**FTG Working Paper Series**

# The Limits of Multi-Dealer Platforms

by

Chaojun Wang

Working Paper No. 00084-00

Finance Theory Group

www.financetheory.com

# The Limits of Multi-Dealer Platforms

Chaojun Wang*

The Wharton School, University of Pennsylvania

September 30, 2022

**Abstract**

On many important multi-dealer platforms, customers mostly request quotes from very few dealers. I build a model of multi-dealer platforms where dealers strategically choose to respond or ignore a request. If the customer contacts more dealers, every dealer responds with a lower probability and offers a stochastically worse price when responding. These two negative effects overturn the customer's benefit from potentially receiving more quotes, worsening her overall price. In equilibrium, the customer contacts only two dealers. Multi-dealer platforms are limited in their ability to promote price competition: No alternative design of information disclosure can improve the customer's payoff above this outcome.

*JEL Classifications: D44, D47, D83*

*Keywords:* Over-the-counter, multi-dealer platforms, request for quote, pre-trade transparency

*Email: wangchj@wharton.upenn.edu I am grateful for helpful comments and suggestions from Yu An, Sergei Glebkin, and John Kuong. Special thanks to Tomy Lee for extensive discussions that helped me better understand the marginal contribution of my paper. I also thank Clarise Huang and Dylan Marchlinski for proof reading the paper.

# 1 Introduction

Many over-the-counter (OTC) markets now feature trading platforms that allow a customer to simultaneously request quotes from multiple dealers.[1] These multi-dealer platforms have the potential to greatly intensify competition among dealers, provided that customers request quotes from a large number of dealers. On many important multi-dealer platforms, customers mostly request quotes from very few dealers, for example from only three on Swap Execution Facilities (SEFs) for index credit default swaps—the minimum required by regulations (Riggs, Onur, Reiffen, and Zhu, 2020).[2] Why do the customers contact so few dealers that even a lowerbound of three seems to bind them? Because the benefit of greater competition from contacting more dealers proposed in existing theory ceases to exist, and in fact becomes a cost, when the dealers are allowed to strategically ignore a customer's request. I add exactly one feature to an otherwise standard model: Dealers can endogenously choose to respond or ignore a request for quote (RFQ). I show that contacting more dealers, rather than spurring price competition among dealers, actually suppresses competition and leads to worse prices. In equilibrium, the customer chooses to contact only two dealers. More generally, no alternative design of information disclosure about the number of contacted dealers can improve the customer's payoff above this outcome. In this sense, multi-dealer platforms are limited in their ability to promote price competition.

Dealers' ability to ignore a trade request is a natural yet often overlooked feature of OTC trading. Whether an OTC trade is requested on a platform or not, dealers are not forced

[1]Examples include Bloomberg and Tradeweb for swaps, MarketAxess for bonds, and Refinitiv for currencies.

[2]At the same time, the volume traded on platforms is relatively small in many OTC markets where platform trading is not mandatory. For example, MarketAxess had 15% of trade volume for U.S. corporate bonds in 2016Q1, and 20% as of August 2022. Most of its market share growth was gained during the COVID pandemic in 2020.

to respond, and indeed they quite often do not respond. Dealers' revealed preference shows that responding cannot be completely cost-free. The dealers must evaluate the asset, their own inventories, and market conditions together with the identity of the customer, which itself might be informative about the asset value or the customer's willingness to pay. In my model, the cost of such effort to properly form a response can be arbitrarily small. Yet, that dealers endogenously decide whether to respond fundamentally transforms the intended benefit from contacting more dealers into a cost.

The underlying economics comes from the following observation: It is more cost-efficient to concentrate response probabilities among fewer dealers. I consider a simple numerical example to illustrate this observation. If three dealers are contacted in an RFQ, I suppose that they each respond with a probability 70%, 60%, and 50%, respectively. When at least one dealer responds, a trade occurs. Thus, the aggregate expected gain from trade depends on the individual dealer response probabilities through a sufficient statistic $(1-70\%)(1-60\%)(1-50\%)$, which is the probability that no dealer responds to the RFQ. On the other hand, the aggregate expected cost of responding to the RFQ depends on the sum of the response probabilities, $70\% + 60\% + 50\%$. Keeping the aggregate gain constant, one can reduce the aggregate cost by reducing one dealer's response probability, say from 50% down to 0%, and raising another dealer's response probability, say from 60% up to 80%. The adjustment does not change the aggregate gain, because the probability that no dealer responds remains the same, $(1-70\%)(1-80\%)(1-0\%) = (1-70\%)(1-60\%)(1-50\%)$. Yet the aggregate cost declines, $70\% + 80\% + 0\% < 70\% + 60\% + 50\%$. Therefore, it is more cost-efficient to shut down one dealer, and concentrate the response probabilities into the remaining dealers.

My benchmark model has one of the most basic structures in economics: A customer buyer chooses to contact a number $n$ of dealers simultaneously in order to purchase an asset. Observing the customer's choice $n$, each dealer chooses whether to respond and what price to offer. Responding to the RFQ incurs a cost.

A dealer naturally trades off the response cost and its expected trading profit: It is willing to respond only if the expected profit justifies responding. In the unique symmetric subgame perfect equilibrium, each dealer mixes between responding or not, and offers a distribution of prices conditional on responding. If the customer were to contact more dealers, every contacted dealer would endogenously respond with a lower probability and offer a stochastically higher price when responding to maintain each dealer's individual rationality. These two negative effects on dealer behavior more than offset the benefit to the customer from potentially receiving more quotes. Anticipating the dealer behavior, the customer contacts precisely 2 dealers in equilibrium.

Moreover, the customer contacts 2 dealers not only in the symmetric subgame perfect equilibrium, but also in *any* subgame perfect equilibrium. The driving force comes from the cost saving of response concentration. The cost saving, as shown in the above numerical example, does not depend on the symmetry of dealers' strategies.

An assumption of the model is that the number of contacted dealers is disclosed to those dealers in a customer RFQ, as is the case on SEFs. I examine alternative platform designs of information disclosure about $n$—the number of dealers contacted by the customer. Not disclosing any information about the number $n$ would make the customer contact as many dealers as is feasible. However, the customer's payoff decreases relative to her status quo payoff when the number $n$ is fully disclosed, as the customer expects a lower response probability from each dealer and a worse overall price. These predictions match the patterns on MarketAxess for corporate bonds, which does not disclose the number of contacted dealers by default. There, a customer on average contacts more than 25 dealers per RFQ, and dealers' response rate is only around 25% (Hendershott and Madhavan, 2015). In comparison, dealers' response rate is slightly below 90% on SEFs (Riggs et al., 2020).

Although making the number $n$ of contacted dealers undisclosed does not lead to more competitive prices, it does cause the customer to contact more dealers in equilibrium. More generally, one may wonder whether some alternative information design that partially discloses the number $n$ could make the dealers' prices more competitive than the status quo. The answer is no unfortunately. No alternative design of information disclosure can improve the customer's payoff above the status quo. In this sense, multi-dealer platforms are limited in their ability to promote price competition. The driving force again comes from the cost saving of response concentration. The cost saving, as shown in the above numerical example, does not depend on what information is disclosed about the number $n$.

The benchmark model also predicts that a dealer responds with a higher probability when facing a larger order or when perceiving a larger gain from trade. Conditional on responding, the dealer offers a stochastically lower price when facing a larger order or when perceiving a smaller gain from trade. The model's predictions are largely consistent with empirical patterns documented in the literature.

## 1.1 Literature

This paper belongs to the recent literature on multi-dealer platforms.[3] On SEFs, the Commodity Futures Trading Commission used to require a customer to contact at least 2 dealers in an RFQ. On average, a customer contacted 2.9 dealers per request (McPartland,

[3]Examples include Collin-Dufresne, Junge, and Trolle (2020), Hau, Hoffmann, Langfield, and Timmer (2021), Hendershott and Madhavan (2015), O'Hara and Alex Zhou (2021), Hendershott, Livdan, and Schürhoff (2021), Liu, Vogel, and Zhang (2017), Vogel (2019), and Wittwer and Allen (2021).

2014). The lowerbound then increased by 1, to 3 dealers per request in 2014. After the change, Riggs et al. (2020) find that customers most frequently contact only 3 dealers, on average 4 (one more than before the change), and rarely more than 5. If weighted by notional quantity, customers contact even fewer dealers on average because larger orders tend to be exposed to fewer dealers. These facts suggest that the lowerbound of 3 is most often binding on customers.

Existing theories are able to explain why customers do not contact as *many* dealers as possible, without explaining why they typically contact as *few* as possible in practice. Most closely related to this paper are the theories of Riggs et al. (2020) and Baldauf and Mollner (2022). Both papers generate an interior solution for the optimal number of dealers to contact by trading off the benefit of dealer competition against either a direct "relationship cost" of contacting more dealers (Riggs et al., 2020)[4] or an indirect cost of front-running (Baldauf and Mollner, 2022). These papers cannot explain why customers contact dramatically more dealers on platforms that by default do not disclose the number of contacted dealers, such as MarketAxess where customers contact more than 25 dealers on average. To reconcile the large gap between SEFs and MarketAxess, those papers would require the relationship or the front-running cost to be sufficiently high on one type of platform yet extremely low on the other. My paper questions whether dealers indeed become more competitive when more potential rivals are present in the first place. Letting dealers strategically decide whether to respond in an otherwise standard model of price competition fundamentally overturns their incentive to compete in the presence of more rivals. As a result, my paper does not need any added trade-offs as those in Riggs et al. (2020) and Baldauf and Mollner (2022). I provide

[4]Riggs et al. (2020) also feature winner's curse. In their model, "[t]he relationship channel generates an interior solution for the optimal number of dealers requested, and the winner's curse channel generates the comparative statics that [they] eventually test."

a parsimonious model that unambiguously explain why customers contact very few dealers when the number of contacted dealers is disclosed to the dealers and many when the number is not disclosed. Moreover, unlike existing theories, my paper goes beyond a specific design of multi-dealer platforms. By exploring general platform designs of information disclosure, my paper contributes a novel result on the limits of such platforms in promoting price competition.

My paper also belongs to the literature on auctions with entry.[5] Existing papers are concerned about the auction format—such as second-price auctions and the commitment to a reservation price—which are far away from practical implementation on multi-dealer platforms in real financial markets. My model differs in that the number of potential bidders is chosen by the auctioneer, and may be fully disclosed, partially disclosed, or not disclosed to the potential bidders. Thereby, my paper contributes a novel result on the optimal information disclosure about the number of potential bidders, which is assumed to be exogenously fixed in this literature.

