Voluntary Disclosure in Bilateral Transactions

Vincent Glode   Christian Opp   Xingtan Zhang *

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Abstract

We analyze optimal voluntary disclosure by a privately informed agent who faces a counterparty endowed with market power in a bilateral transaction. While disclosures reduce the agent's informational advantage, they may increase his information rents by mitigating the counterparty's incentives to resort to inefficient screening. We show that when disclosures are restricted to be ex post verifiable, the privately informed agent always finds it optimal to design a partial disclosure plan that implements socially efficient trade in equilibrium. Our results have important implications for understanding the conditions under which asymmetric information impedes trade and for regulating information disclosure.

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1 Introduction

Asymmetric information might harm agents by disrupting socially efficient trade (e.g., Akerlof 1970, Myerson and Satterthwaite 1983, Glosten and Milgrom 1985). But why would agents *let* their private information be an impediment to trade in the first place? In this paper, we study the incentives of a privately informed agent to share his information with a counterparty endowed with market power prior to a bilateral transaction.

Recent work by Bergemann, Brooks, and Morris (2015) highlights that information available for price discrimination plays a crucial role in determining the total surplus and its allocation in the classic monopoly pricing problem with private values, raising the important question "what forms of price discrimination will endogenously arise, and for whose benefit." We consider an environment with both private- and common-value uncertainty and analyze one natural channel determining the information a seller with market power can use for price discrimination — the privately informed buyer can make voluntary ex post verifiable disclosures prior to the transaction, as in Grossman (1981), Milgrom (1981), and Shin (2003).

Ex post verifiability is a common restriction in the literature that is imposed to ensure that disclosures are not subject to commitment and incentive problems, even in one-shot interactions.[1] If erroneous disclosures can be verified with probability one and are penalized — perhaps by a regulator or courts — the sender optimally designs signals that are always truthful. Moreover, the sharing of verifiable information appears to be relevant in many important economic contexts with hard information, such as the trading of financial securities, corporate takeovers, and supply chain transactions.[2]

[1]The early literature analyzing these types of "persuasion games" is surveyed by Milgrom (2008). Since these games focus on ex post verifiable disclosures, they significantly differ from "cheap talk games" popularized by Crawford and Sobel (1982).

[2]See Boyarchenko, Lucca, and Veldkamp (2016) and Di Maggio, Franzoni, Kermani, and Sommavilla (2016) for empirical evidence consistent with broker-dealers sharing private (deal-flow) information among themselves and with clients, Hong, Kubik, and Stein (2005) and Pool, Stoffman, and Yonkers (2015) for

In this environment, we obtain a surprisingly strong result: the informed agent always designs a partial disclosure plan that yields socially efficient trade in equilibrium. Moreover, this disclosure plan improves both his surplus and that of the counterparty with market power. Whereas possessing superior information allows the informed agent to extract information rents, sharing information reduces the extent to which the agent is being inefficiently screened by his counterparty. We show that the agent is always willing and able to design ex post verifiable signals such that he privately benefits from giving up part of his informational advantage in order to preempt inefficient screening.

We also characterize optimal disclosure plans, which generally pool multiple disjoint intervals of valuations. Although the informed agent benefits from disclosing some information, he finds it privately suboptimal to disclose all information as doing so completely eliminates his information rents. While we initially consider an environment where the disclosure plan is designed before any uncertainty is realized — as is common in models of Bayesian persuasion (e.g., Rayo and Segal 2010, Kamenica and Gentzkow 2011, Goldstein and Leitner 2015, Ely 2017) — we also consider the case where disclosure is chosen after the agent obtains private information (as in, e.g., Grossman 1981, Milgrom 1981, Verrecchia 1983, Shin 2003). We show that, in line with our earlier analysis, partial disclosure leading to socially efficient trade also characterizes all informed-agent-preferred equilibria of this interim disclosure game.

Given the standard set of assumptions we consider and the strong predictions we obtain — trade is always efficient — our paper also contributes to the literature by characterizing economically relevant conditions that must be *violated* for asymmetric information and market power to impede the efficiency of trade. Our paper thus has important implications

empirical evidence consistent with information sharing among socially connected mutual fund managers, Heimer and Simon (2012) for empirical evidence of information sharing among foreign exchange traders, Eckbo and Langohr (1989) and Brennan (1999) for empirical evidence of information sharing among bidders and target companies in corporate takeovers, and Zhou and Benton (2007) for empirical evidence of information sharing among firms part of the same supply chain.

for regulating information disclosure in bilateral transactions with imperfect competition and asymmetric information problems, such as corporate takeovers, real estate transactions, and over-the-counter trading.[3] In an environment like ours, a regulator does not need to mandate what information agents should disclose nor does he need to produce additional information for uninformed market participants. All the regulator needs to do is to enforce the truthfulness of disclosure by disciplining agents who send signals that ex post prove to violate their own disclosure standards.

Related Literature. Our paper contributes to the theoretical literature that studies optimal information sharing among traders. An important result in this literature goes back to Grossman (1981) and Milgrom (1981) who show that, when disclosures are restricted to be ex post verifiable, an agent may find it optimal to fully reveal his private information to his counterparties. However, unlike in our model the agent making the disclosure decision is not being screened by counterparties with market power — either all traders take the price as given (as in Milgrom 1981) or it is the informed agent who sets the price (as in Grossman 1981). In those environments, an informed seller always benefits from improving his customers' perception of product quality (which, as we show, is not necessarily the case once counterparties have market power). He then finds it optimal to fully disclose his private information, since any information he withholds is interpreted to be unfavorable (see also Grossman and Hart 1980, Milgrom and Roberts 1986). Verrecchia (1983) modifies this setting by adding disclosure costs and shows that full disclosure may not be optimal, whereas Admati and Pfleiderer (2000) show that a firm may still pick a socially

[3]For empirical evidence that these types of bilateral transactions often feature imperfect competition, see Ambrose, Highfield, and Linneman (2005), Glaeser, Gyourko, and Saks (2005), Boone and Mulherin (2007), King, Osler, and Rime (2012), Atkeson, Eisfeldt, and Weill (2013), Li and Schürhoff (2014), Begenau, Piazzesi, and Schneider (2015), Hendershott et al. (2015), Di Maggio, Kermani, and Song (2016), Li, Taylor, and Wang (2016), and Siriwardane (2016). For empirical evidence that these types of bilateral transactions often involve heterogeneously informed traders, see Eckbo, Giammarino, and Heinkel (1990), Garmaise and Moskowitz (2004), Green, Hollifield, and Schürhoff (2007), Hollifield, Neklyudov, and Spatt (2014), Jiang and Sun (2015), Menkhoff et al. (2016), and Stroebel (2016).

optimal disclosure plan despite disclosure costs if that firm is a monopolist that captures all gains to trade. Shin (2003), Acharya, DeMarzo, and Kremer (2011), and Guttman, Kremer, and Skrzypacz (2014) show that full disclosure also becomes suboptimal once there is uncertainty about the existence of private information. Unlike in these settings, the information designer in our model is the responder to an ultimatum offer and his private information is thus his only source of profits. As a result, his optimal disclosure plan is partial — despite the existence of his private information being common knowledge and disclosure being costless — yet we show that it always yields socially efficient trade in equilibrium. Our framework therefore speaks to how voluntary information sharing can eliminate inefficient rationing in classic monopoly pricing problems.

Monopoly pricing is also studied in Bergemann, Brooks, and Morris (2015) who analyze how signals providing monopolists with additional information for price discrimination affect total surplus and its allocation. Bergemann, Brooks, and Morris (2015) show in a setting with private value uncertainty that general information structures (including randomization) exist such that total surplus can be increased to any level less than or equal to the one from efficient trade, and any allocation of the incremental surplus is attainable. Information available for price discrimination thus critically determines efficiency and the allocation of surplus, raising the question what information a monopolist will obtain endogenously. Our paper sheds light on this question, but also has other objectives. We analyze a setting with both private- and common-value uncertainty and show that when information disclosure by the informed agent is (a) voluntary and (b) ex post verifiable (with randomization not being possible), precise predictions for both total surplus and its allocation obtain: (i) total surplus is unique and equal to the surplus generated by efficient trade (whether the disclosure plan is designed at an ex ante or interim stage), and (ii) the surplus allocation is unique and both agents weakly benefit from the optimal disclosure plan.

More broadly, our focus on market power also relates our paper to Gal-Or (1985) who models oligopolistic firms that can commit ex ante to sharing noisy signals of their private information about the uncertain demand for their products. Since sharing information increases the correlation of firms' output decisions, thereby lowering their expected profits, the unique symmetric pure-strategy equilibrium is characterized by no information sharing among firms. Lewis and Sappington (1994) investigate in a setting without disclosure whether an uninformed seller with market power would like to help his prospective buyer(s) acquire private information about the value of the asset (see also Eső and Szentes 2007, who assume that trading occurs through an auction). Under general conditions, the seller in Lewis and Sappington (1994) either wants his prospective buyer(s) to be fully informed or completely uninformed about how much the asset is worth to them. Finally, Roesler and Szentes (2016) solve for a buyer's optimal information acquisition in a monopoly setting without disclosure and show that the buyer finds it optimal to limit his information acquisition, avoiding that the monopolist seller inefficiently screens him (see also Glode, Green, and Lowery 2012).

