Why Trade Over the Counter?*

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Abstract

Over-the-counter trading dominates in many highly liquid assets. We provide an explanation: OTC trading is privately optimal for traders who are likely uninformed. Traders choose between an exchange and a dealer, who cream-skims those likely uninformed. Closing the OTC market directly causes certain traders to exit, while inducing some others to enter by improving prices on the exchange. Overall, closing the OTC market raises welfare for assets whose trades are *mostly* over the counter, despite reducing aggregate trade volume and widening average bid-ask spread. We predict and document a positive correlation between the market share of exchanges and their quoted spreads.

JEL-Classification: D47, G14, G18, G23

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1 Introduction

Over-the-counter markets dominate the trading of most financial assets despite being opaque and hard to access.[1] This dominance has perplexed policymakers, who in the past decade sought to shift trades onto transparent and easily accessible exchanges. On the forefront of these efforts are the Dodd-Frank Act and the EU's MiFID II, against which the OTC market has shown remarkable resilience. Under the Dodd-Frank Act, traders of standardized swaps must be offered the option of trading the swap on an exchange. Nonetheless, 95% of trades in standardized swaps remain over the counter (Nagel, 2016). MiFID II imposes several restrictions on OTC trading, yet the OTC share of trades consistently remained near 20% in EU equities from its 2018 implementation to 2022 (Exton and Healey, 2022).[2] Should the OTC market be closed in the first place? If so, for which assets? And what can explain the resilience of OTC trading? We show that the equilibrium outcome starkly deviates from the efficient outcome: closing the OTC market would raise welfare precisely for the *most* OTC-traded assets. While doing so, our model generates predictions consistent with two empirical observations: (1) The effective spread is lower over the counter than on exchanges; and (2) the share of trades on exchanges is increasing in the exchanges' quoted spread.

Our explanation for the resilience of OTC trading builds on its fundamental feature: the dealers' ability to price discriminate among their customers. Price quotes on an exchange are publicly available to all traders. To trade over the counter, a trader must request quotes from a dealer, which reveals her identity and allows the dealer to offer a trader-specific price. This way the dealer can offer a discount to those who pose low adverse selection risk,

[1] In our context, "over-the-counter (OTC) markets" consist of all financial markets in which trades are executed nonanonymously between a client and a dealer. This definition includes traditional voice markets in which clients contact dealers one-by-one, and request-for-quote markets in which clients contact multiple dealers at a time. "Exchanges" include all other markets, including limit order books (e.g., stock exchanges), batch auctions, dark pools, and all-to-all request-for-quote platforms.

Limit order books are available for most important asset classes that are nevertheless OTC-dominated (Group of Thirty Working Group on Treasury Market Liquidity, 2021). Examples of such limit order books include NYSE Bonds for corporate bonds, Saxo Bank SaxoTrader for EU government bonds, Tradeweb Dealerweb for repos, Refinitiv FXall for foreign exchange, and Bloomberg SEF CLOB for swaps. All these are open to any buy-side trading firm.

[2] For example, MiFID II bans OTC dealers from matching client orders or rerouting them to brokers or exchanges under most circumstances.

cream-skimming them into the OTC market. To illustrate, between a low-risk insurer and a high-risk hedge fund, the dealer would price discriminate to the insurer's benefit. The insurer consequently seeks out the dealer, while the hedge fund trades on the exchange. In sum, traders who pose a low adverse selection risk choose the OTC market whenever the dealer can offer a discount for the low risk.[3] Under this explanation, neither expanding access to exchanges nor restrictions that fail to address price discrimination by dealers would shift trades onto exchanges.

We add other key elements of financial markets to analyze social welfare. Traders differ in their gains from trade, and a dealer cannot perfectly distinguish an informed trader from an uninformed one—sometimes, hedge funds have liquidity needs and insurers trade on proprietary information. Because heterogeneous gains from trade and imperfect information crucially affect whether and where a trade occurs, we incorporate them into our analysis.

In our model, traders choose one of two venues to buy or sell an asset with an uncertain payoff. Uninformed traders have heterogeneous hedging benefits that incentivize them to trade. Informed traders receive imperfect signals about the asset payoff and seek profit. Whether a trader is informed or not is the trader's private information, which is imperfectly indicated by her public label either as *Likely Informed (LI-traders)* or *Likely Uninformed (LU-traders)*. All traders optimally choose between trading on an exchange, with a dealer over the counter, or exit. The venues differ solely in that the dealer can condition his prices on each trader's label. In equilibrium, the LI-traders endogenously choose the exchange and the LU-traders choose the OTC market, and thus the share of OTC trades is increasing in the fraction of uninformed traders.

Neither trade volumes nor bid-ask spreads are good guides for policy in our model. Closing the OTC market can raise utilitarian welfare while reducing aggregate trade volume and widening the average bid-ask spread. The dichotomy between the effects on welfare and

[3] In Section 6.3, we cite evidence that assets with higher OTC share of trade volume have less informative prices. Corporate bonds and repurchase agreements are overwhelmingly OTC traded, and their trades are seldom informative. Government bonds are more OTC traded than their futures, and indeed much of the price discovery in government bonds occur in the futures market, not the spot market. Equity options are more OTC traded than equities, and in fact equity prices predict equity option prices, not the reverse. The evidence is mixed on whether the prices of credit default swaps and interest rate swaps lag or lead the prices of equities and interest rate futures, respectively.

volume can be stark. Under our baseline model, closing the OTC market always reduces volume whereas it raises welfare if the share of the informed traders is below a single cutoff.

Closing the OTC market can raise welfare yet reduce aggregate volume due to a *cheap substitution* in hedging benefit: the uninformed traders who are induced to trade upon closing the OTC market ("entrants") substitute for the comparably "cheap" traders who are pushed out ("exiters"). Without the OTC market, the presence of Likely Uninformed traders on the exchange lowers its spread down to the No-OTC-market spread S_{N}. The lower spread induces some uninformed traders, who otherwise would not trade, to do so. Meanwhile, the No-OTC spread S_{N} exceeds the spread the uninformed LU-traders would have paid over the counter, pushing some to exit. Thus, any entrant's hedging benefit must be above the No-OTC spread S_{N} and any exiter's hedging benefit must be below S_{N}—the exiters are comparably "cheap" as they hold the smaller hedging benefits. Aggregate trade volume falls whenever the exiters outnumber the entrants. Cheap substitution overturns this negative effect on welfare if the average entrant has a sufficiently larger hedging benefit than the average exiter.