With different focuses, Glebkin, Yueshen, and Shen (2022) and Yueshen (2017) also feature an uncertain number of dealers who respond to a trade request. My model differs from theirs in two aspects: *(1)* The number of contacted dealers is endogenously chosen by the customer instead of being exogenously fixed; *(2)* each dealer endogenously mixes between responding or not, instead of having response probabilities that do not depend on any agent's endogenous strategy. These two modeling distinctions are crucial for obtaining my paper's main results. In particular, if a dealer's response probability were exogenously fixed at some constant as in Glebkin et al. (2022) and Yueshen (2017), the customer would contact as many dealers as is feasible, and her price would approach the competitive limit

[5] Examples include McAfee and McMillan (1987), Engelbrecht-Wiggans (1987), Levin and Smith (1994), Menezes and Monteiro (2000), and Jovanovic and Menkveld (2022).

when the pool of potential dealers is large (Appendix A).

This paper is broadly related to the literature on search friction,[6] market concentration,[7] and sticky relationship[8] of OTC trading. Can these general features of OTC markets explain why a customer contacts very few dealers on multi-dealer platforms? Most likely not. First, the very objective of multi-dealer platforms is to reduce search friction by making it easier for customers to reach out to many dealers at once. Second, these general arguments cannot explain why a customer contacts many more dealers on platforms that by default do not disclose the number of contacted dealers, such as MarketAxess. Therefore, these general features of OTC markets cannot be the driving force that determines the external margin of *how many* dealers a customer would contact on a multi-dealer platform.[9]

To the consumer search literature,[10] which also feature mixed pricing strategies by firms, this paper contributes a novel model where the number of responding firms is endogenously determined by the firms' own decisions of whether to respond instead of being exogenously chosen by nature. If one replaces the firms' endogenous decisions by an exogenous availability constraint, then the customer would contact as many firms as is feasible (Appendix A).

[6] Duffie, Gârleanu, and Pedersen (2005) pioneered the OTC search literature. Examples include Atkeson, Eisfeldt, and Weill (2015), Bethune, Sultanum, and Trachter (2021), Dugast, Üslü, and Weill (2022), Hugonnier, Lester, and Weill (2020), Li, Rocheteau, and Weill (2012), Maurin (2022), Praz (2014), Tsoy (2021), Vayanos and Weill (2008), and Wang (2022) among many others. Weill (2020) reviews the literature of search models in OTC markets.

[7] Most OTC markets exhibit a highly concentrated core-periphery trading network (Abad, Aldasoro, Aymanns, D'Errico, Fache Rousová, Hoffmann, Langfield, Neychev, and Roukny, 2016; Afonso, Kovner, and Schoar, 2014; Bech and Atalay, 2010; Craig and von Peter, 2014; Hollifield, Neklyudov, and Spatt, 2017; in't Veld and van Lelyveld, 2014; King, Osler, and Rime, 2012; Li and Schürhoff, 2019; Peltonen, Scheicher, and Vuillemey, 2014). Theoretical explanations include Chang and Zhang (2022), Farboodi, Jarosch, and Shimer (2022), Sambalaibat (2022), Üslü (2019), and Wang (2016).

[8] Examples include Di Maggio, Kermani, and Song (2017) and Hendershott, Li, Livdan, and Schürhoff (2020).

[9] Riggs et al. (2020) provide evidence that the relationship channel matters for the internal margin of *which* dealers to contact and *which* dealer would more likely offer a better price, although no evidence is provided for why relationship drives the external margin of *how many* dealers to contact.

[10] Stigler (1961) pioneered the consumer search literature. Examples include Varian (1980), Burdett and Judd (1983), Stahl (1989), and Lester (2011).

Another distinction is the absence of a search cost in my paper. The consumer search literature assume a positive search cost for at least some customers. In my model, the customer chooses to contact only two dealers for prices in the absence of any search cost.

The paper is organized as follows. Section 2 sets up the benchmark model. Section 3 solves for the unique symmetric equilibrium in closed form and obtains the main results in any equilibrium. Section 4 examines alternative designs of information disclosure and establishes the limits of multi-dealer platforms. Section 5 derives the models' other empirical predictions. Section 6 concludes.

# 2 Benchmark Model

## 2.1 Trading game

The trading game proceeds in three stages. In Stage 1, a customer seeking to buy one unit of an asset chooses a number $n$ of ex-ante identical dealers to contact in an RFQ. Observing the customer's choice $n$, each dealer $j$ chooses whether to respond and what price $p_j$ to offer in Stage 2. The asset's expected payoff is 0, and the customer has an additional private value $v$ of owning the asset. Responding to the RFQ incurs a cost $c > 0$, which is assumed to be less than the value $v$ ($c < v$) so that there is a positive gain from trade. In Stage 3, the customer chooses whether and against which dealer's price to trade. I do not impose any tie-breaking rule in the case of an indifference. All agents are risk-neutral with no time discounting. Figure 1 summarizes the timing of the model.

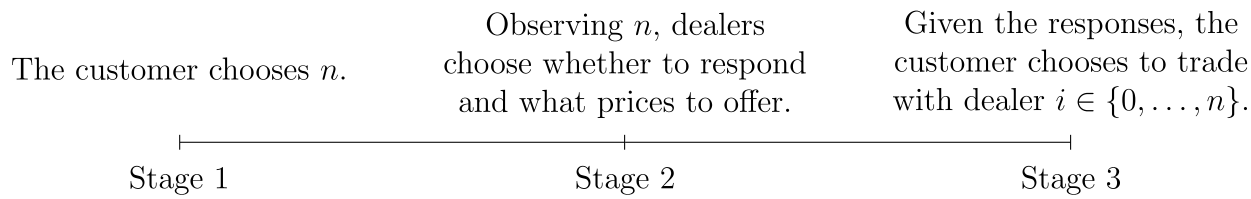


Figure 1: Timing

## 2.2 Strategies and equilibrium concept

The customer's strategy consists of a couple $(n, i)$, following which the customer contacts $n$ dealers in Stage 1 and trades with dealer $i \in \{0, 1, \ldots n\}$ in Stage 3 after receiving the dealers' responses $(p_1, \ldots, p_n)$. If dealer $j$ chooses not to respond to the customer's RFQ in Stage 2, then $p_j = \text{NA}$ by convention. If the customer chooses not to trade in Stage 3, then $i = 0$ by convention. Mixed strategies are allowed. The strategy of dealer $j$ consists of a couple $(a_{j,n}, F_{j,n})$ for each number of dealers $n$ chosen by the customer, where $a_{j,n} \in [0, 1]$ is the probability with which the dealer responds to the RFQ, and $F_{j,n}$ is the CDF of the dealer's price offer if the dealer does respond.

The solution concept is subgame perfect equilibrium. I first solve for the unique *symmetric* subgame perfect equilibrium, where all dealers employ the same strategy $(a^*, F^*)$. Then I show that the main results hold in *all* subgame perfect equilibria (Theorem 2). In a symmetric subgame perfect equilibrium,

$$\text{(symmetry)} \quad a_{j,n} = a_n^*, \text{ and } F_{j,n} = F_n^* \text{ for every } n \in \mathbb{Z}^{++} \text{ and } j = 1, \ldots n.$$

The agents' optimality conditions are derived as follows. In Stage 3, the customer chooses to trade with the dealer who offers the lowest price if that price is less than the customer's private value, and otherwise does not trade:

$$i^* = \begin{cases} \underset{j=1,\ldots,n}{\operatorname{argmin}}\ p_j & \text{if } \underset{j=1,\ldots,n}{\min} p_j < v, \\ 0 & \text{if } \underset{j=1,\ldots,n}{\min} p_j > v. \\ \underset{j=1,\ldots,n}{\operatorname{argmin}}\ p_j \text{ or } 0 & \text{if } \underset{j=1,\ldots,n}{\min} p_j = v. \end{cases} \tag{1}$$

In Stage 2, every price $p$ that belongs to the support of the equilibrium price distribution $F_n^*$ maximizes a dealer's expected payoff given the other dealers' pricing strategy for every $n \geq 1$,

$$p \in \underset{\tilde{p} \in \mathbb{R}}{\operatorname{argmax}} \left( \tilde{p}\ \mathbb{1}_{\{\tilde{p} \leq v\}}\ (a_n^*\,[1 - F_n^*(\tilde{p})] + 1 - a_n^*)^{n-1} \right) \qquad \forall p \in \operatorname{supp} F_n^*, \tag{2}$$

The right hand side of (2) is the expected trading profit that the dealer maximizes: When offering a price $\tilde{p} \leq v$, the dealer trades with the customer if and only if every other dealer either offers a price greater than $p$ or does not respond, an event that occurs with probability $(a_n^*[1 - F_n^*(\tilde{p})] + 1 - a_n^*)^{n-1}$.

The dealer's individual rationality is given by

$$p\ \mathbb{1}_{\{p \leq v\}}\ (a_n^*\,[1 - F_n^*(p)] + 1 - a_n^*)^{n-1} \geq c \qquad \forall p \in \operatorname{supp} F_n^*. \tag{3}$$

That is, the dealer's equilibrium expected trading profit must be at least as large as its cost $c$ of responding to the RFQ. If the dealer responds with probability $a_n^* < 1$, the dealer must be indifferent between responding or not. In this case, (3) must hold as an equality,

$$\text{if } a_n^* < 1, \qquad p\ \mathbb{1}_{\{p \leq v\}}\ (a_n^*\,[1 - F_n^*(p)] + 1 - a_n^*)^{n-1} = c \qquad \forall p \in \operatorname{supp} F_n^*. \tag{4}$$

In Stage 1, the customer chooses the number of dealers $n$ to maximize its expected payoff,

$$n^* \in \underset{n \in \mathbb{Z}^+}{\operatorname{argmax}} \left[ v - \mathbb{E}_{G_n^*}(p \wedge v) \right], \tag{5}$$
$$\text{where } 1 - G_n^*(p) = \left[a_n^*(1 - F_n^*(p)) + 1 - a_n^*\right]^n.$$

Here, $G_n^*$ is the CDF of the best price offer $p = \min_{j=1,\dots,n} p_j$, and $v - \mathbb{E}_{G_n^*}(p \wedge v)$ is the customer's expected payoff upon contacting $n$ dealers.

**Proposition 0.** *A symmetric subgame perfect equilibrium is a strategy profile* $(n^*, i^*, a^*, F^*)$ *such that,*

- *the customer's strategy* $(n^*, i^*)$ *satisfies the optimality conditions* (1) *and* (5)*, and*
- *all dealers employ the same strategy* $(a^*, F^*)$*, which satisfies the optimality conditions* (2) *to* (4)*.*

### 2.3 Discussion

A dealer's cost $c$ of responding to a customer's RFQ can arise from the effort and the resources to evaluate the asset,[11] the customer,[12] market conditions, and the dealer's own inventory—activities that are necessary prior to forming a price offer. Instead of a response cost on dealers, Riggs et al. (2020) impose a cost on the customer to *contact* more dealers. The contact cost directly generates an interior solution for the customer's optimal number of dealers to contact that depends on the magnitude of the contact cost. In my model,

[11] The valuation of non-standard assets requires costly expertise (Glode, Green, and Lowery, 2012; Glode and Opp, 2020; Li and Song, 2020; Chaderina and Glode, 2022).

