Signaling in Over-the-Counter Markets: Benefits and Costs of Transparency

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Abstract

Dealers who acquire inventory in one transaction usually seek to dispose of it in a second transaction. If the terms of the first transaction are disclosed, dealers will engage in costly signaling, offering unduly favorable prices in the first transaction to signal asset quality to the second counterparty. Costly signaling lowers spreads and increases volume, market liquidity, and investor welfare. Aggregate welfare is higher in transparent markets, but dealers prefer opacity when gains from trade are large and/or adverse selection is low.

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1. Introduction

Many important assets trade in over-the-counter (OTC) markets that are intermediated by dealers who do not wish to hold inventories. When a dealer buys an asset from a customer in such a market, she seeks another customer to whom she can sell it, and when she sells an asset to a customer, she seeks another customer from whom she can buy it. In many OTC markets, regulators have imposed trade disclosure (called ex-post transparency) requirements. Typically, these requirements are opposed by dealers, who argue that transparency impairs their ability to offload inventory and hence reduces their incentives to make transactions, reducing market liquidity.¹

We show that transparency can benefit investors and actually improve liquidity while being costly to dealers. In fact, transparency can increase aggregate welfare while reducing dealer rents. The mechanism behind these results is costly signaling. Suppose, for example, that trade is initiated by a seller, and, after acquiring inventory, the dealer needs to find a buyer. If the dealer has information not possessed by the buyer, then the price at which the dealer acquires the asset signals asset quality to the buyer. In a separating equilibrium, dealers “overbid” for the asset in the first transaction to separate in the second transaction from other types of dealers with lower valuations. The overbidding is costly to dealers relative to the first-best world in which all of the dealer’s information is public. While costly to dealers, overbidding increases the likelihood of the dealer’s bid being accepted by the seller. Hence, costly signaling increases the volume of trade and increases gains from trade. In fact, gains from trade are higher in the separating equilibrium of the signaling

¹Bravo (2003), Laughlin (2005), Patterson and Zeng (2010), and Wigglesworth (2015) all provide reports of U.S. corporate bond dealers opposing trade disclosure in the TRACE system, which was implemented in 2002 by the NASD and expanded in stages through 2005 (the reporting requirements are now imposed by FINRA). Similarly, Rothwell (2006) reports European bond dealers opposing disclosure, and Burne (2010) reports swap dealers opposing disclosure.
game than they are either in the “first-best” world or in an opaque market.

On a per-trade basis, dealers always prefer opacity. The overbidding in the separating equilibrium of the signaling game causes spreads to be smaller in transparent than in opaque markets. However, the higher volume in transparent markets can sometimes offset the smaller spreads. Thus, even though signaling is costly (that is, dealers prefer the first-best world in which their information is public), dealers may earn higher profits in the signaling equilibrium than they do in an opaque market. Whether they prefer transparent or opaque markets depends on the magnitude of gains from trade relative to the extent of adverse selection. Dealers prefer opacity when gains from trade are large relative to adverse selection. The gains from trade depend on the private motives for trading of the customer who initiates the transactions. When the customer is highly motivated (or when adverse selection is low), trade is highly probable in both transparent and opaque markets. In that case, the increase in the volume of trade due to transparency is not large enough to overcome the lower spreads, and dealers prefer opacity. On the other hand, if gains from trade are low or adverse selection is high, then dealers benefit from transparency.

In our model, there is only a single quantity traded, and we study price disclosure. In reality, disclosure involves both quantity and price. We show that dealers dislike price disclosure when gains from trade are large or adverse selection is low. Dealers may also dislike quantity disclosure. However, price disclosure seems to be important both in our model and in reality. A high-yield bond trader cited in Laughlin (2005) describes the effects of enforcing transparency in corporate bond markets as “customers felt like they never really knew where a dealer was buying or selling, and they were scared that dealers were working for too much margin. ... Many investors now think the real benefit of TRACE lies in knowing that they are not being raked over coals.”

We assume that the party that initiates the sequence of transactions (the first coun-
terparty) has some private benefit or cost that motivates him to trade; however, he also
exploits his private information when trading. The dealer is less informed about the asset
value than the first counterparty, and the least informed party is the customer approached
by the dealer when the dealer seeks to trade out of the position established in the first trans-
action. This customer (the second counterparty) is one of many traders in the Rolodex of
the dealer who hold assets of the type being traded but who, we assume, have no special
information about this particular asset. The second counterparty and the market at large
are informed by the price at which the first transaction takes place.

We study a single dealer who intermediates between a buyer and a seller. For some
assets, interdealer markets are important. They provide an alternative way for dealers to
offload inventory rather than trading with a second customer. Costly signaling should also
be important in the presence of an interdealer market if the original dealer has information
not possessed by other dealers.

Our assumption that a dealer who acquires inventory searches for a second counterparty
to offload the inventory is shared by Rubinstein and Wolinsky (1987), Duffie, Gărleanu
and Pedersen (2005) and Duffie, Gărleanu and Pedersen (2007). However, in those papers,
search is modeled by random matching and all agents have identical information. The
presence of dealers reduces search time for customers who have private motives for trading,
and some of the welfare gain is captured by dealers. In our model, search for the second
counterparty is costless for the dealer.

Most models of securities dealers (for example, Glosten and Milgrom, 1985; Kyle, 1985)
assume dealers are uninformed. However, there are some exceptions. Duffie, Malamud
and Manso (2014) study information acquisition and diffusion in an OTC market. They
assume a continuum of agents meeting randomly, and they model bilateral trade as a
double auction with simultaneous offers. Because offers are simultaneous, neither trader
uses her offer to influence the other’s perception of her type. Furthermore, because each trader is infinitesimal, neither trader’s offer affects subsequent play. Thus, costly signaling does not occur. Glode and Opp (2015) study intermediation between an uninformed seller and an informed buyer via a chain of increasingly informed dealers. They assume that the less informed party makes the offer in each bilateral trade, so there is no possibility of signaling.

Signaling by intermediaries is a relevant question due to the importance and the distinct nature of OTC markets, but we are not aware of any other paper that studies it. There is a literature using dynamic extensions of Akerlof (1970) and Spence (1973) to study the role of signaling in dynamic asset markets (see Kremer and Skrzypacz, 2007; Daley and Green, 2012; Fuchs and Skrzypacz, 2013; Kurlat, 2013; Guerrieri and Shimer, 2014; Fuchs, Öry and Skrzypacz, 2015, and references therein). However, the market design question related to the effect of transparency on welfare is absent from this literature with the exception of Fuchs, Öry and Skrzypacz (2015). They study a seller’s ability to signal a high asset value by rejecting offers and show that transparency, in the form of disclosing all price offers, reduces the probability of trading. We reach the opposite conclusion because, consistent with actual disclosure requirements, we study disclosure of transaction prices instead of disclosure of rejected offers.