Precisely, closing the OTC market would raise welfare if the asset is *mostly OTC traded*. We find an analogous result once, perhaps due to laxer disclosure rules, the traders' labels become less accurate. The result follows from (1) the OTC market share is high if there are few informed traders, in which case (2) welfare is higher without the OTC market. Point (1) is immediate from cream-skimming. Point (2) says closing the OTC market improves welfare if there are few informed traders and harms welfare if there are many. The effect of closing the OTC market depends on the trade-off between cheap substitution, which raises welfare, and a possible reduction in volume. Cheap substitution is most pronounced with few informed traders, and vanishes with many informed traders. It vanishes because, with the OTC market and many informed traders, the spread on the exchange is near its upper bound, the spread that would be quoted if all traders were informed. Then the entrants' hedging benefits are also near the upper bound, constraining them and allowing the exiters' relatively low hedging benefits to "catch up". The reduction in volume turns out to vanish with few informed traders and is the most pronounced with many. Therefore with few informed traders, the effect of cheap substitution dominates and closing the OTC market raises welfare. The opposite is true with many informed traders.

Our model generates two empirical predictions that we take to the data. First, cream-skimming implies the spread over the counter is lower than the spread on the exchange. Second, the market share of the exchange and its quoted spread are positively correlated. Adding informed traders worsens adverse selection risk, which both widens the exchange spread and causes relatively more trades to occur on the exchange. Hence, the quoted spread on the exchange and its market share increase with the share of informed traders. We investigate the predictions using US equities and find a positive correlation between the market share of exchanges and their quoted spreads. Our finding holds in every quintile of equities by dollar volume with ticker-level clustered standard errors and time fixed effects, and is robust to controlling for proxies of liquidity.

Whether the OTC market is socially beneficial has become an increasingly relevant question as regulators impose unprecedented restraints on OTC trading. Going beyond Dodd-Frank and MiFID II, the Commodities and Futures Trading Commission banned "name give-up" in the swaps market in 2020, partly to boost trading on exchanges. Most recently, proposals to implement blockchain for financial transactions would reveal traders' identities to selected dealers. Our results speak to the welfare implications of these plans and policies.

We make three contributions to the literature discussed shortly. First, we introduce cheap substitution, a new mechanism that can overturn the effects of aggregate volume and the average spread on welfare. The two common proxies for welfare—volume and spread—are in fact poor indicators of welfare with cheap substitution. Second, we provide novel guidance for policymakers, namely that closing the OTC market improves welfare if and only if the asset is mostly traded over the counter. Third, we are the first to theoretically predict and to empirically document a *positive* correlation between the market share of exchanges and their average spread.

1.1 Cheap Substitution, a New Mechanism?

Intuition suggests more choices ought to raise allocative efficiency under perfect competition. We find the opposite can be true. Allowing non-anonymous trade can harm social welfare in perfectly competitive markets. That market segmentation, in our case by whether a trade is anonymous, can be inefficient is well-known. One might then rightly wonder if "cheap substitution" merely repackages a known mechanism.

The Market for Lemons

The Lemon's Problem is a classic mechanism of such kind. Akerlof (1970) showed that adverse selection can cause trade to break down. The insight easily extends to how segmenting a functional market could reduce welfare: Select segments may break down as the segmentation concentrates adverse selection in them. Thereby efficient trades cease, which lowers welfare. Under the Lemon's Problem, aggregate trade and welfare move in lock-step. Cheap substitution decouples welfare from aggregate trade. It says each trade lost embodies a greater private value than each trade gained. Hence cheap substitution captures the fall in the *quality* of trades, whereas the Lemon's Problem captures the decline in the *quantity* of trades.

How do we know cheap substitution drives our results? Because in our model, market segmentation strictly increases aggregate volume and welfare whenever we turn off cheap substitution. We devise a Pigouvian tax to set the effective spread on the exchange equal to the OTC spread, pooling the markets together (Section 4). By equalizing the private values of the marginal traders in the two markets, cheap substitution is eliminated for any local change. Marginally segmenting the markets by locally reducing the tax strictly increases aggregate volume and welfare. A non-marginal segmentation can lower welfare, despite that it always increases aggregate volume in our base specification. That is, the change in aggregate volume pushes *against* our result that segmentation can reduce welfare.

Binding minimum wage

It is also known that price restrictions, in our case the exchange spread without the OTC market, do not always reduce total surplus. Lee and Saez (2012) shows that, where prices and marginal private values are positively correlated (as in our model), a binding minimum wage may have zero effect on the total surplus. In our model, restricting prices to the pooling spread on the exchange can *strictly raise* the surplus due to a *pecuniary externality* that induces entry. Our restriction lowers certain traders' spread at the cost of a higher spread for others, leading to entry in addition to exit. The minimum wage itself only causes exit to unemployment, and a secondary change to policy is necessary to increase the total surplus (see Allen, 1987, Guesnerie and Roberts, 1987, Boadway and Cuff, 2001). Underlying our results is the private value of the entrants relative to the exiters, as captured by cheap substitution and absent in the theories of the minimum wage.

Externality from OTC markets to exchanges

Pecuniary externalities from OTC markets to exchanges already feature in several models (Biais, Foucault and Salanié, 1998, Rust and Hall, 2003, Desgranges and Foucault, 2005, Bolton, Santos and Scheinkman, 2016, Vogel, 2019). Could cheap substitution be derived from their mechanisms? It cannot, because the existing models rely on adding inherent frictions to the OTC market—search costs (Vogel, 2019), the dealers' market power (Desgranges and Foucault, 2005), or their cost of entry and market power (Bolton et al., 2016)—to derive that OTC trading is generically inefficient.[4] In the limit where these frictions vanish, allowing OTC trading becomes socially beneficial in these models. We strip away all inherent frictions from the OTC market, and show how a pecuniary externality can drive inefficiency, via cheap substitution. Doing so preserves a meaningful parameter space—where adverse selection risk is high—in which allowing OTC trading is efficient.