[12] Price discrimination is a prominent feature of OTC trading: A given dealer typically offers different prices to a hedge fund versus to an insurance company (Ramadorai, 2008; Hau et al., 2021; Bjønnes, Kathitziotis, and Osler, 2015; Lee and Wang, 2018; Pinter, Wang, and Zou, 2020, 2021).

contacting more dealers does not incur any cost. The response cost $c$ is materialized only when a dealer strategically decides to *respond* to the RFQ. Therefore, the response cost $c$ does not affect the customer's choice as the cost does not appear in the customer's utility function. Further, the response cost $c$ can be arbitrarily close to 0 or heterogeneous across dealers (as an extension in Appendix C). In both situations, the customer always contacts $n^* = 2$ dealers in equilibrium.

The driving force that pushes the customer to contact only $n^* = 2$ dealers is dealers' ability to endogenously decide whether to respond. Existing work[13] instead assume that every dealer is available with an exogenously fixed probability $\alpha$ and responds whenever available. With such an exogenous response probability, Appendix A shows that the customer would contact as many dealers as is feasible (Proposition 5). Moreover, letting the available dealers endogenously decide whether to respond would restore an interior solution on the number $n$ (Proposition 6). These results illustrate the opposing effects of an exogenous versus an endogenous response probability: Letting dealers respond with an exogenous probability pushes the customer to contact more dealers; whereas endogenizing their response probability pushes the customer to contact fewer dealers. The exogenous availability constraint captures a case of heterogeneous dealer valuations, in that the dealers with a high valuation for the asset is not available to sell the asset.

The probability that a dealer endogenously responds can be interpreted as the attention that the dealer allocates to the customer's RFQ. Attention is costly. Then the cost $c$ is the dealer's marginal cost of attention.

[13]Examples include Glebkin et al. (2022) and Yueshen (2017) and papers in the consumer search literature.

# 3 Equilibrium

This section establishes that *(1)* the customer contacts only $n^* = 2$ dealers in the unique symmetric subgame perfect equilibrium (Theorem 1), *(2)* the customer's ex-ante payoff is the same across all subgame perfect equilibria (Theorem 2), and *(3)* with a mild tie-breaking rule, the customer always contacts $n^* = 2$ dealers in *any* subgame perfect equilibrium (Theorem 2).

## 3.1 Symmetric subgame perfect equilibrium

**Theorem 1.** *The benchmark model has a unique symmetric subgame perfect equilibrium $(n^*, i^*, a^*, F^*)$, where*

$$n^* = 2, \qquad i^* \text{ satisfies (1)},$$

$$a_n^* = \begin{cases} 1 - \left(\dfrac{c}{v}\right)^{\frac{1}{n-1}} & \text{if } n > 1, \\ 1 & \text{if } n = 1, \end{cases} \qquad F_n^*(p) = \begin{cases} \dfrac{1 - \left(\frac{c}{p}\right)^{\frac{1}{n-1}}}{1 - \left(\frac{c}{v}\right)^{\frac{1}{n-1}}}, \text{ and } \operatorname{supp} F_n^* = [c, v] & \text{if } n > 1, \\ \mathbb{1}_{p \geq v} & \text{if } n = 1. \end{cases}$$

Theorem 1 shows that it is strictly optimal for the customer to contact only $n^* = 2$ dealers in the unique symmetric subgame perfect equilibrium. Next, I proceed with a backward induction to derive the symmetric equilibrium.

In Stage 3, the customer's optimal dealer choice $i^*$ is directly given by her optimality condition (1).

In Stage 2, responding with any price higher than the customer's value $v$ is strictly dominated by not responding. Thus, $F_n^*(v) = 1$ for any $n \geq 1$. If the customer contacted only $n = 1$ dealer, then it would be strictly optimal for the dealer to respond with probability

$a_1^* = 1$ and offer the monopoly price $v$ deterministically. When the customer contacts more than 1 dealer, $n > 1$, then the price distribution $F_n^*$ cannot have any atom. If $F_n^*$ had an atom at a price $p^0$, undercutting by offering some price $p^0 - \varepsilon$ would yield a strictly higher payoff than offering the price $p^0$ for at least one dealer.[14] Letting $\bar{p}$ be the upperbound of the dealer's price support, $\bar{p} \coloneqq \sup\left(\operatorname{supp} F_n^*\right)$, then $\bar{p} \leq v$. When a dealer offers a price $\bar{p} - \varepsilon$ that arbitrarily approaches the upperbound $\bar{p}$, the dealer gets to trade with the customer if and only if no other dealers respond, an event that occurs with probability $(1 - a_n^*)^{n-1}$. Thus, the dealer's expected trading profit approaches $\bar{p}(1 - a_n^*)^{n-1}$. If the dealer offers the price $v$, her expected trading profit equals $v(1 - a_n^*)^{n-1}$. The dealer's optimality condition (2) implies that $\bar{p} = v$.

If $a_n^* = 1$, then all the contacted dealers would respond and compete à la Bertrand, offering the price 0 with probability 1 and earning no trading profit. This contradicts the dealer's individual rationality (3), because a given dealer would be strictly better off not responding to save its response cost $c$. Hence, $a_n^* < 1$. Then the dealer's indifference condition (4) is equivalent to

$$p\left(a_n^*\left[1 - F_n^*(p)\right] + 1 - a_n^*\right)^{n-1} = c, \quad \forall p \in \operatorname{supp} F_n^*. \tag{6}$$

Setting $p = v$ in (6) yields

$$v(1 - a_n^*)^{n-1} = c \iff a_n^* = 1 - \left(\frac{c}{v}\right)^{\frac{1}{n-1}}. \tag{7}$$

[14] When every dealer offers the same price $p^0$, at least one dealer trades with the customer with a probability less than 1 regardless of how the customer breaks her tie. Then that dealer is strictly better off offering the slightly lower price $p^0 - \varepsilon$ to undercut the other dealers.

Then equation (6) uniquely determines the price distribution $F_n^*$,

$$F_n^*(p) = \frac{1 - \left(\frac{c}{p}\right)^{\frac{1}{n-1}}}{1 - \left(\frac{c}{v}\right)^{\frac{1}{n-1}}}, \quad \text{and supp } F_n^* = [c, v]\,. \tag{8}$$

**Proposition 1.** *(i) The probability $a_n^*$ that each dealer responds is strictly decreasing in the number of dealers $n > 1$ contacted by the customer. (ii) Conditional on responding, each dealer's price distribution $F_{n'}^*$ first-order stochastically dominates $F_n^*$ for $n' > n > 1$, $F_{n'}^* \succ_{(1)} F_n^*$.*

When the customer contacts one more dealer, two effects arise: *(i)* Each dealer "pays less attention" to the RFQ and responds with a lower probability $a_{n+1}^* < a_n^*$. The decline in the dealers' response probability directly affects the quality of the best price offer that the customer expects. The reduction of dealers' response probability further leads to a second effect: *(ii)* Each responding dealer's price becomes *less* competitive $F_{n+1}^* \succ_{(1)} F_n^*$, despite there being potentially more competing dealers. That the dealers can endogenously decide whether to respond is crucial for Part *(ii)* and thus for Theorem 1. If the response probability were exogenously fixed at some constant $\alpha$ instead of varying endogenously with the number of dealers $n$ contacted by the customer, Appendix A shows that the dealer's price distribution $F_n^\alpha$ would become stochastically *smaller* (that is, *more competitive*) if the customer contacts a larger number $n$ of dealers. With such an exogenous response probability, the customer would contact as many dealers as is feasible in equilibrium (Proposition 5).

Does Proposition 1 rely on any parametric assumption? No. To show this, I derive Proposition 1 from a dealer's individual rationality without resorting to the closed form solutions (7) and (8) for $a_n^*$ and $F_n^*$. First, I show that $a_{n+1}^* < a_n^*$. When dealer $j$ offers the upperbound price $v$, the dealer's expected trading profit is given by $v(1 - a_n^*)^{n-1}$. The dealer's individual rationality equates this expected trading profit to the dealer's response cost $c$. If the dealers were to keep their response probability unchanged when the customer contacts one more dealer, $a^*_{n+1} = a^*_n$, then the probability that dealer $j$ trades with the customer when offering the price $v$ would strictly decrease due to the presence of one more contacted dealer. As a result, $j$ would fail its individual rationality. To offset the effect of including one more dealer and restore the individual rationality for $j$, other dealers' response probability $a^*_{n+1}$ has to decline by just enough to keep the probability of $j$ trading with the customer constant, $(1 - a^*_{n+1})^n = (1 - a^*_n)^{n-1}$.

Next, I explain why $F^*_{n+1} \succ_{(1)} F^*_n$. If the dealers were to keep their price distribution unchanged when the customer contacts one more dealer, $F^*_{n+1} = F^*_n$, then the probability $\left(a^*_{n+1}[1 - F^*_n(p)] + 1 - a^*_{n+1}\right)^n$ that dealer $j$ trades with the customer when offering a given price $p$ would become strictly lower,

$$
\begin{aligned}
\left(a^*_{n+1}\left[1 - F^*_{n+1}(p)\right] + 1 - a^*_{n+1}\right)^{\frac{n}{n-1}} &= \left(1 - F^*_n(p) + F^*_n(p)(1 - a^*_{n+1})\right)^{\frac{n}{n-1}} \\
&< 1 - F^*_n(p) + F^*_n(p)(1 - a^*_{n+1})^{\frac{n}{n-1}} \\
&= 1 - F^*_n(p) + F^*_n(p)(1 - a^*_n) = a^*_n\left[1 - F^*_n(p)\right] + 1 - a^*_n.
\end{aligned}
$$

As a result, $j$ would fail its individual rationality. The inequality above follows from the convexity of the function $x \mapsto x^{n/(n-1)}$. To offset the effect of including one more dealer, other dealers' price distribution $F^*_{n+1}$ has to be stochastically larger to restore the individual rationality for $j$.

These two negative effects on dealer behavior more than offset the benefit to the customer of potentially receiving one more quote, and the customer expects a worse overall price. Therefore, Proposition 1 provides the basis for the customer to contact fewer dealers in Stage 1. I now turn to solve the customer's problem in Stage 1.

