though it does not disappear entirely. With a more generous budget, the incentive to conserve funds on the first unit is reduced, and truthful bidding rates on the first share are similar across formats (26.1% in UPA vs. 28.5% in UPA-I). Even so, as Figure 1 shows, underbidding on the first unit remains somewhat more prevalent in the UPA (28.8%) than in the UPA-I (15.4%), suggesting that the budget-conservation motive does not vanish entirely—it simply diminishes as the constraint relaxes. Overbidding also remains substantial under both formats (45.1% in UPA and 56.1% in UPA-I), a pattern examined in greater detail in Section 5.4.

For second and subsequent units, bidding patterns in the two formats appear broadly similar. In both UPA and UPA-I, bids drop sharply below value from the second share onward, with underbidding remaining high on later shares. This pattern is consistent with the well-documented demand reduction incentive in uniform price auctions: bidders shade later bids to lower the market-clearing price, a pattern observed in prior laboratory and field experiments (Kagel and Levin, 2001; List and Lucking-Reiley, 2000). However, while the aggregate patterns look similar, the underlying strength and sources of bid shading may differ across formats; Section 5.2 examines these differences by analyzing budget binding and demand reduction in more detail.

Result 1 (First-unit bidding). Under $w=100$, first-unit bids in the UPA were significantly less truthful and more often shaded below value than in the UPA-I, with the effect most pronounced among high-value bidders. This is consistent with the budget-conservation incentive present in the UPA but absent in the UPA-I. Under $w=250$, the difference between formats is reduced—truthful

bidding rates converge across formats—but a gap in underbidding rates remains, indicating that the effect of budget rule design persists even under a looser constraint, albeit attenuated.

5.2 Budget Binding and Demand Reduction

Budget binding

Figure 3 plots the frequency of budget binding—cases where a submitted bid reaches or nearly exhausts the applicable limit—as a function of the bidder's value, separately for both formats under each budget level.⁷ Under $w=100$, budget binding occurs at lower values in the UPA than in the UPA-I. As shown in Figure 3(a), the majority of bidders with values above roughly 40 are budget-bound in the UPA, and this proportion remains high across higher values. In the UPA-I, a comparable level of binding is not observed until values approach 60. This reflects the stricter nature of the sum-based budget rule: high-value bidders in the UPA deplete their total allowance earlier in the bid sequence, compressing their ability to compete on later units—effectively making it harder to accommodate high-value bidders.

Under $w=250$, budget binding is rare for low-value bidders in both formats. As values increase, binding becomes more prevalent in the UPA, while the UPA-I maintains consistently low binding rates across most of the value range. The gap between the two formats widens notably at higher values, underscoring that the individual cap structure of the UPA-I meaningfully relaxes the effective constraint precisely for those bidders—high-value bidders—for whom accommodation matters most.

⁷ Budget binding is defined as using at least 98% of the applicable cap. In the UPA under $w=100$ ($w=250$), this means less than 2 (5) ECU remaining from the pooled budget. In the UPA-I, a bidder is classified as budget-bound if at least one individual share bid reaches 98% of the corresponding per-share cap. The 98% threshold is used rather than exact exhaustion because bidders tend to submit bids in multiples of 5 ECU, which can leave a small residual even when the budget is effectively fully utilized.

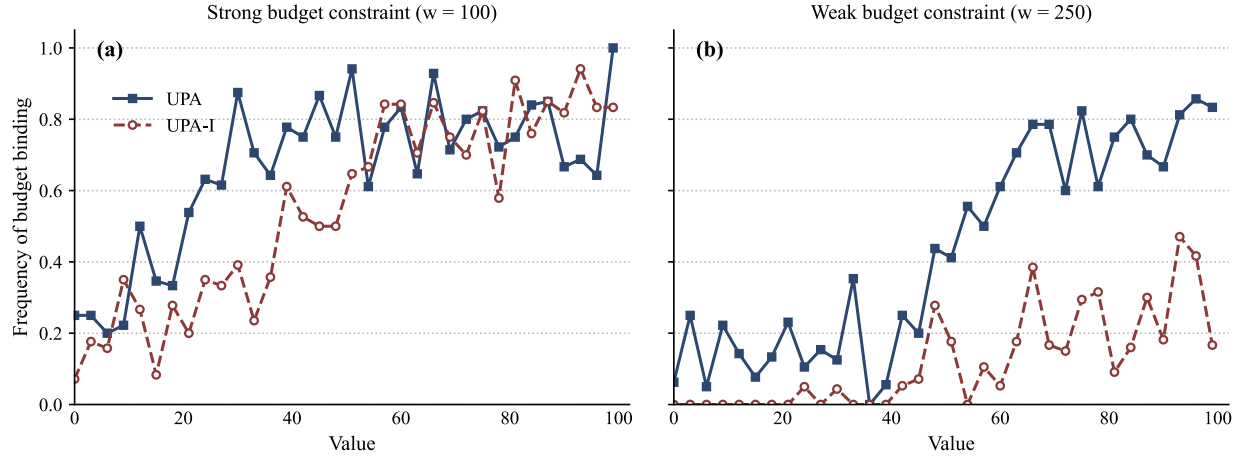


Figure 3. Frequencies of budget binding

Notes: Each data point represents the average over three consecutive values for visual clarity.