Non-anonymity in financial markets

The potential of non-anonymity, allowing OTC trading in our model, to diminish the payoffs of uninformed traders has been known since Röell (1990). Beneath all ensuing models lay large uninformed traders (Röell, 1990, Admati and Pfleiderer, 1991, Forster and George, 1992) or informed traders (Fishman and Longstaff, 1992, Foucault, Moinas and Theissen, 2007, Rindi, 2008) whose orders, once paired with submitters' identities, are informative about the order book or the asset value. Therefore their version of non-anonymity adds a public signal about the *aggregate* state of the market, and does not enable price discrimination on individual traders. Non-anonymity can hurt uninformed traders only by worsening prices

[4]In Bolton et al. (2016), having the OTC market is always inefficient. In Vogel (2019), it is inefficient whenever the cost to access the exchange is not too high . Desgranges and Foucault (2005) focuses on Pareto efficiency. They show that having the OTC market reduces the welfare of traders without a dealer relationship and may even reduce that of traders with a relationship.

for all traders, hence the uninformed traders are worse off only if aggregate liquidity falls. In our model, non-anonymity adds signals about the *idiosyncratic* type of each trader. Using this signal, the dealer can price discriminate without revealing any information about the aggregate state of the market. Because of the price discrimination, allowing OTC trading can leave uninformed traders worse off even as it improves aggregate liquidity.

Third degree price discrimination

Our dealer varies her prices across trader characteristics, namely their labels, therefore engages in *third degree* price discrimination. We show that such price discrimination can lower welfare. Far earlier, Pigou (1920) established that a price discriminating monopolist may be worse for social welfare than a non-discriminating monopoly. His argument, now termed the "misallocation effect", says output is inefficiently distributed whenever different consumers are charged different prices (Aguirre, Cowan and Vickers, 2010). How do our insights depart from this literature? What drives their results is a monopolist seeking to maximally extract private value, whereas competition disciplines our dealer to just cover the common value he loses. In their framework, the distribution of private values entirely determines whether price discrimination raises or reduces welfare. Consequently, there can be *no* guidance on the effects of price discrimination on welfare (Bergemann, Brooks and Morris, 2015).[5] In ours by contrast, competition and the risk of adverse selection jointly discipline the effect of price discrimination. The informed traders absorb a portion of the incremental revenue the dealer needs to break even. The absorbed portion grows with more informed traders. Eventually with many informed traders, prices become insensitive to trader characteristics, the gap between the prices across different traders disappears, and cheap substitution vanishes. This effect is essential to our robust guidance on welfare (Section 3.3): for *any* distribution of private values, price discrimination raises welfare with many informed traders (where cheap substitution vanishes) and reduces welfare with few informed traders (where cheap substitution is pronounced).

[5]Precisely, price discrimination can generate any outcome under which the producer is at least as well off as with a uniform price, consumers receive non-negative payoffs, and the allocation is possible (Bergemann et al., 2015).

1.2 Related Literature

Most closely related to us are the studies of venue choice between centralized and OTC markets. One strand in this literature abstracts away from adverse selection and focuses on the presence of search frictions (Pagano, 1989, Rust and Hall, 2003) or limited trading capacity (Dugast, Üslü and Weill, 2022) in OTC markets. This strand does not explain why certain assets are mostly traded over the counter while some others are mainly traded on exchanges.[6] Others, like this paper, have cream-skimming driven by price discrimination (Seppi, 1990, Desgranges and Foucault, 2005).[7] Because private values are homogenous in these models, they cannot feature cheap substitution from which we derive our results on welfare. Seppi (1990) explains why trade sizes over the counter are larger than the sizes on exchanges. The key parameter of Seppi (1990), the size of an order by a large trader relative to the order size of a small trader, is less relevant in the presence of order splitting. Desgranges and Foucault (2005) examines endogenous dealer-client relationships as another core feature that distinguishes OTC markets from exchanges. They show that the OTC market is viable if traders are sufficiently likely to be informed (their Proposition 5). Thereby they would predict a negative relationship between the exchange market share and its quoted spread—the opposite of our prediction.

We belong to the enduring literature that compares centralized and OTC markets. Benveniste, Marcus and Wilhelm (1992), Pagano and Roell (1996), Biais et al. (1998), Malinova and Park (2013), Glode and Opp (2019) compare a case with only the exchange against one with just the OTC market. Without endogenous venue choice, this literature cannot explain why certain assets are more OTC-traded than others, and cannot study the effects of a tax on OTC trades nor of removing OTC trading as an option.

Section 2 describes the model then derives its unique equilibrium and empirical predic-

[6] Rust and Hall (2003) comes the closest, as they discuss why steel is mostly traded over the counter. They argue operators of trading venues for steel at the time lacked the expertise in operating electronic exchanges. This explanation no longer apply to steel or other liquid assets today.

[7] We are more distantly related to the literature on how traders choose between separate exchanges in the presence of adverse selection (Hendershott and Mendelson, 2000, Zhu, 2014, Pagnotta and Philippon, 2018, Lee, 2019, Chao, Yao and Ye, 2019, Babus and Parlatore, 2021, Baldauf and Mollner, 2021). In these models, a centralized mechanism determines the price at each exchange.

tions. Section 3 analyzes utilitarian welfare, aggregate trade volume, and quoted spread (1) upon closing the OTC market or (2) as the traders' labels become less accurate. Section 5 discusses the policy implications of our results. Section 6 documents empirical patterns predicted by our model and summarizes existing stylized facts related to our theory. Section 7 concludes with a discussion of some potentially important effects that are not captured by our model.

2 A Model of Venue Choice

We first setup the model, which extends Glosten and Milgrom (1985) with endogenous venue choice and imperfect labels for the types of traders. Later we discuss our assumptions in Section 2.2 and derive the unique equilibrium in Section 2.3.

2.1 Setup

A dealer, a market maker, a mass μ of informed traders, and a mass 1 of uninformed traders, all risk-neutral, trade an indivisible asset in a three-stage game. A trader buys or sells 1 unit, or exits without trading. The dealer acts as the counterparty to the traders and absorbs net demand in an OTC market. The market maker does so on the exchange. The asset is equally likely to pay $v = 1$ or -1 in the last stage.