In Stage 1, the customer's payoff is 0 when contacting only $n = 1$ dealer. If the customer contacts more than one dealer, $n > 1$, the distribution $G_n^*$ of the best price offer $p = \min_{j=1,\ldots,n} p_j$ is given by

$$1 - G_n^*(p) = [a_n^*(1 - F_n^*(p)) + 1 - a_n^*]^n = \left(\frac{c}{p}\right)^{\frac{n}{n-1}}, \quad \forall p \in [c, v].$$

If $n$ increases, $1 - G_n^*(p)$ strictly increases. That is, the best price offer $p = \min_{j=1,\ldots,n} p_j$ becomes first-order stochastically *larger* when the customer contacts more dealers. Therefore, the customer's unique optimal choice is $n^* = 2$. This establishes Theorem 1.

Theorem 1 continues to hold in the exact same form when the customer is risk-averse: In Stage 3, the customer optimally trades with the dealer offering the lowest price if that price does not exceed the customer's reservation value $v$; Thus in Stage 2, the dealers' subgame remains unaffected, and the dealers continue to follow the equilibrium strategy $(a^*, F^*)$; In Stage 1, since the stochastic dominance $G_2^* \prec_{(1)} G_3^* \prec_{(1)} \ldots$ is *first-order*, risk aversion does not affect the client's choice of the number $n$ at all. Therefore, a risk-averse customer also contacts 2 dealers in the unique symmetric subgame perfect equilibrium.

## 3.2 Any subgame perfect equilibrium

There exists subgame perfect equilbria other than the symmetric one. For example, one can modify the symmetric equilibrium as follows to obtain another subgame perfect equilibrium: When the customer contacts more than 2 dealers, $n > 2$, one can let $n - 2$ of them not respond, and let the other two respond with probability $a_2^*$ and offer the price distribution $F_2^*$ conditional on responding. In such an equilibrium, the customer still earns the same ex-ante payoff of $\pi_2^*$ as in the symmetric equilibrium, where

$$\pi_n^* \coloneqq v - \mathbb{E}_{G_n^*}(p \wedge v). \tag{9}$$

Generalizing this example, the next result establishes that *(i)* the customer's ex-ante payoff is $\pi_2^*$ in any subgame perfect equilibrium, and *(ii)* subject to a mild tie-breaking rule, the customer always contacts $n^* = 2$ dealers in any subgame perfect equilibrium.

**Theorem 2.** *(i) The customer's ex-ante payoff is $\pi_2^*$ in any subgame perfect equilibrium. (ii) If one imposes a tie-breaking rule that the customer prefers to contact fewer dealers whenever she is indifferent, then the customer always contacts 2 dealers in any subgame perfect equilibrium.*

The proof, provided in Appendix B, generalizes that of Theorem 1. The underlying economicscomes from the observation that it is more *cost-efficient* to concentrate response probabilities among fewer dealers. To illustrate this observation, for a given number of contacted dealers, $n$, I let $a_{1,n}^*, \ldots, a_{n,n}^*$ be the $n$ dealers' equilibrium response probabilities. The aggregate expected gain from trade is $v[1-(1-a_{1,n}^*)\ldots(1-a_{n,n}^*)]$. That is, the aggregate gain depends on the individual response probabilities $a_{1,n}^*, \ldots, a_{n,n}^*$ only through the sufficient statistic $(1-a_{1,n}^*)\ldots(1-a_{n-1,n}^*)(1-a_{n,n}^*)$, which is the probability that no dealer responds to the customer's RFQ. Keeping this aggregate gain constant, one can reduce the expected response cost $c(a_{1,n}^* + \ldots + a_{n-1,n}^* + a_{n,n}^*)$ by reducing one dealer's response probability, say $a_{n,n}^*$, down to 0 and raising another dealer's response probability, say $a_{n-1,n}^*$ appropriately.

That is, the minimization problem

$$\min \; a^*_{n-1,n} + a^*_{n,n}$$
$$\text{subject to } \; (1 - a^*_{n-1,n})(1 - a^*_{n,n}) = \text{constant}$$

is solved when either $a^*_{n-1,n} = 0$ or $a^*_{n,n} = 0$. In other words, it is more *cost-efficient* to concentrate response probabilities among fewer dealers. Applying this argument inductively, one obtains that it is more cost-efficient to let at most 2 dealers respond with a positive probability.

When the customer contacts exactly 2 dealers, her ex-ante payoff is shown to be $\pi^*_2$. Thus in any subgame perfect equilibrium, the customer's ex-ante payoff always equals $\pi^*_2$, which she can achieve by contacting only 2 dealers.

I further exploit this observation of cost-efficiency to generalize Theorem 1 with alternative platform designs. An assumption of the model is that the number $n$ of contacted dealers is disclosed to the $n$ dealers, as is the case on SEFs. The next section shows that no alternative design of information disclosure about the number $n$ can improve the customer's payoff.

# 4 Alternative Designs

In practice, many multi-dealer platforms (such as SEFs) disclose the number of contacted dealers to those dealers in a customer RFQ (Riggs et al., 2020), perhaps as a way to motivate the dealers to offer more competitive prices. Proposition 1 shows that upon observing a larger number $n$ of contacted dealers, the dealers' reduced response probability more than offsets their competitive pressure, leading to both individually and overall less competitive prices.

This section examines alternative platform designs of the information disclosure about the number $n$. I first consider the other extreme case where the platform designer does not disclose any information about the number $n$. Then I search for the optimal design of information disclosure that maximizes price competitiveness. Overall, no alternative design of information disclosure can improve the customer's payoff above her status quo payoff when the number of contacted dealers, $n$, is fully disclosed.

## 4.1 No disclosure

I modify the benchmark model as follows: (1) The dealers cannot observe how many other dealers are contacted by the customer. (2) The customer could contact at most $\bar{n}$ dealers ($\bar{n} > 2$), because it will turn out that the customer would contact as many dealers as is feasible in equilibrium. (3) I assume the tie-breaking rule that the customer prefers to contact fewer dealers whenever she is indifferent. (4) To account for imperfect information as the number $n$ becomes unobservable, I use the solution concept of symmetric perfect Bayesian equilibrium (PBE), where all dealers employ the same strategy $(a^{\text{unobs}}, F^{\text{unobs}})$. I do not impose any restriction on off-path beliefs. The remaining setup is identical to the benchmark model in Section 2.

With the number of contacted dealers $n$ being unobservable, a dealer's response strategy $(a^{\text{unobs}}, F^{\text{unobs}})$ can no longer depend on the number $n$. There are two symmetric PBE, one of which is degenerate in that the customer submits no RFQ at all. I first solve for the unique non-degenerate equilibrium, then spell out the degenerate one.

Formally, a symmetric PBE is *non-degenerate* if the customer submits an RFQ with a positive probability. In a non-degenerate equilibrium, the customer's ex-ante payoff must be strictly positive. Thus, the dealers must respond and offer prices strictly less than the monopolistic $v$ with a positive probability, $a^{\text{unobs}} > 0$ and $F^{\text{unobs}}(v^-) > 0$. Hence, it is strictly optimal for the customer to contact as many dealers as is feasible, $n^{\text{unobs}} = \bar{n}$. In equilibrium, the dealers have the correct conjecture about the equilibrium choice $n^{\text{unobs}} = \bar{n}$ of the customer, leading to the following equilibrium result.

**Proposition 2.** *I consider the modified model where the number of contacted dealers is not disclosed. (i) There exists a unique non-degenerate PBE* $(n^{\text{unobs}}, i^*, a^{\text{unobs}}, F^{\text{unobs}})$*, where* $i^*$ *is the same as in Theorem 1, and*

$$n^{\text{unobs}} = \bar{n}, \quad a^{\text{unobs}} = a^*_{\bar{n}}, \quad F^{\text{unobs}} = F^*_{\bar{n}}.$$

*A dealer believes that the customer contacted* $\bar{n}$ *dealers whenever it receives an RFQ. (ii) The customer's ex-ante payoff becomes strictly lower compared to her status quo payoff* $\pi^*_2$ *given by (9) when the number of contacted dealers,* $n$*, is fully disclosed.*

Once the number $n$ becomes undisclosed, the customer can no longer commit to contact fewer than $\bar{n}$ dealers, and thereby receives a lower equilibrium payoff. Specifically, the customer's equilibrium payoff becomes $\pi^*_{\bar{n}}$, which is what she would have earned if she had contacted $n = \bar{n}$ dealers in the benchmark model. This payoff is strictly less than the customer's equilibrium payoff $\pi^*_2$ in the benchmark model where she contacts 2 dealers in equilibrium, $\pi^*_{\bar{n}} < \pi^*_2$. That is, the customer receives overall worse prices and a lower equilibrium payoff despite her contacting more dealers.

In the U.S. corporate bond market, MarketAxess does not disclose the number of contacted dealers by default.[15] Consistent with Proposition 2, a customer on average contacts more than 25 in an RFQ, and dealers' response rate is only around 25% (Hendershott and

[15] A customer has the option to disclose its number of contacted dealers in a global setting, although not on a request-by-request basis.

Madhavan, 2015, Table VI). In comparison, the response rate is slightly below 90% on SEFs (Riggs et al., 2020, Table 3). To jointly explain these numbers, a rough computation based the relationship $1-(c/v)^{1/(n-1)} = a_n^*$ estimates that the cost-to-value ratios $c/v$ that I would need for SEFs and MarketAxess are nearly identical, $(1-90\%)^{4-1} \approx (1-25\%)^{25-1} \approx 10^{-3}$. The trading cost in basis point is also much higher on MarketAxess than on SEFs, although such a comparison may be confounded by other factors such as the lower liquidity of corporate bonds relative to index credit default swaps.

Next, I turn to spell out the degenerate equilibrium:

- In Stage 1, the customer submits no RFQ at all;
- In Stage 2, a dealer believes that it is the only dealer contacted by the customer whenever it receives an RFQ. The dealer responds and offers the deterministic price $v$ with probability 1;
- In Stage 3, the customer's dealer choice remains to be $i^*$ as given by her optimality condition (1), if the customer had received quotes.

It is easy to verify that the above constitutes a symmetric PBE. Proposition 7 (Appendix B) shows that there exists no other symmetric PBE.

## 4.2 Optimal information disclosure

Although making the number $n$ of contacted dealers undisclosed does not lead to more competitive prices, it does cause the customer to contact more dealers in equilibrium. One may wonder whether there exists an alternative information design with partial disclosure that could make the dealers' prices more competitive than the status quo. The answer is no unfortunately.

Formally, a *design of information disclosure* $(S, \mu)$ consists of a countable realization space $S$ and a family of distributions $\{\mu(\cdot|n)\}_{n\in\mathbb{Z}^{++}}$ over the space $S$. The design of information disclosure is common knowledge among all market participants. Here are three examples of information designs.