There is a literature focused on the welfare effects of transparency in OTC markets. The paper closest to ours is Naik, Neuberger and Viswanathan (1999). They study a dealer who first trades with a customer and then offloads inventory in a competitive interdealer market. They assume that the dealer becomes perfectly informed about the customer’s information during negotiations with the customer, and all welfare enhancing trades are made. This runs counter to the Myerson-Satterthwaite impossibility theorem (Myerson and Satterthwaite, 1983). In contrast, we assume the dealer makes an offer to the customer.
without observing the customer’s information, and the offer is sometimes unacceptable to the customer even when trade would be welfare enhancing.

Other papers concerned with the welfare implications of various forms of transparency in OTC markets include Cujean and Praz (2015). They show that better information about counterparties’ liquidity needs improves aggregate welfare through improved allocative efficiency in an interdealer market. Customers are absent in their model; thus, they do not address the effects of transparency on investors’ welfare. Bhattacharya (2016) assumes that dealers compete in an auction to trade with a customer and may run an auction after the transaction to trade among themselves. He is not able to solve for the equilibrium of his dynamic model explicitly, but he is able to compare some features of equilibrium strategies with and without transparency. Duffie, Dworczak and Zhu (2014) show that the publication of benchmark prices in OTC markets improves market efficiency while reducing per-trade profitability for the dealers. They find that the net effect is often an increase in aggregate welfare, because the publication of benchmarks reduces the information advantage of dealers over customers. Endogenous signaling does not arise in their model, because the market is assumed to be opaque. Asriyan, Fuchs and Green (2015) examine the spillover effects of transparency when investors in distinct markets can observe trades in correlated assets.

Some of our model’s predictions are supported by empirical evidence. Edwards, Harris and Piwowar (2007), Bessembinder, Maxwell and Venkataraman (2006), Goldstein, Hotchkiss and Sirri (2007), and Bessembinder and Maxwell (2008) all find that an increase in transparency leads to a decrease in transaction costs. This is consistent with our model’s prediction that the bid-ask spread is lower in a transparent market than in an opaque market. Regarding the impact of transparency on trading activities, Bessembinder and Maxwell (2008) conjecture that “TRACE likely increased traders’ willingness to submit electronic
limit orders by allowing traders to choose limit prices with enhanced knowledge of market conditions.” This is consistent with our result that the probability of trade is higher in transparent markets. However, our result on trading activities is inconsistent with findings of Goldstein, Hotchkiss and Sirri (2007) from an experiment conducted by the NASD in 2003 that transparency led to no significant increase in trading volume of BBB corporate bonds. Asquith, Covert and Pathak (2013) in fact find a significant decrease in trading activity for high-yield bonds when examining the phase-by-phase expansion of the TRACE coverage.

The next section studies signaling by dealers in transparent markets. Section 3 studies opaque markets. Section 4 compares transparent and opaque markets in a particular example of our model (with a normally distributed asset value). Section 5 concludes. All proofs are in Appendix A.

2. Signaling in a Transparent Market

For concreteness, we assume the first counterparty seeks to sell an asset. The case of a purchase by the first counterparty is symmetric.\textsuperscript{2} We call the first counterparty the seller, and we call the second counterparty the buyer. All parties are risk neutral. We assume the dealer makes take-it-or-leave-it offers in both transactions, which indeed appears to be the norm in OTC markets (see, for example, Duffie, 2012, p. 2).\textsuperscript{3} We call the offer to the

\textsuperscript{2}To be more precise, the case of a purchase is symmetric if the dealer can go short in the first transaction. In reality, a dealer may search for a second counterparty in order to buy the asset before executing a sale to the first counterparty, when the first counterparty wishes to buy an asset. In this case, the second counterparty is obviously not informed by the price of the “first” transaction, as we assume in our model.

\textsuperscript{3}The assumption that the dealer makes a take-it-or-leave-it offer in the first transaction can be rationalized by assuming search is costly for the seller. In this case, the Diamond paradox applies, and equilibrium pricing in the first transaction is as if the dealer were a monopolist, which is equivalent to the dealer making a take-it-or-leave it offer. A take-it-or-leave-it offer by the dealer in the second transaction implies that the second counterparty earns no rents, which is natural when there are many equally informed traders whom the dealer could contact for the second transaction. Papers in the literature that assume take-it-or-leave-it offers include Naik, Neuberger and Viswanathan (1999), Zhu (2012), Duffie, Dworczak and Zhu (2014), Glode and Opp (2015), and Golosov, Lorenzoni and Tsyvinski (2014), among others.
seller the dealer’s bid and denote it by \( B \), and we call the offer to the buyer the dealer’s ask and denote it by \( A \). We assume the dealer has a strong aversion to holding inventories, and we model that by taking the dealer’s value for the asset to be \(-\infty\). In equilibrium, the dealer never ends up holding the asset, and we could replace \(-\infty\) by any sufficiently low number. The dealer will choose to participate in the game only if the expected profit is nonnegative, so a requirement for equilibrium (an individual rationality constraint) is that each type of dealer earn nonnegative expected profit.

We denote the seller’s value for the asset as \( \tilde{v} - \Delta \). Here, \( \tilde{v} \) is a common-value component and is the value to all other market participants (excluding dealers), and \( \Delta > 0 \) is a private-value component that could represent a liquidity shock to the seller (for example, it could represent the haircut if the asset has to be used as collateral to raise cash). The parameter \( \Delta \) represents the increase in investor welfare that is realized when trade occurs. We assume \( \Delta \) is common knowledge and that the realization of \( \tilde{v} \) is known only to the seller. The seller has a dominant strategy, which is to accept all bids above \( \tilde{v} - \Delta \) and to reject all others. We assume the seller plays his dominant strategy, and we focus on the subgame between the dealer and the buyer.

The dealer has a signal \( \hat{s} \) about \( \tilde{v} \). Assume that \( \tilde{v} = \hat{s} + \hat{\varepsilon} \), where \( \hat{s} \) and \( \hat{\varepsilon} \) are independently distributed and the mean of \( \hat{\varepsilon} \) is zero. We call \( s \) the dealer’s type. Assume the support of \( \hat{s} \) is a finite interval \([s_L, s_H]\).

Note that we do not need to assume that the seller knows the dealer’s signal \( \hat{s} \), because the seller has a dominant strategy that does not depend on \( \hat{s} \). We assume the seller has the best information about the asset value \( \tilde{v} \), because it is likely that the owner of an asset has done the most due diligence regarding it. We assume the buyer has the least information, because we assume the buyer’s interest in the asset is solely a function of being called by the dealer regarding it. As mentioned in the introduction, we assume the buyer is one of
many possible buyers who are known to the dealer to invest in assets of the same general
type but who have no special information about the particular asset in question.

Denote the distribution function of \( \tilde{\varepsilon} \) by \( F \) and the density function of \( \tilde{\varepsilon} \) by \( f \). Assume
the support of \( \tilde{\varepsilon} \) is the entire real line, \( \log F \) is strictly concave, and

\[
\lim_{x \to -\infty} \frac{F(x)}{f(x)} = 0. \tag{1}
\]

Strict log concavity implies that the function

\[
x \mapsto g(x) = \frac{F(x)}{f(x)}
\]
is strictly increasing. Of course, \( g \) is positive. Condition (1) implies that all positive
numbers are in the range of \( g \), so \( g^{-1}(a) \) is well defined for all \( a > 0 \).