The next section presents the classic problem of a monopolist who inefficiently screens a privately informed agent. In Section 3, we study the agent's incentives to share some of his private information with the monopolist and how the resulting disclosure plan affects the efficiency of trade. Section 4 shows that our main insights survive when the agent designs his disclosure plan after obtaining private information rather than before. The last section concludes. All proofs are collected in Appendix A.

2 The Bilateral Transaction

The monopolist seller of an asset (or good) chooses the price he will quote to a prospective buyer (or customer) in a take-it-or-leave-it offer.[4] The seller is uncertain about how much

[4]The buyer/seller roles could be reversed without affecting our results.

the buyer is willing to pay for the asset but knows that the buyer's valuation of the asset, which we denote by v, has a cumulative distribution function (CDF) denoted by $F(v)$. The buyer only accepts to pay a price p in exchange for the asset if $v \geq p$; otherwise, the seller must retain the asset, which is worth $c(v) \geq 0$ to him. The CDF $F(v)$ is continuous and differentiable and the probability density function (PDF), denoted by $f(v)$, takes strictly positive values everywhere on the support $[v_L, v_H]$.[5] The function $c(v)$ is assumed to be weakly increasing and continuous. Both agents are risk neutral and the functions $F(v)$ and $c(v)$ are common knowledge.[6]

Whenever the buyer's valuation is greater than the seller's — perhaps due to heterogeneity in preferences, in inventories, or in liquidity needs — trade would create a social surplus. However, the seller may find it privately optimal to use his market power and inefficiently screen the informed buyer, thereby jeopardizing the gains to trade $[v - c(v)]$. We assume that whenever indifferent between two strategies, an agent picks the one that maximizes the social surplus in the resulting subgame-perfect Nash equilibrium.

The seller's expected payoff from quoting a price p is given by:

$$\Pi(p) = [1 - F(p)]p + F(p)\mathbb{E}[c(v)|v < p]. \tag{1}$$

When picking a price, the seller considers the trade-off between the probability that a sale occurs and the profit he gets if a sale occurs. The seller's marginal profit of increasing the price p is:

$$\Pi'(p) = [1 - F(p)] - f(p)p + f(p)\mathbb{E}[c(v)|v < p] + F(p)\frac{\partial}{\partial p}\mathbb{E}[c(v)|v < p], \tag{2}$$

[5] As should become clear later, our results would also hold if the support of v was unbounded above, whereas if it was unbounded below, our results would hold as long as $\lim_{v \to -\infty} v - c(v) \leq 0$.

[6] See Hirshleifer (1971), Diamond (1985), and Kurlat and Veldkamp (2015), among many others, for the costs and benefits of disclosure linked with traders' risk aversion.

which simplifies to:

$$\Pi'(p) = [1 - F(p)] - f(p)[p - c(p)]. \tag{3}$$

The first term on the right-hand side of equation (3) is the seller's marginal expected benefit from collecting a higher price when trade occurs. The second term is the marginal expected cost from reducing the probability of trade and destroying gains to trade. We impose the following condition on the surplus from trade $[v - c(v)]$:

Assumption 1. *The surplus from trade* $[v - c(v)]$ *crosses zero at most once (from below).*

This condition is implied by any of the following assumptions common in the literature: (i) the seller's valuation for the asset is a constant; (ii) the seller's valuation for the asset is a fraction of v ; (iii) the surplus from trade $[v - c(v)]$ is a constant; (iv) the ratio of the above-mentioned cost and benefit of marginally increasing the price, i.e., $\frac{f(v)}{1-F(v)}[v - c(v)]$, is strictly increasing in v.[7] Any one of these fairly standard assumptions is sufficient to obtain our results.

Assumption 1 implies that we can designate a cutoff $\hat{v} \in [v_L, v_H]$ such that trade is socially efficient when it occurs if and only if $v \geq \hat{v}$. Since it is possible under Assumption 1 that $[v - c(v)]$ remains at zero for a positive-measure subset of $[v_L, v_H]$ and then becomes positive for higher values of v, we define the relevant cutoff as $\hat{v} \equiv \inf\{v \in [v_L, v_H] : v > c(v)\}$. Since $f(v)$ is strictly positive everywhere on the support $[v_L, v_H]$, the maximum price the seller can quote and still maintain socially efficient trade is $p = \hat{v}$. As a result, trade can be efficient only if:

$$\Pi'(\hat{v}) \leq 0. \tag{4}$$

[7]See, e.g., Glode and Opp (2016) and Glode, Opp, and Zhang (2016) who specifically impose this condition, Fuchs and Skrzypacz (2015) who define a "strictly regular environment" in a similar way and Myerson (1981) who similarly assumes that bidders' virtual valuation functions are strictly increasing.

This necessary condition for efficient trade can be interpreted as follows. Efficient trade requires that $\hat{v} - c(\hat{v}) \geq \frac{1-F(\hat{v})}{f(\hat{v})}$, which means that either the gains to trade are large, or that the seller's beliefs about v are concentrated (i.e., the density $f(v)$ is high enough) when the surplus from trade becomes positive. If instead $\Pi'(\hat{v}) > 0$, the seller inefficiently screens the buyer and jeopardizes the gains to trade. Moreover, the seller never quotes a price $p < \hat{v}$, because quoting a price $p = \hat{v}$ yields strictly higher profits.[8]

Also note that, since we assume that whenever indifferent, an agent picks the strategy that maximizes social surplus, we can rule out any equilibrium where the seller inefficiently mixes between quoting multiple prices $p_n \in [v_L, v_H]$. If he were to mix over several prices, the seller would have to be indifferent between mixing and quoting any of these prices with probability one (taking into account the buyer's best response to each price). The tie-breaking rule implies that the seller instead plays the pure strategy of quoting the price that socially dominates all other prices. Similarly, we can rule out equilibria where the buyer inefficiently mixes between accepting and not accepting a price quote. A tie-breaking rule based on social optimality thus ensures that we can restrict our attention to pure-strategy subgame-perfect Nash equilibria in our model.

We further illustrate the seller's incentives to set inefficient prices through a simple parameterized example that we will revisit later.

Example 1. *Suppose the buyer values the asset at* $v \sim U[1, 2]$ *and the seller values it at a constant* $c \leq 1$. *The surplus from trade is then always positive (i.e.,* $\hat{v} = 1$*) and trade is efficient if and only if it occurs with probability* 1. *The seller's optimization problem when*

[8]Specifically, if the seller quotes a price $p < \hat{v}$, his expected payoff can be written as:

$$\Pr(v \geq \hat{v})p + \Pr(p \leq v < \hat{v})p + \Pr(v < p)\mathbb{E}[c(v)|v < p].$$

In contrast, if the seller quoted a price $\hat{v}$, his payoff would increase by $\hat{v} - p > 0$ when $v \geq \hat{v}$, by $c(v) - p \geq 0$ when $p \leq v < \hat{v}$ and would remain the same when $v < p$.

picking a price can be written as:

$$\max_{p\in[1,2]} \Pi(p) = \Pr(v \geq p)p + \Pr(v < p)c = (2-p)p + (p-1)c. \tag{5}$$

Since $\Pi'(1) = c$, the seller quotes a price $p = 1$ whenever $c \leq 0$ and the buyer always accepts, implying that trade is efficient. However, when $c \in (0, 1]$ the seller finds it optimal to quote a price $p = 1 + \frac{c}{2}$, which destroys the surplus from trade with probability $\frac{c}{2}$.

The example above shows a simple case where $\hat{v} = v_L$, that is, the surplus from trade is positive for any realization of v. In cases like that, efficient trade requires that $v_L - c(v_L) \geq \frac{1}{f(v_L)}$. For cases where $\hat{v} \in (v_L, v_H)$ however, efficient trade can never be sustained in equilibrium since $\hat{v} - c(\hat{v}) = 0 < \frac{1-F(\hat{v})}{f(\hat{v})}$, implying that the seller always finds it optimal to quote a price that is at least marginally higher than the efficient price $p = \hat{v}$. This situation arises, for example, whenever the seller values the asset at a constant $c \in (v_L, v_H)$.

3 Information Disclosure prior to Trading

In this section, we analyze the buyer's decision to share a subset of his information with the seller before trade occurs. Clearly, if trade is already socially efficient without disclosure, the buyer is only paying $\hat{v}$ for the asset and information disclosure is suboptimal — with additional information the seller might raise the price he quotes, but he would never lower it. Thus, for the remainder of the paper we focus on situations where trade would be socially inefficient if the buyer did not disclose any of his private information. Sharing information might hurt the buyer since possessing private information yields informational rents, but it might also reduce the seller's incentives to charge inefficient mark-ups that reduce the expected gains from trade.

For now, we assume that the agent must design his disclosure plan prior to acquiring private information, and that he can commit to not manipulating the signal later, as is common in models of Bayesian persuasion. Assuming that the buyer is uninformed at the time of the information design facilitates our analysis as it eliminates the existence of signaling concerns. We relax this assumption in Section 4. We also restrict our attention to ex post verifiable disclosures or signals, as in Grossman (1981), Milgrom (1981), and Shin (2003).

In practice, the ex ante design of such disclosure plans is likely relevant in economic contexts with hard information. In a variety of industries, information is shared automatically between firms via information technology (IT) systems according to pre-determined algorithms. For example, firms in the same supply chain are typically connected to a common IT system that automatically shares information about inventories and production problems. Similarly, in the context of financial markets, hedge funds systematically share financial data (e.g., holdings and performance data) with broker-dealers and clients, which reduces information asymmetries about trading motives, such as liquidity needs (see, also, footnote 2).