Demand reduction on subsequent units

Figures 4 and 5 decompose underbidding across shares into two categories: (i) intended demand reduction, where the bidder had sufficient remaining budget to bid higher but chose not to; and (ii) budget-forced reduction, where the remaining budget was insufficient to submit a higher bid. Each figure fixes the budget level and compares UPA (panel a) against UPA-I (panel b), so that differences across panels directly reflect the effect of the budget rule. This distinction is important because only intended underbidding reflects the strategic incentive to suppress the market-clearing price; budget-forced reduction is a mechanical consequence of the budget constraint.

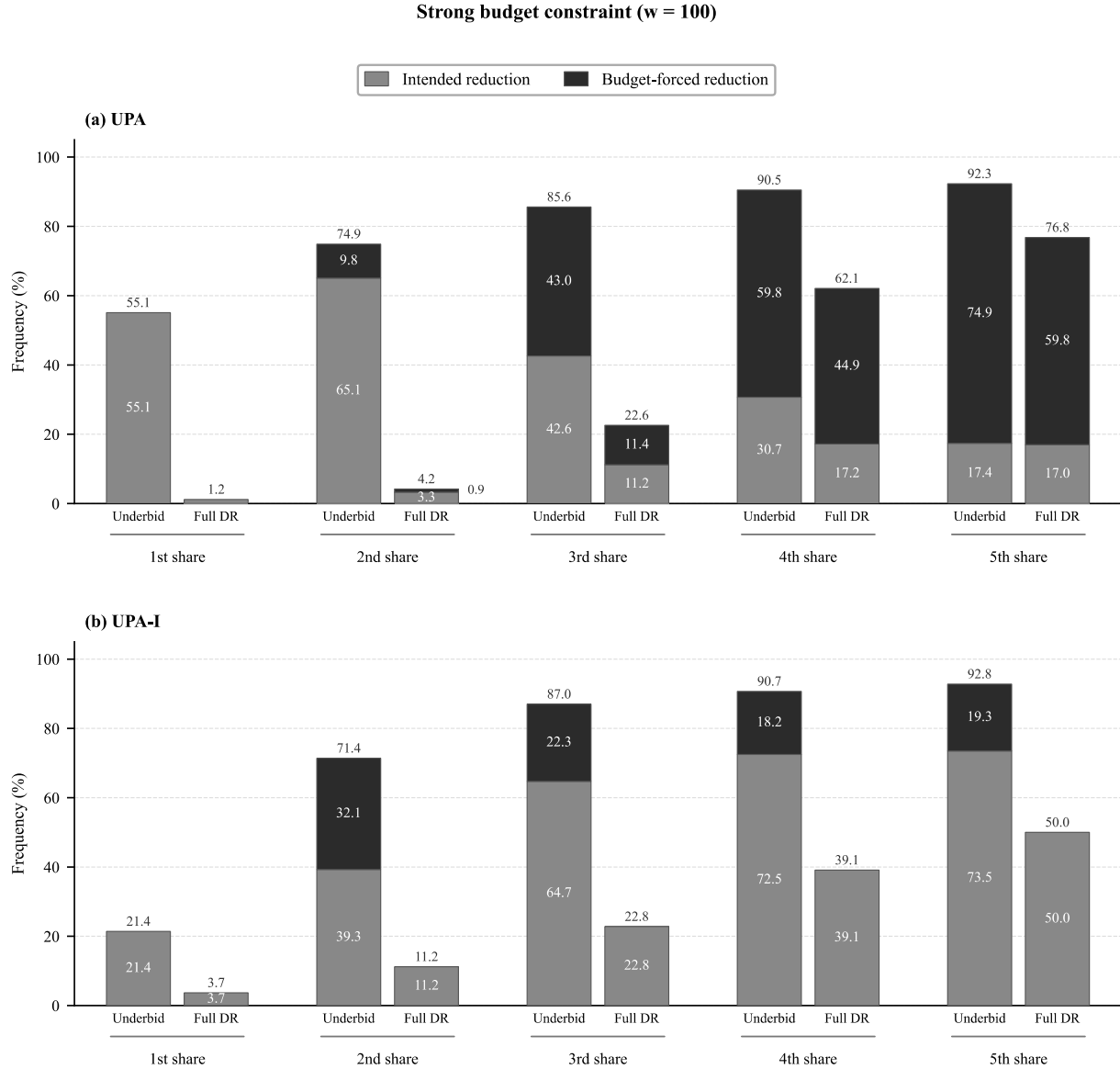


Figure 4. Decomposition of demand reduction motive ($w=100$)