Define

\[
u(s, A, B) = (A - B) \cdot F(B + \Delta - s).
\]

This is the expected utility of a dealer of type \( s \) who plays the bid \( B \) and ask \( A \) when
the ask is accepted by the buyer. As in other cases, log concavity implies single crossing.

Using subscripts to denote partial derivatives, the marginal rate of substitution

\[
\frac{-u_3(B, A, s)}{u_2(B, A, s)} = 1 - \frac{A - B}{g(B + \Delta - s)}
\]
is a decreasing function of the dealer’s type due to log concavity (for \( B < A \), which must
be true in equilibrium). Thus, higher type dealers require less compensation in the form
of a higher ask in exchange for submitting higher bids.

Define

\[
A^*(s, B) = \mathbb{E}[\tilde{v} \mid \tilde{v} - \Delta \leq B, \tilde{s} = s] = s + \mathbb{E}[\tilde{\varepsilon} \mid \tilde{\varepsilon} \leq B + \Delta - s].
\]

This would be the buyer’s reservation value for the asset if the buyer observed the dealer’s
type $\tilde{s} = s$ and observed a prior transaction at the dealer’s bid $B$. For any $x$, set

$$G(x) = \frac{1}{F(x)} \int_{-\infty}^{x} \varepsilon f(\varepsilon) \, d\varepsilon,$$

so we have

$$A^*(s, B) = s + G(B + \Delta - s). \quad (2)$$

The strict log concavity of $F$ implies that $A^*$ is strictly increasing in $s$ (Bagnoli and Bergstrom, 2005).

The dealer’s strategy consists of a bid function $B(\cdot)$ and an ask function $A(\cdot)$. The dealer quotes an ask price $A(\tilde{s})$ to the buyer only when the dealer’s bid has been accepted by the seller. The buyer observes the bid and ask and forms beliefs about $\tilde{v}$ and $\tilde{s}$. The beliefs put probability 1 on the bid having been accepted, which is the event $B(\tilde{s}) \geq \tilde{v} - \Delta$.

Let $\mu(\cdot \mid B, A)$ denote the buyer’s marginal distribution over $\tilde{s}$ after observing a bid $B$ and ask $A$. The buyer’s joint distribution over $(\tilde{s}, \tilde{v})$ is determined by $\mu(\cdot \mid B, A)$ and by the exogenously given conditional distribution of $\tilde{v}$, conditioning on $\tilde{s}$ and on the event $B(\tilde{s}) \geq \tilde{v} - \Delta$.

We have defined $A^*(s, B)$ as the buyer’s reservation value after observing a bid $B$ when the dealer’s type $s$ is known. However, the buyer does not directly observe the dealer’s type but instead makes an inference about the type by observing the bid and ask. The buyer’s reservation value after observing a bid $B$ and ask $A$ is

$$V(B, A) \overset{\text{def}}{=} \int_{s_L}^{s_H} A^*(s, B) \mu(ds \mid B, A). \quad (3)$$

It is optimal for the buyer to accept an ask $A$ if and only if $A \leq V(B, A)$. Define

$$\alpha(B) = \sup\{a \mid a \leq V(B, a)\}. \quad (4)$$

This is the maximum ask that will be accepted by the buyer after the dealer plays a bid $B$. 

9
The game between the dealer and the buyer is a signaling game with the multivariate signal \((B, A)\). There are many equilibria to the game, some of which are not ruled out by standard refinements. At the time the dealer chooses the ask price, all dealer types have the same preferences regarding the ask—namely, the utility of the dealer is one-for-one in the ask price up to the point that the buyer rejects it. There are equilibria in which the buyer believes high asks are played by low dealer types. Consequently, all dealer types play low asks. These equilibria are not excluded by standard refinements, because all dealer types have the same incentive to deviate. In such equilibria, the buyer can earn rents. Our interest is in the signaling role of the first transaction price and the effects of disclosing or not disclosing it. We rule out equilibria in which the second transaction price also signals by assuming the buyer’s beliefs are weakly monotone in the ask price. Our assumption allows for beliefs to be independent of the ask price. The following shows that, under this monotonicity condition, the ask price is a function of the bid price and hence is not a separate signal to the buyer. Furthermore, the buyer does not earn rents.

**Proposition 1.** Suppose the buyer’s beliefs are monotone in the ask price in the sense that \(V(B, \cdot)\) is a nondecreasing function for each \(B\). Then, for each bid \(B\), the supremum in (4) is attained at a unique ask, and \(V(B, \alpha(B)) = \alpha(B)\). Furthermore, in equilibrium, the bid-ask pairs played are all of the form \((B, \alpha(B))\) for some \(B\). If the equilibrium is separating, then

\[
(\forall s) \quad A(s) = \alpha(B(s)) = V(B(s), A(s)) = A^*(s, B(s)).
\]  

(5)

An implication of Proposition 1 is that if two dealer types \(s\) and \(s'\) play the same bid—in an equilibrium with beliefs that are monotone in the ask—then they must also play the same ask. Thus, pooling in bids implies pooling in asks. We can rule out pooling in bids
by invoking the D1 criterion. The single-crossing property implies that higher type dealers have the most incentive to deviate to higher bids, which implies that pooling equilibria violate the D1 criterion (Ramey, 1996). Therefore, we focus on separating equilibria henceforth.

If a dealer plays a bid $B$ and is believed to be of type $s'$, then the ask price that she could charge the buyer would be $A^*(s', B)$, and her expected profit would be

$$U(s, s', B) \overset{\text{def}}{=} u(s, A^*(s', B), B) = [s' + G(B + \Delta - s') - B] \cdot F(B + \Delta - s). \quad (6)$$

Like $u$, the function $U$ has a single-crossing property. We have

$$-\frac{U_3(s, s', B)}{U_2(s, s', B)} = 1 - \frac{s' + G(B + \Delta - s') - B}{1 - G'(B + \Delta - s')} \cdot \frac{1}{g(B + \Delta - s)}. \quad (7)$$

Log concavity implies that $G' < 1$ and $g$ is increasing, so (7) is a decreasing function of the dealer’s type $s$ [whenever the numerator of the second term on the right hand side of (7) is positive, which is equivalent to $U(s, s', B) > 0$]. This means that dealers of higher types find it less expensive to make higher bids—they require less compensation in the form of increases in their perceived types.

The expected profit of a dealer of type $s$ in a separating equilibrium—in which beliefs are monotone in the ask price—is $U(s, s, B(s))$. Among other things, the following states that our model satisfies the initial value condition of Mailath (1987).