In the following, we formally define *ex post verifiability* in the context of our model.

Definition 1. *A signal s whose realization belongs to a set S is called "ex post verifiable" if it can be represented by a function $g : [v_L, v_H] \to S$ such that $g^{-1}(s) \equiv \{v : g(v) = s\} \in \mathcal{B}([v_L, v_H])$, where $\mathcal{B}([v_L, v_H])$ denotes the Borel algebra on $[v_L, v_H]$.*

This definition implies that for any signal $s \in S$, $g^{-1}(s)$ is a Borel set in $[v_L, v_H]$. Since a Borel set of $[v_L, v_H]$ must be characterized by unions of intervals, designing a disclosure plan implies combining partitions to inform the seller about possible realizations of v. If the buyer sends a signal, the seller must be able to confirm once uncertainty about v is resolved that the true realization of v was indeed possible given the signal sent. Signals that are subject to additional random shocks (due to "noise" components or randomization) are thus ruled out by ex post verifiability. This restriction is common in the literature on disclosure (see Verrecchia 2001, Milgrom 2008, Beyer, Cohen, Lys, and Walther 2010, for related surveys) and strikes us as a natural one given the assumption that the "sender" of the information does not manipulate his signal, as is common in the literature on persuasion games. In a more general setting with verifiable disclosures, erroneous disclosures could be penalized heavily, providing the sender with the incentives to indeed send signals that are truthful, even when manipulation is a feasible action.[9]

Before going further, we summarize the timeline in our baseline model. First, the buyer designs a disclosure plan to send ex post verifiable signals to the seller. Then the buyer learns his private valuation and the seller receives a signal consistent with the chosen disclosure plan. Finally, the seller quotes a price and the buyer decides whether to accept or not. We can now state our main result.

Proposition 1. *If the buyer can commit to any disclosure plan that sends ex post verifiable signals to the seller, he designs a partial disclosure plan that yields socially efficient trade.*

Proposition 1 states that if private information can only be shared in a verifiably truthful manner, the incentives of the privately informed buyer, who is being screened by the seller, are aligned with social welfare. By sharing a subset of his information with the seller, the buyer is making sure that he will be quoted more efficient prices, which leads to incremental surplus from trade that is shared between both agents. An optimal disclosure plan thereby ensures that the buyer can increase his information rents even though it reduces his informational advantage. The proposition also reveals that it is never optimal

[9]Due to the absence of noise, penalties would then remain off-equilibrium — penalties would only be triggered if the sender intentionally violates the standards set by his own disclosure plan.

for the buyer to share all his information with the seller, as such a disclosure plan would drive the buyer's rents to zero. Unlike in Grossman (1981) where full disclosure is optimal, the informed trader in our model does not have market power and can only extract rents if he conceals some information from his counterparty. We now return to our earlier parameterized example to illustrate this new result.

Example 2. *As in Example 1, we assume the buyer values the asset at $v \sim U[1,2]$ and the seller values it at a constant $c \leq 1$. We have already shown that since $c \in (0,1]$ the seller quotes a price $p = 1 + \frac{c}{2}$, which destroys the gains to trade with probability $\frac{c}{2}$. The buyer acquires the asset whenever $v \geq p$ and he collects an expected profit of:*

$$\Pr\left(v \geq 1 + \frac{c}{2}\right)\left[E\left(v|v \geq 1 + \frac{c}{2}\right) - \left(1 + \frac{c}{2}\right)\right] = \frac{(2-c)^2}{8}. \tag{6}$$

Consider what happens if the buyer promises to share some of his information with the seller, for example, by disclosing whether $v \in \left[1, 1 + \frac{c}{2}\right)$ or $v \in \left[1 + \frac{c}{2}, 2\right]$. The seller's optimization problem when quoting a price to the buyer now depends on the realization of the signal. If the seller learns that $v \geq 1 + \frac{c}{2}$, his optimization problem becomes:

$$\max_{p \in \left[1+\frac{c}{2}, 2\right]} \Pr\left(v \geq p | v \geq 1 + \frac{c}{2}\right) p + \Pr\left(v < p | v \geq 1 + \frac{c}{2}\right) c = \left(\frac{2-p}{1-\frac{c}{2}}\right) p + \left(\frac{p - (1+\frac{c}{2})}{1-\frac{c}{2}}\right) c, \tag{7}$$

and if instead he learns that $v < 1 + \frac{c}{2}$, it becomes:

$$\max_{p \in \left[1, 1+\frac{c}{2}\right)} \Pr\left(v \geq p | v < 1 + \frac{c}{2}\right) p + \Pr\left(v < p | v < 1 + \frac{c}{2}\right) c = \left(\frac{1 + \frac{c}{2} - p}{\frac{c}{2}}\right) p + \left(\frac{p-1}{\frac{c}{2}}\right) c. \tag{8}$$

In the first case, it is easy to verify that the seller finds it optimal to quote $p_h = 1 + \frac{c}{2}$, just as he did without disclosure. However, in the second case, the seller finds it optimal to quote $p_l = \max\{\frac{1}{2} + \frac{3}{4}c, 1\}$. Under this disclosure plan, the buyer collects an expected *profit of:*

$$\begin{aligned} &\Pr\left(v \geq 1+\frac{c}{2}\right)\left[E\left(v|v \geq 1+\frac{c}{2}\right)-\left(1+\frac{c}{2}\right)\right] \\ +\quad &\Pr\left(p_l \leq v < 1+\frac{c}{2}\right)\left[E\left(v|p_l \leq v < 1+\frac{c}{2}\right)-p_l\right]. \end{aligned} \tag{9}$$

The first term is equal to the expected profit the buyer would collect without disclosure. The second term is the additional expected profit the buyer is able to collect with disclosure, which is strictly positive whenever $c > 0$. Thus, the buyer is strictly better off under this disclosure plan than without any disclosure. Moreover, if $c \leq \frac{2}{3}$ the seller quotes $p_l = 1$ when $v < 1 + \frac{c}{2}$, which implies that trade is efficient regardless of the signal realization.

If $c > \frac{2}{3}$ however, the seller quotes $p_l = \frac{1}{2} + \frac{3}{4}c$ when $v < 1 + \frac{c}{2}$, which leads to a higher probability of trade than without disclosure, but still causes trade to break down with positive probability. The proof of Proposition 1 shows that in cases like this, a similar reasoning can be applied again to construct an alternative disclosure plan that splits the region of inefficient trade $\left[1, 1+\frac{c}{2}\right)$ into $\left[1, \frac{1}{2}+\frac{3}{4}c\right)$ and $\left[\frac{1}{2}+\frac{3}{4}c, 1+\frac{c}{2}\right)$, such that the buyer is strictly better off and trade is more efficient than under the first disclosure plan. Hence, given any proposed disclosure plan that does not yield efficient trade, it is always possible to construct a more efficient disclosure plan that strictly dominates from the buyer's perspective.

Before solving for the optimal disclosure plan in our parameterized example, we analyze the tradeoff the buyer faces when designing the signals he will share with the seller under a general CDF $F(\cdot)$.

Consider the decision of a buyer to pool or separate two generic intervals in a disclosure plan $g(v)$. Let $A \equiv [a_L, a_H)$ and $B \equiv [b_L, b_H)$ denote these two intervals, where $b_L \geq a_H$ and $a_L \geq \hat{v}$. Specifically, the buyer decides whether his disclosure plan $g(v)$ should generate separate signals, s_a when $v \in A$ and s_b when $v \in B$, or whether it should pool these regions, such that there is only one signal s_{ab} indicating that $v \in A \cup B$. Since we know from Proposition 1 that the optimal disclosure plan always leads to efficient trade, we now focus on a situation where the seller quotes an efficient price after receiving any of the two separating signals. When the disclosure plan generates signals separating the two intervals, the signal-dependent price quote, which we denote as $x(s)$, must satisfy the following two conditions to allow for efficient trade: $x(s_a) = a_L$ and $x(s_b) = b_L$. The buyer then expects to collect a surplus of:

$$\int_{a_L}^{a_H} (v - a_L) dF(v) + \int_{b_L}^{b_H} (v - b_L) dF(v). \tag{10}$$

If instead the disclosure plan generates a pooling signal s_{ab}, the buyer's expected surplus depends on the seller's response to the disclosure, that is, the price he quotes after receiving a signal that $v \in A \cup B$. If this price is weakly greater than $x(s_b) = b_L$ then the buyer is clearly strictly better off sending separating signals. Yet, if the seller responds to the disclosure by quoting a price $p \in [a_L, a_H)$,[10] the buyer expects to collect a surplus of:

$$\int_{p}^{a_H} (v - p) dF(v) + \int_{b_L}^{b_H} (v - p) dF(v). \tag{11}$$

The net benefit of pooling can then be written as:

$$\begin{aligned} & \left[\int_p^{a_H} (v-p) dF(v) + \int_{b_L}^{b_H} (v-p) dF(v) \right] - \left[\int_{a_L}^{a_H} (v - a_L) dF(v) + \int_{b_L}^{b_H} (v - b_L) dF(v) \right] \\ = \quad & (b_L - p)[F(b_H) - F(b_L)] - (p - a_L)[F(a_H) - F(p)] - \int_{a_L}^{p} (v - a_L) dF(v). \end{aligned} \tag{12}$$

By pooling the regions, the buyer lowers the price he is being quoted when $v \in B$, but he

[10] When $a_H < b_L$, it is never optimal for the seller to quote a price $p \in [a_H, b_L)$ as quoting b_L always dominates any of these prices — a price quote of b_L is accepted with the same probability, but the price paid is strictly higher.

might also increase the price he is quoted when $v \in A$.