Figure 4 presents results under the tight budget constraint ($w=100$). In the UPA (panel a), demand reduction on the second share is predominantly intentional: 65.1% of underbids reflect a deliberate choice to shade the bid, with only 9.8% budget-forced. This pattern is consistent with bidders strategically conserving funds from early shares to sustain bidding capacity on later ones.

As the sequence progresses, however, the composition shifts markedly. By the third share, budget-forced reduction already accounts for roughly half of all underbidding (43.0% out of 85.6%), indicating that budget exhaustion begins to bind well before the final units. Full demand reduction—zero bids—tells the same story: on the third share, about half of zero bids are budget-

driven (11.4% out of 22.6%). By the fourth and fifth shares, budget-forced reduction becomes the dominant motive, accounting for 59.8% and 74.9% of all underbids respectively, while full demand reduction rises sharply to 62.1% and 76.8%—with the vast majority attributable to budget exhaustion (44.9% and 59.8%). Together, these patterns reveal how a tight pooled budget progressively strips away bidders' ability to compete on later units, converting what begins as strategic demand reduction into largely involuntary withdrawal.

The UPA-I (panel b of Figure 4) tells a strikingly different story under $w=100$. On the second share, budget-forced reduction is already substantial at 32.1%—more than three times the corresponding UPA figure (9.8%)—while intended underbidding falls to 39.3% (from 65.1% in the UPA). Importantly, this high rate of budget-forced reduction does not reflect prior budget exhaustion. Rather, it reflects the incentive structure of the individual cap itself: because each share's bid is capped independently, bidding aggressively on the second share does not reduce the budget available for later shares. Bidders therefore have no reason to hold back, and many high-value bidders bid up to the per-share cap ($w/2 = 50$) directly—resulting in budget-forced reduction not from running out of funds, but from bidding competitively within the cap.

From the third share onward, the budget-forced share remains large but the intended component actually dominates: bidders continue to shade for price-suppression reasons even when caps are not binding. Crucially, full demand reduction is substantially less common in the UPA-I than in the UPA—39.1% and 50.0% on the fourth and fifth shares, compared to 62.1% and 76.8% in the UPA—confirming that the individual caps, despite binding frequently on early shares, preserve meaningful bidding competition through the full sequence.

