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ABSTRACT

Central counterparties (CCPs) are systemically important. When a clearing member defaults, the CCP sells the defaulted portfolio to surviving members in an auction, and losses, if any, are partly absorbed by a cash pool prefunded by the surviving members. We propose a tractable auction model that incorporates this salient feature. We find that “juniorization” – the CCP first uses prefunded cash of members who submit bad bids – increases the auction price. However, too aggressive juniorization can reduce members’ total profit, presenting a misalignment between the CCP’s objective and that of the members. A wider customer participation can increase both the auction price and the total profit of members and customers.

1. Introduction

A central counterparty (CCP) stands between a buyer and a seller in a derivatives trade or securities financing transaction, protecting the two parties from each other’s default. Since the financial crisis of 2008–09 and the ensuing central clearing mandate for standardized over-the-counter derivatives, CCPs have grown substantially in size and scope and become systemically important.¹ As of end-2022, about \$373 trillion notional amount of interest rate derivatives are cleared by CCPs, with a gross market value of about \$10 trillion (BIS, 2023).

A CCP may come under stress when a clearing member defaults, at which point the CCP inherits the defaulted portfolio and its directional exposure. If market prices continue to move against the defaulted portfolio, the CCP is obligated to make payments to the other side, though it no longer receives payment from the defaulted member. In a market turmoil that can push a clearing member into default, the CCP’s directional exposures can quickly lead to large losses that threaten its own stability and the stability of the financial system.

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¹ In 2012, the Financial Stability Oversight Council of the United States designated eight systemically important financial market utilities: The Clearing House Payment Company, CLS Bank International, Chicago Mercantile Exchange, the Depositor Trust Company, Fixed Income Clearing Corporation, ICE Clear Credit, National Securities Clearing Corporation, the Options Clearing Corporation. Among the eight, five are CCPs (CME, FICC, ICE, NSCC, and OCC). See <https://home.treasury.gov/system/files/261/here.pdf>.

As a key component of risk management, CCPs use auctions to sell the defaulted portfolio, therefore eliminating the directional exposure and stopping the losses (CPMI-IOSCO, 2012, 2020). The CCP's losses are covered by prefunded resources from the defaulting member, the CCP, and the surviving members, in this order. Importantly, resources that the CCP uses to pay the winners of the auction partly come from the bidders themselves. In this sense, CCP auctions are unique.

In this paper, we analyze CCP auction design that incorporates this important feature: bidders are also potential payers. In particular, we study the “juniorization” mechanism of surviving members’ resources, known as guarantee funds.² The principle of juniorization is that members submitting bad bids will see their guarantee funds used ahead of, i.e., junior to, members submitting better bids. Building on Du and Zhu (2017), we model a CCP auction as a divisible, uniform-price auction, which tends to be used for large defaulted portfolios that few or no single bidders have the capacity to absorb.³

In our baseline model, only surviving members of the CCP can participate in the auction. The fundamental value of the auctioned portfolio is common knowledge, and bidders incur quadratic costs for holding inventories, which is equivalent to linearly decreasing marginal values in acquired quantity. The bidders submit demand schedules and pay for their allocations at the market clearing price, which can be negative. A very negative price means the CCP has to pay a substantial amount to the auction winners out of the prefunded resources.

We model the CCP's resources as two parts. The first part is the defaulters’ and the CCP's resources, which is used first to absorb losses. If that is insufficient, the CCP uses the guarantee funds contributed by the surviving members. Surviving members have heterogeneous guarantee fund contributions that follow a probability distribution. To model juniorization, we assume that the use of a member's guarantee fund is linearly decreasing in the member's equilibrium winning amount of the defaulted portfolio, subject to the constraint that the used guarantee fund is positive and no more than the prefunded amount.⁴

The key design variable is the degree of juniorization c , modeled as how much guarantee fund a bidder can save by buying each additional unit of the defaulted portfolio. With juniorization, a bid serves two purposes: On top of the conventional motivation of making a profit, bidders in CCP auctions have an additional incentive to save their guarantee funds, and this incentive is increasing in the size of one's own guarantee funds at stake.

When c is relatively small, all bidders are incentivized by the juniorization scheme equally, leading to a symmetric strategy. As a result, juniorization does not affect the equilibrium allocation. Furthermore, with a higher c , members bid more aggressively and “save” more guarantee fund; but they gain less from the auction because the aggressive bidding pushes up the price. The two channels perfectly cancel out each other. Thus, juniorization becomes *irrelevant*. Bidders are indifferent between paying for the default loss via the guarantee fund contributions or via the auction, and juniorization does not affect members' total profit. In this symmetric equilibrium, the CCP can increase c to raise the auction price without hurting members' total profit.

When c is sufficiently high, however, some members with small guarantee fund contributions become less incentivized by the juniorization scheme, compared to those with large contributions. Because the small members only need to purchase a small fraction of the defaulted portfolio to save all their guarantee fund contributions. The different incentives give rise to asymmetric equilibria, in which the irrelevance result does not hold. Since the small members are less incentivized than the rest, the juniorization scheme in the asymmetric equilibria becomes less efficient compared to the symmetric equilibrium, in the sense that the auction price increases in c at a slower speed. There is a trade-off between extensive margin and intensive margin: a higher c provides stronger incentives (i.e., higher intensive margin), but it affects a smaller mass of members (i.e., lower extensive margin). This creates a larger wedge between the two channels, which are balanced in the symmetric equilibrium. As a result, a higher c in the asymmetric equilibria jeopardizes members' total profit, although it still pushes up the auction price.

The asymmetric impact of juniorization on the bidding incentives of members with various guarantee fund sizes leads to a misalignment between the CCP's objective and the members' objective. The CCP aims to achieve a high auction price for two major reasons: For one, the rationale to have a default management auction is to avoid the market distortions typically associated with fire sales, thereby preserving price stability (CPMI-IOSCO, 2020). For another, a high price is often perceived as indicative of the auction's success, enhancing the CCP's reputation (Norman, 2011). By contrast, the goal of members is to increase their total profit. A higher c , in the asymmetric equilibria, benefits the CCP at the expense of the members.

In an extension of the baseline model, we study the auction participation of customers who have zero guarantee fund contributions. We show that a wider customer participation promotes competition and increases the auction price. The higher auction price in turn reduces the usage of members' guarantee fund contributions, increasing their total profit. Furthermore, when the mass of customers is smaller than the members, a wider customer participation also increases the total profit of the customer sector.

Our results shed lights on recent market and regulatory debate around the design of CCP auctions. Although in principle a CCP should ensure that participation in the auction is sufficiently broad to promote the auction's success, practical application often sees CCPs limiting participation primarily to their larger members. This restriction is typically justified by concerns over potential

² The size of members' guarantee fund contributions is increasing in their required initial margin. Thus, members who have larger or riskier positions have larger guarantee fund contributions.

³ In practice, CCP auctions are generally sealed-bid. Some CCPs such as ICE Credit use divisible auctions, whereas others such as Nasdaq clearing use indivisible ones.

⁴ In practice, CCPs tend to sort bidders into discrete tiers according to their bids. For instance, CME CDS/IRS Clear in its rulebook defines “non-qualifying bidders” as the ones that either submit no bids or their bids are worse than a pre-defined price range. If the loss from the auction dips into surviving members' guarantee fund contributions, the non-qualifying bidders' contributions will be used first, followed by the non-winning bidders', whereas the winning bidders' guarantee fund contributions have highest seniority. Because bids with higher prices are filled ahead of those with lower prices in a divisible auction, juniorization based on equilibrium allocation captures the core spirit of this design and retains analytical tractability.

information leakage that could negatively impact the portfolio's market position (CPMI-IOSCO, 2020). A salient example is Nasdaq Clearing. In September 2018, a single (albeit large) trader's default loss wipes away two-thirds of surviving members' guarantee funds in Nasdaq Clearing (Financial Times, 2018). Out of more than 100 clearing members, Nasdaq Clearing only invited five to the auction.⁵ The restriction to a small number of participants could have contributed to the large default loss (Faruqui et al., 2018). Our results also suggest that Nasdaq Clearing could have used juniorization, as well as a wider customer participation, to promote more competitive bidding.

To the best of our knowledge, the only other papers that study CCP auctions are Ferrara et al. (2020) and Oleschak (2019). Both papers apply the standard model of private-value indivisible auctions to the CCP setting. Ferrara et al. (2020) introduce a reduced-form penalty for submitting bad bids, but the penalty is independent of the default losses of the CCP. Oleschak (2019) finds that the CCP's loss allocation method does not affect the CCP's losses or the bidders'. This is because in his model, loss allocations are not constrained by the prefunded amount of guarantee funds. Our model incorporates key institutional details of CCP auctions and derive novel results, in particular, the effect of juniorization on prices, bidding strategies, and profits across heterogeneous bidders.

Our results contribute to the broad literature on central clearing. In particular, the strategic incentives of clearing members to bid in CCP auctions can be combined with other known aspects of the economics of central clearing, including netting efficiency (Duffie and Zhu, 2011), risk sharing and risk management (Haene and Sturm, 2009; Biais et al., 2016; Raykov, 2017), loss allocation rules (Elliott, 2013; Nahai-Williamson et al., 2013; Wang et al., 2021), and the choice between for-profit and utilities (Huang, 2019), among others. Menkveld and Vuillemeij (2021) provide an in-depth review of the literature on central clearing.

2. A model of CCP default management auctions

A CCP inherits a portfolio from its defaulting members and need to sell it in an auction. The portfolio has size $Q > 0$. The auction is uniform price and fully divisible. We assume that the auction is held immediately after default, and the marked-to-market value of the portfolio is zero.⁶ Let p denote the per unit price of the portfolio paid by the bidders. Typically, $p < 0$, so $-pQ > 0$ is the loss from the auction that the CCP has to pay from the prefunded resources.

The CCP has three types of prefunded resource to absorb the loss: (i) the defaulting members' initial margin and guarantee funds; (ii) the CCP's skin-in-the-game; and (iii) the surviving member's guarantee funds. Resources (i) and (ii) add up to $M > 0$, whereas resource (iii) is $G > 0$.