- Example 1 (full disclosure): When $S = \mathbb{Z}^{++}$ and $\mu(s|n) = \mathbb{1}_{\{s=n\}}$, $\forall s \in S$, the information design fully discloses the number $n$.

- Example 2 (no disclosure): When $S$ is a singleton, the information design discloses nothing about the number $n$.

- Example 3 (partial disclosure): When $S = \{\text{odd}, \text{even}\}$ and $\mu(\text{odd}|n) = \mathbb{1}_{\{n \text{ is odd}\}}$, the information design discloses and only discloses whether $n$ is odd or even.

I generalize the benchmark model to allow for any arbitrary design of information disclosure $(S, \mu)$. In Stage 1, the customer chooses the number $n$ of dealers to contact. A signal $s$ is drawn from the distribution $\mu(\cdot|n)$ and is observed by the contacted dealers, who then chooses whether to respond and which price to offer in Stage 2. In Stage 3, the customer chooses whether and against which dealer's price to trade. As in the benchmark model, I do not impose any tie-breaking rule in the case of an indifference. All agents are risk-neutral with no time discounting. The solution concept is symmetric PBE, where all dealers employ the same strategy $(a^\mu, F^\mu)$. I do not impose any restriction on off-path beliefs. Figure 2 summarizes the timing of the generalized model.

The way that information is optimally disclosed is identical to that of Bayesian Persuation (Kamenica and Gentzkow, 2011), in that the platform designer sends a signal about the state of the world $n$, and the contacted dealers receive the signal. There is one fundamental

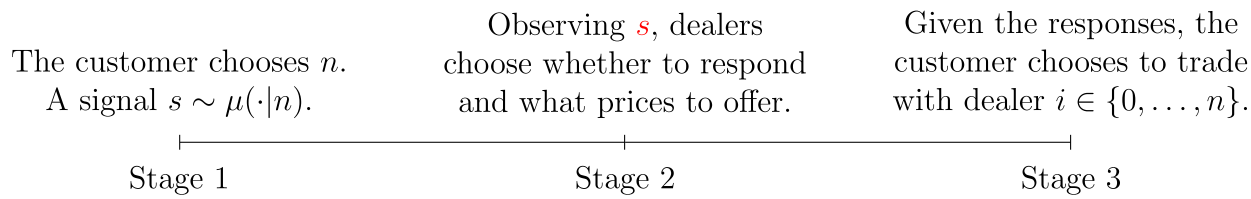


Figure 2: Timing: Dealers now observe a signal $s$ instead of the number $n$ directly

distinction: Here, the receivers' prior belief about the state of the world $n$ is endogenously determined by the customer's equilibrium choice. In Bayesian Persuasion, the receiver's prior belief about the state of the world is exogenously given.

In my setup, fully disclosing the state of the world $n$ is optimal.

**Theorem 3.** *Given any design of information disclosure $(S, \mu)$, the customer's ex-ante payoff in any symmetric PBE is less than or equal to her status quo payoff $\pi_2^*$ given by (9).*

Although the customer contacts only 2 dealers when the number of her contacted dealers is fully disclosed, no alternative design of information disclosure can improve her payoff above this outcome. Theorem 3 establishes the limits of multi-dealer platforms in promoting price competition.

The proof of Theorem 3, provided in Appendix B, generalizes that of Theorem 1. The underlying economics again comes from the cost saving of response concentration. The cost saving does not depend on what information is disclosed about the number $n$. Specifically, conditional on any signal realization $s \in S$ that is drawn with a positive probability under a given equilibrium, I let $\chi_s(n)$ be the posterior probability that the customer contacted $n$ dealers. The conditional expectations of the aggregate gain from trade and the aggregate response cost simply average the gain and the cost across all on-path choices $n$ with their respective posterior probabilities $\chi_s(n)$. Given each on-path choice $n \geq 2$, it is more cost-efficient to concentration response probabilities among fewer dealers. Taking the expectations across all on-path choices $n$ naturally preserves this property of cost saving.

# 5 Empirical Predictions

The benchmark model in Section 2 can be easily extended to include an order size $q$ and to yield more testable predictions. These predictions are largely consistent with facts documented in the literature.

The benchmarket model is extended as follows: In Stage 1, a customer seeking to buy $q$ units of the asset chooses a number $n$ of ex-ante identical dealers to contact in an RFQ. The order size $q$ is an exogenous parameter and thus is common knowledge among market participants. Stages 2 and 3 remain identical to those in the benchmark model. To ensure a positive gain from trade, I assume that $c < vq$.

**Proposition 3.** *The extended model with an order size $q$ has a unique symmetric subgame perfect equilibrium $(n^*, i^*, a^q, F^q)$, where $n^*$ and $i^*$ are the same as in Theorem 1, and*

$$a_n^q = \begin{cases} 1 - \left(\dfrac{c}{vq}\right)^{\frac{1}{n-1}} & \text{if } n > 1, \\ 1 & \text{if } n = 1, \end{cases} \qquad F_n^q(p) = \begin{cases} \dfrac{1 - \left(\frac{c}{pq}\right)^{\frac{1}{n-1}}}{1 - \left(\frac{c}{vq}\right)^{\frac{1}{n-1}}}, \text{ and supp } F_n^q = \left[\dfrac{c}{q}, v\right] & \text{if } n > 1, \\ \mathbb{1}_{p \geq v} & \text{if } n = 1. \end{cases}$$

Compared to Theorem 1, the customer's equilibrium strategy $(n^*, i^*)$ remains unchanged. The only difference lies in the expressions of the dealer's equilibrium strategy $(a_n^q, F_n^q)$, in that the cost $c$ is normalized by the quantity $q$ and becomes the per-unit cost $c/q$. This difference arises from the fact that equation (7) becomes

$$vq(1-a_n^q)^{n-1} = c \iff a_n^q = 1 - \left(\frac{c}{vq}\right)^{\frac{1}{n-1}}.$$

The remaining proof is otherwise identical to that for Theorem 1.

Based on the above equilibrium result, the next proposition provides testable predictions on a dealer's response probability and price distribution. I write $a_2^{q,v}$ for the response probability $a_2^q$ and $F_2^{q,v}$ for the price distribution $F_2^q$ to state the effects of the value $v$.

**Proposition 4.** *(i) The equilibrium response probability $a_2^{q,v}$ is strictly increasing in the order size $q$ and the value $v$. (ii) Conditional on responding, each dealer's equilibrium price distribution $F_2^{q,v}$ becomes first-order stochastically smaller with a larger size $q$ or a smaller value $v$,*

$$F_2^{q,v} \succ_{(1)} F_2^{q',v} \text{for } q < q' \text{ and } F_2^{q,v'} \succ_{(1)} F_2^{q,v} \text{ for } v < v'.$$

On SEFs for index credit default swaps, Riggs et al. (2020) document patterns that are largely consistent with the predictions of Propositions 1 and 4. Specifically, they find that a dealer's likelihood of responding to an RFQ decreases in the number of contacted dealers (Proposition 1 Part *(i)*) and increases in notional quantity (Proposition 4 Part *(i)*). Customer RFQs are more likely to result in actual trades if order sizes are larger or nonstandard, which is consistent with the interpretation that those orders imply larger gain from trade between customers and dealers (Proposition 4 Part *(i)*). Conditional on responding to RFQs, they find that dealers' quoted spreads and customers' transaction costs become larger if more dealers are contacted in the RFQ (Proposition 1 Part *(ii)*) or if order sizes are nonstandard (Proposition 4 Part *(ii)*), although the effects are mild. If order sizes are larger, however, they find that dealers' quoted spreads become slightly larger, with an economically and statistically insignificant magnitude.

# 6 Conclusion

On many important multi-dealer platforms such as SEFs, customers mostly request quotes from very few dealers. I build a model of multi-dealer platforms where a customer can simultaneously request quotes from any number of dealers, and each dealer strategically chooses to respond or ignore the request. In this otherwise standard model of price competition, letting dealers endogenously decide whether to respond overturns their incentive to compete. If the customer contacts more dealers, every dealer responds with a lower probability and offers a stochastically worse price when it responds. These two negative effects more than offset the benefit to the customer from potentially receiving more quotes and worsen the overall price for the customer. The more general underlying economics is response concentration: It is more cost-efficient to concentrate response probabilities among fewer dealers. In equilibrium, the customer optimally contacts only two dealers. Multi-dealer platforms are limited in their ability to promote price competition: No alternative design of information disclosure can improve the customer's payoff above this outcome.

# References


Abad, J., I. Aldasoro, C. Aymanns, M. D'Errico, L. Fache Rousová, P. Hoffmann, S. Langfield, M. Neychev, and T. Roukny (2016): "Shedding Light on Dark Markets: First Insights from the New EU-wide OTC Derivatives Dataset," ESRB Occasional Paper Series 11, European Systemic Risk Board.

Afonso, G., A. Kovner, and A. Schoar (2014): "Trading Partners in the Interbank Lending Market," Working Paper, Federal Reserve Bank of New York and MIT Sloan.

Atkeson, A. G., A. L. Eisfeldt, and P.-O. Weill (2015): "ENTRY AND EXIT IN OTC DERIVATIVES MARKETS," *Econometrica*, 83, 2231–2292.

Baldauf, M. and J. Mollner (2022): "Competition and Information Leakage," Working Paper.

Bech, M. L. and E. Atalay (2010): "The Topology of the Federal Funds Market," *Physica A: Statistical Mechanics and its Applications*, 389, 5223–5246.

Bethune, Z., B. Sultanum, and N. Trachter (2021): "An Information-based Theory of Financial Intermediation," *The Review of Economic Studies*, rdab092.

Bjønnes, G., N. Kathitziotis, and C. Osler (2015): "Price Discrimination and the Cost of Liquidity in OTC Markets," Working Paper.

Burdett, K. and K. L. Judd (1983): "Equilibrium Price Dispersion," *Econometrica*, 51, 955–969.

Chaderina, M. and V. Glode (2022): "Trading with Expert Dealers," Working Paper.

Chang, B. and S. Zhang (2022): "Financial Market Structure and Risk Concentration," Working Paper.

Collin-Dufresne, P., B. Junge, and A. B. Trolle (2020): "Market Structure and Transaction Costs of Index CDSs," *The Journal of Finance*, 75, 2719–2763.

Craig, B. and G. von Peter (2014): "Interbank Tiering and Money Center Banks," *Journal of Financial Intermediation*, 23, 322–347.

Di Maggio, M., A. Kermani, and Z. Song (2017): "The Value of Trading Relations in Turbulent Times," *Journal of Financial Economics*, 124, 266–284.