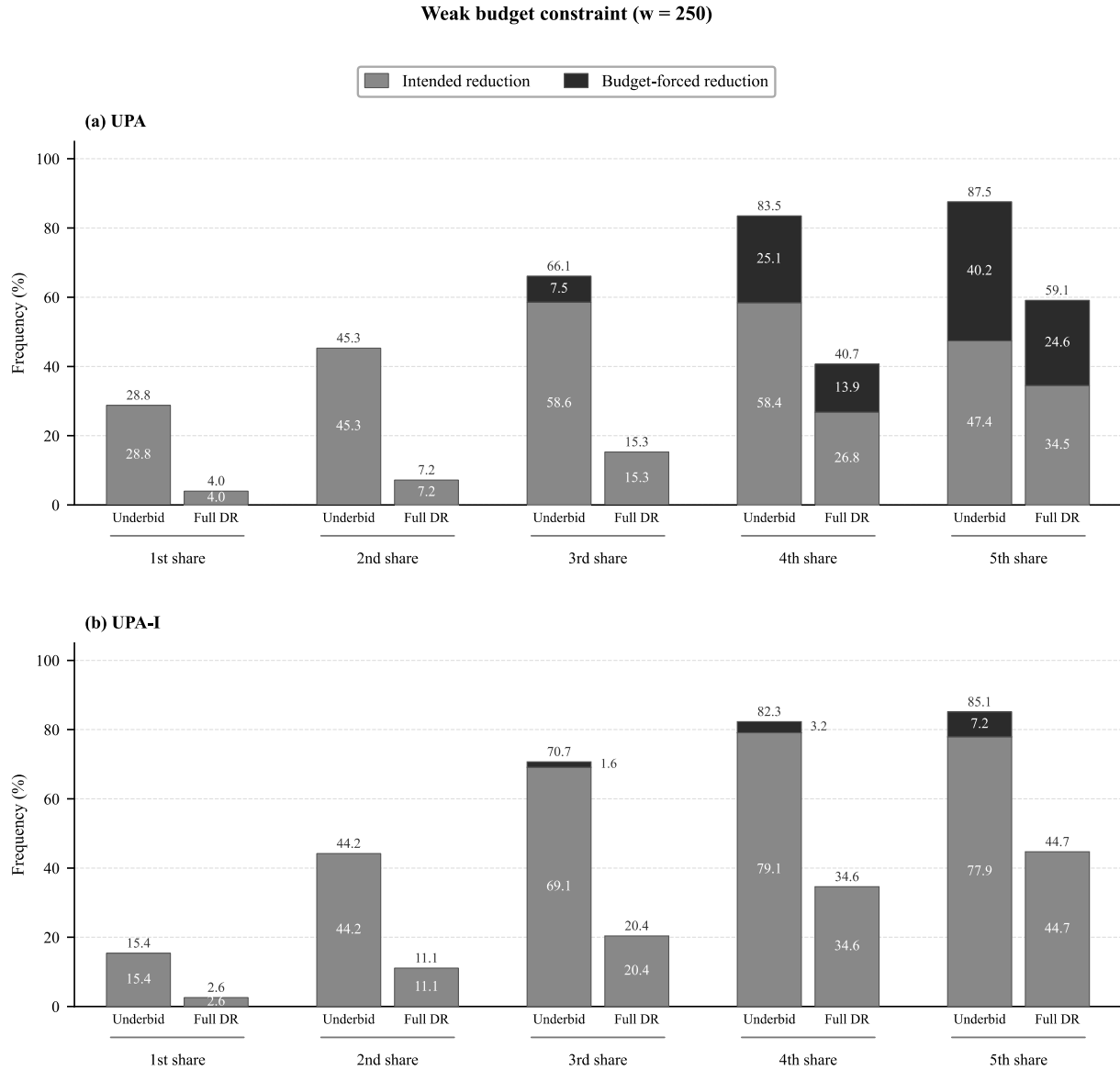


Figure 5. Decomposition of demand reduction motive ($w=250$)

Figure 5 turns to the loose budget ($w=250$). In the UPA (panel a), the overall pattern is similar in structure to $w=100$ but less extreme. Intended underbidding on the second share stands at 45.3%, down from 65.1% under $w=100$, reflecting the diminished incentive to conserve budget when the constraint is looser. Budget-forced reduction remains negligible on the second and third shares but rises on the fourth (25.1%) and fifth (40.2%), as even a generous budget eventually becomes depleted across five bids. Full demand reduction accumulates on later shares—40.7% on the fourth and 59.1% on the fifth—with both intended and budget-forced components contributing.

In the UPA-I under $w=250$ (panel b of Figure 5), the pattern is particularly clear: budget-forced reduction is nearly absent throughout the sequence, remaining below 8% even on the fifth share (1.6%, 3.2%, and 7.2% on the third through fifth shares). With the more generous per-bid caps, the individual limits rarely bind, and virtually all underbidding reflects the standard price-suppression motive rather than mechanical budget constraints. This stands in contrast to both the UPA under $w=250$ —where budget-forced reduction rises substantially on the fourth and fifth shares—and to the UPA-I under $w=100$, where the tighter caps generated forced reduction even in early bids. Intended underbidding in the UPA-I under $w=250$ rises steadily to 77.9% on the fifth share, yet full demand reduction on the fourth and fifth shares remains well below the UPA counterparts, indicating that later bids are strategically shaded rather than mechanically compressed by binding budget limits.

Comparing across the two figures reveals the key interaction between budget tightness and auction format. In the UPA, tightening the budget from $w=250$ to $w=100$ sharply amplifies both intended underbidding on early shares (as bidders more aggressively conserve) and budget-forced reduction on later shares (as budgets deplete sooner). In the UPA-I, the same change in budget tightness has a different profile: budget-forced reduction rises on early shares because the per-bid caps become more restrictive, but intended underbidding is largely unaffected across the sequence—since the budget-conservation channel is closed regardless of w . The UPA-I thus absorbs tighter budgets through mechanical bid compression rather than strategic conservation, and does not produce the budget exhaustion that drives zero bids on later shares in the UPA.