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4Our setup is slightly different from Ramey’s, but the difference is immaterial. Our function $u$ matches Ramey’s function $U$ with $B$ being the action of the sender, $A$ being the action of the receiver, and $s$ being the sender’s type. In our model, $A$ is actually chosen by the sender (the dealer) and the receiver’s decision is just to accept or reject. However, in an equilibrium with beliefs that are monotone in $A$, $A$ depends on $B$ as shown in Proposition 1 and hence is not an additional signal to the receiver, so it is immaterial whether it is chosen by the sender or the receiver. Furthermore, the function $A^*$ plays the role in our model of the optimal action of the receiver that is denoted by $R^*$ by Ramey. In particular, $A^*$ is an increasing function of the sender’s type $s$, as assumed by Ramey.
Proposition 2. For any $s$, there exists $B$ such that $U(s, s, B) > 0$. The maximization problem

$$\max_B U(s_L, s_L, B)$$

has a unique solution, which is

$$B_L \overset{\text{def}}{=} s_L - \Delta + g^{-1}(\Delta).$$

A necessary condition for a separating equilibrium in which the buyer’s beliefs are monotone in the ask price—in the sense that $V(B, \cdot)$ is a nondecreasing function for each $B$—is that $B(s_L) = B_L$.

The incentive compatibility condition for a separating equilibrium is

$$(\forall s, s') \quad U(s, s, B(s)) \geq U(s, s', B(s')).$$

When $B(\cdot)$ is differentiable, the first-order condition for incentive compatibility produces the following ordinary differential equation (ODE) for $B(\cdot)$.

$$(\forall s) \quad U_2(s, s, B(s)) + U_3(s, s, B(s))B'(s) = 0.$$  

The first part of the following proposition states that the ODE is a sufficient condition for incentive compatibility. It follows from Mailath and von Thadden (2013, Theorem 6). For the last part, we assume differentiability. Mailath and von Thadden state several sets of conditions that imply differentiability, but none apply directly to our model.

Proposition 3. Suppose $B(\cdot)$ is a nondecreasing function that satisfies the ODE (11) and has the property that $U(s, s, B(s)) > 0$ for all $s$. Then, the incentive compatibility condition (10) is satisfied. Conversely, if $B(\cdot)$ is differentiable and satisfies the incentive compatibility condition (10), then $B(\cdot)$ must satisfy the ODE (11).
To analyze the ODE, it is convenient to make a change of variables. Set

\[ x(s) = B(s) + \Delta - s. \tag{12} \]

Using the fact that \( G'(x) = [x - G(x)]/g(x) \), we obtain

\[ x'(s) = B'(s) - 1 = \frac{U_2(s, s, B(s))}{U_3(s, s, B(s))} - 1 = \frac{G(x(s)) + \Delta - x(s)}{g(x(s)) - \Delta}. \tag{13} \]

Set \( x_L = B_L + \Delta - s_L \), where \( B_L \) is defined in (9). As Mailath (1987) points out, the ODE is degenerate at the initial condition, because the first-order condition for the optimization problem in Proposition 3 is \( U_3(s_L, s_L, B(s_L)) = 0 \), equivalently, \( g(x_L) = \Delta \). We follow Mailath (1987) by studying the inverse differential equation. The inverse to (13) is

\[ s'(x) = \frac{g(x) - \Delta}{G(x) + \Delta - x}. \tag{14} \]

We can solve this simply by integrating as

\[ s(x) = s_L + \int_{s_L}^{x} \frac{g(a) - \Delta}{G(a) + \Delta - a} \, da. \tag{15} \]

We need to integrate up to the point that \( s(x) = s_H \) so that the inverse \( x(\cdot) \) is defined on \([s_L, s_H] \). We now explain why this is possible.

Define

\[ x_H = \inf\{a \mid G(a) + \Delta - a \leq 0\}. \]

The function \( G(a) + \Delta - a \) is monotone decreasing due to log concavity (\( G' < 1 \)). Hence, it is positive below \( x_H \) and negative above. Furthermore, \( g(a) - \Delta > 0 \) for \( a > x_L \) due to the initial condition \( x_L = g^{-1}(\Delta) \) and the monotonicity of \( g \). Thus, the integrand in (15) is positive for \( x \) between \( x_L \) and \( x_H \), implying that \( s(\cdot) \) defined in (15) is increasing between
We show in the proof of the theorem below that
\[
\int_{x_L}^{x_H} \frac{g(a) - \Delta}{G(a) + \Delta - a} \, da = \infty.
\]  
(16)

Therefore, there exists \( x_H \) between \( x_L \) and \( x^*_H \) such that
\[
s(x_H) \overset{\text{def}}{=} s_L + \int_{x_L}^{x_H} \frac{g(a) - \Delta}{G(a) + \Delta - a} \, da = s_H.
\]  
(17)

Thus, the solution \( s(\cdot) \) of (15) on the domain \([x_L, x_H]\) is strictly monotone with range \([s_L, s_H]\). Its inverse \( x(\cdot) \) defines the equilibrium bidding rule as \( B(s) = x(s) - \Delta + s \).

Propositions 1–3 state necessary conditions for a separating equilibrium (in which \( V(B, \cdot) \) is monotone). Now, we show that there is a unique solution of the necessary conditions and that the solution is an equilibrium. Off-equilibrium beliefs and a strategy for the buyer that support the equilibrium are as follows. These beliefs are independent of the ask price and hence satisfy the monotonicity condition in Propositions 1 and 2.

**Buyer’s Beliefs and Strategy.** If \( b = B(s) \) for some \( s \), then, for any \( a \), \( \mu(b, a) \) puts probability 1 on \( \tilde{s} = s \). If \( b < B(s_L) \) then, for any \( a \), \( \mu(b, a) \) puts probability 1 on \( \tilde{s} = s_L \). If \( b > B(s_H) \) then, for any \( a \), \( \mu(b, a) \) puts probability 1 on \( \tilde{s} = s_H \). The buyer accepts the dealer’s ask \( a \) if and only if either:

- \( b = B(s) \) for some \( s \) and \( a \leq A^*(s, b) \), or
- \( b < B(s_L) \) and \( a \leq A^*(b, s_L) \), or
- \( b > B(s_H) \) and \( a \leq A^*(b, s_H) \).

**Theorem.** There is a unique strictly monotone solution \( B(\cdot) \) of the ODE (11) on the domain \([s_L, s_H]\) that satisfies the initial condition \( B(s_L) = B_L \). The solution is obtained by inverting the function \( s(\cdot) \) defined in (15) on the domain \([x_L, x_H]\), where \( x_H \) is defined in (17). In conjunction with the ask price \( A(s) = A^*(s, B(s)) \) and the buyer’s beliefs and
strategy described above, the strictly monotone solution \( B(\cdot) \) of the ODE defines a separating equilibrium. In this equilibrium, \( B'(s) > 1 \) for all \( s \), the bid-ask spread \( A(s) - B(s) \) is strictly decreasing in \( s \), the probability of trade \( F(B(s) + \Delta - s) \) is strictly increasing in \( s \), and the dealer’s expected profit \( U(s, s, B(s)) \) is positive and strictly decreasing in \( s \).