For analytical simplicity, we assume that there is a continuum of infinitesimal surviving members of mass one.⁷ Member i contributes $g_i \geq 0$ into the guarantee fund, where g_i has the probability distribution function F with support $[\underline{g}, \infty)$. Hence, the total guarantee fund is the integral of all individual guarantee fund contributions, i.e., $G \equiv \int g dF(g)$.

The fundamental value of the defaulted portfolio is v per unit, reflecting the bidders' view that the value of the defaulted portfolio may continue to decline ($v < 0$) or rebound ($v > 0$) after the auction.⁸

The distribution function $F(\cdot)$, as well as v, Q, M and G , is common knowledge to all bidders.

Once the auction produces a price p for the defaulted portfolio, there are three scenarios:

- I. $pQ + M \geq 0$: The defaulters' and CCP's resources are sufficient to cover the auction losses, and there is no need to use the guarantee fund.
- II. $pQ + M < 0 \leq pQ + M + G$: The defaulters' and CCP's resources are insufficient, but the guarantee fund is sufficient to cover the losses.
- III. $pQ + M + G < 0$: The resources from the defaulters, the CCP, and the surviving clearing members are insufficient to cover losses, and the auction "fails." The CCP resorts to more extreme methods of default management such as variation margin gains haircutting (VMGH) and partial tear-ups, among others. If these mechanisms are not credible or their consequences are not deemed to be acceptable, the official sector may step in and resolve the CCP.

In this paper, we focus on Scenarios I and II. Because Scenario I is the best outcome and is relatively straightforward, most of our modeling effort is devoted to Scenario II. Scenario III threatens the viability of the CCP itself and will likely involve the official sector and its political constraints, which are beyond the scope of our simple model.

The CCP's objective is to achieve a high auction price p . For one, the rationale to have a default management auction is to avoid the inefficiencies associated with fire sales, maintaining a high price (CPMI-IOSCO, 2020). For another, a high price is typically taken as a sign of a successful auction, giving rise to reputational benefits for the CCP (Norman, 2011).

⁵ Anecdote evidence suggests that Nasdaq Clearing selected only the five large members that have the capacity to purchase the defaulted portfolio.

⁶ This is for simplicity. With a negative marked-to-market value r , the loss of the portfolio is $-(r + p)Q$. As long as the marked-to-market value is determined before the auction, we can normalize it to zero without loss of generality.

⁷ In practice, of course, there are finitely many members, and some are very large. The main advantage of using infinitesimal members is that they have zero price impact and hence do not wish to affect the auction price. This simplification shortens the analytical solutions dramatically. One can extend this model to allow for finitely many clearing members and positive price impact.

⁸ In reality, the fundamental value of the defaulted portfolio is not necessarily common knowledge to all bidders and the CCP. But modeling such asymmetric information makes the model intractable quickly. This paper proposes a prototype model in which the novelty comes from heterogeneous guarantee fund contributions and associated incentives, while keeping all other dimensions as simple as possible.

Now we turn to the auction mechanism and the preference of bidders. In the main model, the auction is open only to clearing members. In the auction, each bidder i submits a demand curve $x_i(p)$, that is, at the price p bidder i is willing to purchase quantity $x_i(p)$. As in practice, bidders cannot release additional supply in the auction, so $x_i(p) \geq 0$. The market-clearing condition is

$$\int x_i(p) di = Q. \quad (1)$$

As described before, CCPs typically adopt a “juniorization” mechanism to incentivize bids. If a clearing member fails to submit bids or submits “bad” bids relative to peers, its guarantee fund contribution is “juniorized,” that is, used before the guarantee fund contribution of other members who submit better bids. To model juniorization, we directly specify the use of bidder i ’s guarantee fund to be

$$T_i = \max \left[\frac{-(pQ + M)}{A} g_i - c x_i, 0 \right], \quad (2)$$

where $x_i \geq 0$ is the equilibrium allocation to bidder i , and $A > 0$ and $c \geq 0$ are constants to be determined by the CCP. Once they are set, A and c are common knowledge. All else equal, a bidder who wins more in the auction sees a less amount of her guarantee funds used by the CCP. As it becomes clear shortly, A is chosen to balance the CCP’s budget, so it is a function of c . This leaves c to be the only design variable. In addition, T_i is non-negative, meaning that the CCP cannot “subsidize” the members beyond saving their contributed guarantee fund – an assumption that is consistent with current CCP rulebooks. A special case is the “pro-rata” use of guarantee funds: $c = 0$, $A = G$, and $T_i = -(pQ + M) \frac{g_i}{G}$, where the transfer T_i is proportional to guarantee fund contribution g_i .

Finally, each bidder i maximizes the risk-adjusted profit

$$\pi_i \equiv (v - p)x_i - 0.5\lambda x_i^2 - T_i. \quad (3)$$

The first term $(v - p)x_i$ is the profit made for purchasing the portfolio at the price p , but with fair value v ; the second term $-0.5\lambda x_i^2$ is the inventory cost of acquiring a part of the defaulted portfolio in the auction, where $\lambda > 0$ is a constant; and the last term $-T_i$, given in (2), represents the use of bidder i ’s guarantee fund.

3. Equilibria and properties

In this section, we analyze the equilibrium bidding strategies. For simplicity, we omit the subscript i whenever there is no potential confusion.

3.1. Equilibrium for scenario I

The first and simplest scenario is if the defaulters’ resource M is sufficient to cover the CCP’s losses, that is, $p^*Q + M \geq 0$. In this case, surviving members’ guarantee funds are not used at all, i.e., $T_i = 0$. Everyone bids

$$x(p) = \frac{1}{\lambda}(v - p). \quad (4)$$

And the equilibrium price satisfies $\frac{1}{\lambda}(v - p) = Q$, or

$$p^* = v - \lambda Q. \quad (5)$$

The condition for obtaining this case of equilibrium is that $p^*Q + M = (v - \lambda Q)Q + M \geq 0$.

3.2. Equilibrium for scenario II: pro-rata allocation

Before analyzing juniorization, it is useful to first examine the special case of pro-rata allocation of losses, i.e., $c = 0$ and $A = G$. The pro-rata use of guarantee funds means $T_i = \frac{-(pQ + M)}{G} g_i$, and thus $\int T_i = -(pQ + M)$, i.e., budget balance is satisfied.

Because the guarantee fund use T_i is independent of x_i , the bidding strategy is the same as Scenario I: $x = \frac{v - p}{\lambda}$. And the equilibrium price is $p^* = v - \lambda Q$.

To ensure that this equilibrium indeed belongs to Scenario II, we need $p^*Q + M < 0 \leq p^*Q + M + G$, or $-G < (v - \lambda Q)Q + M < 0$.

3.3. Equilibrium for scenario II: juniorization

3.3.1. Three types of bidders

Now let’s turn to the key part of the analysis with juniorization, i.e., $c > 0$. Important for the equilibrium characterization of juniorization is the fact that T has a kink at $x = \frac{-(pQ + M)}{A} g/c$. Therefore, a bidder’s profit π is differentiable in x in the interval

$$\left[0, \frac{-(pQ + M)}{A} g/c \right) \text{ and } \left(\frac{-(pQ + M)}{A} g/c, \infty \right), \text{ but not at the kink.}$$

We start by conjecturing that bidders adopt different strategies in equilibrium:

1. $x < \frac{-(pQ + M)}{A} g/c$, and $T > 0$;

2. $x = \frac{-(pQ+M)}{A}g/c$, and $T = 0$; and
3. $x > \frac{-(pQ+M)}{A}g/c$, and $T = 0$.

Type 1 and Type 3 are “interior” cases in the sense that if a bidder changes her demand slightly, she remains in the same case. But Type 2 is at the kink because a slight decrease in x pushes a bidder into Type 1 and a slight increase in x pushes the bidder into Type 3. Therefore, the first-order conditions of Type 1 and Type 3 are equalities, whereas the first-order condition of Type 2 should be inequalities.

We further conjecture that there are two thresholds, g_L and $g_H > g_L$, such that Type 1 applies if $g \geq g_H$, Type 2 applies if $g \in [g_L, g_H)$, and Type 3 applies if $g < g_L$.

The first-order conditions of Type 1 and Type 3 are, respectively,

$$v - p - \lambda x_1 + c = 0;$$

$$v - p - \lambda x_3 = 0.$$

The corresponding demand functions are

$$x_1(p) = \frac{1}{\lambda}(v - p + c); \quad (6)$$

$$x_3(p) = \frac{1}{\lambda}(v - p). \quad (7)$$

For Type 2,

$$x_2(p) = \frac{-(pQ + M)}{A}g/c \quad (8)$$

is conjectured to be optimal. An increase of x_2 pushes a bidder into Type 3 (where juniorization is ineffective), and a decrease of x_2 pushes the bidder into Type 1 (where juniorization is effective). Thus, for $g \in (g_L, g_H)$, we have

$$v - p - \lambda \frac{-(pQ + M)}{A} \frac{g}{c} + c > 0,$$

$$v - p - \lambda \frac{-(pQ + M)}{A} \frac{g}{c} < 0.$$

At the equilibrium price p^* , the boundary conditions are

$$v - p^* - \lambda \frac{-(p^*Q + M)}{A} \frac{g_H}{c} + c = 0, \quad (9)$$

$$v - p^* - \lambda \frac{-(p^*Q + M)}{A} \frac{g_L}{c} = 0. \quad (10)$$

3.3.2. Symmetric equilibrium

If $\underline{g} \geq g_H$, all members are Type 1 bidders and adopt a symmetric bidding strategy given by (6). The market clearing condition is

$$Q = \int_{\underline{g}}^{\infty} \frac{v - p + c}{\lambda} dF(g), \quad (11)$$

which means the equilibrium price is

$$p^* = v + c - \lambda Q \quad (12)$$

and the equilibrium allocation is

$$x(p^*) = Q. \quad (13)$$

As c increases, members bid more aggressively compared to the pro-rata case, pushing up the equilibrium price in an one-to-one ratio (i.e., $dp^*/dc = 1$). In some sense, the degree of juniorization c is similar to a per-unit subsidy for buying the auctioned portfolio. Thus, it is intuitive that a higher subsidy gives rise to a higher equilibrium price. Furthermore, as all members are incentivized to the same degree and adopt the same bidding strategy, juniorization does not affect the equilibrium allocation.