Result 2 (Budget binding and demand reduction). Budget binding was more frequent in the UPA than in the UPA-I, particularly among high-value bidders. Under the tight budget ($w=100$), demand reduction in the UPA on early shares was predominantly intentional, reflecting strategic budget conservation; on later shares, budget exhaustion took over and drove high rates of zero bids. The UPA-I showed more budget-forced reduction on early shares—not because of budget exhaustion, but because bidders had no incentive to hold back and bid aggressively up to the per-share cap. Under the loose budget ($w=250$), the influence of the budget constraint became much weaker overall. In the UPA, however, budget exhaustion still appeared on later shares, whereas in the UPA-I the individual caps rarely bound and underbidding largely reflected strategic demand reduction rather than mechanical constraints.

5.3 Efficiency and Revenue

The behavioral differences documented in Sections 5.1 and 5.2 translate directly into differences in allocative efficiency and seller revenue. Tables 1 and 2 report session-level averages for these outcomes, and the Appendix A2 presents regression estimates with session-clustered standard errors.

Table 1. Realized efficiency

	Session 1		Session 2		Session 3		All	
	UPA	UPA-I	UPA	UPA-I	UPA	UPA-I	UPA	UPA-I
w=100	76.7% (1.52%)	79.7% (1.51%)	74.8% (1.79%)	79.0% (1.63%)	74.1% (1.41%)	80.8% (1.31%)	75.2% (0.9%)	79.8% (0.9%)
w=250	82.9% (1.73%)	84.0% (1.61%)	80.3% (2.03%)	82.4% (1.69%)	78.9% (1.87%)	82.8% (1.82%)	80.8% (1.1%)	83.2% (1.0%)

Note: Parentheses are standard errors of the mean

Table 2. Realized Revenue

	Session 1		Session 2		Session 3		All	
	UPA	UPA-I	UPA	UPA-I	UPA	UPA-I	UPA	UPA-I
w=100	20.6 (0.97)	30.8 (1.45)	21.4 (1.31)	23.3 (1.53)	21.6 (1.09)	28.3 (1.54)	21.2 (0.64)	27.6 (0.89)
w=250	45.0 (2.27)	43.7 (2.35)	42.7 (3.48)	37.9 (2.52)	40.6 (2.49)	47.8 (2.55)	42.8 (1.54)	43.2 (1.45)

Note: Parentheses are standard errors of the mean. The numbers are in ECUs

Under $w=100$, the UPA-I outperformed the UPA on both dimensions. The efficiency advantage was sharp: every UPA-I session achieved higher efficiency than every UPA session, so that even the lowest UPA-I session (79.0%, Session 2) exceeded the highest UPA session (76.7%, Session 1). A Mann-Whitney test using session averages as the unit of observation confirmed the significance of this difference ($p<0.05$). The revenue advantage followed the same pattern: the lowest UPA-I revenue session (23.3 ECUs, Session 2) exceeded the highest UPA revenue session (21.6 ECUs, Session 3), and the Mann-Whitney test was again significant ($p<0.05$). Regression analysis confirms these findings: under $w=100$, the UPA-I achieved 4.6 percentage points higher efficiency and 6.479 ECU higher revenue on average, both significant at the 5% level (Appendix A2).

Under $w=250$, the efficiency and revenue advantage of the UPA-I effectively disappears. Session-level rankings were mixed, and neither the Mann-Whitney tests (efficiency: $p=0.14$; revenue: $p=0.413$) nor the regression estimates reached conventional significance levels. The UPA-I's regression-estimated advantage shrank to 2.4 percentage points in efficiency and 0.379 ECU in

revenue. These results confirm that the design improvement is most valuable when the budget constraint is tight, precisely the setting where the pooled budget rule's distortions are most severe.

Result 3 (Efficiency and revenue). Under $w=100$, the UPA-I achieved significantly higher allocative efficiency and seller revenue than the UPA, with no session-level overlap between formats. Under $w=250$, differences were small and statistically insignificant. The improvement from the individual bid constraint rule is concentrated in the tight-budget regime where the pooled budget rule distorts high-value bidders most severely.

5.4 Overbidding and Bid Dispersion: Evidence from Bid Plots

This section examines bid-level patterns using scatter plots. Figures 6 and 7 display bids for all five shares under $w=100$ and $w=250$, respectively, with the UPA shown in the upper panels and the UPA-I in the lower panels. The 45-degree line indicates truthful bidding. While the earlier analysis focused on the strategic and mechanical sources of underbidding, these plots reveal the full distribution of submitted bids across the value range. In particular, they highlight patterns—such as overbidding—that are not captured by the demand-reduction decomposition and cannot be explained by standard theoretical predictions, allowing us to consider behavioral motives alongside the strategic mechanisms examined earlier.