**Example.** Take \( \tilde{s} \) to be uniformly distributed on \([s_L, s_H]\), and assume \( \tilde{\varepsilon} \) is normally distributed with mean zero and variance \( \sigma^2 \). The normal distribution has all of the properties we have assumed for \( \tilde{\varepsilon} \). Let \( N \) denote the standard normal distribution function, and let \( n \) denote the standard normal density function. Then, \( F(x) = N(x/\sigma) \) and \( f(x) = n(x/\sigma)/\sigma \). Hence, \( g(x) = \sigma N(x/\sigma)/n(x/\sigma) \). Also,

\[
G(x) = -\sigma n(x/\sigma)/N(x/\sigma) = -\frac{\sigma^2}{g(x)}.
\]

Therefore, the solution (15) of the inverse ODE is

\[
s(x) = s_L + \int_{x_L}^{x} \frac{g(a)^2 - \Delta g(a)}{(\Delta - a)g(a) - \sigma^2} \, da.
\]  

(15’)

In this example, the parameters are the gain from trade \( \Delta \), the variance \( \sigma^2 \) of the seller’s private information \( \tilde{\varepsilon} \), and the boundaries \( s_L \) and \( s_H \) of the distribution of the dealer’s signal \( \tilde{s} \). We analyze the example in each of the next two sections. Rather than using \( \sigma, s_L, \) and \( s_H \) as parameters, we present the results in terms of parameters that may be somewhat more intuitive, namely, the total amount of private information (seller’s plus dealer’s) and the fraction of the total that is explained by the dealer’s information. The variance of the uniformly distributed \( \tilde{s} \) is \( (s_H - s_L)^2/12 \), so the variance of \( \tilde{v} = \tilde{s} + \tilde{\varepsilon} \) (the total amount of private information) is

\[
\phi^2 = \frac{(s_H - s_L)^2}{12} + \sigma^2.
\]  

(18)
The fraction of the variance of \( \tilde{v} \) that is explained by \( \tilde{s} \) is \( \rho^2 \), where \( \rho \) is the correlation of \( \tilde{s} \) and \( \tilde{v} \); that is,

\[
\rho = \frac{s_H - s_L}{\phi \sqrt{12}}.
\]  

We can exogenously specify the total amount of private information \( \phi^2 \) and the fraction \( \rho^2 \) that is explained by the dealer’s signal and then recover \( s_H - s_L \) and \( \sigma \) as \( s_H - s_L = \rho \phi \sqrt{12} \) and \( \sigma^2 = (1 - \rho^2) \phi^2 \).

The separating equilibrium of the signaling game is depicted in Figure 1. The figure illustrates the general properties established in the theorem: The bid-ask spread is decreasing in the dealer’s type, the probability of trade is increasing in the dealer’s type, and the dealer’s expected profit is decreasing in her type. Figure 1 also shows what the outcomes would be if the dealer’s signal were publicly observable (the first-best world). In the first-best world, the dealer chooses her bid to maximize \( U(s, s, B) \). The maximum, as shown in (9) for \( s = s_L \), is \( B = s - \Delta + g^{-1}(\Delta) \). Thus, if the dealer’s type were publicly observable, her bid would rise one-for-one with her type, which implies that the bid-ask spread, the probability of trade, and her expected profit would all be independent of her type.

The top left panel of Figure 1 illustrates the overbidding in the separating equilibrium that is discussed in the introduction. Dealers overbid to separate from dealers of lower types. Because of the higher bids, the average quality of assets purchased is higher, so the ask is also higher in the signaling game than when the dealer’s signal is publicly observable. However, the ask increases less than the bid, so the bid-ask spread is smaller in the signaling game. Because of the higher bids, the probability of trade is higher (the market is more liquid) in the signaling game. However, from the dealer’s point of view, the higher volume is not sufficient to offset the lower spread, and the dealer’s profit is lower than if the signal were publicly observable. Of course, the dealer’s profit cannot be
higher in a separating equilibrium of the signaling game than when the dealer’s signal is publicly observable, because \( U(s, s, B(s)) \leq \max_B U(s, s, B) \). This is the standard result that signaling is costly, relative to the first-best world.

3. An Opaque Market

To determine the benefits and costs of transparency, we describe the market equilibrium when the terms of the first transaction cannot be credibly disclosed. Without disclosure, all dealer types must play the same ask in equilibrium (if two different asks were accepted by the buyer in equilibrium, then all dealer types should play the higher of the two). The same arguments as in the proof of Proposition 1 show that the equilibrium ask must be the buyer’s reservation value, which here is

\[
\tilde{A} \overset{\text{def}}{=} \mathbb{E}[\tilde{v} \mid \tilde{v} - \Delta \leq B(\tilde{s})] = \frac{1}{\text{prob}(\tilde{v} - \Delta \leq B(\tilde{s}))} \mathbb{E}\left[\tilde{v}1_{\{\tilde{v} - \Delta \leq B(\tilde{s})\}}\right]
\]

\[
= \frac{1}{\text{prob}(\tilde{v} - \Delta \leq B(\tilde{s}))} \mathbb{E}\left[A^*(\tilde{s}, B(\tilde{s}))F(B(\tilde{s}) + \Delta - \tilde{s})\right]
\]

The equilibrium bids satisfy

\[
(\forall s) \quad B(s) \in \arg \max_B (\tilde{A} - B) \cdot F(B + \Delta - s).
\]

For all real \( x \), define \( h(x) = x + g(x) \), where \( g(x) = F(x)/f(x) \) as before. With some simple algebra, we can write the derivative with respect to \( B \) of the objective function in (21) as

\[
f(B + \Delta - s) \left[ A + \Delta - s - h(B + \Delta - s) \right].
\]

This has a unique critical point given by

\[
B + \Delta - s = h^{-1}(A + \Delta - s).
\]
Furthermore, the monotonicity of $h$ (which it inherits from $g$) implies that the derivative (22) is positive to the left of the critical point and negative to the right, so the critical point is the unique maximum. Therefore, we have

$$(\forall s) \quad B(s) = s - \Delta + h^{-1}(\bar{A} + \Delta - s). \quad (23)$$

When we substitute this into the right-hand side of (20), we obtain a fixed-point condition for the equilibrium $\bar{A}$.

In the signaling equilibrium, $B'(s) > 1$, but in an opaque market $0 < B'(s) < 1$. To see that, differentiate (23) and use the fact that $h'(x) = 1 + g'(x) > 1$. As in the signaling equilibrium, the bid-ask spread decreases with the dealer’s type in an opaque market (because the bid rises with the type and the ask is fixed). In the signaling equilibrium, some of the smaller spread for higher types is offset by a higher probability of trade. However, in an opaque market, the probability of trade is smaller for higher types—this is a consequence of the probability of trade being $F(B + \Delta - s)$ and the fact that $B'(s) < 1$ in an opaque market. Because both the spread and the probability of trade are smaller for higher types, expected profits are smaller for higher types in an opaque market.