Finally, A is determined by the budget balance constraint: the usage of members' guarantee funds equals the default loss, i.e.,

$$\begin{aligned} & \int_{\underline{g}}^{\infty} \left(\frac{-(p^*Q + M)}{A} g_i - cx(p^*) \right) dF(g) = -(p^*Q + M); \\ & \Leftrightarrow \frac{-(p^*Q + M)}{A} G - cQ + ((v + c - \lambda Q)Q + M) = 0; \end{aligned}$$

$$\leftrightarrow \frac{-(p^*Q + M)}{A} = \frac{-((v - \lambda Q)Q + M)}{G}. \quad (14)$$

Thus, $\frac{-(p^*Q + M)}{A}$ is also independent from c . Note that the parameter space of interest is $0 < \frac{-(p^*Q + M)}{A} < 1$, i.e., we are interested in the case when $-G < (v - \lambda Q)Q + M < 0$. Under such a parameter assumption, the CCP has to use prefunded resources from the surviving members even if they bid competitively, and the resources from the members are large enough to cover the losses.

Additionally, to ensure such an equilibrium exist, by the boundary condition (9) and $\underline{g} \leq g_H$, there is a cap on c

$$c \leq \underline{g} \frac{-((v - \lambda Q)Q + M)}{QG} \equiv c_1. \quad (15)$$

Proposition 1 characterizes the symmetric equilibrium.⁹

Proposition 1 (Symmetric equilibrium). Suppose that $-G < (v - \lambda Q)Q + M < 0$, for $0 < c \leq c_1$, all bidders use the symmetric strategy (6). The equilibrium price is given by (12) and the equilibrium allocation is given by (13).

By (3), (6), (12) and (13), bidder i 's profit is

$$\begin{aligned} \pi_i &= (v - p^*)x(p^*) - \frac{\lambda}{2}x(p^*)^2 - \frac{-(p^*Q + M)}{A}g_i + cx(p^*), \\ &= \frac{\lambda}{2}x(p^*)^2 - \frac{-(p^*Q + M)}{A}g_i, \\ &= \frac{\lambda Q^2}{2} - \frac{-((v - \lambda Q)Q + M)}{G}g_i. \end{aligned} \quad (16)$$

Hence, in the symmetric equilibrium, juniorization does not affect bidders' profits. With a higher c , the equilibrium price is higher, leading to two channels that affect bidders' profits. On the one hand, a bidder "saves" more guarantee fund. On the other hand, the bidder gains less from the auction. The equilibrium price, stemming from the bidder's first-order condition (6) and the market clearing condition (11), balances the two channels because of the one-to-one ratio between the increase of p^* and c (i.e., $dp^*/dc = 1$). Hence, it is irrelevant whether the auction loss is born directly by members' guarantee fund or it is born indirectly by members via their lower gains from the auction. Corollary 1 summarizes this result.

Corollary 1 (Irrelevance). In the symmetric equilibrium, juniorization is irrelevant to bidders' profits. The highest price that can be achieved is $p_1^* = v - \lambda Q + c_1$ where c_1 is given by (15).

3.3.3. Asymmetric equilibrium with two strategies

When c is slightly above c_1 , $\underline{g}$ is marginally lower than g_H . Additionally, note that g_L is strictly lower than $\underline{g}$ because of (9) and (10). Thus, bidders with $g \geq \underline{g}$ are Type 1 and those with $g \in [\underline{g}, g_H]$ are Type 2. By (6) and (8), bidders adopt the following asymmetric strategies:

$$x(p) = \begin{cases} \frac{1}{\lambda}(v - p + c), & \text{if } g \geq g_H \\ \frac{-(pQ + M)}{A} \frac{\underline{g}}{c}, & \text{if } \underline{g} \leq g < g_H. \end{cases}$$

The budget balance constraint is

$$pQ + M + \int_{g_H}^{\infty} \left[\frac{-(pQ + M)}{A}g - c \frac{v - p + c}{\lambda} \right] f(g)dg = 0, \quad (17)$$

where the integral starts with g_H because only bidders with guarantee funds larger than g_H lose part of it. Substituting $v - p + c = \lambda \frac{-(pQ + M)}{A} \frac{\underline{g}}{c}$ and simplifying, we get

$$A = \int_{g_H}^{\infty} (g - g_H) f(g) dg, \quad (18)$$

which depends on c only through g_H . The market clearing condition in this case is

$$Q = \int_{\underline{g}}^{g_H} \frac{-(pQ + M)}{A} \frac{\underline{g}}{c} f(g) dg + \int_{g_H}^{\infty} \frac{1}{\lambda}(v - p + c) f(g) dg,$$

⁹ We delegate all detailed proofs, if necessary, to Appendix A but only discuss the intuition in the main text.

$$= \frac{v - p + c}{\lambda} \left(\underbrace{\int_{\underline{g}}^{g_H} \frac{g}{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg}_{= \frac{G-A}{g_H} < 1} \right) \quad (19)$$

where the second equality comes from the boundary condition (9).

The equilibrium price is

$$p^* = v + c - \lambda Q \underbrace{\frac{g_H}{G-A}}_{>1}. \quad (20)$$

The equilibrium allocation is

$$x(p^*) = \begin{cases} \frac{g_H}{G-A} Q, & \text{if } g \geq g_H \\ \frac{g}{G-A} Q, & \text{if } \underline{g} \leq g < g_H. \end{cases} \quad (21)$$

In this asymmetric equilibrium, Type 2 bidders with $g < g_H$ are less incentivized to bid aggressively compared to Type 1 bidders, as they are stuck at the kink of T . Hence, they just bid enough to save all their guarantee funds but not more, i.e., $T = 0$. As a result, the equilibrium price by (20) does not increase in c as fast as that in the symmetric equilibrium, since $d \frac{g_H}{G-A} / dc$ is positive (see proof in Appendix A). In other words, juniorization in this asymmetric equilibrium is less efficient in increasing the auction price. Furthermore, Type 1 bidders with $g \geq g_H$ end up with allocation larger than Q and Type 2 bidders were allocated less than Q .

Before characterizing the asymmetric equilibrium, the following Lemma establishes a form of continuity at $c = c_1$ and results about the effect of c on g_H and p^* .

Lemma 1. For a fixed $c > c_1$, let g_H , A and p^* are given by (9), (18) and (20). As $c \rightarrow c_1$, we have

$$g_H \rightarrow \underline{g}, \quad \frac{g_H}{G-A} \rightarrow 1, \quad p^* \rightarrow v + c - \lambda Q.$$

Additionally, $\frac{dg_H}{dc} > 0$ and $0 < \frac{dp^*}{dc} < 1$.

As c increases from c_1 , g_H increases from $\underline{g}$. A higher c leads to a larger distance between $\underline{g}$ and g_H , hence a larger A . Thus, as c increases from c_1 , $(G-A)/g_H$ decreases from 1. Furthermore, there is a trade-off between the extensive margin and intensive margin: On the one hand, a higher c leads to a higher g_H , shrinking the mass of bidders that are fully incentivized. On the other hand, it also provides members stronger incentives to bid aggressively. The proposition below characterizes the equilibrium when c is (slightly) larger than c_1 :

Proposition 2 (Asymmetric equilibrium with two strategies). Suppose that $-G < (v - \lambda Q)Q + M < 0$, when $c > c_1$, the following is an equilibrium: Let g_H and p^* solve (9) and (20), where the constant A is given by (18). Bidders use the asymmetric strategies of (6) and (8). The equilibrium price is given by (20) and the equilibrium allocation is given by (21).

In this equilibrium, $\underline{g} \geq g_L$ where g_L is given by the boundary condition (10).

In this asymmetric equilibrium, the irrelevance result established in Proposition 1 does not hold, because the bidders do not have an equal incentive. Corollary 2 shows that juniorization jeopardizes bidders' total profit.

Corollary 2 (Decreasing profit). In the asymmetric equilibrium with two strategies, as c increases, bidders' total profit decreases.

As c increases and hence g_H increases, the mass of Type 2 bidders increases. These bidders are not fully incentivized by juniorization, as they are bounded by $T = 0$ and just bid enough to save all their guarantee fund contributions but not more. Thus, the speed that the equilibrium price p^* increases in juniorization degree c slows, creating a larger wedge between the two channels at work, which are balanced via the one-to-one ratio between p^* and c in the symmetric equilibrium. As a result, the total profit of all bidders suffers from a more aggressive juniorization scheme in the asymmetric equilibrium.

3.3.4. Asymmetric equilibrium with three strategies

Note that g_L is strictly lower than $\underline{g}$ when c is in the neighborhood of c_1 . The following lemma specifies sufficient conditions in which $\underline{g} < g_L$ and an asymmetric equilibrium with three strategies may exist.