An informed trader has a private binary signal which equals the true value v with probability $\alpha \in (1/2, 1)$ and $-v$ otherwise. We call probability α the accuracy of the informed traders' signals. Each uninformed trader is equally likely to be a buyer or a seller, and obtains a hedging benefit b_i upon trading in her desired direction. The hedging benefits are independently and uniformly distributed over $[0, 1]$, $b_i \overset{\text{iid}}{\sim} \mathbb{U}[0, 1]$. Whether an uninformed trader is a buyer or a seller and her realized hedging benefit b_i are her private information.

An informed trader is labeled $\ell_i = LI$ with probability θ. An uninformed trader is LI with probability $1 - \gamma$. Otherwise, a trader is LU. LI-traders are "Labeled Informed" and LU-traders are "Labeled Uninformed". The labels are informative, $\theta > 1 - \gamma$, in that an LI-trader is more likely to be informed than an LU-trader. The labels become more informative as their accuracy θ or γ increases. We assume $\theta < 1$ and $\gamma < 1$, so that the labels are imperfectly informative.

In Stage 1, the dealer posts a bid to buy and an ask to sell one unit of the asset to every trader i. The dealer's price can depend on the trader's label $\ell_i \in \{LI, LU\}$. The market maker posts one bid and one ask available to all traders. Prices are competitive in each market: the dealer offers the highest bid and the lowest ask to earn a zero expected profit conditional on the label ℓ_i, while the market maker does so unconditionally. That is, the OTC market differs from the exchange in one way, that the dealer observes the label ℓ_i before setting the prices for trader i.

In Stage 2, every trader makes two decisions: *whether* to buy, sell, or not trade, and *where* to trade. Figure 1 summarizes the timing of the model. All distributions, parameters, and the structure of the game are common knowledge.

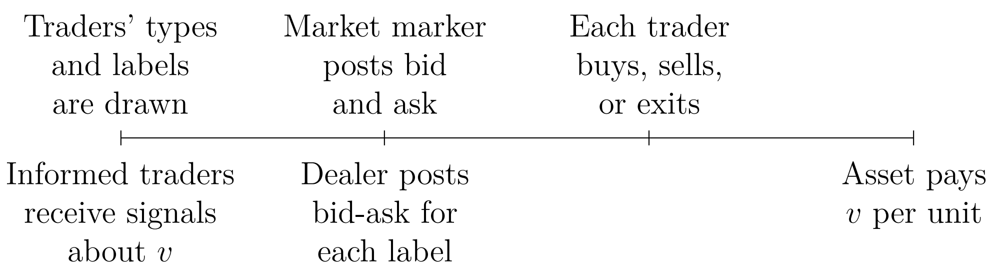

Figure 1: Timing

We impose a tie-breaking rule to pin down a unique equilibrium.

Assumption 1. *If indifferent between trading over the counter or on the exchange, a trader chooses to trade on the exchange.*

Assumption 1 is purely expositional, as our results only require that an otherwise indifferent trader chooses the exchange with a positive probability.[8] The rule is equivalent to imposing a small cost on OTC trades, which can represent the inconvenience of soliciting prices that is absent on exchanges.

[8] Every equilibria that would exist without Assumption 1 are payoff equivalent.

2.2 Discussion

Our setup features competitive prices as defined by Glosten and Milgrom (1985). That prices on exchanges are competitive is a good proxy of reality. However, search friction and dealer market power make OTC prices far from competitive in practice. We assume competitive OTC prices without any search friction to show that, despite making the OTC market artificially efficient, it can nonetheless raise welfare upon closing the OTC market. Granting monopoly power to the dealer would increase the social benefit of closing the OTC market, as the dealer would still cream-skim from the exchange while offering worse-than-competitive prices.

The dealer in the model posts label-dependent prices. In practice, a trader approaches dealers with requests-for-quote (RFQ), and the dealers quote trader-specific prices upon receiving the RFQ. If, in the model, traders must submit an RFQ to trade over the counter, there would be two equilibria: one is the equilibrium solved below. The other is a degenerate equilibrium in which no trader sends an RFQ and no one trades over the counter. This degenerate equilibrium requires the dealer to believe that an Likely Uninformed trader who requests a quote is more likely to be informed than a random trader. Such off-equilibrium beliefs are ruled out by, for example, the sequential equilibrium refinement. We let the dealer post label-dependent prices instead of responding to an RFQ so that the dealer never faces an off-equilibrium information set, eliminating the degenerate equilibrium.

We interpret a trader's label as a summary statistic of her observable characteristics and reputation. The observables may include the trader's industry (hedge fund versus insurer), marketing or public filings (active versus passive fund), name ("Two-Sigma" versus "AIG"), and any public factoid that is informative about the trader's motive. The labels are imperfectly informative since the true motive behind a trade is not known for certain. This uncertainty is illustrated in the commodities futures market, where the US Commodity Futures Trading Commission classifies traders based on their typical strategies. Cheng and Xiong (2014) find that the trades of "hedgers" often deviate from their label. The hedgers' trades are far more volatile than output, and the volatility is especially high in their short positions. These positions are consistently profitable and uncorrelated with output, which suggests that even the traders who typically hedge sometimes speculate.

We fix the mass of uninformed traders and will vary the mass of informed traders μ in the welfare analysis. This choice ensures that the maximum welfare that can be achieved is fixed and equal to the total hedging benefit of all uninformed traders.

2.3 Equilibrium

A Nash equilibrium consists of the dealer's and the market maker's price setting strategies, and the traders' venue choice and trading strategies. Each trader maximizes her expected profit while the dealer and the market maker offers the highest bid and the lowest ask to earn zero expected profit.

We study the equilibrium without OTC trading, then introduce venue choice. Here, the market maker posts one bid and one ask price symmetrically around zero, and thus his strategy is summarized by the half bid-ask spread s. For brevity, we write "half bid-ask spread" and "spread" interchangeably. The equilibrium spread $S(\beta)$ is the smallest solution to the market maker's zero profit condition

$$\underbrace{s \cdot (1-s)}_{\substack{\text{Profit from} \\ \text{uninformed traders}}} = \underbrace{(2\alpha - 1 - s)^{+} \cdot \beta}_{\text{Loss to informed traders}}, \tag{1}$$

where β denotes the *informed ratio*, the ratio of the mass of informed traders to the mass of uninformed traders who *choose* a given market.[9] Under this No-OTC case, the informed ratio on the exchange is $\beta = \mu/1 = \mu$. The market maker's profit from uninformed traders is $s \cdot (1-s)$. He earns the spread s per trade with an uninformed trader. As each uninformed trader trades if and only if her hedging benefit exceeds the spread s, a mass $(1-s)$ of them actually trade. The market maker's loss to the informed traders is $(2\alpha - 1 - s)^{+} \cdot \beta$ because every informed trader trades if and only if her expected profit $(2\alpha - 1)$ exceeds the spread s. The market maker thereby suffers an expected loss of $(2\alpha - 1 - s)^{+}$ per unit mass of informed traders. The zero-profit condition (1) has a unique solution that we denote as $S(\beta)$. Formally, this is Proposition 0 Part (a). Proofs are in Appendix A.