When a pooling signal s_{ab} is generated by the disclosure plan, the condition for efficient trade is:

$$a_L - c(a_L) \geq \frac{\Pr(v \in A \cup B)}{f(a_L)}, \tag{13}$$

which is strictly more restrictive than the corresponding condition when a separating signal s_a is generated:

$$a_L - c(a_L) \geq \frac{\Pr(v \in A)}{f(a_L)}. \tag{14}$$

As a result, the seller is more likely to deviate to a price $p > a_L$ once the regions A and B are pooled. Yet, as long as pooling the two regions still allows for efficient trade, the benefit of pooling from equation (12) simplifies to:

$$(b_L - a_L)[F(b_H) - F(b_L)] > 0, \tag{15}$$

implying that the buyer is strictly better off sending a pooling signal s_{ab}.

For similar reasons, the buyer may benefit from pooling disjoint intervals that are "far" away from each other. When regions A and B are far apart, the buyer receives large information rents from obtaining an asset at a price of $p = a_L$ when valuing the asset at $v \in B$ with positive probability. An optimal disclosure plan might therefore pool intervals of v that are separated by gaps. On the other hand, this type of pooling tends to increase the seller's incentives to quote a high, inefficient price.

Overall, when designing a disclosure plan, the buyer thus aims to pool multiple intervals of v in order to minimize the requested price, but he is also concerned with the seller's potential response to screen him, which leads to inefficient rationing. In order to fully characterize the buyer's optimal disclosure plan, we return to our parameterized example.

Example 3. *In earlier analyses of the parameterized example with* $v \sim U[1, 2]$*, we ana-*

lytically showed that the buyer is better off disclosing a subset of his private information whenever trade is otherwise inefficient. However, solving for the buyer's optimal disclosure plan is a complex problem that involves functional optimization that generally does not admit closed-form solutions. We thus rely on numerical methods and discretize the interval $[1, 2]$ *equally using* $n = 11$ *points denoted by* v_i*. (We discuss below how our results generally apply to discrete distributions.) Given each possible disclosure plan, the optimal price quote* $x(s)$ *is equal to one of the* n *possible realizations for* v*. The buyer's optimization problem effectively aims to pool possible sets of* v_i *to minimize the expected transaction price while ensuring that trade remains socially efficient. Since the choice variables are integers and the system is linear, this is an integer linear programming problem. Figure 1 shows a solution to the optimal disclosure problem when* $c = 0.5$*.*

The buyer finds it optimal to split the interval $[1, 2]$ *into two combinations of subintervals. Figure 1 also shows that the signal structure involves gaps between these subintervals, allowing the buyer to pay low prices and to extract large information rents. When the seller receives a signal that* v *belongs to the lower/darker combination of sub-intervals, he responds by quoting a price* $p = 1$*. Panel (a) of Figure 2 illustrates the seller's pricing problem conditional on receiving the low signal. The seller's conditional expected payoff from owning the asset is maximized by quoting either a price* $p = 1$*, or a less efficient price* $p = 1.5$*. When the seller instead receives a signal that* v *belongs to the higher/paler combination of sub-intervals, quoting a price* $p = 1.2$ *maximizes his conditional expected payoff as shown in Panel (b) of Figure 2. In both cases, these price quotes are equal to the lowest possible realizations of* v*, given the signal, and as a result the buyer always accepts them.*

The low signal is generated with probability 0.36 *and results in the buyer paying* 1 *in exchange for an asset worth, on average,* 1.3 *to him. The high signal arises with probability* 0.64 *and results in the buyer paying* 1.2 *in exchange for an asset worth, on average,* 1.6

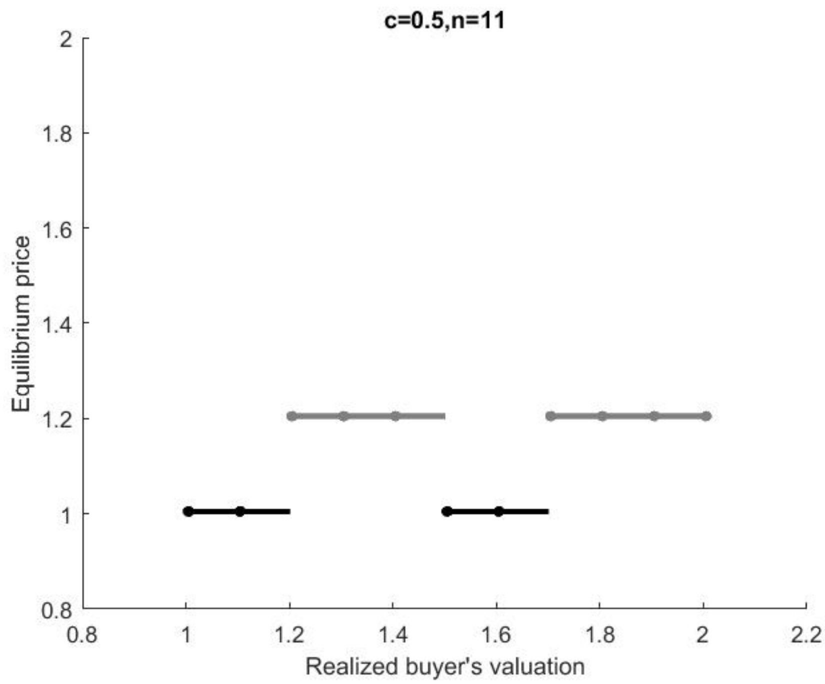
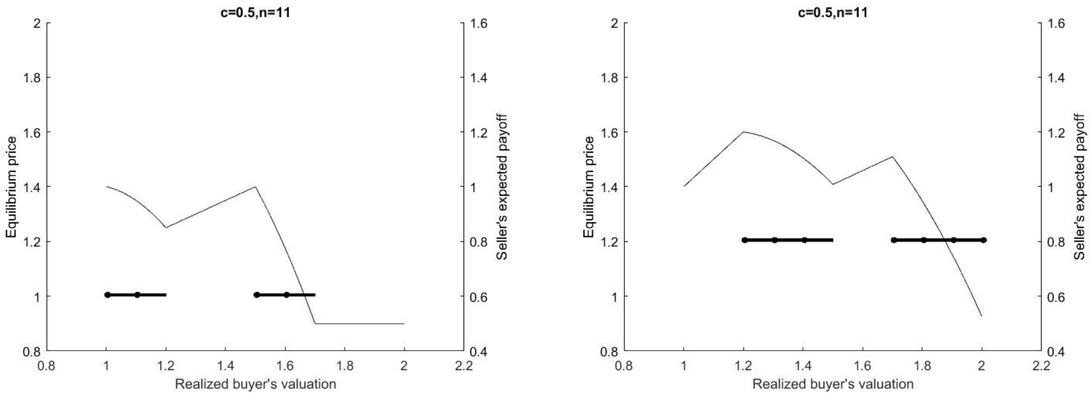


Figure 1: **Optimal disclosure plan when** $c = 0.5$ **and** $v \sim U[1, 2]$**.** In this parameterization, the buyer finds it optimal to release two signals. When the realization of v belongs to the lower (and darker) combination of sub-intervals the seller receives a signal that leads him to quote a price 1. Otherwise, the seller receives a signal that leads him to quote a price of 1.2. Trade is socially efficient under this disclosure plan.

to him. Overall, the buyer collects an expected surplus of 0.37*, whereas the seller collects an expected surplus of* 0.63 *under this disclosure plan. The expected social surplus is* 1*, since trade occurs with probability* 1 *and the seller values the asset at* $c = 0.5$*. In contrast, without disclosure the seller would have quoted an inefficient price* $p = 1.25$*, resulting in an expected surplus of* 0.56 *for the seller and an expected surplus of* 0.28 *for the buyer. Thus, both agents benefit from the buyer's optimal disclosure plan. Note that there exist alternative disclosure plans that deliver identical payoffs to all agents. Hence the equilibrium disclosure plan is not unique.*

As featured in the example above, our restriction that disclosure plans must be ex post



(a) Low signal.

(b) High signal.

Figure 2: **Seller's expected payoff under the disclosure plan illustrated in Figure 1.** The seller's expected payoff from quoting a price $p \in [1, 2]$ is plotted as a thin solid line in both panels (values are indicated on the right axis). These expected payoffs depend on the signal, and thus vary across the two panels. When the seller receives the first signal (left panel), he maximizes his expected payoff by quoting a price $p = 1$. When he receives the second signal (right panel), he maximizes his expected payoff by quoting a price $p = 1.2$.

verifiable still allows for the design of signals that pool multiple disjoint intervals.[11] Such disclosure plans can allow the buyer to minimize the average price paid while preventing the seller from quoting prices that cause inefficient rationing. We note, however, that the proof of Proposition 1 does not rely on allowing for disjoint intervals, or equivalently, non-monotonic signal structures. If the buyer can only design ex post verifiable signals associated with connected intervals, our result that the buyer's optimal disclosure plan always leads to socially efficient trade still holds.