Lemma 2. When $\underline{g} < \frac{(vQ+M)G}{\lambda Q^2}$ and $0 < vQ + M < \lambda Q^2$, there exists a positive $c_2 > c_1$ such that $\underline{g} < g_L$ when $c > c_2$:

$$c_2 \equiv \frac{vQ + M}{Q}. \quad (22)$$

Note that the above parameter restrictions are merely sufficient conditions and not necessary conditions. To simplify the analysis, however, the analysis below only focus on this parameter space. By (6), (8) and (7), the three types of bidders adopt the following asymmetric strategies:

$$x(p) = \begin{cases} \frac{1}{\lambda}(v - p + c), & \text{if } g \geq g_H \\ \frac{-(pQ+M)}{A} \frac{g}{c}, & \text{if } g \in [g_L, g_H) \\ \frac{1}{\lambda}(v - p), & \text{if } g < g_L. \end{cases}$$

The budget balance constraint is the same as (17). Using the boundary conditions (9) and (10), the market clearing condition is

$$\begin{aligned} Q &= \int_{\underline{g}}^{g_L} \frac{1}{\lambda}(v - p) f(g) dg + \int_{g_L}^{g_H} \frac{-(pQ+M)}{A} \frac{g}{c} f(g) dg + \int_{g_H}^{\infty} \frac{1}{\lambda}(v - p + c) f(g) dg, \\ &= \frac{v - p + c}{\lambda} \left(\underbrace{\int_{\underline{g}}^{g_L} \frac{g_L}{g_H} f(g) dg}_{<1} + \underbrace{\int_{g_L}^{g_H} \frac{g}{g_H} f(g) dg}_{<1} + \int_{g_H}^{\infty} f(g) dg \right) \\ &\quad \underbrace{\hspace{10em}}_{=\frac{G-A+B}{g_H} < 1} \end{aligned} \quad (23)$$

where we define B as

$$B = \int_{\underline{g}}^{g_L} (g - g_L) f(g) dg. \quad (24)$$

The equilibrium price is

$$p^* = v + c - \lambda Q \underbrace{\frac{g_H}{G - A + B}}_{>1}. \quad (25)$$

The equilibrium allocation in this case is

$$x(p^*) = \begin{cases} \frac{g_H}{G - A + B} Q, & \text{if } g \geq g_H \\ \frac{g}{G - A + B} Q, & \text{if } g_L \leq g < g_H \\ \frac{g_L}{G - A + B} Q, & \text{if } g < g_L. \end{cases} \quad (26)$$

Proposition 3 characterizes the equilibrium when $c > c_2$:

Proposition 3 (Asymmetric equilibrium with three strategies). Suppose that $\underline{g} < \frac{(vQ+M)G}{\lambda Q^2}$ and $0 < vQ + M < \lambda Q^2$, when $c > c_2$, the following is an equilibrium: Let g_H , g_L and p^* solve (9), (10) and (25), where the constant A is given by (18) and the constant B is given by (24). Bidders use the asymmetric strategies of (6), (7) and (8). The equilibrium price is given by (25) and the equilibrium allocation is given by (26).

In this asymmetric equilibrium, Type 3 bidders with $g < g_L$ bids not to save their guarantee fund contributions, but to gain from the auction. Because their guarantee fund contributions are so small such that under the juniorization scheme they can always save all their contributions. For this type of bidders, the incentive to participate in the auction is to gain from the difference between the fundamental value and the auction price ($v - p^*$). In other words, their bidding incentives are not directly linked to the juniorization degree c (as shown in (7)); but via the equilibrium effect, their equilibrium allocation depends on c (as shown in (26)). As Type 2 bidders are not fully incentivized by juniorization, and Type 3 bidders are not incentivized by juniorization, the equilibrium price p^* does not increase in an one-to-one relationship, which is in contrary to the symmetric equilibrium. As a result, when c increases, the wedge between the two channels at work also becomes larger, leading to lower total profit of all bidders. Corollary 3 highlights this result.

Corollary 3. *In the asymmetric equilibrium with three strategies, as c increases, bidders' total profit decreases.*

Lastly, we would like to note that in the symmetric equilibrium and the asymmetric equilibrium with two strategies, it is possible that the equilibrium price p^* exceeds the fundamental value v . In the symmetric equilibrium, by (15) and the parameter constraint $-(v - \lambda Q)Q + M < G$, we have $c_1 < \frac{g}{Q}$. By (12), when $\lambda < \frac{g}{Q^2}$, there exists a positive c such that $\lambda Q < c < c_1$. In this case, the equilibrium price p^* is higher than v in the symmetric equilibrium when $c = c_1$. By the continuity property established by Lemma 1, when c is slightly above c_1 , the asymmetric equilibrium with two strategies has $p^* > v$. However, this is not possible with the asymmetric equilibrium with three strategies, as Type 3 bidders will not be active in the auction when $v - p^* < 0$.

3.3.5. Welfare implications of juniorization

Suppose a social planner would like to maximize the weighted average of the CCP's objective – which is to increase the equilibrium price – and the bidders' objective – which is to increase the total profit $\Pi(c) = \int_{\underline{g}}^{\infty} \pi(c)f(g)dg$:

$$\max_c W = \omega p^*(c) + (1 - \omega)\Pi(c) \quad (27)$$

The socially optimal c^* is pinned down by

$$\underbrace{\omega \frac{dp^*}{dc}}_{>0} = - \underbrace{(1 - \omega) \frac{d\Pi}{dc}}_{<0} \quad (28)$$

If $\omega = 0$, i.e., the social planner only cares about the total profit, the optimal juniorization degree c^* is any value between 0 and c_1 . Because, as shown in Proposition 1, in the symmetric equilibrium, a higher c increases price but does not affect the total profit of the bidders. However, the price is capped by $v - \lambda Q + c_1$.

When ω is strictly positive, i.e., the social planner also cares about the CCP's objective of maintaining a high auction price, the optimal c^* is larger than c_1 . In this case, we have the asymmetric equilibria in which increasing the equilibrium price is at the expense of lowering members' total profit – i.e., the objective of the CCP is not aligned with that of the members. The higher is ω , the more the social planner cares about the CCP's objective of achieving a high price and thus the larger is c^* . The following proposition summarizes the welfare implications of juniorization.

Proposition 4 (Welfare implications of juniorization). *When $c > c_1$, the objective of the CCP is not aligned with that of the members, i.e., a higher c increases the auction price but jeopardizes members' total profit.*

When the social planner only maximizes members total profit, i.e., when $\omega = 0$, the optimal $c^* \in [0, c_1]$. As long as $\omega > 0$, we have $c^* > c_1$ and

$$\frac{dc^*}{d\omega} > 0. \quad (29)$$

3.3.6. A numerical illustration of the impact of juniorization

To further illustrate the results and the intuition, we now conduct a numerical exercise by setting the model parameters to plausible magnitude in the interest rate swaps market.¹⁰ The CFTC (2019) finds that as of September 5, 2018, LCH has a guarantee fund of 6.6 billion USD and a skin-in-the-game of 56 million USD. The CFTC stress testing results show that in the stress scenario of Lehman's default on 15 September, 2008, the shortfall in excess of the defaulter's initial margin in LCH would be 0.31 billion USD.

Based on these statistics, we set $v = -0.31$, $M = 0.056$, $g = 1.5$ and $G = 6.6$, all with the unit of billions of USD. (The \$0.31 billion shortfall is before the use of the defaulter's guarantee fund contribution, so the mapping to the model is not exact.) We normalize $Q = 1$. These parameters already imply that $vQ + M < 0$, i.e., the defaulter's and CCP's resources are insufficient to cover the losses. The last two parameters, g and λ , do not have a direct empirical counterpart. We provisionally set $g = 1$. As regards to λ , we set it to be 0.31, so that the loss beyond initial margin would double if the defaulted portfolio is sold without juniorization (i.e., $v - \lambda Q = -0.62$).

For simplicity, we will use the exponential distribution of default fund contributions:

$$f(g) = \frac{1}{\beta} e^{-\frac{g-g}{\beta}}, \quad \text{if } g \geq \underline{g}, \quad (30)$$

where the mean of the distribution is G as the mass of clearing members is normalized to be one, and $\beta = G - \underline{g}$.

The first five panels in Fig. 1 show the comparative statics of market outcomes with respect to c , the aggressiveness of juniorization. The vertical lines separate the region of c that gives rise to the symmetric equilibrium ("Sym"), the asymmetric equilibrium with two strategies ("Asy-2") and the asymmetric equilibrium with three strategies ("Asy-3"). As characterized in Propositions 1, 2 and 3, the first panel shows that p^* is monotonically increasing in c , but with a slower speed in the asymmetric equilibria (i.e., below the 45-degree dashed line). Consistent with Lemma 1, there is a form of continuity between the equilibria. The second panel confirms

¹⁰ Ideally, our analytical results would encompass comparative statics across the full spectrum of c . But unfortunately we do not have analytical comparative statics for certain regions of c , e.g., $c \in (c_1, c_2)$.

The first five panels show comparative statics with respect to c . The base case is $\lambda = 0.31, Q = 1, M = 0.056, v = -0.31, G = 6.6, g = 1, \beta = 5.6$. The two vertical lines separate the symmetric equilibrium (Sym), the asymmetric equilibrium with two strategies (Asy-2) and the asymmetric equilibrium with three strategies (Asy-3). Similarly, the two dots in the last panel separate the equilibria.