[9] We say "a trader chooses a market" if the trader would trade in that market were she forced to trade.

Proposition 0. *(a) If the OTC market is closed, the equilibrium spread on the exchange is the No-OTC spread $S_N = S(\mu)$. (b) If the OTC market is open, every LU-trader chooses the OTC market and receives the OTC spread $S_O = S\left(\frac{1-\theta}{\gamma}\,\mu\right)$ in equilibrium, and every LI-trader chooses the exchange and receives the exchange spread $S_E = S\left(\frac{\theta}{1-\gamma}\,\mu\right)$.*

Part (a) is a standard result of Glosten and Milgrom (1985) and follows from the definition of competitive prices as the highest bid and the lowest ask that satisfy the zero profit condition (1). Part (b) incorporates venue choice by allowing OTC trading. The LU-traders would receive a lower spread alone than if all traders are pooled together. The LI-traders would receive a higher spread alone. Thus, the LU-traders want to separate while the LI-traders wish to pool. To avoid being pooled by the LI-traders, the LU-traders choose the label-dependent OTC spread. The LI-traders, unable to pool over the counter, choose the exchange due to the tie-breaking Assumption 1.[10] Hence in equilibrium, those who are less likely to be informed are cream-skimmed into the OTC market.

2.4 Empirical Predictions

Cream-skimming supplies a battery of testable predictions. As our leading prediction, the assets that mostly attract traders who pose low adverse selection risk (say, insurers and passive funds) have high OTC market shares. Equivalently, most trades are uninformative in OTC-dominated assets. Second, trading costs over the counter are lower than on exchanges. Third, the share of trades on exchanges and the exchanges' quoted spreads are positively correlated, driven by variation in informed trading. Proposition 1 formalizes these predictions.

We let V_{O} denote the equilibrium volume of trades over the counter, V_{E} the trade volume on the exchange, and $V := V_{\text{O}} + V_{\text{E}}$ the aggregate trade volume.[11] Market shares are V_{O}/V

[10]We can relax Assumption 1 to have the traders indifferent between the exchange or the OTC market choose the exchange with probability $\rho > 0$. Then, all LU-traders choose the OTC market, while ρ share of LI-traders choose the exchange and $1-\rho$ share choose the OTC market. All results are unchanged under this relaxed assumption.

[11]Explicitly, $V_{\text{O}} = (1-\theta)\mu + \gamma \cdot (1 - S_{\text{O}})$, $V_{\text{E}} = \theta\mu + (1-\gamma)\cdot(1-S_{\text{E}})$, $m_{\text{LU}} = (1-\theta)\mu + \gamma$, and $m_{\text{LI}} = \theta\mu + 1 - \gamma$.

over the counter and V_{E}/V on the exchange. The mass of LU-traders is denoted m_{LU} and the mass of LI-traders is m_{LI}.

Proposition 1. *(a) For any given $\underline{O} \in (0,1)$, the set of label accuracies (θ,γ) such that the OTC market share $V_O/V > \underline{O}$ is non-empty and strictly expanding as the mass of informed traders μ decreases. (b) The exchange spread S_E is strictly higher than the OTC spread S_O. (c) Both the exchange spread S_E and its market share V_{E}/V are strictly increasing in the informed mass μ for given label accuracies (θ,γ).*

Part (a) rests on the OTC market share V_{O}/V being strictly decreasing in the mass of informed traders μ, as Part (c) shows. Then high OTC market share is easier to attain with fewer informed traders. An additional, technical argument in Appendix A.1 proves that it is *strictly* easier. Part (b) is a direct consequence of cream-skimming. Part (c) is due to a mechanical increase in the ratio of LI- to LU-traders as the mass of informed traders μ increases. When there are an additional $\mathrm{d}\mu$ mass of informed traders, a mass $\mathrm{d}m_{\mathrm{LI}} := \theta \mathrm{d}\mu$ of them are labeled as Likely Informed and the remaining $\mathrm{d}m_{\mathrm{LU}} := (1-\theta)\mathrm{d}\mu$ as Likely Uninformed. The resulting growth rate in the LI-traders $\mathrm{d}m_{\mathrm{LI}}/m_{\mathrm{LI}}$ is strictly smaller than that for the LU-traders $\mathrm{d}m_{\mathrm{LU}}/m_{\mathrm{LU}}$. Hence, the ratio of LI- to LU-traders increases, which in turn raises the exchange market share V_{E}/V.

We cite evidence related to the predictions of Parts (a) and (b) in Section 6.3. To test Part (c), we require observations to share similar trader label accuracies (θ,γ) while varying substantively in the mass of informed traders μ. We use cross-asset variation within narrowly defined asset classes for this test. Across assets within a narrow asset class (say, Alphabet (GOOG) and Apple (APPL) stocks), the amount of available information about their individual traders (for example, the type of firm, reputation, past disclosures) is similar, so their trader label accuracies are also similar. Meanwhile even within a narrow asset class, a cross-asset variation in the informed mass μ arises from day-to-day changes in the composition of the true types of traders (GOOG might attract more informed traders than AAPL on dates with more news about GOOG). In Section 6.2, our choice of the narrow asset class is US-listed stocks in the same quintile by dollar volume. We document a positive correlation between exchange market share and exchange quoted spreads within every quintile.

3 Welfare, Volume, and Spread

We analyze utilitarian welfare, aggregate trade volume, and the average bid-ask spread upon (A) closing the OTC market or as (B) the traders' labels become less accurate. Closing the OTC market or less accurate labels raise welfare if the share of trades in the OTC market is *high*, and lowers welfare if the OTC share is *low*. Moreover, welfare can decline while the aggregate volume rises and the average spread falls.