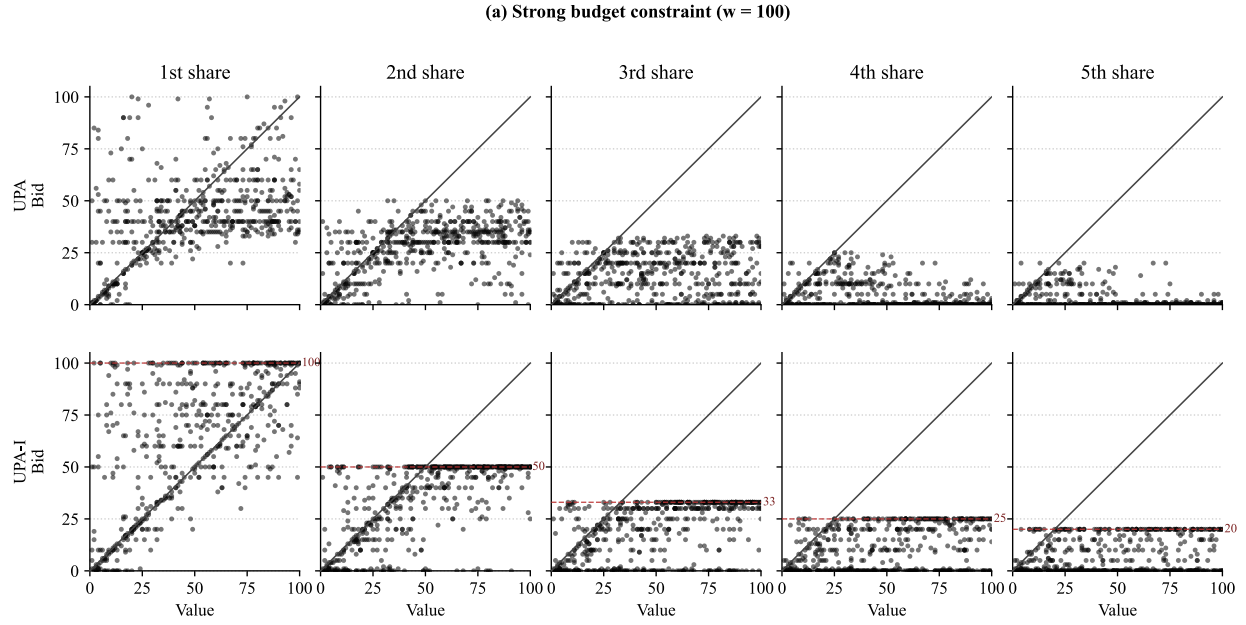


Figure 6. Bid plots in UPA and UPA-I ($w=100$)

Figure 6 presents bid plots under $w=100$. As already suggested by the aggregate statistics in Section 5.1, the first share exhibits a clear contrast between the two formats.

In the UPA (upper panels), bids from mid-to high-value bidders fall predominantly below the 45-degree line, scattered in the 30–60 range regardless of true value. These bidders submit bids well below their values on the first share, consistent with the strategic incentive to conserve budget for later units under the pooled constraint—a visual counterpart to the 55.1% underbidding rate documented in Section 5.1. As a result, the usual positive relationship between values and bids weakens in this region, indicating that the pooled budget rule can distort the ranking of bids and potentially reduce allocative efficiency.

In the UPA-I (lower panels), bids on the first share are more dispersed around the 45-degree line, reflecting the absence of any budget-conservation incentive. A particularly striking feature is the concentration of bids at or near 100: approximately 21% of first-share bids are extreme overbids (bids of 98–100), accounting for nearly half of the 54.0% overbidding rate identified in Section 5.1. At first glance, this behavior appears irrational. However, from an individual bidder's perspective, a single overbid on one unit is unlikely to crucially affect the market-clearing price, leaving the probability of paying above one's value low. The overbid thus functions as an attempt to secure the first unit with limited downside risk.

This type of overbidding is not unique to the current experiment and has been documented across theoretical, experimental, and empirical settings. Levin (2005) develops a theoretical framework in which very high bids on early units can arise in equilibrium in certain environments. In the laboratory, Kagel and Levin (2001) report similar high-bid behavior in uniform-price auctions. In the field, Delaney and Sidel (2004) and Jagannathan et al. (2015) describe incentives to submit very high bids for a small number of units in uniform-price IPO auctions, such as Google's IPO.⁸ The current experiment documents a similar pattern of extreme overbidding.

For the second through fifth shares, the underbidding patterns described in Section 5.2 become clearly visible. In the UPA, bids for the second share still show relatively limited budget binding or full demand reduction, but high-value bidders visibly shade their bids below value, consistent with efforts to conserve budget. By the third share, full demand reduction becomes more prevalent, and the positive relationship between value and bids largely disappears: bids scatter almost randomly in the 0–30 range regardless of true value. As documented in Section 5.2, this is largely budget-forced rather than strategic—bidders who bid aggressively on earlier shares find their remaining budget insufficient to sustain competitive bids on later units. On the fourth and fifth shares, this pattern intensifies to the point where the value-bid relationship reverses: high-value bidders frequently submit lower bids than low-value bidders, and zero bids become common. This inversion illustrates how the pooled budget rule can substantially distort both bidding behavior and auction outcomes.