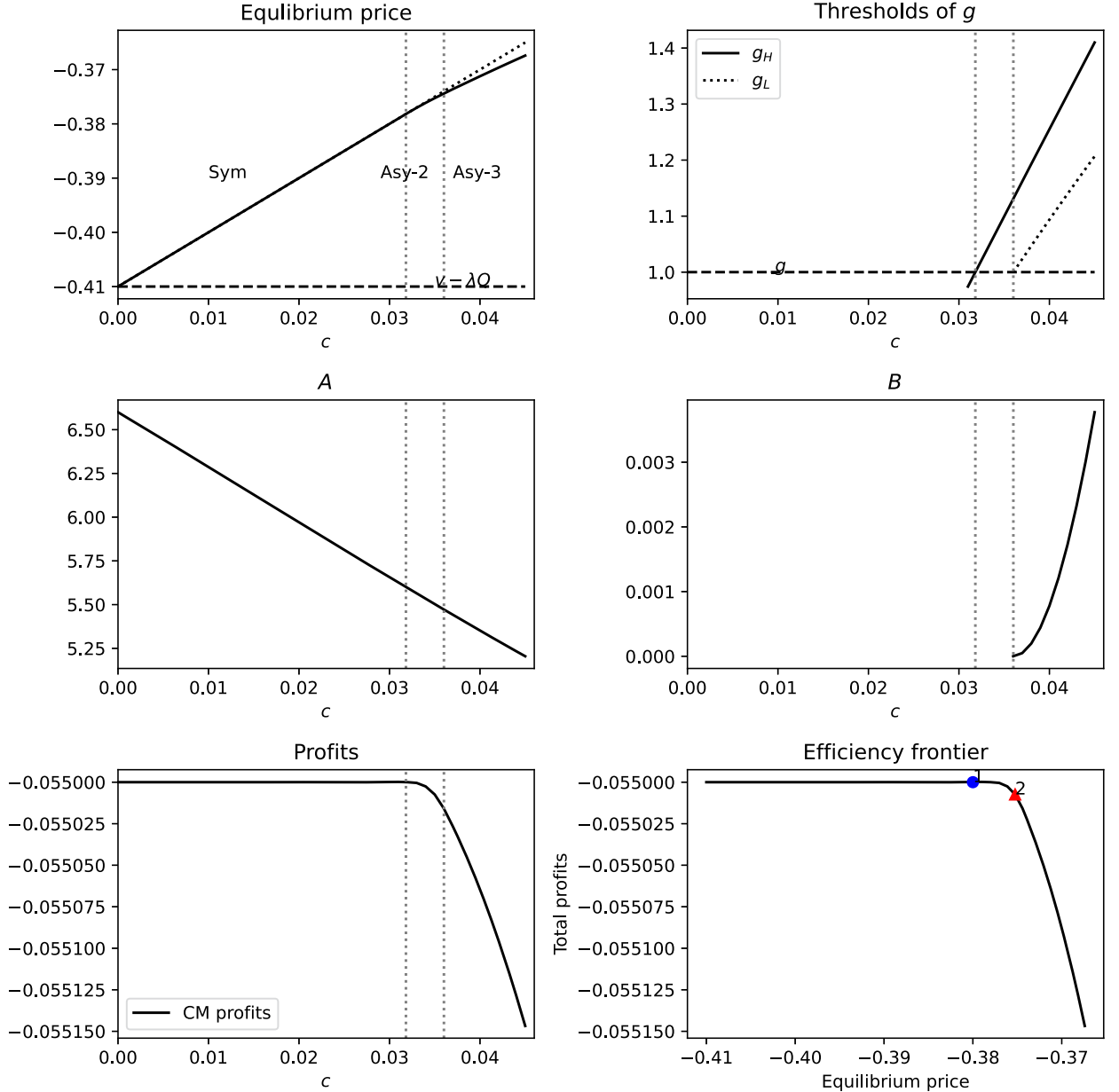


Fig. 1. Comparative statics w.r.t. c .

that $\underline{g} < g_H$ in the asymmetric equilibrium with two strategies and $\underline{g} < g_L$ in the asymmetric equilibrium with three strategies. The third and fourth panel shows that A decreases in c and B increases in c (see analytical proofs in the Appendix). The fifth panel shows that the total profit of all members does not change in c in the symmetric equilibrium as proved in Corollary 1. But the irrelevance does not hold in the asymmetric equilibria as the total profit is decreasing in c , consistent with Corollaries 2 and 3.

The last panel in Fig. 1 shows the efficiency frontier, contrasting the equilibrium price (the x-axis) with members' total profit (the y-axis). The two dots separate the symmetric, 2-strategy asymmetric and 3-strategy asymmetric equilibria. Consistent with Corollary 1, increasing the equilibrium price does not affect the total profit of the bidders in the symmetric equilibrium. However, the price is capped by $v - \lambda Q + c_1$ which is -0.378 (point 1). When $c > c_1$, we have the asymmetric equilibria in which increasing the equilibrium price is at the expense of lowering the total profit, consistent with Proposition 4. Depending on the weights of the social planner assigns to the two objectives, the optimal c^* is determined by a tangent line along the efficiency frontier with the slope of $-\omega/(1 - \omega)$.

4. Customer participation

In the baseline model, auction participation is exclusive to CCP members. This reflects prevailing practices wherein CCPs often restrict auction participation to their prominent members, rooted in concerns that broader dissemination of auction information could prove move against CCPs. For instance, in the default management auction of Nasdaq Clearing in 2018, only five members were invited to participate (Bell and Holden, 2018). Nonetheless, the role of customer participation remains a salient topic in policy discussions on CCP default management auction frameworks (Financial Times, 2018; CPMI-IOSCO, 2020).

To better understand the impact of customer participation on the equilibrium outcome, we now turn to the case in which customers, of mass $\mu > 0$, can also participate. Customers contribute zero guarantee funds. A customer's risk-adjusted profit is similar to that of a member, i.e., (3), except that the customer does not have the term of guarantee fund usage:

$$\pi_c = (v - p)x_c - 0.5\lambda x_c^2. \quad (31)$$

The customers' first-order condition gives rise the following demand function

$$x_c(p) = \frac{1}{\lambda}(v - p), \quad (32)$$

which is the same as that of a Type 3 bidder. Apparently, the customers will only buy a positive amount of the portfolio when $p^* < v$. Hence, for the following analysis, we only consider the parameter space in which $p^* < v$.

For Scenario I, i.e., $p^*Q + M > 0$, the equilibrium price should satisfy $(v - p^*)(1 + \mu)/\lambda = Q$ based on (4), which is

$$p^* = v - \frac{\lambda Q}{1 + \mu}. \quad (33)$$

As a result, increasing the mass of participating customers pushes up the equilibrium price. The condition for obtaining this case of equilibrium is that $(v - \frac{\lambda Q}{1 + \mu})Q + M > 0$, which is also less stringent when the mass of customers is larger.

For Scenario II, the special case of the pro-rata use of guarantee funds (i.e., $c = 0$ and $A = G$) leads to the same equilibrium price in (33). However, a positive juniorization c can only give rise to asymmetric equilibria when customers also participate in the auction. When $\underline{g} > g_H$, all members are Type 1 with the demand function $x_1(p)$ given by (6) and the customers' demand function is $x_c(p)$. Thus, the market clearing condition is

$$Q = \int_{\underline{g}}^{\infty} \frac{v - p^* + c}{\lambda} f(g) dg + \mu \frac{v - p^*}{\lambda} \quad (34)$$

which gives rise to the following equilibrium price

$$p^* = v - \frac{\lambda Q - c}{1 + \mu}. \quad (35)$$

When μ goes to zero, the above equilibrium price converges to (12). With a larger μ , i.e., when more customers are invited to the auction, p^* increases. In other words, a wider customer participation enhances competition, pushing up the equilibrium price.

Similarly, the equilibrium price is

$$p^* = v - \frac{\lambda Q - mc}{m + \mu}, \quad (36)$$

where $m = (G - A)/g_H$ when $g_L \leq \underline{g} < g_H$ and $m = (G - A + B)/g_H$ when $\underline{g} < g_L$ in which g_H , g_L , A and B are given by (9), (10), (18) and (24). Thus, across all different scenarios, $dp^*/d\mu$ is always positive, meaning that more customers participating in the auction increases the auction price.

In addition, when $\underline{g} > g_H$, the budget balance constraint is

$$\int_{\underline{g}}^{\infty} \left(-\frac{p^*Q + M}{A} g - cx_1 \right) f(g) dg + p^*Q + M = 0. \quad (37)$$

Substituting the equilibrium price, the equilibrium allocation for a member and a customer is $x_1(p^*) = \frac{\lambda Q + \mu c}{\lambda(1 + \mu)}$ and $x_c(p^*) = \frac{\lambda Q - c}{\lambda(1 + \mu)}$.

With customer participation, equilibrium allocation varies in c even when $\underline{g} > g_H$. This result stands in contrast to Proposition 1. With a higher c , members' allocation x_1 increases while customers' allocation x_c decreases. Because the members are more incentivized to bid a higher price with a higher c but the customers are not.

The total profit of all members is

$$\Pi = \int_{\underline{g}}^{\infty} \left((v - p^*)x_1 - \frac{\lambda}{2}x_1^2 - \left(-\frac{p^*Q + M}{A} g - cx_1 \right) \right) f(g) dg.$$

$$= \underbrace{\left(\frac{\lambda}{2}x_1^2 - cx_1\right)}_{\text{gain from auction}} - \underbrace{(p^*Q + M)}_{\text{loss from guarantee fund}} \quad (38)$$

where the last equality comes from the budget balance constraint and the equilibrium allocation for members. Thus, members' profit increases in the mass of the customers μ because

$$\frac{d\Pi}{d\mu} = (\lambda x_1 - c) \frac{dx_1}{d\mu} + Q \frac{dp^*}{d\mu} = \frac{(\lambda(Q - x_1) + c)(\lambda Q - c)}{\lambda(1 + \mu)^2} > 0 \quad (39)$$

where the last equality comes from $\frac{dx_1}{d\mu} = -\frac{1}{\lambda} \frac{dp^*}{d\mu}$ and $\frac{dp^*}{d\mu} = \frac{\lambda Q - c}{(1 + \mu)^2}$ and the inequality comes from $Q > x_1$.

The profit of an individual customer is $\pi_c = (v - p^*)x_c - \frac{\lambda}{2}x_c^2 = \frac{\lambda}{2}x_c^2$. Since $\frac{dx_c}{d\mu} = -\frac{1}{\lambda} \frac{dp^*}{d\mu}$ and $\frac{dp^*}{d\mu} = \frac{\lambda Q - c}{(1 + \mu)^2}$, we have $\frac{d\pi_c}{d\mu} < 0$, i.e., the profit of an individual customer decreases in μ because higher μ increases the auction price.

The total profit of the customers however increases in μ when the mass of customers is smaller than that of the members (i.e., $\mu < 1$) because

$$\Pi_c = \mu \pi_c = \frac{\mu \lambda}{2} x_c^2, \quad (40)$$

$$\frac{d\Pi_c}{d\mu} = \frac{\lambda}{2} x_c^2 + \mu \lambda x_c \frac{dx_c}{d\mu} = \frac{(1 - \mu)(\lambda Q - c)^2}{2\lambda(1 + \mu)^3} > 0 \quad (41)$$

where the last equality comes from $\frac{dx_c}{d\mu} = -\frac{1}{\lambda} \frac{dp^*}{d\mu}$ and $\frac{dp^*}{d\mu} = \frac{\lambda Q - c}{(1 + \mu)^2}$.

Proposition 5 (Customer participation). *A wider customer participation increases competition, pushing up auction price.*

When $\underline{g} > g_H$, members' total profit always increases in the mass of customers μ . An individual customer's profit decreases in μ . When $\mu < 1$, customers' total profit also increases in μ .