Section 3.1 formally presents our main result. Section 3.2 explains how our results arise from two opposing effects: "cheap substitution" that raises welfare upon (A) or (B) versus "volume effect" that lowers welfare. Section 3.3 shows that our findings are robust when the distribution of the hedging benefits b is generalized to a generic distribution F.

3.1 Main Result

We define *welfare* as follows.

Welfare W is the sum of all agents' expected payoffs at the start of the game. (2)

In our model, welfare W measures the total gains from trade and equals the total hedging benefits of the uninformed traders who elect to trade.

Proposition 2. *Given any triple* (α, θ, γ) *and any constants* $\theta_0, \theta_1 \in (1-\gamma, 1), \theta_1 > \theta_0$*:*

(a) Closing the OTC market strictly raises welfare W *(defined in (2)) if the OTC market share* V_O/V *is above a single cutoff, and strictly reduces* W *if* V_O/V *is below the single cutoff.*

(b) Lowering the traders' label accuracy θ *from* θ_1 *to* θ_0 *strictly raises* W *if* V_O/V *is above a single cutoff, and strictly reduces* W *if* V_O/V *is below the single cutoff.*

Proposition 2 provides simple guides to policy. Closing the OTC market would improve utilitarian welfare for assets whose trades mostly occur over the counter, and harm welfare for assets mostly traded on exchanges. Lowering the accuracy of traders' labels, perhaps by easing disclosure requirements, would likewise improve welfare if and only if the OTC market share is high. These predictions are the products of two results: *(i)* the OTC market share is decreasing in the mass of informed traders μ (Proposition 1), and *(ii)* closing the OTC market or less accurate labels raise welfare if and only if the informed mass μ is small. In stark contrast, *(iii)* closing the OTC market or less accurate labels *always worsen* conventional measures of liquidity.

Proposition 3 formalizes the results *(ii)* and *(iii)*. It uses aggregate trade volume V and *average bid-ask spread* $\bar{S}$ as the measures of liquidity. The average spread $\bar{S}$ is the volume-weighted average of the bid-ask spreads in the OTC market and on the exchange,

$$\bar{S} := \frac{V_{\mathrm{E}}}{V} S_{\mathrm{E}} + \frac{V_{\mathrm{O}}}{V} S_{\mathrm{O}}. \tag{3}$$

We write "lower average spread $\bar{S}$" interchangeably with "higher aggregate volume V", because the average spread $\bar{S}$ is the inverse of the aggregate volume V in equilibrium.[12]

Proposition 3. *Given any triple (α, θ, γ) and any constants $\theta_0, \theta_1 \in (1-\gamma, 1), \theta_1 > \theta_0$:*

(a) There exists a cutoff $\mu^* > 0$ such that closing the OTC market strictly raises welfare W across all mass of informed traders $\mu < \mu^*$ and strictly lowers W across all $\mu > \mu^*$.

(b) There exists a cutoff $\mu^*(\theta_0, \theta_1) > 0$ such that lowering the traders' label accuracy θ from θ_1 to θ_0 raises W across all $\mu < \mu^*(\theta_0, \theta_1)$ and strictly lowers W across all $\mu > \mu^*(\theta_0, \theta_1)$.

(c) Closing the OTC market or lowering θ from θ_1 to θ_0 strictly lowers the aggregate trade volume V and widens the average bid-ask spread $\bar{S}$ (defined in (3)) across all $\mu > 0$.

Proposition 3 says either closing the OTC market or less accurate labels raise welfare for the assets with small mass of informed traders μ. Yet, they always reduce the aggregate

[12] Competitive prices imply that the market maker and the dealer's aggregate revenue equals their gross loss from trading with the informed traders in equilibrium. Formally,

$$\underbrace{V \cdot \bar{S}}_{\text{Revenue}} = \underbrace{(2\alpha - 1) \cdot \mu}_{\text{Gross loss}},$$

which yields the inverse relationship between V and $\bar{S}$.

volume V and widen the average spread $\bar{S}$. In other words, trade volumes and spreads are poor measures of welfare.

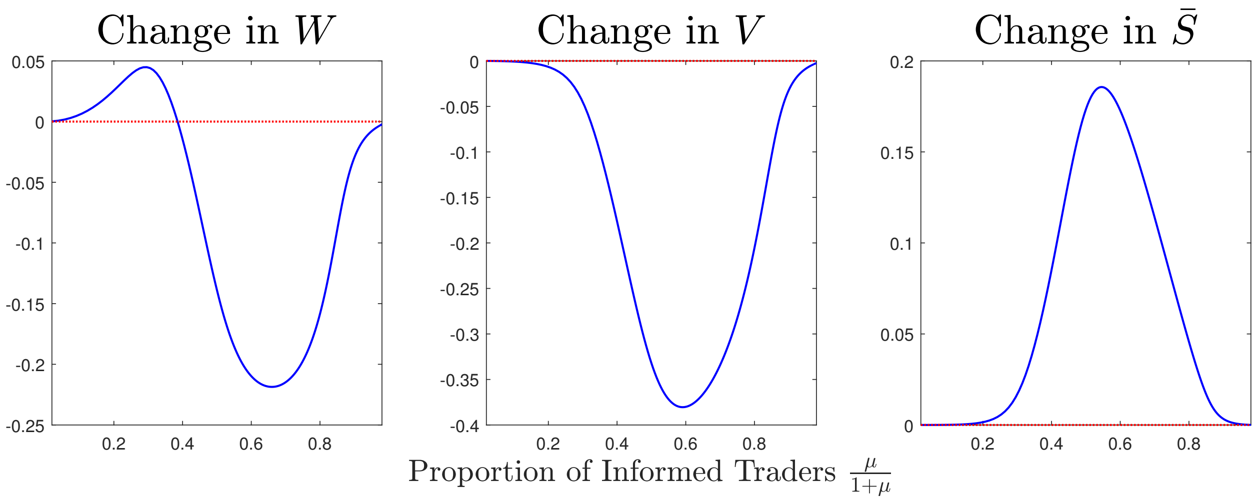

Figure 2: Effects of Closing the OTC Market

Figure 2 illustrates Proposition 3 with parameters $\gamma = 0.6$, $\theta = 0.9$, and $\alpha = 0.98$. It plots the numerical changes in welfare W, aggregate trade volume V, and average spread $\bar{S}$ upon closing the OTC market, for varying values of the mass of informed traders μ. The changes are positive above the red line. Figure 2 confirms that closing the OTC market always reduces trade volume and widens average spread, whereas welfare rises if the mass μ is small and falls if μ is large. The rise and the fall in welfare are on the same order of magnitude. Other OTC frictions not modeled here—such as search frictions or dealers' market power—would contribute to the rise and lessen the fall. Therefore, adding search frictions or relaxing competitive prices in the OTC market would only reinforce our message, by expanding the range of informed mass μ for which closing the OTC market raises welfare.