Example 4. *In Appendix B, we characterize in closed form the optimal disclosure plan for a buyer constrained to pick ex post verifiable signals associated with connected intervals. Using these derivations, we can show that the disclosure plan in Figure 3 is a solution to the optimal disclosure problem when* $c = 0.5$.

[11]Non-monotonicity is also a property of the signal function of the optimal disclosure plan in Goldstein and Leitner (2015) who study an information design problem for a regulator who observes banks' stress test results and wants to maximize banks' funding.

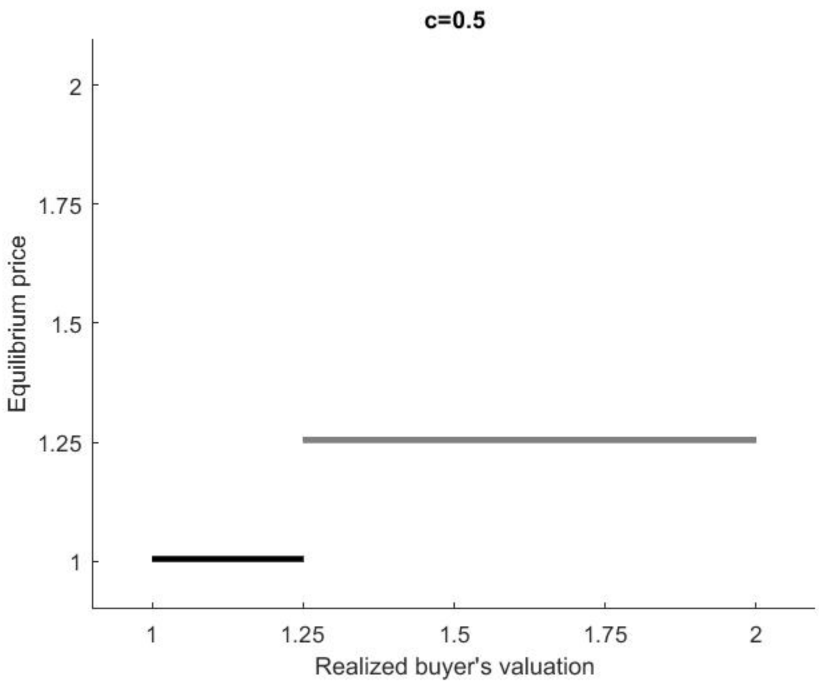


Figure 3: **Optimal disclosure plan with connected intervals when $c = 0.5$ and $v \sim U[1, 2]$.** In this parameterization, the buyer finds it optimal to release two signals. When the realization of v belongs to the lower (and darker) sub-interval the seller receives a signal that leads him to quote a price of 1. Otherwise, the seller receives a signal that leads him to quote a price of 1.25. Trade is socially efficient under this disclosure plan.

The optimal disclosure plan splits the interval $[1, 2]$ into two sub-intervals: $v \in [1, 1.25)$ and $v \in [1.25, 2]$. After both signals, the seller quotes the lowest possible realization of v given the disclosure and the buyer always accepts. Overall, the buyer collects an expected surplus of 0.31, whereas the seller collects an expected surplus of 0.69 under this disclosure plan. Again, both agents benefit from the buyer's optimal disclosure plan. Moreover, the expected social surplus is 1, since trade occurs with probability 1 and the seller values the asset at $c = 0.5$.

It is also worth emphasizing that the proof of Proposition 1 can easily be adapted to discrete distributions of v. As mentioned above, our main insight is that whenever a disclosure plan leads to inefficient trade, the buyer can design an alternative disclosure plan that improves the efficiency of trade and allows him to extract additional surplus from states where trade would have failed under the original disclosure plan. This intuition still holds with a discrete distribution of v, except that there may exist cases where the alternative, more efficient disclosure plan makes the buyer only weakly better off, rather than strictly better off as in our baseline model with a continuous distribution.[12] Under the tie-breaking rule mentioned above (i.e., whenever indifferent an agent takes the action that maximizes social surplus), the buyer's optimal disclosure plan still always leads to socially efficient trade when the distribution of v is discrete. For similar reasons, however, the optimal disclosure plan may then be fully revealing for some parameterizations (for example, when v can only take one of two values and trade would be inefficient without disclosure). In Appendix B we provide a simple numerical example of optimal disclosure with a discrete distribution.

4 Interim Disclosure

In the previous section, we assumed that the buyer designs the disclosure plan prior to obtaining private information. We now discuss the robustness of our results to "interim" disclosure, that is, disclosure that is chosen after the buyer obtains private information, but before the realization of v becomes publicly observable. Specifically, the timeline of the sequential game we now study is as follows. First, the buyer privately observes v. Second, he designs an ex post verifiable signal that he sends to the seller. Finally, the seller quotes a price and the buyer decides whether to accept or reject. Below we show that in any "buyer-preferred" equilibrium, information disclosure is partial and leads to socially efficient trade, just as in the baseline setting (see Proposition 1).

[12] Specifically, while the second term of equation (A7) in the proof of Proposition 1 is strictly positive when v is continuously distributed with strictly positive density everywhere on the support, this term may occasionally take a value of 0 when the distribution is discrete.

We start by describing each agent's strategy profile. Consistent with earlier notation, let $g(v)$ denote the signal that the buyer sends when his valuation for the asset is v. In the context of interim disclosure (where the buyer does not commit ex ante to a mapping between realizations of v and signals), ex post verifiability requires that any signal $s = g(v)$ is itself a Borel set in $[v_L, v_H]$ and that $v \in g(v)$ for any v. Since $g(v)$ is now designed by the buyer after he observes v, we can interpret $g(v)$ as the pure-strategy message that the buyer sends in this signaling game (see also Bertomeu and Cianciaruso 2016). Upon receiving a signal s, the seller forms a belief about the buyer's types (i.e., valuations), which we denote as $\mu(s) \in \Delta([v_L, v_H])$.[13] Then the seller quotes a price $x(s)$ that maximizes his expected profit, and the buyer decides whether to accept. A buyer's optimal strategy in that last stage is simply to accept the offer if and only if the quoted price is weakly less than his true valuation. For ease of exposition, we do not introduce extra notation for this final stage and directly impose that the buyer follows this dominant strategy.

To summarize, we now consider a signaling game where the buyer sends a message and the seller chooses an action based on that message. We dub this signaling game as the *interim disclosure game*. We can now state the definition of an equilibrium in this setting.

Definition 2. *A $(g(\cdot), \mu(\cdot), x(\cdot))$ profile forms a perfect Bayesian equilibrium of the interim disclosure game if:*

1. *For every possible signal s, $x(s)$ solves $\max_p \pi(p, s)$, where $\pi(p, s)$ denotes the seller's expected profit if he quotes a price p and the buyer's valuation is drawn from $\mu(s)$.*

2. *For every $v \in [v_L, v_H]$, $g(v)$ solves $\max_s \max(v - x(s), 0)$, where $v \in g(v)$.*

3. *For every s in the range of g (that is, every Borel set s that can be disclosed in*

[13] We use $\Delta([v_L, v_H])$ to denote the set of all possible probability distributions on $[v_L, v_H]$.

equilibrium), the seller's belief function $\mu(s)$ is obtained by applying Bayes' rule given the particular signal s.

Since beliefs are unrestricted following off-equilibrium deviations, there exist beliefs such that the seller (who has market power) drives the buyer's information rents to zero following any off-equilibrium deviation in disclosure. This leads to the existence of multiple perfect Bayesian equilibria with various degrees of information revelation, as opposed to a unique equilibrium with full revelation as in Grossman (1981) and Milgrom (1981) (see Perez-Richet 2014, for a broader discussion of equilibrium multiplicity when the information designer picks a signal structure after acquiring private information). For instance, either full disclosure, partial disclosure, or no disclosure can be supported in equilibrium if the seller has the following beliefs: if for any s not in the range of g (that is, whenever s is an off-equilibrium signal), the belief $\mu(s)$ assigns probability 1 to type $\bar{v}(s)$, where $\bar{v}(s) \equiv \sup s$ (recall that s is a Borel set).[14]

Given the multiplicity of equilibria, we focus on buyer-preferred equilibria in order to capture the spirit of our previous setting where the buyer moved first. What it means for the buyer to "prefer" an equilibrium is now complicated by the fact that he can be of many types when designing the disclosure plan. Thus, we define as buyer-preferred equilibria the set of equilibria that are not dominated among buyer types (in the Pareto sense) by another equilibrium based on their interim payoffs. As in Riley (1979), we are treating different informed-agent types as distinct players and looking for equilibria in which none of these types can be strictly worse off, while all the other types are as well off as in an alternative equilibrium. We conclude our analysis by stating the main result for this section.

[14] An equilibrium is said to feature full disclosure if $\mu(g(v))$ assigns probability 1 to type v, whereas it is said to feature no disclosure if $g(v) = [v_L, v_H]$ for all $v \in [v_L, v_H]$, and thus $\mu([v_L, v_H])$ is equal to $F(v)$, the prior distribution of v.