Duffie, D., N. Gârleanu, and L. H. Pedersen (2005): "Over-the-Counter Markets," *Econometrica*, 73, 1815–1847.

Dugast, J., S. Üslü, and P.-O. Weill (2022): "A Theory of Participation in OTC and Centralized Markets," *The Review of Economic Studies*, rdac010.

Engelbrecht-Wiggans, R. (1987): "On Optimal Reservation Prices in Auctions," *Management Science*, 33, 763–770.

Farboodi, M., G. Jarosch, and R. Shimer (2022): "The Emergence of Market Structure," *The Review of Economic Studies*, rdac014.

Glebkin, S., B. Z. Yueshen, and J. Shen (2022): "Simultaneous Multilateral Search," *The Review of Financial Studies*, hhac009.

Glode, V., R. C. Green, and R. Lowery (2012): "Financial Expertise as an Arms Race," *The Journal of Finance*, 67, 1723–1759.

Glode, V. and C. C. Opp (2020): "Over-the-Counter versus Limit-Order Markets: The Role of Traders' Expertise," *The Review of Financial Studies*, 33, 866–915.

Hau, H., P. Hoffmann, S. Langfield, and Y. Timmer (2021): "Discriminatory Pricing of Over-the-Counter Derivatives," *Management Science*, 67, 6660–6677.

Hendershott, T., D. Li, D. Livdan, and N. Schürhoff (2020): "Relationship Trading in Over-the-Counter Markets," *The Journal of Finance*, 75, 683–734.

Hendershott, T., D. Livdan, and N. Schürhoff (2021): "All-to-All Liquidity in Corporate Bonds," Working Paper.

Hendershott, T. and A. Madhavan (2015): "Click or Call? Auction versus Search in the Over-the-Counter Market: Click or Call? Auction versus Search in the Over-the-Counter Market," *The Journal of Finance*, 70, 419–447.

Hollifield, B., A. Neklyudov, and C. Spatt (2017): "Bid-Ask Spreads, Trading Networks, and the Pricing of Securitizations," *The Review of Financial Studies*, 30, 3048–3085.

Hugonnier, J., B. R. Lester, and P.-O. Weill (2020): "Heterogeneity in Decentralized Asset Markets," Working Paper.

in't Veld, D. and I. van Lelyveld (2014): "Finding the Core: Network Structure in Interbank Markets," *Journal of Banking & Finance*, 49, 27–40.

Jovanovic, B. and A. J. Menkveld (2022): "Equilibrium Bid-Price Dispersion," *Journal of Political Economy*, 130, 426–461.

Kamenica, E. and M. Gentzkow (2011): "Bayesian Persuasion," *American Economic Review*, 101, 2590–2615.

King, M. R., C. Osler, and D. Rime (2012): "Foreign Exchange Market Structure, Players, and Evolution," in *Handbook of Exchange Rates*, John Wiley & Sons, Ltd, chap. 1, 1–44.

Lee, T. and C. Wang (2018): "Why Trade Over-the-Counter? When Investors Want Price Discrimination," Working Paper.

Lester, B. (2011): "Information and Prices with Capacity Constraints," *American Economic Review*, 101, 1591–1600.

Levin, D. and J. L. Smith (1994): "Equilibrium in Auctions with Entry," *The American Economic Review*, 84, 585–599.

Li, D. and N. Schürhoff (2019): "Dealer Networks," *The Journal of Finance*, 74, 91–144.

Li, W. and Z. Song (2020): "Dealer Expertise and Market Concentration in OTC Trading," Working Paper.

Li, Y., G. Rocheteau, and P.-O. Weill (2012): "Liquidity and the Threat of Fraudulent Assets," *Journal of Political Economy*, 120, 815–846.

Liu, Y., S. Vogel, and Y. Zhang (2017): "Electronic Trading in OTC Markets vs. Centralized Exchange," Working Paper.

Maurin, V. (2022): "Liquidity Fluctuations in Over-the-Counter Markets," *The Journal of Finance*, 77, 1325–1369.

McAfee, R. P. and J. McMillan (1987): "Auctions with Entry," *Economics Letters*, 23, 343–347.

McPartland, K. (2014): "The SEF RFQ Minimum Is Moving to 3. Does It Matter? Nope." https://www.greenwich.com/blog/sef-rfq-minimum-moving-3-does-it-matter-nope.

Menezes, F. M. and P. K. Monteiro (2000): "Auctions with Endogenous Participation," *Review of Economic Design*, 5, 71–89.

O'Hara, M. and X. Alex Zhou (2021): "The Electronic Evolution of Corporate Bond Dealers," *Journal of Financial Economics*, 140, 368–390.

Peltonen, T. A., M. Scheicher, and G. Vuillemey (2014): "The Network Structure of the CDS Market and Its Determinants," *Journal of Financial Stability*, 13, 118–133.

Pinter, G., C. Wang, and J. Zou (2020): "Information Chasing versus Adverse Selection," Working Paper.

——— (2021): "Size Discount and Size Penalty: Trading Costs in Bond Markets," Working Paper.

Praz, R. (2014): "Equilibrium Asset Pricing with Both Liquid and Illiquid Markets," Working Paper.

Ramadorai, T. (2008): "What Determines Transaction Costs in Foreign Exchange Markets?" *International Journal of Finance and Economics*, 13, 14–25.

Riggs, L., E. Onur, D. Reiffen, and H. Zhu (2020): "Swap Trading after Dodd-Frank: Evidence from Index CDS," *Journal of Financial Economics*, 137, 857–886.

Sambalaibat, B. (2022): "Endogenous Specialization and Dealer Networks," Working Paper.

Stahl, II, D. O. (1989): "Oligopolistic Pricing with Sequential Consumer Search," *American Economic Review*, 79, 700–712.

Stigler, G. J. (1961): "The Economics of Information," *Journal of Political Economy*, 69, 213–225.

Tsoy, A. (2021): "Over-the-Counter Markets for Non-Standardized Assets," Working Paper.

Üslü, S. (2019): "Pricing and Liquidity in Decentralized Asset Markets," *Econometrica*, 87, 2079–2140.

Varian, H. R. (1980): "A Model of Sales," *The American Economic Review*, 70, 651–659.

Vayanos, D. and P.-O. Weill (2008): "A Search-Based Theory of the On-the-Run Phenomenon," *The Journal of Finance*, 63, 1361–1398.

Vogel, S. (2019): "When to Introduce Electronic Trading Platforms in Over-the-Counter Markets?" Working Paper.

Wang, C. (2016): "Core-Periphery Trading Networks," Working Paper.

——— (2022): "Search Friction in Over-the-Counter Markets," Working Paper.

Weill, P.-O. (2020): "The Search Theory of Over-the-Counter Markets," *Annual Review of Economics*, 12, 747–773.

Wittwer, M. and J. Allen (2021): "Centralizing Over-the-Counter Markets?" .

Yueshen, B. Z. (2017): "Uncertain Market Making," Working Paper.

# Appendices

## A Exogenous Availability Constraint

The dealers' ability to endogenously decide whether to respond is a driving feature of the model. To illustrate its role, this appendix considers two variants of the model that include an exogenous availability constraint.

**First variant.**

The first variant differs from the benchmark model in two aspects: (1) Instead of deciding whether to respond at a cost, each contacted dealer is available with an exogenously fixed probability $\alpha$ and responds whenever available, and (2) the customer could contact at most $\bar{n}$ dealers ($\bar{n} > 1$), because it will turn out that the customer would contact as many dealers as is feasible in equilibrium. The first variant is otherwise identical to the benchmark model. That is, this variant differs from the benchmark model in that the dealers' exogenous availability constraint *replaces* their ability to endogenously decide whether to respond.

With such an exogenous response probability $\alpha$, the next proposition establishes that each dealer's pricing becomes *more* competitive when the customer contacts more dealers (as in a standard model of price competition), and the customer contacts $\bar{n}$ dealers in equilibrium.

**Proposition 5.** *(i) The first variant has a unique symmetric subgame perfect equilibrium* $(n^\alpha, i^*, F^\alpha)$*, where* $i^*$ *is the same as in Theorem 1, and*

$$n^\alpha = \bar{n}, \qquad F_n^\alpha(p) = \begin{cases} \dfrac{1 - (1-\alpha)\left(\frac{v}{p}\right)^{\frac{1}{n-1}}}{\alpha}, \text{ and } \operatorname{supp} F_n^\alpha = \left[v(1-\alpha)^{n-1}, v\right] & \text{if } n > 1, \\ \mathbb{1}_{p \geq v} & \text{if } n = 1. \end{cases}$$

*In particular, each dealer's price distribution $F_n^\alpha$ becomes first-order stochastically smaller as $n$ increases. When $\bar{n} \to \infty$, the equilibrium price distribution $F_{\bar{n}}^\alpha$ converges to the competitive limit 0 in distribution.*

PROOF. The backward induction for the first variant is similar to that for the benchmark model. The only change is that a contacted dealer no longer needs to be indifferent between responding or not, as it now responds with an exogenous probability instead of endogenously deciding whether to respond. That is, the indifference condition (4) need not hold.

In Stage 3, the customer's optimal dealer choice $i^*$ is directly given by her optimality condition (1).

In Stage 2, responding with any price higher than the customer's value $v$ is strictly dominated by not responding. Thus, $F^\alpha(v) = 1$. If the customer contacted only $n = 1$ dealer, then it is strictly optimal for the dealer to offer the monopoly price $v$ deterministically whenever the dealer is available. When the customer contacts more than 1 dealer, $n > 1$, then the price distribution $F_n^\alpha$ cannot have any atom. If $F_n^\alpha$ had an atom at a price $p^0$, undercutting by offering some price $p^0 - \varepsilon$ would yield a strictly higher payoff than offering the price $p^0$ for at least one dealer. Letting $\tilde{p}$ be the upperbound of the dealer's price support, $\tilde{p} \coloneqq \sup(\operatorname{supp} F_n^\alpha)$, then $\tilde{p} \leq v$. When the dealer offers a price $\tilde{p} - \varepsilon$ that arbitrarily approaches the upperbound $\tilde{p}$, the dealer's expected trading profit approaches $\tilde{p}(1-\alpha)^{n-1}$. If the dealer offers the price $v$, her expected trading profit equals $v(1-\alpha)^{n-1}$. The dealer's optimality condition (2) implies that $\tilde{p} = v$.