By contrast, the effect of the individual bid caps in the UPA-I becomes immediately apparent in the lower panels. Bids cluster densely at the cap: at 50 on the second share, 33 on the third, 25 on the fourth, and 20 on the fifth. These concentrations reflect the absence of any incentive to hold back—because the cap applies independently to each bid, bidders have no reason to conserve budget for later shares and instead bid as competitively as the cap permits. As a result, the positive relationship between values and bids is better preserved than in the UPA, and the collapse of bids to zero on later shares is much less pronounced.

⁸ Jagannathan et al. (2015) describe such extremely high bids in IPO auctions as a form of free-riding on the price discovery process. In this setting, bidders submit noncompetitive (i.e., arbitrarily high-priced) bids that place them first in line for shares while having little effect on the clearing price.



Figure 7. Bid plots in UPA and UPA-I ($w=250$)

Figure 7 presents bid plots under $w=250$. Compared to Figure 6, the differences between the two formats are considerably less pronounced, consistent with the intuition that the budget rule matters less when the constraint is not tight.

On the first share, bidding patterns in the two formats are broadly similar. In the UPA, very high-value bidders still shade their bids somewhat below value, reflecting the residual budget-conservation incentive, but the degree of underbidding is far less severe than under $w=100$. A notable feature common to both formats is the prevalence of extreme overbids at or near 100. Such bids account for 17.2% of bids in the UPA and 21.2% in the UPA-I—roughly one-third of the overall overbidding rates (45.1% and 56.1%, respectively). As discussed above, these extreme bids reflect an attempt to secure the first unit while having little expected effect on the clearing price.

On the second share, the budget constraint remains largely non-binding, and the overall bidding pattern is broadly similar to that of the first share. One visible change, however, is that extreme overbids at or near 100 become noticeably less frequent, falling to 6.1% in the UPA and 10.2% in the UPA-I. Overall overbidding also declines to 29.5% and 30.0%, respectively.

For the third through fifth shares, the two formats continue to display broadly similar patterns, though some differences remain visible. On the third share, the positive relationship between values and bids is largely preserved, though full demand reduction becomes increasingly common, indicating strategic bid shading aimed at lowering the market-clearing price. On the fourth and

fifth shares, some clustering at the bid cap appears in the UPA-I as bidders continue to bid competitively up to the allowed limit. In the UPA, by contrast, high-value bidders occasionally appear unable to sustain similarly high bids, suggesting that some bidders have already expended much of their budget earlier in the sequence—an effect that is particularly visible on the fifth share.

Overall, however, the influence of the budget constraint is substantially weaker than under $w=100$, and the differences in bidding behavior between the two formats are correspondingly muted. This suggests that when the budget constraint is not tight, the choice of budget rule has a more limited effect on bidding behavior and auction outcomes.

Result 4 (Bid-level patterns). Under $w=100$, the two formats exhibit strikingly different bidding patterns. In the UPA, first-unit bids are compressed well below the 45-degree line, reflecting deliberate budget conservation, and the value–bid relationship progressively breaks down on later shares as budget exhaustion increasingly forces bidders to submit low or zero bids. In the UPA-I, extreme overbids cluster at or near 100 on the first share, and bids on subsequent shares cluster at the individual caps—confirming that bidders compete up to the cap with no incentive to hold back. Under $w=250$, these differences largely disappear: both formats show broadly similar bidding patterns across all shares, with extreme overbidding present in both, consistent with the diminished influence of the budget rule when the constraint is not tight.

6. Discussion

This paper experimentally studies the effects of two budget rules on the uniform price auction: one conventionally adopted in practice, and one proposed in this paper. The conventional rule—employed in settings such as Google's IPO and Korea's emissions trading auction—prevents a bidder from submitting bids whose sum exceeds the budget. Although straightforward and easy to implement, the rule is unnecessarily restrictive. The alternative rule proposed here restricts a bidder's k th bid to no more than the budget divided by k . Although it appears more complex, the rule is implementable⁹ and strictly more lenient than the conventional rule.