Proposition 2. *In any buyer-preferred equilibrium of the interim disclosure game, the buyer's optimal disclosure is partial and yields socially efficient trade.*

In Appendix C, we show the robustness of this result to an alternative equilibrium refinement known as Grossman-Perry-Farrell.[15]

5 Conclusion

We analyze the optimal disclosure strategy of a privately informed agent who faces a counterparty endowed with market power in a bilateral transaction. While disclosures reduce the agent's informational advantage, they may increase his information rents by mitigating the counterparty's incentives to inefficiently screen the agent. We show that when disclosures are restricted to be ex post verifiable, the privately informed agent always finds it optimal to design a partial disclosure plan that implements socially efficient trade in equilibrium. Moreover, our analysis shows how the optimal disclosure plan maximizes the privately informed agent's rents by potentially pooling multiple disjoint intervals.

Our paper speaks to the fundamental origins of asymmetric information problems that impede efficient trade under imperfect competition. The type of information agents privately observe (i.e., hard vs. soft, verifiable vs. unverifiable, transaction-specific vs. valuable in multiple transactions) and the enforceability of truthfulness (due to the regulatory and legal environments) greatly matter for determining the extent to which efficient trade is impeded despite voluntary disclosure.

In particular, if information is ex post verifiable and if truthfulness is enforced, bilateral trade should be socially efficient even though the buyer and seller are asymmetrically informed when they meet. Moreover, our model assumes that traders' private infor-

[15]We adopt the terminology "Grossman-Perry-Farrell" from Gertner, Gibbons, and Scharfstein (1988), Lutz (1989), and Bertomeu and Cianciaruso (2016).

mation pertains only to the bilateral transaction considered and has no value outside of bargaining. If these conditions are violated however, social efficiency might require the involvement of informed intermediaries (as in, e.g., Biglaiser 1993, Li 1998, Glode and Opp 2016, Zhang 2016), or some other external intervention. Our insights thus have important implications for regulating information disclosure in bilateral transactions. In our model, a regulator would not need to mandate what information agents must disclose, nor would it need to produce additional information for uninformed market participants. The regulator should instead focus on enforcing the truthfulness of disclosures by disciplining agents who send signals that ex post prove to violate their own disclosure standards. Agents would then have incentives to share their private information in ways that maximizes the social efficiency of trade.

Appendix A: Proofs Omitted from the Text

Proof of Proposition 1: By contradiction, suppose that the buyer's optimal disclosure plan is represented by $g(\cdot)$, which does not implement efficient trade. Just like in the setup without disclosure, we can rule out any case where trade is inefficient, given the disclosure plan, due to trade occurring for some $v < \hat{v}$ where $c(v) > v$. Suppose the seller receives a signal s_0 and quotes a price $p < \hat{v}$. His expected payoff is then:

$$\begin{aligned} & \Pr(v \geq p|s_0)p + \Pr(v < p|s_0)\mathbb{E}[c(v)|v < p, s_0] \\ = \quad & \Pr(v \geq \hat{v}|s_0)p + \Pr(p \leq v < \hat{v}|s_0)p + \Pr(v < p|s_0)\mathbb{E}[c(v)|v < p, s_0]. \end{aligned} \tag{A1}$$

If the seller quoted a price $\hat{v}$ instead, his payoff would increase by $\hat{v} - p > 0$ when $v \geq \hat{v}$, by $c(v) - p \geq 0$ when $p \leq v < \hat{v}$ and it would remain the same when $v < p$. This deviation is strictly profitable for the seller, implying that in equilibrium the seller always quotes prices weakly greater than $\hat{v}$.

Now suppose that trade is inefficient, given the disclosure plan, because trade fails for some $v > \hat{v}$ where $c(v) < v$. We show that there exists another disclosure plan that yields a higher profit for the buyer. Denote by $x(s)$ the price the seller would quote upon receiving a signal s. Then there exists $s_0 \in S$, such that if the signal is s_0, the seller quotes a price $x(s_0) > \hat{v}$ and $x(s_0) > \inf\{v \in [v_L, v_H] : g(v) = s_0\}$. A buyer whose valuation belongs to $\{v : g(v) = s_0\} \cap (\hat{v}, x(s_0))$ would refuse to pay the seller's quoted price $x(s_0)$, leading to inefficient trade.

Now, consider the following disclosure plan where $S' = S \cup \{s'\}$ for some $s' \notin S$ and

$$\tilde{g}(v) = \begin{cases} g(v) & \text{if } g(v) \neq s_0 \\ s_0 & \text{else if } g(v) = s_0, v \geq x(s_0) \\ s' & \text{otherwise.} \end{cases} \tag{A2}$$

By definition, the disclosure plan $\tilde{g}(\cdot)$ would also be ex post verifiable. We now show that $\tilde{g}(\cdot)$ would give the buyer a strictly higher ex ante expected profit. First, note that if $s \neq s_0$, the seller would still quote a price $x(s)$. Second, if $s = s_0$, the seller would also quote $x(s_0)$ under the alternative disclosure plan $\tilde{g}(\cdot)$ as long as he receives a signal s_0. To see this, it is sufficient to establish the following lemma.

Lemma 1. *Suppose that the seller would quote a price x if the buyer's valuation was drawn from a distribution with CDF $H(v)$. Let $H_0(v)$ denote the distribution $H(v)$ truncated from below at x, i.e., $H(v|v \geq x)$. Then the seller would also quote a price x if the buyer's valuation was drawn from $H_0(v)$.*

Proof. We argue by contradiction. Suppose the seller would instead quote a price y if the buyer's valuation was drawn from $H_0(\cdot)$. Then $y > x$ since the support of $H_0(\cdot)$ is bounded below at x. Thus,

$$(1 - H_0(y))y + H_0(y)\mathbb{E}_H[c(v)|x \leq v < y] > x \tag{A3}$$

where the subscript H in $\mathbb{E}_H$ reminds the distribution of v. Note that $H_0(y) = \frac{H(y)-H(x)}{1-H(x)}$ and we thus have:

$$(1 - H(y))y + (H(y) - H(x))\mathbb{E}_H[c(v)|x \leq v < y] > (1 - H(x))x. \tag{A4}$$

Since $(H(y)-H(x))\mathbb{E}_H[c(v)|x \leq v < y] = \int_x^y c(v)dH(v) = \int_{v_L}^y c(v)dH(v) - \int_{v_L}^x c(v)dH(v)$, we can rewrite the inequality as:

$$(1 - H(y))y + \int_{v_L}^{y} c(v)dH(v) > (1 - H(x))x + \int_{v_L}^{x} c(v)dH(v) \tag{A5}$$

or equivalently,

$$(1 - H(y))y + H(y)\mathbb{E}_H[c(v)|v < y] > (1 - H(x))x + H(x)\mathbb{E}_H[c(v)|v < x]. \tag{A6}$$

This inequality contradicts our initial statement that the seller would quote a price x if the buyer's valuation was drawn from $H(\cdot)$. $\square$

Given this lemma, we know that the seller would quote a price at $x(s_0)$ upon receiving a signal s_0 under the alternative disclosure plan $\tilde{g}(\cdot)$.

Finally, suppose the seller would quote a price at z if he receives a signal s'. Since quoting $x(s_0)$ yields zero profit in this case, it must be that $z \in [\inf g^{-1}(s_0), x(s_0))$. As a result, the buyer's ex ante expected profit under the alternative disclosure plan $\tilde{g}(\cdot)$ is given by:

$$\underbrace{\sum_{s \in S} \int_{g^{-1}(s) \cap [x(s), v_H]} (v - x(s))dF(v)}_{\text{Profit from } s \in S} + \underbrace{\int_{g^{-1}(s_0) \cap [z, x(s_0))} (v - z)dF(v)}_{\text{Profit from } s'} \tag{A7}$$

while the profit under the disclosure plan $g(\cdot)$ is only the first term. Since $x(s_0) > z$, the second term is strictly positive. So the buyer earns a strictly higher profit under the disclosure plan $\tilde{g}(\cdot)$ than that under $g(\cdot)$. This is a contradiction to the optimality of $g(\cdot)$.