Then (2) is equivalent to

$$p\left(\alpha[1-F_n^\alpha(p)]+1-\alpha\right)^{n-1}=v\left(1-\alpha\right)^{n-1}, \quad \forall p\in \operatorname{supp} F_n^\alpha.$$

$$\Longleftrightarrow F_n^\alpha(p)=\frac{1-(1-\alpha)\left(\frac{v}{p}\right)^{\frac{1}{n-1}}}{\alpha}, \quad \text{and supp } F_n^\alpha=\left[v(1-\alpha)^{n-1},v\right].$$

In Stage 1, the customer's payoff is 0 when contacting only $n=1$ dealer. If $n>1$, the distribution $G_n^\alpha$ of the best price offer $p=\min_{j=1,\ldots,n} p_j$ is given by

$$1-G_n^\alpha(p)=\left[\alpha\left(1-F_n^\alpha(p)\right)+1-\alpha\right]^n, \quad \forall p\in[v(1-\alpha)^{n-1},v].$$

If $n$ increases, $F_n^\alpha(p)$ strictly increases and thus $1-G_n^\alpha(p)$ strictly decreases. That is, the best price offer $p=\min_{j=1,\ldots,n} p_j$ becomes first-order stochastically *smaller* when the customer contacts more dealers. Therefore, the customer's unique optimal choice is $n^\alpha=\bar{n}$. □

**Second variant.**

The second variant differs from the first in two aspects: (1) Each available dealer can endogenously decide whether to respond at a cost $c$, while a non-available dealer simply does not respond, and (2) the customer could contact any arbitrary number of dealers. The second variant is otherwise identical to the first one. That is, the second variant *reintroduces* dealers' decisions of whether to respond to the first variant.

This feature restores an interior solution for the equilibrium number of contacted dealers.

**Proposition 6.** *The second variant has a unique symmetric subgame perfect equilibrium*

$(n^{\alpha,c}, i^*, a^{\alpha,c}, F^{\alpha,c})$, *where* $i^*$ *is the same as in Theorem 1, and*

$$n^{\alpha,c} = m \text{ or } m-1, \qquad m \text{ is uniquely determined by } a^*_{m-1} > \alpha \geq a^*_m,$$

$$a^{\alpha,c}_n = \begin{cases} 1 & \text{if } n < m, \\ \dfrac{a^*_n}{\alpha} & \text{if } n \geq m, \end{cases} \qquad F^{\alpha,c}_n = \begin{cases} F^\alpha_n & \text{if } n < m, \\ F^*_n & \text{if } n \geq m. \end{cases}$$

When the available dealers are able to endogenously decide whether to respond, the exogenous availability constraint becomes non-binding when $a^*_n \leq \alpha$, because the dealers would respond with a probability $a^*_n$ that is lower than $\alpha$ anyway. Since the endogenous response probability $a^*_n$ decreases to 0 as $n$ increases, it declines below the exogenous probability $\alpha$ when $n$ is above a certain threshold $m$. When $n \geq m$, the exogenous availability constraint becomes irrelevant and the dealers behave as in the benchmark model of Section 2. That is, each dealer's effective response probability remains to be $\alpha a^{\alpha,c}_n = a^*_n$ and its price distribution is $F^{\alpha,c}_n = F^*_n$. Thus, the customer strictly prefers to contact fewer dealers in this range. When $n < m$, the exogenous availability constraint is binding and the dealers behave as in the first variant. Thus, the customer strictly prefers to contact more dealers in this range. Overall, the customer's optimal choice is $n^{\alpha,c} = m$ or $m-1$, depending on how close the two probabilities $a^*_m$ and $\alpha$ are when $a^*_m$ declines below $\alpha$.

The backward induction for the second variant is similar to that for the benchmark model. The only change is that the dealers need not be indifferent between responding or not when the exogenous availability constraint is strictly binding. That is, the indifference condition (4) need not hold when $n < m$. I do not repeat the formal proof.

# B Proofs

Proof of Theorem 1. The proof is given immediately after Theorem 1. $\square$

Proof of Proposition 1. *Part (i)*: Since $c < v$, then $(c/v)^{1/(n-1)}$ is strictly increasing in $n$. Thus, the probability $a_n^*$ is strictly decreasing in $n$.

*Part (ii)*: Fixing any $p \in [c, v]$, I let $c/p = \eta$ and $c/v = \delta$, then $\delta < \eta < 1$ and

$$\ln F_n^*(p) = \ln\left(1 - \eta^{\frac{1}{n-1}}\right) - \ln\left(1 - \delta^{\frac{1}{n-1}}\right).$$

It suffices to show that $\ln F_n^*(p)$ is strictly decreasing in $n$. I view $n$ as a continuous variable and take the partial derivative of $\ln F_n^*(p)$ with respect to $n$ to obtain

$$\frac{\partial}{\partial n} \ln F_n^*(p) = \frac{1}{n-1}\left[\frac{\tilde{\eta}\ln(\tilde{\eta})}{1-\tilde{\eta}} - \frac{\tilde{\delta}\ln(\tilde{\delta})}{1-\tilde{\delta}}\right],$$

where $\tilde{\delta} := \delta^{1/(n-1)} < \eta^{1/(n-1)} =: \tilde{\eta}$. Since the function $x \mapsto (x\ln x)/(1-x)$ is strictly decreasing in $x \in (0,1)$, then $\frac{\partial}{\partial n} \ln F_n^*(p) < 0$. Hence for any $p \in [c, v]$, $F_n^*(p)$ is strictly decreasing in $n$. That is, $F_n^* \prec_{(1)} F_{n'}^*$ for $n < n'$. $\square$

The next two lemmas are useful to prove Theorem 2.

**Lemma 1.** *Given a price $p^0$, after the customer contacts any number $n$ of dealers, at most one contacted dealer's price distribution can have an atom at the price $p^0$ in any subgame perfect equilibrium of the benchmark model.*

Proof. I suppose that two price distributions $F_{j,n}^*$ and $F_{j',n}^*$ have an atom at $p^0$. Since dealer $j$ and $j'$ must earn strictly positive expected trading profits when offering the price $p^0$ to compensate for the cost of responding, then either $j$ or $j'$ is strictly better off undercutting by offering some price $p^0 - \varepsilon$. This contradicts the optimality of the price $p^0$ for dealer $j$ and $j'$. Lemma 1 follows. $\square$

**Lemma 2.** *Given a contacted dealer $j$, if there exits some price $p^0 < v$ and $\varepsilon > 0$ such that $(p^0, p^0 + \varepsilon) \cap \text{supp } F^*_{j',n} = \emptyset$ for any other contacted dealer $j' \neq j$, then the price $p^0$ cannot be in the price support of dealer $j$, $p^0 \notin \text{supp } F^*_{j,n}$.*

Proof. I suppose that the condition of Lemma 2 holds.

*Step 1*: By offering any price $p \in (p^0, p^0 + \varepsilon)$, dealer $j$ gets to trade with the customer with a constant probability. Conditional on such a trade, the trading profit earned by $j$ equals the price $p$, which is strictly increasing in $p$. Thus, the expected trading profit earned by $j$ is either 0, which is not enough to cover the response cost $c$, or strictly increasing in $p \in (p^0, p^0 + \varepsilon)$. Hence, no price $p \in (p^0, p^0 + \varepsilon)$ can be in the price support of dealer $j$,

$$p \notin \text{supp } F^*_{j,n}, \qquad \forall p \in (p^0, p^0 + \varepsilon).$$

*Step 2*: If the distribution $F^*_{j,n}$ has an atom at $p^0$, no other price distribution $F^*_{j',n}$ can have an atom at $p^0$ (Lemma 1). Then dealer $j$ is strictly worse off offering the price $p^0$ than some price $p \in (p^0, p^0 + \varepsilon)$. Hence, the distribution $F^*_{j,n}$ cannot have an atom at $p = p^0$. By the same argument, any other price distribution $F^*_{j',n}$ cannot have an atom at $p = p^0$ either.

*Step 3*: When dealer $j$ offers a price $p^0 - \varepsilon'$ that arbitrarily approaches the price $p^0$ from below, $j$ either gets to trade with the customer with probability 0 or is strictly better off offering some price $p \in (p^0, p^0 + \varepsilon)$ since no other price distributions have an atom at $p^0$. Hence for some $\varepsilon' > 0$, no price $p \in (p^0, p^0 - \varepsilon')$ can be in the price support of dealer $j$,

$$p \notin \text{supp } F^*_{j,n}, \qquad \forall p \in (p^0, p^0 - \varepsilon').$$

The conclusions of Steps *1-3* together imply that $p^0$ cannot be in the price support of dealer $j$, $p^0 \notin \text{supp } F^*_{j,n}$. $\square$

Proof of Theorem 2. I fix any arbitrary subgame perfect equilibrium. If the customer contacts only $n = 1$ dealer, the dealer would respond with probability 1 and offer the monopoly price $v$. Thus, the customer's payoff is 0.

If the customer contacts some given number $n \geq 2$ of dealers, I show that the customer's expected payoff does not exceed $\pi^*_2$.

Given a dealer $j$, I let $\bar{p}_j$ be the upperbound of the dealer's price support, and $\bar{p}_{-j}$ be the highest upperbound of the other contacted dealers' price supports:

$$\bar{p}_j \coloneqq \text{supp } F^*_{j,n}, \qquad \bar{p}_{-j} \coloneqq \max_{j' \neq j} \bar{p}_{j'}.$$

If a dealer $j'$ responds with probability 0, then $\bar{p}_{j'} \coloneqq -\infty$ by convention. If $\bar{p}_{-j} < v$, then Lemma 2 implies that $\bar{p}_{-j} \notin \text{supp } F^*_{j,n}$. Hence, Lemma 2 further implies that $\bar{p}_{-j} \notin \text{supp } F^*_{j',n}$ for any other dealer $j' \in j$. Then $\bar{p}_{-j}$ cannot be the upperbound of any dealer's price distribution, which contradicts the definition of $\bar{p}_{-j}$. Thus, $\bar{p}_{-j} = v$ for any dealer $j$.

At most one of the contacted dealers can have an atom at $v$ in its price support (Lemma 1). Without loss of generality, I let dealer 1 be such that $\bar{p}_1 = v$ and all other dealers do not have an atom at $v$. When dealer 1 offers a price $p \in \text{supp } F^*_{1,n}$ that arbitrarily approaches $v$, the dealer's expected trading profit approaches $v\left(1 - a^*_{2,n}\right) \ldots \left(1 - a^*_{n,n}\right)$. This limiting gain must be at least $c$,

$$\begin{aligned} & v\left(1 - a^*_{2,n}\right) \ldots \left(1 - a^*_{n,n}\right) \geq c \\ \iff & \left(1 - a^*_{2,n}\right) \ldots \left(1 - a^*_{n,n}\right) \geq \frac{c}{v}. \end{aligned} \tag{10}$$

Thus, all the other dealers must respond with a probability less than 1. Hence, their expected payoffs must all equal 0.