3.2 Intuition: Cheap Substitution and the Volume Effect

Proposition 3 has two messages. First, there is a generic mismatch between the effects of policies on traders' welfare versus aggregate volume or the average spread. Second, closing the OTC market or less accurate labels improve welfare if the mass of informed traders μ is small, and harm welfare if μ is large. The trade-off between cheap substitution and a volume effect drives our results. Below, we illustrate this trade-off upon closing the OTC market.[13] (Proofs are in Appendix A.)

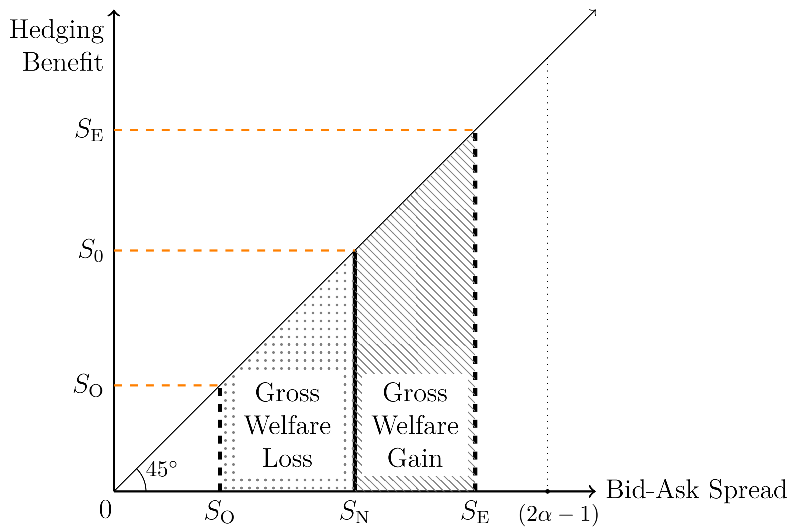

Figure 3: Cheap Substitution

Upon closing the OTC market, some uninformed LU-traders exit while some uninformed LI-traders enter. The exiters have smaller hedging benefits than the entrants. In welfare terms, the exiters are "cheap" relative to their substitutes.

The volume-welfare mismatch

Cheap substitution drives the mismatch between volume and welfare, as we illustrate in Figure 3. The 45-degree line marks the hedging benefit of a marginal uninformed trader for a given spread. With the OTC market, the spread on the exchange is S_E and the spread over the counter is S_O. Upon closing the OTC market, some uninformed LU-traders exit since their spread rises from the OTC spread S_O to the No-OTC spread S_N. Those exiters' hedging benefits are in the range $[S_O, S_N]$. Meanwhile, the LI-traders' spread falls from the exchange spread S_E to the No-OTC spread S_N, inducing some uninformed LI-traders to enter. These entrants' hedging benefits are in the strictly higher range $[S_N, S_E]$ than the exiters.

[13]Closing the OTC market is equivalent to lowering the label accuracy θ from the current level $\theta_1 > 1 - \gamma$ to the uninformative level $\theta_0 = 1 - \gamma$. This is why the two counterfactuals share the same intuition and the same effect on welfare and volume. We return to less accurate labels in Section 3.3 and Section 5.

In welfare terms, the exiters are "cheap" relative to their substitutes. Cheap substitution places a natural upward pressure on welfare upon closing the OTC market: welfare declines only if the fall in volume is large enough to overcome the positive effect of cheap substitution on welfare.

Cheap substitution versus the volume effect

Why does closing the OTC market raise welfare if and only if the mass of informed traders μ is small? Because cheap substitution is pronounced with a small informed mass μ, exactly where the countervailing *volume effect* is weak. Upon closing the OTC market, welfare adjusts by the newly-attained hedging benefits of the entrants ("gross gain in welfare") less the hedging benefits of the exiters. ("gross loss in welfare"),

$$\text{Gross Welfare Gain} = \bar{b}(\text{entrants}) \times m(\text{entrants})$$
$$\text{Gross Welfare Loss} = \bar{b}(\text{exiters}) \times m(\text{exiters}),$$

where $\bar{b}$(exiters) and $\bar{b}$(entrants) are the exiters' and the entrants' average hedging benefits, and m(exiters) and m(entrants) are their respective mass. It is immediate from these definitions that

$$\text{welfare rises if and only if } \underbrace{\frac{\bar{b}(\text{entrants})}{\bar{b}(\text{exiters})}}_{\substack{\text{Cheap}\\ \text{Substitution}}} > \underbrace{\frac{m(\text{exiters})}{m(\text{entrants})}}_{\text{Volume Effect}}. \tag{4}$$

Condition (4) gives a precise definition to each of cheap substitution and the volume effect. Upon closing the OTC market, each entrant gains a larger hedging benefit than each exiter (cheap substitution), yet the exiters outnumber the entrants (volume effect). *Cheap substitution* is defined as $\bar{b}$(entrants)/$\bar{b}$(exiters) and captures how much the entrants' hedging benefits outsize those of the exiters. The *volume effect* is defined as m(exiters)/m(entrants) and measures the relative magnitude by which the exiters outnumber the entrants. We illustrate these terms in Figure 4.