**Example.** Consider the uniform/normal example of the previous section. We have

$$A^*(s, B) = s + G(B + \Delta - s) = s - \frac{\sigma^2}{g(B + \Delta - s)}.$$

Therefore,

$$A^*(s, B)F(B + \Delta - s) = sF(B + \Delta - s) - \sigma^2 f(B + \Delta - s).$$
Substitute this and (23) into (20) to obtain

\[
\begin{align*}
\bar{A} &= \left( \int_{s_L}^{s_H} F(h^{-1}(\bar{A} + \Delta - s)) \, ds \right)^{-1} \\
&\quad \times \int_{s_L}^{s_H} \left[ sF(h^{-1}(\bar{A} + \Delta - s)) - \sigma^2 f(h^{-1}(\bar{A} + \Delta - s)) \right] \, ds.
\end{align*}
\]

In the integrals, make the change of variable \( z = h^{-1}(\bar{A} + \Delta - s) \). In this normal example, \( h'(x) = 2 + xg(x)/\sigma^2 \). Therefore, \( ds = -[2 + zg(z)/\sigma^2] \, dz \). We obtain

\[
\bar{A} = \left( \int_{z_H}^{z_L} F(z) \left[ 2 + \frac{zg(z)}{\sigma^2} \right] \, dz \right)^{-1} \\
\quad \times \int_{z_H}^{z_L} \left[ (\bar{A} + \Delta - z - g(z))F(z) - \sigma^2 f(z) \left[ 2 + \frac{zg(z)}{\sigma^2} \right] \right] \, dz,
\]

where \( z_i = h^{-1}(\bar{A} + \Delta - s_i) \) for \( i = L, H \) (note \( z_H < z_L \)). Figure 2 depicts this fixed point condition. The figure shows that the equilibrium \( \bar{A} \) equals the unconditional expected value \( (s_L + s_H)/2 \) minus a discount for adverse selection. The discount for adverse selection is smaller when the gain from trade \( \Delta \) is larger and when the total amount of private information \( \phi \) is smaller. More details about how the equilibrium varies with parameters are presented in the next section.

4. Benefits and Costs of Transparency

We compare the efficiency of the transparent and opaque markets, and we examine the effect of transparency on dealer profits. We analyze the uniform/normal example discussed in the previous sections. Figure 3 compares the transparent and opaque markets for one set of parameters. It illustrates many of the features of the equilibria discussed earlier: Bids rise faster with the dealer’s type in the signaling equilibrium than in the opaque market, the spread falls with the dealer’s type in both markets, the probability of trade rises with
the dealer’s type in the signaling equilibrium but falls with the dealer’s type in the opaque market, and the dealer’s expected profit falls with the dealer’s type in both markets. The dealer’s expected profit falls more rapidly with the dealer’s type in the opaque market than in the signaling equilibrium, because both the spread and the probability of trade fall with the dealer’s type in the opaque market. Dealers with bad news about the asset value prefer opacity, and dealers with good news prefer transparency. On an ex ante basis, dealers prefer transparency for the particular set of parameters used in Figure 3.

Figure 4 compares the two markets for different sets of parameters. It shows that volume is higher and spreads are lower in the transparent market, so the transparent market is the more liquid of the two. The higher volume implies higher aggregate welfare, because higher volume implies higher gains from trade. However, dealers may prefer opacity.

The top row of Figure 4 shows the effect of varying the gain from trade $\Delta$. Trade is more likely and spreads are higher in both markets when $\Delta$ is larger. The top right panel shows that dealers prefer transparency when $\Delta$ is small and prefer opacity when $\Delta$ is large. As discussed earlier, the reason is that, when $\Delta$ is large, trade is highly probable in both markets, so the overriding factor is the higher spread earned in the opaque market.

The second row of Figure 4 shows the effects of varying the amount of private information, which are the opposite of those from varying the gains from trade. Trade is less likely and spreads are lower in both markets when adverse selection is more severe. Dealers prefer opacity when adverse selection is low and prefer transparency when adverse selection is high. They prefer opacity when adverse selection is low because trade is highly probable in both markets in that circumstance, causing the higher spreads in opaque markets to be the most important factor.

The bottom row of Figure 4 shows the effects of varying the informativeness of the dealer’s signal. Trade is more likely, spreads are higher, and dealer profits are higher when
the dealer’s signal is more informative. However, dealers’ preferences for transparency or opacity seem to be independent of the quality of the dealer’s signal.

Figure 5 provides more information about dealers’ preferences for transparency versus opacity. In each of the plots in the top row, we fix $\phi$ (and $\rho$) and vary $\Delta$. In each of the plots in the bottom row, we fix $\Delta$ and vary $\phi$. Naturally, profits are higher when the gains from trade are larger and/or when there is less adverse selection. The most important feature of Figure 5 is the crossing of the two curves shown in most of the plots: Dealers prefer opacity when adverse selection is low and gains from trade are high, and they prefer transparency in the opposite situations.

Figure 6 shows that, in all circumstances, sellers prefer transparency. In our model, buyers earn no rents in either type of market, so aggregate investor (non-dealer) welfare is higher in transparent markets. The increase in investor welfare due to transparency is equal to $\Delta$ times the increase in the probability of trade minus the change in the dealer’s expected profit.

### 5. Conclusion

When dealers make round-trip transactions and have information not possessed by the second counterparty, they engage in costly signaling, offering unduly favorable prices in the first transaction to signal to the second counterparty. This costly signaling increases volume, liquidity, and market efficiency. From the perspective of dealers, the lower spreads and higher volume are partially offsetting factors. Which is more important depends on the magnitude of gains from trade and the extent of adverse selection. Dealers prefer opacity when gains from trade are high and/or adverse selection is low. Thus, dealers and investors may have opposing preferences regarding transparency.

We have assumed a single seller, a single dealer, and many buyers, one of whom is contacted by the dealer when the dealer acquires inventory. Our model applies to multiple
sellers, because it applies to each individually. Our model also applies to multiple dealers if search is costly for sellers. When search is costly, the Diamond paradox applies (Diamond, 1971), and it is an equilibrium for each dealer to quote as if he were a monopolist. So, the outcome is the same as in our model. On the other hand, if search is costless for sellers, then dealers compete in a Bertrand fashion, shifting rents from dealers to sellers. Because dealers earn no rents in such a world, they are indifferent about transparency. The assumption of costly search seems more reasonable to us, because investors risk information leakage if they contact multiple dealers before executing a trade.
Appendix A. Proofs

Proof of Proposition 1. We begin by showing that the supremum is attained. We prove this by constructing a compact set that has the same supremum. Define \( A(B) = \{ a | A^*(s_L, B) \leq a \leq V(B, a) \} \). Clearly, the supremum of \( A(B) \) is the same as the supremum in (4) if \( A(B) \neq \emptyset \). Because \( A^*(\cdot, B) \) is nondecreasing, \( A^*(s_L, B) \leq V(B, A) \leq A^*(s_H, B) \) for all \( A \), so
\[
A^*(s_L, B) \in A(B) \subset [A^*(s_L, B), A^*(s_H, B)].
\]
Therefore, \( A(B) \neq \emptyset \). Because \( V \) is continuous, \( A(B) \) is closed, hence compact. Therefore, the supremum in (4) is attained at some \( A = \alpha(B) \). Clearly, the supremum is unique.