Nonetheless, when $\underline{g} > g_H$, the speed of p^* increases in c – i.e., dp^*/dc – equals to $1/(1 + \mu)$, meaning that with a wider customer participation, the equilibrium price increases at a slower pace in the aggressiveness of the juniorization scheme. This is because the customers have no contributions to the guarantee fund and they are not incentivized by juniorization. Taking the first order derivative of members' total profit with respect to c , we have

$$\frac{d\Pi}{dc} = (\lambda x_1 - c) \frac{dx_1}{dc} - x_1 + Q \frac{dp^*}{dc} = \frac{\mu(\lambda x_c - c)}{\lambda(1 + \mu)} \quad (42)$$

where the last equality comes from $\frac{dx_1}{dc} = -\frac{1}{\lambda} \frac{dp^*}{dc} + \frac{1}{\lambda}$, $\frac{dp^*}{dc} = \frac{1}{1 + \mu}$, and $Q = x_1 + \mu x_c$. Given (32) and (35), when $c < (\lambda Q)/(2 + \mu)$, $d\Pi/dc > 0$. It means that with a higher c , members' total profit increases, which is in sharp contrast to the cases without customer participation. This is because members benefit from a higher c in two channels, when customers also participate in the auction. First, similar to the cases without customer participation, a higher c increases the equilibrium price, allowing members to save more guarantee fund. Second, different from the cases without customer participation, members gain more from the auction because they are incentivized more compared to the customers. Although with a higher equilibrium price, members earn less for each unit of purchase, i.e., with a lower $v - p^*$. But the amount of their purchase increases more in c , which compensates the lower per unit profit. Overall, their gain from auction increases in c .

The derivative of the total profit of all customers with respect to c is

$$\frac{d\Pi_c}{dc} = \mu \lambda x_c \frac{dx_c}{dc} = -\frac{\mu x_c}{1 + \mu} < 0. \quad (43)$$

A higher c decreases the customers' total profit. Because on the one hand, the customers are less incentivized compared to the members, hence buying less in the equilibrium with a higher c . On the other hand, a higher c lowers the per unit profit from the auction, as discussed before.

To sum up, a higher c decreases the total profit of the members and the customers because

$$\frac{d\Pi + \Pi_c}{dc} = \frac{\mu(\lambda x_c - c)}{\lambda(1 + \mu)} - \frac{\mu x_c}{1 + \mu} = -\frac{\mu c}{\lambda(1 + \mu)} < 0. \quad (44)$$

It means that when c increases, the increase of the members' profit is smaller than the decrease of the customers' profit. Fig. 2 illustrates the comparative statics with respect to c , as well as the efficiency frontier, in the model with customer participation. In the first panel, note that when $c = 0$, the equilibrium price p^* is higher than $(v - \lambda Q)$, which is consistent with (35). The second to the fourth panel are qualitatively the same as those in Fig. 1. The fifth panel shows that members' profit increases in c while customers' profit decreases in c , consistent with (42) and (43). The last panel illustrates the efficiency frontier: With a higher c , the equilibrium price increases, but the total profit of members and customers decreases.

The first five panels show comparative statics with respect to c with customers. The base case is $\lambda = 0.31$, $Q = 1$, $M = 0.056$, $v = -0.31$, $G = 6.6$, $\underline{g} = 1$, $\beta = 5.6$, $\mu = 0.2$. The two vertical lines separate the symmetric equilibrium (Sym), the asymmetric equilibrium with two strategies (Asy-2) and the asymmetric equilibrium with three strategies (Asy-3). Similarly, the two dots in the last panel separate the equilibria.

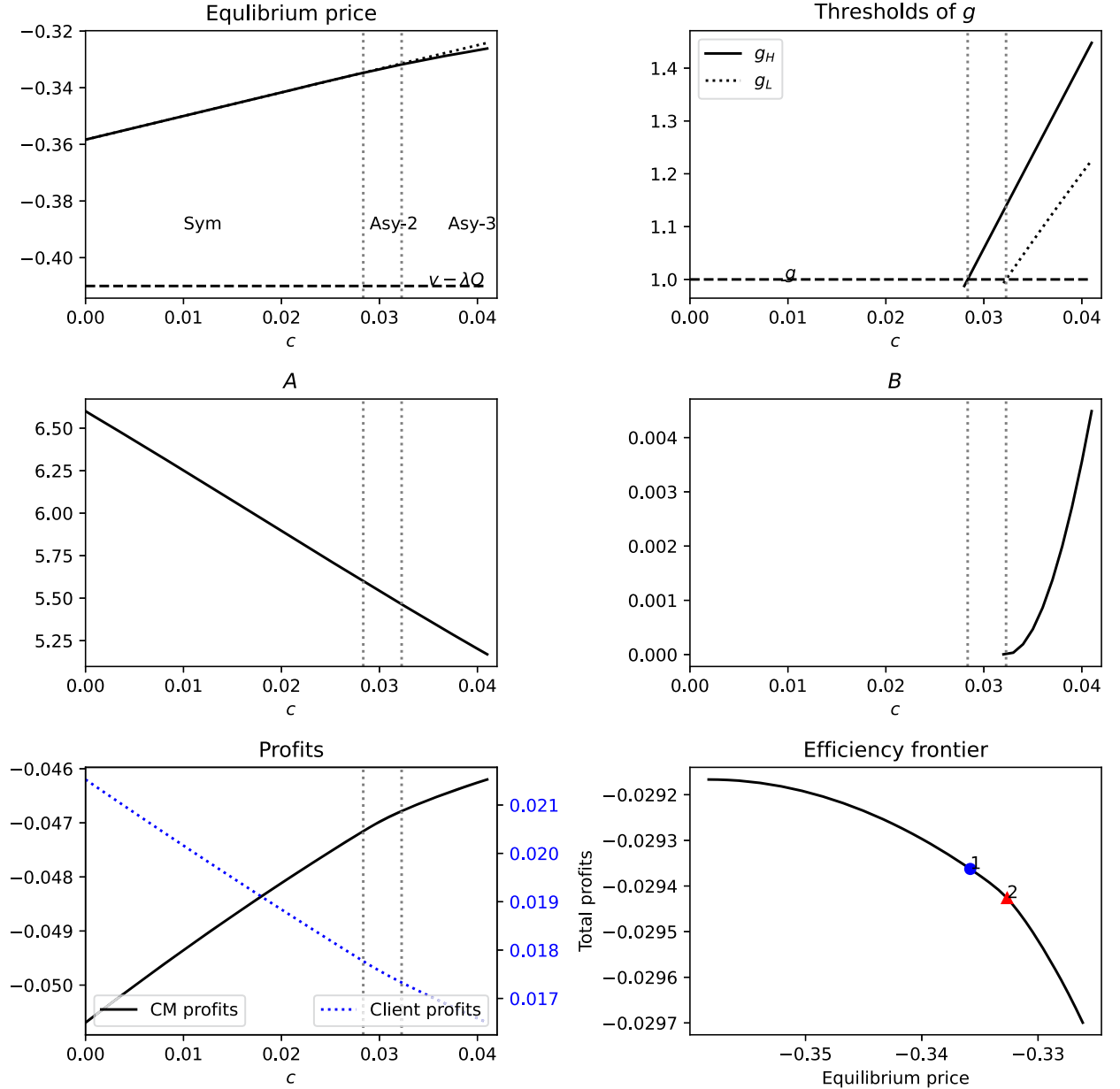


Fig. 2. Comparative statics w.r.t. c with customers.

5. Concluding remarks

This paper proposes a tractable modeling framework for CCP auctions, with the unique feature that some financial resources that the CCP uses to pay auction winners come from the bidders themselves. We find that the juniorization of guarantee funds is an effective mechanism to encourage aggressive bidding and raise the auction price. Too aggressive juniorization can jeopardize the total profit of members. The objective of the CCP (i.e., to increase the auction price) and that of the members (i.e., to increase their total profit) diverge. The optimal juniorization depends on the weights that the social planner assigns to the two objectives. However, a wider customer participation can increase both auction price and the total profits of members and customers. It would be an interesting future research question to identify an optimal c that maximizes members' total profits.

The model framework of this paper can be adapted to analyze other dimensions of CCP auctions. For example, one could incorporate heterogeneous inventory costs $\{\lambda_i\}$, assuming they are common knowledge. In that setup, $1/\lambda$ in the market clearing condition

becomes an integral of $1/\lambda_i$. This extension involves additional complexity because bidders would be sorted by the combination of g_i and λ_i .

Furthermore, endogenizing members' guarantee fund contributions g_i could shed light on how juniorization may affect the *ex ante* incentives of central clearing. While the potential depletion of members' guarantee funds could act as a disincentive for central clearing, juniorization's potential to enhance the auction price and reduce fire sale risks might bolster the appeal of central clearing. Consequently, the choice to centrally clear is influenced by not only the netting benefits (Duffie and Zhu, 2011), but also the likelihood of the guarantee fund usage and fire sales in the event of defaults. However, given the intricate challenges associated with coordinating auctions amidst market turmoil, CCPs often prioritize maintaining flexibility in their auction processes (Norman, 2011; CPMI-IOSCO, 2020), leading to nuanced effects on members' *ex ante* incentives.

Another potential dimension is to model the end of the waterfall. Under variation margin gain haircutting or partial tear-up, the in-the-money side does not receive the full value. To the extent that some surviving members are on the opposite side of the defaulted portfolio, the potential to lose some of the mark-to-market profit adds another layer of heterogeneous bidding incentives.

A fourth possibility is to incorporate the pre-auction hedging by the CCP, which may be conducted secretly. This calls for a dynamic model: a hedging stage conducted in the open market, followed by an auction stage that we already modeled. In this case, the juniorization of guarantee funds should probably recognize the liquidity provision of surviving members in the hedging stage.

Last but not least, future research could further investigate the impact of juniorization with a small number of bidders – i.e., in a noncompetitive bidding environment. The current assumption of perfect competition among bidders simplifies mathematical calculation drastically, yielding fruitful analytical outcomes. However, the practical scenario of CCP auctions often involves a restricted pool of bidders, leading to a scenario of imperfect competition.¹¹ These compelling areas warrant further investigation.

CRedit authorship contribution statement

Wenqian Huang: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Haoxiang Zhu:** Conceptualization, Formal analysis, Methodology, Writing – original draft.