Thus, the optimal disclosure plan must result in socially efficient trade. We also know that the optimal disclosure plan must reveal the buyer's information only partially. Otherwise, the seller quotes the buyer a price $p = v$ for all realizations of v and the buyer obtains no surplus. A full disclosure plan is therefore weakly dominated by a no-disclosure plan that leads to inefficient trade, which is then strictly dominated by a partial disclosure plan that leads to efficient trade, consistent with the arguments above. □

Proof of Proposition 2: To show that trade is socially efficient in any buyer-preferred equilibrium $(g(\cdot), \mu(\cdot), x(\cdot))$, we argue by contradiction. Suppose there exists a signal $s_0 = g(v)$ for some $v \in [v_L, v_H]$ such that $x(s_0) > \hat{v}$ and $x(s_0) > \inf\{v \in [v_L, v_h] : g(v) = s_0\}$. A buyer whose valuation belongs to $\{v : g(v) = s_0\} \cap (\hat{v}, x(s_0))$ would refuse to pay the seller's quoted price $x(s_0)$, leading to inefficient trade. Let $s' \equiv \{v \in s_0 : \hat{v} \leq v < x(s)\}$. Consider the following candidate equilibrium $(\tilde{g}(\cdot), \tilde{\mu}(\cdot), \tilde{x}(\cdot))$, where

$$\tilde{g}(v) = \begin{cases} g(v) & \text{if } v \notin s_0 \\ s' & \text{else if } v \in s' \\ s_0 \backslash s' & \text{otherwise .} \end{cases} \tag{A8}$$

We obtain $\tilde{\mu}(s')$ and $\tilde{\mu}(s_0 \backslash s')$ using Bayes' rule at s' and $s_0 \backslash s'$, respectively. For any signal outside the range of s_0, $\tilde{\mu}(s) = \mu(s)$. For any other signal s, $\tilde{\mu}(s)$ assigns probability 1 to $\bar{v}(s) \equiv \sup s$. Let $\tilde{x}(s_0)$ solves $\max_p \pi(p, s_0)$, where $\pi(p, s_0)$ denotes the seller's profit if she quotes a price p and the buyer's valuation is drawn from $\tilde{\mu}(s_0)$. It is clear that we are indeed in an equilibrium, since deviating to any other disclosure yields a profit of 0 for the buyer. Now consider the buyer's interim payoffs in this alternative equilibrium. For buyer types $v \notin s_0$ and $v \in s_0 \backslash s'$, they receive payoffs identical to those from the original equilibrium $(g(\cdot), \mu(\cdot), x(\cdot))$. However, for buyer types in s', they receive weakly higher payoffs. Moreover, a buyer type $x(s_0) - \epsilon$, where ϵ is a small positive number, receives a strictly higher payoff, since he made zero profit in the original equilibrium. Overall, if trade is not efficient in an equilibrium, then it is Pareto dominated among buyer types by a more efficient equilibrium. Consequently, in any buyer-preferred equilibrium of the interim disclosure game, trade must be socially efficient.

To show that a buyer-preferred equilibrium does not feature full disclosure, where each buyer type is quoted $p = v$ and makes zero profit, it is sufficient to construct an equilibrium where some buyer types receive positive payoffs (as no buyer type can do worse than zero profit given their right to reject a price quote). Consider the equilibrium induced by the ex ante disclosure plan we solved for in Proposition 1 of Section 3. Formally, suppose $g(\cdot)$ is the ex post verifiable disclosure plan chosen by the buyer in the ex ante disclosure game and let the interim disclosure plan follow $g(v)$ for all $v \in [v_L.v_H]$. Now, let $\mu(\cdot)$ be a belief function obtained using Bayes' rule on the equilibrium path and that assigns probability 1 to the highest type for any signal off the equilibrium path. Lastly, $x(s)$ maximizes the seller's profit based on the belief $\mu(s)$. The profile $(g(\cdot), \mu(\cdot), x(\cdot))$ is clearly an equilibrium of the interim disclosure game. In this equilibrium, the buyer receives profits identical to those in the ex ante disclosure. Thus, this equilibrium featuring partial disclosure Pareto dominates among buyer types any equilibrium with full disclosure. □

Appendix B: Alternative Environments

Discrete Distributions of v. As pointed out in the main text, the proof of Proposition 1 can easily be adapted to discrete distributions of v and yield similar results. The main difference is that there may now exist cases where the alternative, more efficient disclosure plan being considered makes the buyer only weakly better off, rather than strictly better off as in our baseline model. Specifically, while the second term of equation (A7) in the proof of Proposition 1 is strictly positive when v is continuously distributed with strictly positive density everywhere on the support, this term may occasionally take a value of 0 with a discrete distribution. If we apply the tie-breaking rule that assumes that whenever indifferent between disclosure plans the buyer chooses the one that maximizes social surplus, our result that the buyer's optimal disclosure plan always leads to socially efficient trade also holds with discrete distributions. For similar reasons, however, it is now possible that the optimal disclosure plan is fully revealing for some parameterizations (for example, when v can only take one of two values and trade would be inefficient without disclosure).

We now present a simple parameterized example with a discrete distribution and solve for the optimal disclosure plan. To make this example analogous to that in the main text, we assume that the buyer's valuation $v \in \{1, 1.5, 2\}$ with equal probabilities. We also assume that the seller values the asset at $c \leq 1$. For trade to be efficient without disclosure, we need the seller to prefer quoting a price 1 over a price 1.5 or a price 2, that is, we need:

$$1 \geq \frac{2}{3} \cdot 1.5 + \frac{1}{3}c, \tag{B1}$$

and

$$1 \geq \frac{1}{3} \cdot 2 + \frac{2}{3}c. \tag{B2}$$

Taken together, these two conditions are satisfied only when $c \leq 0$. As in the continuous example of the main text, we focus on cases where $c \in (0, 1]$ and trade is inefficient without disclosure. Analogously to the continuous setting, the buyer must choose a disclosure plan that trades off the benefits from pooling realizations of v and extracting information rents with the downside of strengthening the seller's incentives to screen as the range of possible realizations gets wider. The buyer can choose among these five disclosure plans:

1. The buyer separately discloses $\{\{1\}, \{1.5\}, \{2\}\}$ (i.e., full disclosure), collects a profit of 0, and trade is always socially efficient.

2. The buyer separately discloses $\{\{1, 1.5\}, \{2\}\}$ (i.e, partial disclosure). For efficient trade to occur, the seller must quote a price 1 upon receiving a signal that

$v \in \{1, 1.5\}$:

$$1 \geq \frac{1}{2} \cdot 1.5 + \frac{1}{2}c, \tag{B3}$$

which yields a profit of $\frac{1}{6}$ to the buyer. Otherwise, the buyer collects a profit of 0.

3. The buyer separately discloses $\{\{1\}, \{1.5, 2\}\}$ (i.e, partial disclosure). For efficient trade to occur, the seller must quote a price 1.5 upon receiving a signal that $v \in \{1.5, 2\}$:

$$1.5 \geq \frac{1}{2} \cdot 2 + \frac{1}{2}c, \tag{B4}$$

which yields a profit of $\frac{1}{6}$ to the buyer. Otherwise, the buyer collects a profit of 0.

4. The buyer separately discloses $\{\{1, 2\}, \{1.5\}\}$ (i.e, partial disclosure). For efficient trade to occur, the seller must quote a price 1 upon receiving a signal that $v \in \{1, 2\}$:

$$1 \geq \frac{1}{2} \cdot 2 + \frac{1}{2}c, \tag{B5}$$

which yields a profit of $\frac{1}{3}$ to the buyer. Otherwise, the buyer collects a profit of 0.

5. The buyer always discloses $\{\{1, 1.5, 2\}\}$ (i.e, no disclosure). If the seller quotes a price 1.5:

$$\frac{2}{3} \cdot 1.5 \geq \frac{1}{3} \cdot 2 + \frac{2}{3}c, \tag{B6}$$

it yields a profit of $\frac{1}{6}$ to the buyer. Otherwise, the buyer collects a profit of 0.

For $c \in (0, 1]$ the no-disclosure strategy implies that the seller screens the buyer. Disclosing some information can benefit the buyer by reducing the seller's incentives to quote a high, inefficient price. Due to the associated profit of $\frac{1}{3}$, the buyer prefers to disclose $\{\{1, 2\}, \{1.5\}\}$ whenever it leads to efficient trade. However, this requires that $c \leq 0$, which is violated in our scenario. In other words, this disclosure plan does not sufficiently weaken the seller's incentives to screen the buyer and thus yields a profit of 0 for the buyer.

When $c \in (0.5, 1)$, however, the buyer is strictly better off disclosing $\{\{1\}, \{1.5, 2\}\}$ as any other disclosure plan, including no disclosure, yields a profit of 0. His choice of disclosure then leads to socially efficient trade. If $c \in (0, 0.5]$ instead, the buyer is indifferent among three disclosure plans, including no disclosure, that each yield a profit of $\frac{1}{6}$. Our tie-breaking rule then ensures that he picks a disclosure plan that maximizes the social surplus, which means he either discloses $\{\{1, 1.5\}, \{2\}\}$ or $\{\{1\}, \{1.5, 2\}\}$, as either one of these disclosure plans yields efficient trade and therefore strictly dominates no disclosure from a social standpoint.

Connected Intervals. Our restriction that disclosure plans must be ex post verifiable allows for the design of signals that pool multiple disjoint intervals (e.g., see Figure 1 for the optimal disclosure plan in the uniform-distribution example). However, the proof of Proposition 1 does not rely on this possibility — thus, if the buyer can only design ex post verifiable signals associated with connected intervals (or, equivalently, weakly monotonic signal functions), our result that the buyer's optimal disclosure plan always leads to socially efficient trade still holds.

We now return to our simple parameterized example from the main text and solve for the optimal disclosure plan with connected intervals. The buyer values the asset at $v \sim U[1, 2]$ and the seller values it at a constant c. As before, we focus on the case where $c \in (0, 1]$, that is, trade is inefficient without disclosure.

We start by establishing the following result.

Lemma 2. *Suppose $v \sim U[a, b]$ where $1 \leq a < b \leq 2$ and $\frac{b+c}{2} > a$, such that trade is inefficient without disclosure. Among the disclosure plans that split the interval into two sub-intervals $[a, x)$ and $[x, b]$, the buyer optimally chooses the interior cutoff $x^* = \frac{b+c}{2}$.*

Proof. If the seller learns from the disclosure that $v \in [a, x)$, the seller finds it optimal to quote:

$$p_1 = \max\{a, \frac{x+c}{2}\}. \tag{B7}$$

If the seller instead learns that $v \in [x, b]$, the seller finds it optimal to quote:

$$p_2 = \max\{x, \frac{b+c}{2}\}. \tag{B8}$$

We prove the lemma separately for the following two exhaustive cases.