It then follows that the customer's expected payoff does not exceed $\pi_2^*$,

$$\begin{aligned}
&\underbrace{v\left[1-\prod_{j=1}^{n}\left(1-a_{j,n}^*\right)\right]-c\sum_{j=1}^{n}a_{j,n}^*}_{\text{aggregate expected payoff}}-\underbrace{\left[v\prod_{j'=2}^{n}\left(1-a_{j',n}^*\right)-c\right]a_{1,n}^*}_{\text{expected payoff of dealer 1}}\\
&=v\left[1-\left(1-a_{2,n}^*\right)\dots\left(1-a_{n,n}^*\right)\right]-c\left[a_{2,n}^*+\dots+a_{n,n}^*\right]\\
&\leq v\left[1-\left(1-a_{2,n}^*\right)\dots\left(1-a_{n,n}^*\right)\right]-c\left[1-\left(1-a_{2,n}^*\right)\dots\left(1-a_{n,n}^*\right)\right] \qquad (11)\\
&\leq v\left[1-\frac{c}{v}\right]-c\left[1-\frac{c}{v}\right] \qquad \text{(following from (10))} \qquad (12)\\
&=v\left[1-\left(1-a_2^*\right)^2\right]-c\left[a_2^*+a_2^*\right]=\pi_2^*.
\end{aligned}$$

Inequality (11) above follows from $x+y\leq xy+1$ for $0\leq x,y\leq 1$ and an induction over $n$:

$$\begin{aligned}
&a_{2,n}^*+\dots+a_{n,n}^*\\
&=n-1-\left[\left(1-a_{2,n}^*\right)+\dots+\left(1-a_{n-2,n}^*\right)+\left(1-a_{n-1,n}^*\right)+\left(1-a_{n,n}^*\right)\right]\\
&\geq n-1-\left[\left(1-a_{2,n}^*\right)+\dots+\left(1-a_{n-2,n}^*\right)+\left(1-a_{n-1,n}^*\right)\left(1-a_{n,n}^*\right)+1\right]\\
&\geq \dots\\
&\geq n-1-\left[\left(1-a_{2,n}^*\right)\dots\left(1-a_{n,n}^*\right)+n-2\right]\\
&\geq 1-\left(1-a_{2,n}^*\right)\dots\left(1-a_{n,n}^*\right).
\end{aligned}$$

In the special case where the customer contacts 2 dealers, I show that the customer's expected payoff equals $\pi_2^*$. First, inequality (11) becomes an equality. Further, Lemma 2 implies that both dealers' price supports must share the same lowerbound $\underline{p}\geq c$. If $\underline{p}>c$, then undercutting by offering some price $\underline{p}-\varepsilon$ would yield a strictly positive payoff to dealer

2. Thus, $\underline{p} = c$. When dealer 1 offers a price $p \in \operatorname{supp} F^*_{1,2}$ that arbitrarily approaches $c$, the dealer's limiting payoff is non-positive. Thus, the expected payoff of dealer 1 must also be 0. Thus, (10) must hold as an equality, $1 - a^*_{2,2} = c/v$. Hence, (12) becomes an equality too.

Thus in any subgame perfect equilibrium, the customer's ex-ante payoff equals $\pi^*_2$, which she can achieve by contacting only 2 dealers. Theorem 2 follows. □

Proof of Proposition 2. The proof is given immediately before Proposition 2. □

**Proposition 7.** *I consider the modified model where the number of contacted dealers is not disclosed. All symmetric PBE are provided in Section 4.1 and there exists no other symmetric PBE.*

Proof. Proposition 2 establishes the unique non-degenerate symmetric PBE. It is easy to verify that the other candidate degenerate equilibrium provided in Section 4.1 indeed constitutes an PBE. It suffices to show that there exists no other degenerate symmetric PBE.

In a given degenerate symmetric PBE, the customer's ex-ante payoff is 0. Thus, every dealer must offer the monopolistic price $v$ deterministically whenever it receives an RFQ and decides to respond, $F^{\text{unobs}}(v^-) = 0$. Upon receiving an RFQ and under any belief about how many other dealers are contacted by the customer, a given dealer $j$ can secure a strictly positive payoff by offering some price $p \in (c, v)$. Hence, dealer $j$ optimally responds and offers the monopolistic price $v$ with probability 1. For such a response strategy to be optimal for dealer $j$ against other dealers' response strategy, dealer $j$ has to believe that the customer contacted no other dealers. Proposition 7 follows. □

Proof of Theorem 3. Given a design of information disclosure $(S, \mu)$ and a symmetric PBE, I fix any signal realization $s \in S$ that is drawn with a positive probability under the

PBE. That is, $\sum_{n=1}^{\infty} \mu(s|n)\xi(n) > 0$, where $\xi(n)$ is the prior probability that the customer contacts $n$ dealers under the PBE. It suffices to show that the customer's expected payoff conditional on the signal realization $s$ does not exceed $\pi_2^*$.

I let $(a_s^\mu, F_s^\mu)$ denote the dealer's equilibrium strategy upon observing the signal $s$. Responding with any price higher than the customer's value $v$ is strictly dominated by not responding. Thus, $F_s^\mu(v) = 1$. Further, the price distribution $F_s^\mu$ cannot have any atom. If $F_s^\mu$ had an atom at some price $p^0$, then undercutting by offering some price $p^0 - \varepsilon$ would yield a strictly higher payoff than offering the price $p^0$ for at least one contacted dealer.

Letting $\hat{p}$ be the upperbound of the dealer's price support, $\hat{p} \coloneqq \sup(\operatorname{supp} F_s^\mu)$, then $\hat{p} \leq v$. When a dealer offers a price $\hat{p} - \varepsilon$ that arbitrarily approaches the upperbound $\hat{p}$, the dealer's expected trading profit approaches $\hat{p} \sum_{n \geq 1} \chi_s(n) \left(1 - a_s^\mu\right)^{n-1}$, where $\chi_s$ is the dealer's posterior belief about the number $n$ of contacted dealers upon observing the signal $s$. When the dealer offers the price $v$, her expected trading profit equals $v \sum_{n \geq 1} \chi_s(n) \left(1 - a_s^\mu\right)^{n-1}$. Thus, $\hat{p} = v$. Then the dealer's individual rationality is given by

$$
\begin{aligned}
& v \sum_{n \geq 1} \chi_s(n) \left(1 - a_s^\mu\right)^{n-1} \geq c \\
\iff & \sum_{n \geq 1} \chi_s(n) \left(1 - a_s^\mu\right)^{n-1} \geq \frac{c}{v}. \qquad (13)
\end{aligned}
$$

It then follows that the customer's expected payoff conditional on the signal realization $s$

does not exceed $\pi_2^*$,

$$\begin{aligned}
&\underbrace{v\left[1-\sum_{n\geq 1}\chi_s(n)\left(1-a_s^\mu\right)^n\right]-c\sum_{n\geq 1}\chi_s(n)na_s^\mu}_{\text{aggregate conditional expected payoff}}-\underbrace{\left[v\sum_{n\geq 1}\chi_s(n)\left(1-a_s^\mu\right)^{n-1}-c\right]a_s^\mu}_{\text{one dealer's conditional expected payoff}}\\
&=v\left[1-\sum_{n\geq 1}\chi_s(n)\left(1-a_s^\mu\right)^{n-1}\right]-c\sum_{n\geq 1}\chi_s(n)(n-1)a_s^\mu\\
&\leq v\left[1-\sum_{n\geq 1}\chi_s(n)\left(1-a_s^\mu\right)^{n-1}\right]-c\sum_{n\geq 1}\chi_s(n)\left[1-\left(1-a_s^\mu\right)^{n-1}\right]\\
&\leq v\left[1-\frac{c}{v}\right]-c\left[1-\frac{c}{v}\right] \qquad \text{(following from (13))}\\
&=\pi_2^*. \qquad \square
\end{aligned}$$

Proof of Proposition 4. *Part (i)*: Since $c/(vq)$ is strictly decreasing in the order size $q$ and the value $v$. Thus, the probability $a_2^q$ is strictly increasing in the size $q$ and the value $v$.

*Part (ii)*: Fixing any $p \in [c/q, v]$,

$$1-F_2^q(p)=\frac{\frac{c}{p}-\frac{c}{v}}{q-\frac{c}{v}}$$

is strictly decreasing in the size $q$ and strictly increasing in the value $v$. Therefore, $F_2^q \succ_{(1)} F_2^{q'}$ for $q < q'$ and $F_2^{v'} \succ_{(1)} F_2^v$ for $v < v'$. $\square$

# C Heterogeneous Response Costs

The benchmark model in Section 2 can be easily extended to allow for heterogeneous response costs across dealers. In the extended model, this appendix shows that the customer always contacts 2 dealers in equilibrium.

To the benchmark model in Section 2, I add a Stage 0 in which each dealer $j$ privately observes its response cost $c_j$. The response costs are independently and identically distributed with a CDF $H$ whose support is within $[0, v]$, $c_j \overset{\text{iid}}{\sim} H$, $H(0) = 0$ and $H(v^-) = 1$. The remaining setup is identical to the benchmark model in Section 2.

**Theorem 4.** *The extended model with heterogeneous response costs has a unique symmetric subgame perfect equilibrium* $\left(n^*, i^*, a^H, F^*\right)$, *where* $n^*$, $i^*$ *and* $F^*$ *are the same as in Theorem 1, and* $a^H$ *is a function of the response cost* $c_j$,

$$a_n^H(c_j) = \begin{cases} 1 & \text{if } n > 1 \text{ and } H(c_j) \leq a_n^*, \\ 0 & \text{if } n > 1 \text{ and } H(c_j^-) \geq a_n^*, \\ \dfrac{a_n^* - H(c_j^-)}{H(c_j) - H(c_j^-)} & \text{if } n > 1, H(c_j^-) < a_n^*, \text{ and } H(c_j) > a_n^*, \\ 1 & \text{if } n = 1, \end{cases}$$

Compared to Theorem 1, the only difference is how a dealer decides whether to respond in equilibrium. Instead of mixing between responding or not, dealer $j$ decides to respond based on its response cost $c_j$: Dealer $j$ responds with probability 1 if its response cost $c_j$ is below a threshold, and does not respond if its cost $c_j$ is above the threshold; if the cost $c_j$ equals the threshold, $j$ might mix between responding or not. When the cost distribution $H$ has no atom, allowing heterogeneous costs purifies the dealer's decision to respond. A dealer's unconditional response probability remains at $a_n^*$ as in Theorem 1. Then conditional on responding, the dealer's problem of what prices to offer remains unaffected. Therefore, the customer's problem of how many dealers to contact also remains unaffected. The proof is otherwise identical to that for Theorem 1.