Declaration of competing interest

The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Proofs

Proof of Proposition 1. See the discussion precedes the proposition. ■

Proof of Corollary 1. See the discussion precedes the proposition. ■

Proof of Lemma 1. When $c > c_1$, from (9) and (20), we have

$$\begin{aligned} \frac{-(p^*Q + M)}{A} g_H &= c \frac{g_H}{G - A} Q \Leftrightarrow \frac{-(v + c - \lambda Q \frac{g_H}{G - A})Q + M}{A} = \frac{cQ}{G - A}, \\ \Leftrightarrow \frac{-(v - \lambda Q \frac{g_H}{G - A})Q + M}{A} &= \frac{cQ}{G - A} + \frac{cQ}{A} = \frac{cQG}{(G - A)A}, \\ \Leftrightarrow -(v - \lambda Q \frac{g_H}{G - A})Q + M &= \frac{cQG}{G - A}. \end{aligned} \quad (\text{A.1})$$

Substituting c with c_1 , we have

$$-(v - \lambda Q \frac{g_H}{G - A})Q + M = -(v - \lambda Q)Q + M \frac{g}{G - A} \quad (\text{A.2})$$

In addition, from (19), we see that when $g_H \rightarrow \underline{g}$, we have

$$\frac{g_H}{G - A} \rightarrow 1, \quad \frac{g}{G - A} \rightarrow 1. \quad (\text{A.3})$$

Combining the equations above, when $c \rightarrow c_1$, we have $g_H \rightarrow \underline{g}$ and $p^* \rightarrow v + c - \lambda Q$ from (20). ■

¹¹ Previous unpublished versions of this manuscript developed a discrete model with n_1 large members, n_2 small members and n_3 customers. Despite this alteration, the main trade-off between extensive and intensive margins remained qualitatively unchanged.

Proof of Proposition 2. See the discussion precedes the proposition. ■

Proof of Corollary 2. The total profit of all members is

$$\begin{aligned} \Pi &= \int_{\underline{g}}^{g_H} \left((v - p^*) \frac{g}{G - A} Q - \frac{\lambda}{2} \left(\frac{g}{G - A} Q \right)^2 \right) f(g) dg \\ &\quad + \int_{g_H}^{\infty} \left((v + c - p^*) \frac{g_H}{G - A} Q - \frac{\lambda}{2} \left(\frac{g_H}{G - A} Q \right)^2 - \frac{-(p^* Q + M)}{A} g \right) f(g) dg, \end{aligned} \quad (\text{A.4})$$

$$= \int_{\underline{g}}^{g_H} \left(\lambda Q \frac{g_H}{G - A} \frac{g}{G - A} Q - \frac{\lambda}{2} \left(\frac{g}{G - A} Q \right)^2 - \frac{cQ}{G - A} g \right) f(g) dg + \int_{g_H}^{\infty} \left(\frac{\lambda}{2} \left(\frac{g_H}{G - A} Q \right)^2 - \frac{cQ}{G - A} g \right) f(g) dg, \quad (\text{A.5})$$

$$= \frac{\lambda}{2} \left(\frac{g_H}{G - A} Q \right)^2 - \frac{\lambda}{2} \int_{\underline{g}}^{g_H} \left(\frac{(g_H - g)Q}{G - A} \right)^2 f(g) dg - \frac{cQ}{G - A} G. \quad (\text{A.6})$$

Taking derivatives of the first and third term of the total profit, we have

$$\frac{d \left(\frac{\lambda}{2} \left(\frac{g_H}{G - A} Q \right)^2 - \frac{cQ}{G - A} G \right)}{dc} = \lambda \frac{g_H}{G - A} Q^2 \frac{d \frac{g_H}{G - A}}{dc} - Q \left(1 - \frac{dp^*}{dc} \right), \quad (\text{A.7})$$

$$= \lambda Q^2 \left(\frac{g_H}{G - A} - 1 \right) \frac{d \frac{g_H}{G - A}}{dc}. \quad (\text{A.8})$$

For the first equality, we use $\frac{d \frac{c}{G - A}}{dc} = (1 - \frac{dp^*}{dc})/G$. For the second one, we use $\frac{dp^*}{dc} = 1 - \lambda Q \frac{d \frac{g_H}{G - A}}{dc}$. Taking the derivative of the second term (without the minus sign) of the total profit, we have

$$\frac{d \frac{\lambda}{2} \int_{\underline{g}}^{g_H} \left(\frac{(g_H - g)Q}{G - A} \right)^2 f(g) dg}{dc} = \lambda \frac{Q}{G - A} \left(\frac{Q}{(G - A)^2} \frac{dA}{dc} \right) \int_{\underline{g}}^{g_H} (g_H - g)^2 f(g) dg + \lambda \left(\frac{Q}{G - A} \right)^2 \frac{d g_H}{dc} \int_{\underline{g}}^{g_H} (g_H - g) f(g) dg. \quad (\text{A.9})$$

In addition, we have

$$\frac{d \frac{g_H}{G - A}}{dc} = - \frac{dA}{dc} \frac{1}{(G - A)^2} \frac{\int_{\underline{g}}^{g_H} g f(g) dg}{\int_{g_H}^{\infty} f(g) dg}, \quad (\text{A.10})$$

$$\frac{d g_H}{dc} = - \frac{dA}{dc} \frac{1}{\int_{g_H}^{\infty} f(g) dg}. \quad (\text{A.11})$$

Hence, the derivative of the total profit with respect to c is

$$\begin{aligned} \frac{d\Pi}{dc} &= \frac{\lambda Q^2}{(G - A)^2} \frac{dA}{dc} \frac{\int_{\underline{g}}^{g_H} g f(g) dg}{\int_{g_H}^{\infty} f(g) dg} \left(1 - \frac{g_H}{G - A} \right) \\ &\quad - \frac{\lambda Q^2}{(G - A)^2} \frac{dA}{dc} \left(\frac{\int_{\underline{g}}^{g_H} (g_H - g)^2 f(g) dg}{G - A} - \frac{\int_{\underline{g}}^{g_H} (g_H - g) f(g) dg}{\int_{g_H}^{\infty} f(g) dg} \right) \end{aligned} \quad (\text{A.12})$$

$$\begin{aligned} &= \frac{\lambda Q^2}{(G - A)^2} \frac{dA}{dc} \frac{1}{(G - A) \int_{g_H}^{\infty} f(g) dg} \\ &\quad \left(\int_{\underline{g}}^{g_H} g_H f(g) dg \int_{\underline{g}}^{g_H} g f(g) dg + \int_{\underline{g}}^{g_H} g_H f(g) dg \int_{g_H}^{\infty} g_H f(g) dg \right. \\ &\quad \left. - \int_{\underline{g}}^{g_H} g g_H f(g) dg - \int_{\underline{g}}^{g_H} (g_H - g)^2 f(g) dg \int_{g_H}^{\infty} f(g) dg \right) \end{aligned} \quad (\text{A.13})$$

$$= \frac{\lambda Q^2}{(G-A)^3} \frac{dA}{dc} \int_{\underline{g}}^{g_H} (g g_H + g_H^2 - (g_H - g)^2) f(g) dg \quad (\text{A.14})$$

$$= \underbrace{\frac{\lambda Q^2}{(G-A)^3}}_{>0} \underbrace{\frac{dA}{dc}}_{<0} \underbrace{\int_{\underline{g}}^{g_H} g(3g_H - g) f(g) dg}_{>0} \quad (\text{A.15})$$

$$< 0. \quad \blacksquare \quad (\text{A.16})$$

Proof of Lemma 2. From (9) and (20), we have

$$\begin{aligned} \frac{v - p^* + c}{\lambda} &= \frac{Q}{G-A} g_H = \frac{-(p^*Q + M)}{Ac} g_H, \\ -((v - \lambda Q \frac{g_H}{G-A} + c)Q + M) \frac{1}{A} &= \frac{cQ}{G-A}, \\ g_H &= (vQ + M) \frac{G-A}{\lambda Q^2} + \frac{cQ}{\lambda Q}. \end{aligned} \quad (\text{A.17})$$

From (10), we have

$$\begin{aligned} g_L &= (vQ + M) \frac{G-A}{\lambda Q^2} + \frac{cA}{\lambda Q}, \\ &= \frac{(vQ + M)G}{\lambda Q^2} + \frac{A(cQ - (vQ + M))}{\lambda Q^2}. \end{aligned} \quad (\text{A.18})$$

Taking the first order derivative with respect to c , we have

$$\frac{dg_L}{dc} = \frac{cQ - (vQ + M)}{\lambda Q^2} \frac{dA}{dc} + \frac{A}{\lambda Q}. \quad (\text{A.19})$$

Replacing c with c_2 , we have $g_L > \underline{g}$ and $\frac{dg_L}{dc} > 0$. Hence, when c is slightly above c_2 , g_L is guaranteed to be larger than $\underline{g}$. $\blacksquare$

Proof of Proposition 3. See the discussion precedes the proposition. $\blacksquare$

Proof of Corollary 3. The total profit of all members is

$$\begin{aligned} \Pi &= \int_{\underline{g}}^{g_L} \left((v - p^*) \frac{g_L}{G-A+B} Q - \frac{\lambda}{2} \left(\frac{g_L}{G-A+B} Q \right)^2 \right) f(g) dg \\ &+ \int_{g_L}^{g_H} \left((v - p^*) \frac{g}{G-A+B} Q - \frac{\lambda}{2} \left(\frac{g}{G-A+B} Q \right)^2 \right) f(g) dg \\ &+ \int_{g_H}^{\infty} \left((v + c - p^*) \frac{g_H}{G-A+B} Q - \frac{\lambda}{2} \left(\frac{g_H}{G-A+B} Q \right)^2 - \frac{-(p^*Q + M)}{A} g \right) f(g) dg, \end{aligned} \quad (\text{A.20})$$

$$\begin{aligned} &= \int_{\underline{g}}^{g_L} \left(\lambda Q \frac{g_H}{G-A+B} \frac{g_L}{G-A+B} Q - \frac{\lambda}{2} \left(\frac{g_L}{G-A+B} Q \right)^2 - \frac{cQ}{G-A+B} g_L \right) f(g) dg \\ &+ \int_{g_L}^{g_H} \left(\lambda Q \frac{g_H}{G-A+B} \frac{g}{G-A+B} Q - \frac{\lambda}{2} \left(\frac{g}{G-A+B} Q \right)^2 - \frac{cQ}{G-A+B} g \right) f(g) dg \\ &+ \int_{g_H}^{\infty} \left(\frac{\lambda}{2} \left(\frac{g_H}{G-A+B} Q \right)^2 - \frac{cQ}{G-A+B} g \right) f(g) dg, \end{aligned} \quad (\text{A.21})$$

$$= \frac{\lambda}{2} \left(\frac{g_H}{G-A+B} Q \right)^2 - \frac{\lambda}{2} \int_{g_L}^{g_H} \left(\frac{(g_H - g)Q}{G-A+B} \right)^2 f(g) dg - \frac{\lambda}{2} \int_{\underline{g}}^{g_L} \left(\frac{(g_H - g_L)Q}{G-A+B} \right)^2 f(g) dg - \frac{cQ(G+B)}{G-A+B}. \quad (\text{A.22})$$

The first equality comes from (26) and the second one from re-organizing the terms (i.e., adding and subtracting $\frac{\lambda}{2} \left(\frac{g_H}{G-A+B} Q \right)^2$ in the first two terms).