To see that \( \alpha(B) = V(B, \alpha(B)) \), note first that, because \( \alpha(B) \in A(B) \), \( \alpha(B) \leq V(B, \alpha(B)) \). Suppose \( \alpha(B) < V(B, \alpha(B)) \). Choose any real number \( a \) satisfying \( \alpha(B) < a < V(B, \alpha(B)) \). By monotonicity of beliefs, \( a < V(B, \alpha(B)) \leq V(B, a) \), so \( a \in A(B) \).

But, then \( \alpha(B) < a \) contradicts the fact that \( \alpha(B) \) is the supremum of \( A(B) \). This contradiction implies \( \alpha(B) = V(B, \alpha(B)) \).

The fact that equilibrium asks are \( \alpha(B) \) is immediate from the fact that \( \alpha(B) \) is the unique optimal ask for the dealer given a bid \( B \). The first equality in (5) holds because of the optimality of \( \alpha(B) \), the second has already been shown, and the third is due to separation and the definition (3) of \( V \).

Proof of Proposition 2. First, we show that there exists \( B \) such that \( U(s, s, B) > 0 \). Setting \( x = B + \Delta - s \), we have \( U(s, s, B) = [\Delta - x + G(x)]F(x) \). Integrate by parts to obtain
\[
G(x) - x = -\frac{1}{F(x)} \int_{-\infty}^{x} F(\epsilon) \, d\epsilon
\]
and then apply l’Hôpital’s rule to obtain

\[
\lim_{x \to -\infty} [G(x) - x] = - \lim_{x \to -\infty} g(x) = 0.
\]

Therefore, for \( x \) (equivalently \( B \)) sufficiently small, we have \( \Delta - x + G(x) > 0 \), which implies \( U(s, s, B) > 0 \).

The derivative of \( U \) with respect to \( B \) is

\[
U_3(s, s, B) = [G'(x) - 1] \cdot F(x) + [(\Delta + G(x) - x) \cdot f(x)
= f(x)[\Delta - g(x)].
\]

For any \( s \), there is a unique critical point \( B \) defined by \( x = g^{-1}(\Delta) \). This critical point is a maximum, because (A.1) and the monotonicity of \( g \) imply that \( U_3 > 0 \) for \( B \) below the critical point and \( U_3 < 0 \) for \( B \) above the critical point. Thus, the solution to (8) is \( B_L \) defined in the proposition.

Now, we show that \( B(s_L) = B_L \) in a separating equilibrium. Consider any bid \( B \). If the dealer of type \( s_L \) plays bid \( B \), then her optimal ask is \( \alpha(B) \) and the maximum expected profit is

\[
[\alpha(B) - B] \cdot F(B + \Delta - s_L).
\]

The equilibrium bid must be optimal, so

\[
U(s_L, s_L, B(s_L)) \geq [\alpha(B) - B] \cdot F(B + \Delta - s_L). 
\]

Because \( A^* \) is increasing in \( s \), \( V(B, A) \geq A^*(s_L, B) \) for all \( A \). Hence, Proposition 1 implies

\[
\alpha(B) = V(B, \alpha(B)) \geq \pi(B, s_L) \geq A^*(s_L, B).
\]
Combining (A.2) and (A.3) produces

\[ U(s_L, s_L, B(s_L)) \geq [A^*(s_L, B) - B] \cdot F(B + \Delta - s_L) \overset{\text{def}}{=} U(s_L, s_L, B). \]

Therefore, an equilibrium \( B(s_L) \) solves (8).

Proof of Proposition 3. To establish that a solution of the ODE satisfies incentive compatibility, we can apply Theorem 6 of Mailath and von Thadden (2013). It suffices to verify that \( U_2(s, s', B(s')) > 0 \) and that

\[ \frac{U_3(s, s', B(s'))}{U_2(s, s'B(s'))} \]

is a nondecreasing function of \( s \). We have

\[ U_2(s, s', B) = [1 - G'(B + \Delta - s')] \cdot F(B + \Delta - s). \]

Log concavity implies \( G' < 1 \), so \( U_2 > 0 \). The fact that \( U_3/U_2 \) is nondecreasing in \( s \) is the single-crossing property discussed before. If \( B(\cdot) \) is differentiable, then the first-order condition for the incentive compatibility condition is the ODE, so a differentiable \( B(\cdot) \) that satisfies incentive compatibility must satisfy the ODE.

Proof of the Theorem. First, we show that (16) holds. From the definition of \( x_H^* \), \( \Delta = x_H^* - G(x_H^*) \). Also, the initial condition is \( g(x_L) = \Delta \). Make these substitutions and change variables to \( z = x_H^* - a \) to write the integral in (16) as

\[ \int_{x_H^*-x_L}^{x_H^*} \frac{g(x_H^* - z) - g(x_L)}{z + G(x_H^* - z) - G(x_H^*)} \, dz. \quad (A.4) \]

As discussed in the text, both the numerator and the denominator of the integrand in
(A.4) are positive, except for the denominator being zero at the lower endpoint and the numerator being zero at the upper endpoint. Consider any \( x \) between 0 and \( x^*_H - x_L \). The integral (A.4) is at least as large as the integral of the same integrand from 0 to \( x \). Between 0 and \( x \), the numerator of the integrand is at least as large as \( g(x^*_H - x) - g(x_L) > 0 \). Also, \( G(x^*_H - z) - G(x^*_H) < 0 \), so the denominator is smaller than \( 1/z \). Therefore, the integral is at least as large as

\[
[g(x^*_H - x) - g(x_L)] \int_0^x \frac{1}{z} \, dz = \infty.
\]

Now, assume \( B(\cdot) \) is a strictly monotone solution of the ODE (11) satisfying the initial condition \( B(s_L) = B_L \). Then \( x(\cdot) \) defined in (12) satisfies the ODE (13) and the initial condition \( x(s_L) = x_L \). As already discussed, the derivative \( x'(s) \) in (12) is positive for \( x < x^*_H \), so \( x(\cdot) \) is strictly monotone and has an inverse \( s(\cdot) \) that must satisfy (14). Due to (16), we know that the inverse reaches \( s_H \) before \( x \) reaches \( x^*_H \). This establishes the uniqueness of the solution of the ODE (11) and the characterization of the solution stated in the theorem.

From \( x'(s) > 0 \), we obtain \( B'(s) > 1 \). The bid-ask spread is

\[
s + G(x(s)) - B(s) = G(x(s)) + \Delta - x(s) ,
\]

which is strictly decreasing in \( s \) because \( x \) is strictly increasing in \( s \) and \( G' < 1 \). The probability of trade is \( F(x(s)) \), which is strictly decreasing in \( s \) because \( x \) is strictly increasing in \( s \) and \( F \) is monotone. To see how the dealer’s expected profit depends on her type, note that, due to the ODE (11),

\[
\frac{d}{ds} U(s, s, B(s)) = U_1(s, s, B(s)) .
\]
Furthermore,

\[ U_1(s, s, B(s)) = -[s + G(x(s)) - B(s)]f(x(s)) = -\frac{U(s, s, B(s))}{F(x(s))}f(x(s)). \]

Hence, \( dU/U = -1/g \), which implies

\[ U(s, s, B(s)) = U(s_L, s_L, B_{L}) \exp \left( -\int_{s_L}^{s} \frac{1}{g(x(a))} da \right) > 0, \]

which implies further that \( U_1(s, s, B(s)) < 0 \).