- Case 1: $\frac{b+c}{2} \geq 2a - c$.
  - If $\frac{b+c}{2} \leq x \leq b$, then $p_1 = \frac{x+c}{2}$ and $p_2 = x$. The buyer's ex ante expected profit is $\frac{(b-x)^2}{2} + \frac{(x-c)^2}{8}$, which is maximized at $x^* = \frac{b+c}{2}$. The maximal value is $\frac{5(b-c)^2}{32}$.
  - If $2a - c \leq x \leq \frac{b+c}{2}$, then $p_1 = \frac{x+c}{2}$ and $p_2 = \frac{b+c}{2}$. The buyer's ex ante expected profit is $\frac{(b-c)^2}{8} + \frac{(x-c)^2}{8}$, which is maximized at $x^* = \frac{b+c}{2}$.
  - If $a \leq x \leq 2a - c$, then $p_1 = a$ and $p_2 = \frac{b+c}{2}$. The buyer's ex ante expected profit is $\frac{(b-c)^2}{8} + \frac{(x-a)^2}{2}$, which is maximized at $x^* = 2a - c$ but the value is no greater than $\frac{5(b-c)^2}{32}$ because $\frac{b+c}{2} \geq 2a - c$.

  Thus, in this case the optimal $x^* = \frac{b+c}{2}$.

- Cases 2: $\frac{b+c}{2} \leq 2a - c$.
  - If $a \leq x \leq \frac{b+c}{2}$, then $p_1 = a, p_2 = \frac{b+c}{2}$.The buyer's ex ante expected profit is $\frac{(x-a)^2}{2} + \frac{(b-c)^2}{8}$, which is maximized at $x^* = \frac{b+c}{2}$. The maximal value is $V_B \equiv \frac{(b-2a+c)^2}{8} + \frac{(b-c)^2}{8}$.
  - If $\frac{b+c}{2} \leq x \leq 2a - c$, then $p_1 = a, p_2 = x$.The buyer's ex ante expected profit is $\frac{(x-a)^2}{2} + \frac{(b-x)^2}{2}$, which is maximized at $x^* = \frac{b+c}{2}$.

- If $x \geq 2a - c$, then $p_1 = \frac{x+c}{2}, p_2 = x$. The buyer's ex ante expected profit is $\frac{(b-x)^2}{2} + \frac{(x-c)^2}{8}$, which is maximized at end points. If $x = b$, the value is $\frac{(b-c)^2}{8} < V_B$. If $x = 2a - c$, the value is $\frac{(b-2a+c)^2}{2} + \frac{(a-c)^2}{2}$. We next show that $\frac{(b-2a+c)^2}{2} + \frac{(a-c)^2}{2} \leq \frac{(b-2a+c)^2}{8} + \frac{(b-c)^2}{8}$, which is equivalent to $3(b-2a+c)^2 + 4(a-c)^2 \leq (b-c)^2$. Recall that $\frac{b+3c}{4} \leq a < \frac{b+c}{2}$. Note $3(b-2a+c)^2+4(a-c)^2$ as a function of a achieves maximum at end points of a, which we can show is equal to $(b-c)^2$. Thus, if $x \geq 2a - c$, the buyer's ex ante expected profit is no greater than V_B.

Thus, the optimal $x^* = \frac{b+c}{2}$ in this case as well. □

We denote a buyer's connected disclosure plan as:

$$\{[v_0, v_1), [v_1, v_2), \cdots, [v_M, v_{M+1}]\}, \tag{B9}$$

where $v_0 = 1$ and $v_{M+1} = 2$. Since the lemma above holds for any interval as long as $\frac{b+c}{2} > a$, we conclude that any cutoff $\{v_i\}$ must satisfy $v_i = \frac{v_{i+1}+c}{2}, \forall i = 1, \cdots, M$. Note that v_0 does not have to be equal to $\frac{v_1+c}{2}$, but we need $v_0 \geq \frac{v_1+c}{2}$, otherwise trade is inefficient, which contradicts our result in Proposition 1. To solve for the optimal disclosure plan, we define the following sequence. Let $k_0 = 2$ and for $i \geq 1$,

$$k_i = \begin{cases} \frac{k_{i-1}+c}{2} & \text{if } k_{i-1} > 1 - 2c \\ 1 & \text{otherwise.} \end{cases} \tag{B10}$$

It is straightforward to show that this sequence is weakly decreasing. For any $c \in (0, 1)$, this sequence will reach 1 in finite steps whereas if $c = 1$ we need a countable, infinite set of intervals to span the whole support of v. Let $M + 1$ be the smallest subscript i

such that $k_i = 1$. Reversing the sequence, we define $v_i = k_{M+1-i}, \forall i = 0, \cdots, M+1$. Such a disclosure plan is optimal for the buyer when he is restricted to disclosing signals associated with connected intervals.

Appendix C: Alternative Equilibrium Refinement

For the interim disclosure game of Section 4, we showed that in any "buyer-preferred" equilibrium information disclosure is partial and leads to socially efficient trade. In this Appendix, we show the robustness of this result to an alternative equilibrium refinement known as Grossman-Perry-Farrell, based on the perfect sequential equilibrium of Grossman and Perry (1986) and the neologism-proof equilibrium of Farrell (1993).

Recall that $\mu(s)$ is the seller's equilibrium belief about the buyer's valuation, upon receiving a signal s. Denote by $U(v, s, \mu(s))$ the buyer's utility if his valuation is v, he sends a message s, and the seller quotes an optimal price given the belief $\mu(s)$. For any signal s that is a Borel set in $[v_L, v_H]$ (including off-equilibrium messages), denote by μ_s the distribution of v conditional on $v \in s$. (Recall that we restrict the sets of signals to be Borel sets in the interim disclosure game, to be consistent with ex post verifiability.)

As in Bertomeu and Cianciaruso (2016), we first define a *self-signaling* set.

Definition 3. *Given a pure-strategy perfect Bayesian equilibrium of the interim disclosure game,* $(g(\cdot), \mu(\cdot), x(\cdot))$*, a nonempty Borel set* $s \in [v_L, v_H]$ *is a self-signaling set if*

$$s = \{v \in s : U(v, s, \mu_s) > U(v, g(v), \mu(g(v)))\}. \tag{C1}$$

Notice that only buyers whose valuation $v \in s$ can send the signal s because ex post verifiability requires that the true valuation belongs to the chosen signal. A self-signaling set s contains all buyer types who could be strictly better off by sending the signal s rather than playing according to the considered perfect Bayesian equilibrium.

A deviation from an equilibrium consists of a message announcing "my type is in s."[16] The deviation is credible if s is self-signaling. An equilibrium survives the refinement if it does not admit any credible deviation.

Definition 4. *A pure-strategy perfect Bayesian equilibrium of the interim disclosure game,* $(g(\cdot), \mu(\cdot), x(\cdot))$*, is a Grossman-Perry-Farrell equilibrium if there are no self-signaling sets.*

We now derive our result.

Proposition 3. *In any Grossman-Perry-Farrell equilibrium of the interim disclosure game, the buyer's optimal disclosure is partial and yields socially efficient trade.*

Proof. To show that trade is socially efficient in any Grossman-Perry-Farrell equilibrium $(g(\cdot), \mu(\cdot), x(\cdot))$, we argue by contradiction. Suppose there exists a signal $s_0 = g(v)$ for some $v \in [v_L, v_H]$ such that $x(s_0) > \hat{v}$ and $x(s_0) > \inf\{v \in [v_L, v_h] : g(v) = s_0\}$. A buyer whose valuation belongs to $\{v : g(v) = s_0\} \cap (\hat{v}, x(s_0))$ would refuse to pay the seller's quoted price $x(s_0)$, leading to inefficient trade. Let $s_1 \equiv \{v \in s_0 : \hat{v} \leq v < x(s_0)\}$. Suppose the seller would quote a price x_1 under the belief μ_{s_1}.

Now consider the following set: $s_2 \equiv \{v \in s_0 : x_1 < v < x(s_0)\}$. From Lemma 1 in Appendix A, we know that the seller would also quote a price x_1 under the belief μ_{s_2}. Thus, $U(v, s_2, \mu_{s_2}) > 0, \forall v \in s_2$. Recall that all types of buyers in s_2 does not trade in the equilibrium $(g(\cdot), \mu(\cdot), x(\cdot))$, thus $U(v, g(v), \mu(g(v))) = 0, \forall v \in s_2$. So, all types of

[16] Unlike Farrell (1993) who allows for the possibility of any type of senders announcing "my type is in s", we assume only buyer types whose true valuation $v \in s$ can do so, consistent with our restriction of verifiably truthful disclosure.

buyers in s_2 are strictly better off by announcing "my type is in s_2." Therefore, s_2 is a self-signaling set, contradicting the conjecture that a Grossman-Perry-Farrell equilibrium can feature inefficient trade.

To show that full disclosure cannot be a feature of a Grossman-Perry-Farrell equilibrium, it is sufficient to construct a self-signaling set. Suppose the seller would quote a price x' under the prior belief. Then, it is clear that $(x', v_H]$ is a self-signaling set, since these buyer types would be strictly better off being quoted a price x' than a price equal to their respective valuation v. $\square$

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