Taking derivatives of the first and fourth term of the total profit, we have

$$\frac{d \frac{\lambda}{2} \left(\frac{g_H}{G-A+B} Q \right)^2 - \frac{cQ(G+B)}{G-A+B}}{dc} = \lambda \frac{g_H Q}{G-A+B} \frac{d \frac{v-p^*+c}{\lambda}}{dc} - \frac{d(cQ + \frac{AcQ}{G-A+B})}{dc}, \quad (\text{A.23})$$

$$= \frac{g_H Q}{G-A+B} \left(1 - \frac{dp^*}{dc} \right) - Q \left(1 - \frac{dp^*}{dc} \right), \quad (\text{A.24})$$

$$= \lambda Q^2 \left(\frac{g_H}{G-A+B} - 1 \right) \frac{d \frac{g_H}{G-A+B}}{dc}. \quad (\text{A.25})$$

For the first equality, we use (26). The second equality comes from (18). For the third one, we use $1 - \frac{dp^*}{dc} = \lambda Q \frac{d \frac{g_H}{G-A+B}}{dc}$ from (25).

Taking the derivative of the second and third term (without the minus sign) of the total profit, we have

$$\begin{aligned} \frac{d \frac{\lambda}{2} \int_{g_L}^{g_H} \left(\frac{(g_H-g)Q}{G-A+B} \right)^2 f(g) dg}{dc} &= \lambda \frac{Q}{G-A+B} \left(\frac{Q}{(G-A+B)^2} \frac{dA-B}{dc} \right) \int_{g_L}^{g_H} (g_H-g)^2 f(g) dg \\ &\quad + \frac{\lambda}{2} \left(\frac{Q}{G-A+B} \right)^2 \left(2 \int_{g_L}^{g_H} (g_H-g) f(g) dg \frac{dg_H}{dc} - f(g_L)(g_H-g_L)^2 \frac{dg_L}{dc} \right), \end{aligned} \quad (\text{A.26})$$

$$\frac{d \frac{\lambda}{2} \int_{\underline{g}}^{g_L} \left(\frac{(g_H-g_L)Q}{G-A+B} \right)^2 f(g) dg}{dc} = \frac{d \frac{\lambda}{2} \left(\frac{(g_H-g_L)Q}{G-A+B} \right)^2}{dc} \int_{\underline{g}}^{g_L} f(g) dg + \frac{\lambda}{2} \left(\frac{(g_H-g_L)Q}{G-A+B} \right)^2 f(g_L) \frac{dg_L}{dc} \quad (\text{A.27})$$

$$= \frac{\lambda}{2} \frac{d \left(\frac{c}{\lambda} \right)^2}{dc} \int_{\underline{g}}^{g_L} f(g) dg + \frac{\lambda}{2} \left(\frac{(g_H-g_L)Q}{G-A+B} \right)^2 f(g_L) \frac{dg_L}{dc} \quad (\text{A.28})$$

$$= \frac{c}{\lambda} \int_{\underline{g}}^{g_L} f(g) dg + \frac{\lambda}{2} \left(\frac{(g_H-g_L)Q}{G-A+B} \right)^2 f(g_L) \frac{dg_L}{dc}. \quad (\text{A.29})$$

In addition, from (18) and (24), we have

$$\frac{dA-B}{dc} = - \int_{g_H}^{\infty} f(g) dg \frac{dg_H}{dc} - \int_{\underline{g}}^{g_L} f(g) dg \frac{dg_L}{dc}, \quad (\text{A.30})$$

$$\frac{dg_H}{dc} - \frac{dg_L}{dc} = \frac{(G-A-B) - c \frac{dA-B}{dc}}{\lambda Q}. \quad (\text{A.31})$$

Reorganizing the above two equations, we can express $\frac{dg_H}{dc}$ with $\frac{dA-B}{dc}$:

$$\frac{dg_H}{dc} = - \frac{\left(1 + \frac{c}{\lambda Q} \int_{\underline{g}}^{g_L} f(g) dg \right)}{\int_{g_H}^{\infty} f(g) dg + \int_{\underline{g}}^{g_L} f(g) dg} \frac{dA-B}{dc} + \frac{G-A+B}{\lambda Q} \frac{\int_{\underline{g}}^{g_L} f(g) dg}{\int_{\underline{g}}^{g_L} f(g) dg + \int_{g_H}^{\infty} f(g) dg}. \quad (\text{A.32})$$

Cancelling some terms, substituting $\frac{dg_H}{dc}$, we have

$$\begin{aligned} &\frac{d \frac{\lambda}{2} \int_{g_L}^{g_H} \left(\frac{(g_H-g)Q}{G-A+B} \right)^2 f(g) dg + \frac{\lambda}{2} \int_{\underline{g}}^{g_L} \left(\frac{(g_H-g_L)Q}{G-A+B} \right)^2 f(g) dg}{dc} \\ &= \lambda \left(\frac{Q}{G-A+B} \right)^2 \left(\frac{\int_{g_L}^{g_H} (g_H-g)^2 f(g) dg}{G-A+B} \frac{dA-B}{dc} + \int_{g_L}^{g_H} (g_H-g) f(g) dg \frac{dg_H}{dc} \right) + \frac{c}{\lambda} \int_{\underline{g}}^{g_L} f(g) dg \end{aligned} \quad (\text{A.33})$$

$$\begin{aligned}
&= \lambda \left(\frac{Q}{G-A+B} \right)^2 \frac{dA-B}{dc} \left(\frac{\int_{g_L}^{g_H} (g_H-g)^2 f(g) dg}{G-A+B} - \frac{\int_{g_L}^{g_H} (g_H-g) f(g) dg}{\int_{g_H}^{\infty} f(g) dg \frac{dg_H}{dc} + \int_{g_L}^{g_H} f(g) dg} \left(1 + \frac{c}{\lambda Q} \int_{g_L}^{g_H} f(g) dg \right) \right) \\
&+ \frac{Q}{G-A+B} \int_{g_L}^{g_H} (g_H-g) f(g) dg \frac{\int_{g_L}^{g_H} f(g) dg}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg} + \frac{c}{\lambda} \int_{g_L}^{g_H} f(g) dg
\end{aligned} \quad (A.34)$$

$$\begin{aligned}
&= -\frac{\lambda Q^2}{(G-A+B)^3} \frac{dA-B}{dc} \frac{\int_{g_L}^{g_H} g(g_H-g) f(g) dg}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg} + \frac{Q}{G-A+B} \frac{\int_{g_L}^{g_H} f(g) dg (g_H-g_L + \int_{g_L}^{g_H} (g_H-g) f(g) dg)}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg}.
\end{aligned} \quad (A.35)$$

Moreover, from $\frac{dg_H}{dc}$ we have

$$\frac{d \frac{g_H}{G-A+B}}{dc} = \frac{\int_{g_L}^{g_H} (g_H-g) f(g) dg}{(G-A+B)^2} \frac{d(A-B)}{dc} + \frac{1}{\lambda Q} \frac{\int_{g_L}^{g_H} f(g) dg}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg} \quad (A.36)$$

Hence, the derivative of the total profit is

$$\begin{aligned}
\frac{d\Pi}{dc} &= \frac{\lambda Q^2}{(G-A+B)^3} \frac{d(A-B)}{dc} (g_H - (G-A+B)) \int_{g_L}^{g_H} (g_H-g) f(g) dg \\
&+ \frac{Q}{G-A+B} \frac{(g_H - (G-A+B)) \int_{g_L}^{g_H} f(g) dg}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg} \\
&+ \frac{\lambda Q^2}{(G-A+B)^3} \frac{dA-B}{dc} \frac{\int_{g_L}^{g_H} g(g_H-g) f(g) dg}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg} - \frac{Q}{G-A+B} \frac{\int_{g_L}^{g_H} f(g) dg (g_H-g_L + \int_{g_L}^{g_H} (g_H-g) f(g) dg)}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg}
\end{aligned} \quad (A.37)$$

$$\begin{aligned}
&= \frac{\lambda Q^2}{(G-A+B)^3} \underbrace{\frac{d(A-B)}{dc}}_{<0} \underbrace{\left((g_H - (G-A+B)) \int_{g_L}^{g_H} (g_H-g) f(g) dg + \frac{\int_{g_L}^{g_H} g(g_H-g) f(g) dg}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg} \right)}_{>0} \\
&- \frac{Q}{G-A+B} \underbrace{\frac{\int_{g_L}^{g_H} f(g) dg (g_H-g_L + \int_{g_L}^{g_H} (g_H-g) f(g) dg)}{\int_{g_L}^{g_H} f(g) dg + \int_{g_H}^{\infty} f(g) dg}}_{>0}
\end{aligned} \quad (A.38)$$

$$< 0. \quad \blacksquare \quad (A.39)$$

Proof of Proposition 4. See the discussion precedes the proposition. $\blacksquare$

Proof of Proposition 5. See the discussion precedes the proposition. $\blacksquare$

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