Clearly, the buyer’s strategy is optimal given the beliefs, and the beliefs are consistent with Bayes’ rule. Furthermore, because \( B(\cdot) \) satisfies the ODE, Proposition 3 shows that the dealer does not wish to deviate to any bid that is played by a dealer of a different type. Hence, to verify that this is an equilibrium, it suffices to show that the dealer does not wish to deviate to any bid that is not played. First, consider any bid \( B < B(s_L) \). The dealer’s expected profit at that bid is

\[ U(s, s_L, B) = U(s_L, s_L, B) \cdot \frac{F(B + \Delta - s)}{F(B + \Delta - s_L)}. \]

We can assume that \( U(s_L, s_L, B) > 0 \), because otherwise \( U(s, s_L, B) \leq 0 < U(s, s, B(s)) \).

We have

\[ U_3(s, s_L, B) = U_3(s_L, s_L, B) \cdot \frac{F(B + \Delta - s)}{F(B + \Delta - s_L)} + U(s_L, s_L, B) \cdot \frac{F(B + \Delta - s)}{F(B + \Delta - s_L)} \cdot \left[ \frac{1}{g(B + \Delta - s)} - \frac{1}{g(B + \Delta - s_L)} \right]. \quad (A.5) \]

The first term in (A.5) is positive, as shown in the proof of Proposition 2—the proof that \( B_L > B \) maximizes \( U(s_L, s_L, B) \). The second term is also positive due to the monotonicity
of \( g \). Hence, \( U_3(s, s_L, B) > 0 \), which implies that the utility is increased by increasing \( B \) to \( B(s_L) \). This gives us

\[
U(s, s_L, B) < U(s, s_L, B(s_L)) \leq U(s, s, B(s))
\]

using incentive compatibility (10) for the second inequality.

Now, consider \( B > B(s_H) \). The dealer’s expected profit at such a bid is

\[
U(s, s_H, B) = U(s, s_H, B(s_H)) \cdot \frac{F(B + \Delta - s)}{F(B + \Delta - s_H)}.
\]

As in the previous case, we can assume \( U(s_H, s_H, B) > 0 \). Also as before, we have

\[
U_3(s_H, s_H, B(s_H)) = U_3(s_H, s_H, B) \cdot \frac{F(B + \Delta - s)}{F(B + \Delta - s_H)}
\]

\[
+ U(s_H, s_H, B) \cdot \frac{F(B + \Delta - s)}{F(B + \Delta - s_H)} \left[ \frac{1}{g(B + \Delta - s)} - \frac{1}{g(B + \Delta - s_H)} \right]. \tag{A.6}
\]

The second term in (A.6) is negative, due to the monotonicity of \( g \). To show that the first term is negative, we first observe that \( U_3(s_H, s_H, B(s_H)) < 0 \). This follows from the ODE (11) and the fact that \( U_2 = (1 - G')F < 0 \). Now, observe that, setting \( x_1 = B(s_H) + \Delta - s_H \) and \( x_2 = B + \Delta - s_H \), we have from (A.1) that

\[
U_3(s_H, s_H, B(s_H)) = f(x_1)[\Delta - g(x_1)]
\]

\[
U_3(s_H, s_H, B) = f(x_2)[\Delta - g(x_2)]
\]

Hence, from \( U_3(s_H, s_H, B(s_H)) < 0 \) and the monotonicity of \( g \) we have

\[
\Delta - g(x_2) < \Delta - g(x_1) < 0.
\]
Thus, $U_3(s_H, s_H, B) < 0$. This completes the proof that (A.6) is negative, which implies that utility is increased by decreasing $B$ to $B(s_H)$. This gives us

$$U(s, s_H, B) < U(s, s_H, B(s_H)) \leq U(s, s, B(s)),$$

using incentive compatibility (10) for the second inequality. \qed
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Figure 1: **Signaling vs. First Best**  The blue curves depict the separating equilibrium of the signaling game. The red dashed lines depict the outcomes when the dealer’s signal is publicly observable. In this example, the standard deviation of \( \tilde{v} \) is \( \phi = 5 \), the gain from trade is \( \Delta = 5 \), the fraction of the variance of \( \tilde{v} \) explained by the dealer’s signal is \( \rho^2 = 0.5 \), and the mean dealer type is \( (s_L + s_H)/2 = 100 \).
Figure 2: Equilibrium Ask in an Opaque Market  The solid blue curves depict the function of $\bar{A}$ that is on the right-hand side of (24). The intersection with the $45^\circ$ line is the equilibrium $\bar{A}$. In these examples, the mean dealer type is $(s_L + s_H)/2 = 100$. In the top left panel, the standard deviation of $\tilde{v}$ is $\phi = 5$, the gain from trade is $\Delta = 5$, and the fraction of the variance of $\tilde{v}$ explained by the dealer’s signal is $\rho^2 = 0.25$. The parameters in the top right panel are the same except $\Delta = 10$. The parameters in the bottom left panel are the same as in the top left panel except $\phi = 10$. The parameters in the bottom right panel are the same as in the top left panel except $\rho^2 = 0.75$. 
Figure 3: **Signaling vs. Opacity**   The separating equilibrium of the signaling game and the equilibrium of the opaque market are presented. In this example, the gain from trade is $\Delta = 5$, the standard deviation of $\tilde{v}$ is $\phi = 5$, the fraction of the variance of $\tilde{v}$ explained by the dealer’s signal is $\rho^2 = 0.5$, and the mean dealer type is $(s_L + s_H)/2 = 100$. 
Figure 4: **Comparative Statics**  The equilibria of the signaling game and the opaque market are compared for various parameter values. The base parameters are that the gain from trade is $\Delta = 5$, the standard deviation of $\tilde{v}$ is $\phi = 5$, and the fraction of the variance of $\tilde{v}$ explained by the dealer’s signal is $\rho^2 = 0.5$. Each row shows the effects of varying a single parameter, relative to the base case.
Figure 5: **Dealer Profits** Expected dealer profits are calculated in the separating equilibrium of the signaling game and in the equilibrium of the opaque market. In each case, the fraction of the variance of $\tilde{v}$ explained by the dealer’s signal is $\rho^2 = 0.5$. The standard deviation of $\tilde{v}$ (denoted by $\phi$) and the gain from trade (denoted by $\Delta$) are as shown.
Figure 6: Seller Gains  Expected seller gains are calculated in the separating equilibrium of the signaling game and in the equilibrium of the opaque market. In each case, the fraction of the variance of $\tilde{v}$ explained by the dealer’s signal is $\rho^2 = 0.5$. The standard deviation of $\tilde{v}$ (denoted by $\phi$) and the gain from trade (denoted by $\Delta$) are as shown.