The experimental results show that the alternative rule improves both allocative efficiency and seller revenue relative to the conventional rule, with the magnitude of improvement depending

⁹ The auctioneer can request a security deposit that is equal to $\max_k (b_i^k \times k)$

critically on budget tightness. Under the tight budget constraint ($w=100$), the gains are economically meaningful and statistically significant. The conventional rule heavily distorts the bidding behavior of high-value bidders, who underbid substantially even on the first share in order to conserve budget for later units, yet often exhaust their budgets early and are therefore forced to submit very low bids on later shares. By contrast, the individual bid constraint removes the need to conserve budget across bids, allowing bidders to compete more aggressively on early units while retaining bidding capacity on later ones.

Under the looser budget constraint ($w=250$), however, the improvement becomes only marginal and statistically insignificant. In this regime the pooled-budget rule binds less frequently, and the two formats generate broadly similar bidding behavior and auction outcomes. These findings suggest that the benefits of the alternative rule arise primarily in environments where bidders face meaningful financial constraints.

Several directions for future research remain. One important extension would be to examine how the proposed rule performs in environments with common or affiliated values, where strategic considerations differ from those in private-value settings. Another natural extension would be to consider heterogeneous budget constraints across bidders, which are common in real-world auctions. Finally, further research could explore the external validity of these results by examining how frequently bidders are actually budget constrained in field settings or by testing the alternative rule in large-scale field experiments.

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Appendix

A.1 Theoretical predictions in UPA, UPA-I.

Proposition 1. In the UPA-I, bidding v_i on the first share is a dominant strategy. In the UPA, however, it is **not** a dominant strategy.

Proof. In both auctions, bidding above v_i can only result in winning additional units when the market-clearing price exceeds v_i , in which case the bidder incurs a loss on those units. Hence such bids are weakly dominated by bidding exactly v_i .

In the UPA-I, lowering the first bid below v_i neither increases the bidder's ability to bid more aggressively on subsequent shares nor affects the price he pays, since the first bid does not determine the market-clearing price when the bidder wins that unit. The only effect of shading the first bid is to reduce the probability of winning a share that is worth v_i , thereby reducing the bidder's chance of earning a positive payoff. Accordingly, bidding v_i on the first share is a dominant strategy in the UPA-I.

In the UPA, by contrast, the budget constraint applies to the **sum** of all bids. This creates an incentive to shade the first bid in order to reserve budget for subsequent bids, which can increase total quantity won and total payoff. A simple example illustrates this.

Example. Consider a UPA with $n=2$ bidders and $m=2$ identical shares. Each bidder has a budget $w=100$. Bidder i 's value is $v_i=100$ per share, while bidder j 's value is $v_j=40$ per share. Suppose bidder j bids truthfully on both shares: 40 on the first share and 40 on the second, for a total bid of $80(\leq w)$.

Case 1 – Truthful first bid:

Bidder i bids 100 on the first share and 0 on the second (using her full budget on the first unit). The two winning bids are $100(i)$ and $40(j)$. The market price is 40, so bidder i wins one share, pays 40, and earns $100-40=60$.

Case 2 – Shaded first bid:

Bidder i bids 50 on the first share and 50 on the second (splitting the budget evenly). The winning bids are $50(i)$ and $50(i)$, with the market price again 40. Bidder i now wins both shares, pays $2 \times 40 = 80$, and earns $200 - 80 = 120$.

The shaded first bid yields strictly higher profit, demonstrating that truthful bidding on the first share is **not** dominant in the UPA. The reason is straightforward: with a pooled budget constraint, an excessively high first bid can waste budget that could have been used to secure additional units at the same clearing price.

A.2 Regression analysis for efficiency and revenue

Efficiency and revenue with auction format dummy variables				
VARIABLES	Efficiency (w=100)	Efficiency (w=250)	Revenue (w=100)	Revenue (w=250)
Period	0.002 (0.001)	0.006** (0.002)	0.040 (0.163)	-0.095 (0.342)
UPA-I	0.046*** (0.009)	0.024 (0.012)	6.479** (2.022)	0.379 (2.741)
Constant	0.739*** (0.014)	0.772*** (0.017)	20.941*** (0.807)	43.311*** (2.703)
Observations	380	380	380	380
R-squared	0.038	0.024	0.085	0.000

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

This table shows regression results of efficiency and revenue with dummy variables for auction formats and clustering errors at the session level. The base treatment is the UPA.

Hypotheses predict that the UPA-I achieves a higher efficiency and revenue than the UPA. Under $w=100$, the UPA-I achieved 4.6% higher efficiency and 6.479 higher revenue. Both differences were statistically significant ($p<0.05$). Under $w=250$, the UPA-I achieved 2.4% higher efficiency and 0.379 higher revenue. However, these differences are slight and not statistically significant. This implies that the improvement of the UPA-I in response to its relaxed rule is only effective when the budget constraint is tight.