Cheap substitution is strong if the benefits ratio $\bar{b}$(entrants)/$\bar{b}$(exiters) rises well above 1 and vanishes as the ratio falls to 1. When the informed mass μ becomes small enough (de-

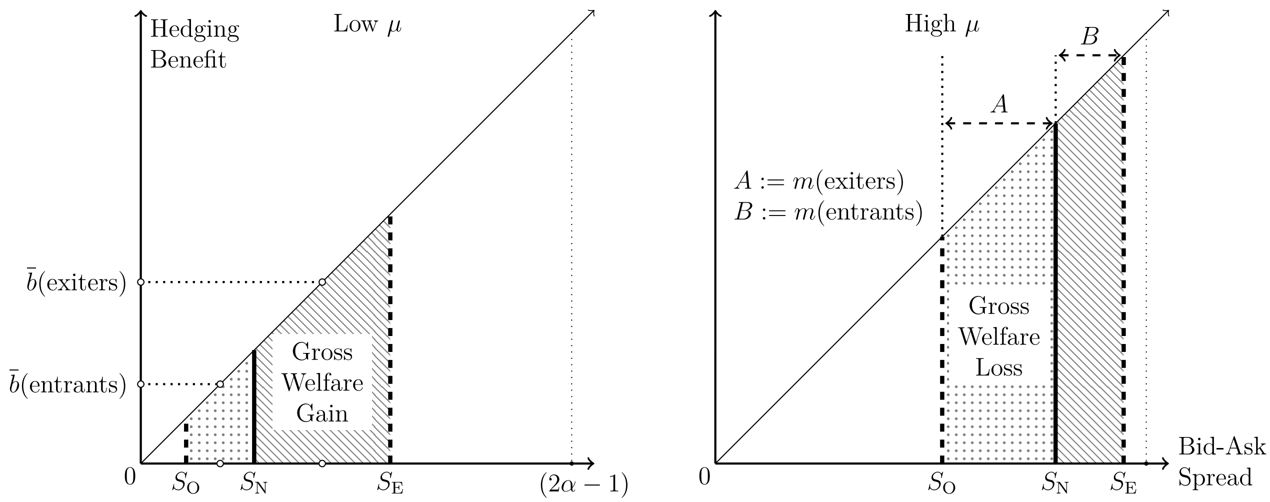

Figure 4: Closing the OTC market improves welfare if μ is small

Cheap substitution dominates if the mass of informed traders μ is small. The volume effect dominates if the informed mass μ is large.

picted in the left panel of Figure 4), the two lower bid-ask spreads, the OTC spread S_{O} and the No-OTC spread S_{N}, are the first to be constrained by the zero lower bound. Then the range of the exiters' hedging benefits $[S_{\text{O}}, S_{\text{N}}]$ is squeezed next to zero, thereby the exiters' average hedging benefit $b(\text{exiters}) = (S_{\text{O}} + S_{\text{N}})/2$ is close to zero. Meanwhile, the exchange spread S_{E} is not yet constrained by the zero lower bound, and the same is true for the entrants' average benefit $b(\text{entrants}) = (S_{\text{E}} + S_{\text{N}})/2$. Together, with a small informed mass μ, the exiters' average benefit $b(\text{exiters})$ nears zero whereas the entrants' benefit $b(\text{entrants})$ does not, thus cheap substitution $\bar{b}(\text{entrants})/\bar{b}(\text{exiters})$ well exceeds 1. Even as the informed traders disappear $\mu \to 0$, the entrants' benefit $b(\text{entrants})$ stays a factor larger than $b(\text{exiters})$ in the limit[14] and cheap substitution converges to a number greater than 1. With a large enough informed mass μ (depicted in the right panel of Figure 4), all spreads lie just below the upper bound $2\alpha - 1$, and pull the exiters' and the entrants' average benefits close

[14] In the limit when $\mu \to 0$, $\lim_{\mu\to 0} \bar{b}(\text{entrants})/\bar{b}(\text{exiters}) = \lim_{\mu\to 0}(S_{\text{N}} + S_{\text{E}})/(S_{\text{N}} + S_{\text{O}}) = (1 - \gamma + \theta)\gamma/[(\gamma + 1 - \theta)(1 - \gamma)] > 1$.

together.[15] Accordingly, cheap substitution $\bar{b}$(entrants)/$\bar{b}$(exiters) falls to 1 at large informed mass μ. Overall, cheap substitution is strong with small informed mass μ and weak with large μ.

The **volume effect** is the reverse: it is strong with a large mass of informed traders μ and vanishes with small μ. When the informed mass μ becomes large enough (right panel of Figure 4), the No-OTC spread S_{N} and the exchange spread S_{E} are pushed up against their upper bound $2\alpha - 1$, forcing S_{N} close to S_{E}. The fall from the exchange spread S_{E} down to the No-OTC spread S_{N} is small, which limits the number of entrants. The number of exiters is not as limited, since the OTC spread S_{O} lies further below the upper bound and hence S_{O} is less constrained by the upper bound. Then the exiters easily outnumber the entrants and the mass ratio $m(\text{exiters})/m(\text{entrants})$ well exceeds 1. The exiters continue to outnumber the entrants in the limit as almost all traders are informed $\mu \to \infty$, and indeed the volume effect converges to a constant greater than 1.[16] Where the informed mass μ is small enough, the opposite occurs—the rise from the OTC spread S_{O} to the higher No-OTC spread S_{N}

[15] The upper bound $2\alpha - 1$ is the spread that the market maker would charge if every trader were informed.

[16] We show that $\lim_{\mu \to \infty} m(\text{exiters})/m(\text{entrants}) > 1$ here. First, we note that

$$\frac{m(\text{exiters})}{m(\text{entrants})} = \frac{\gamma}{1-\gamma} \cdot \frac{S_{\mathrm{N}} - S_{\mathrm{O}}}{S_{\mathrm{E}} - S_{\mathrm{N}}}.$$

The difference $S_{\mathrm{N}} - S_{\mathrm{O}}$ can be Taylor expanded to

$$S_{\mathrm{N}} - S_{\mathrm{O}} \approx S'_{\mathrm{N}}(\beta_{\mathrm{N}})(\beta_{\mathrm{N}} - \beta_{\mathrm{O}}) + \frac{1}{2} S''_{\mathrm{N}}(\beta_{\mathrm{N}})(\beta_{\mathrm{N}} - \beta_{\mathrm{O}})^2,$$

where $\beta_{\mathrm{N}} = \mu$ and $\beta_{\mathrm{O}} = (1-\theta)\mu/\gamma$ are the ratios of informed to uninformed traders who trade or choose the OTC market, respectively. These approximations can be simplified using the zero profit condition (1), whose second derivative with respect to the informed ratio β is

$$0 = S''(\beta) \cdot (1 - 2S(\beta) + \beta) + S'(\beta) \cdot (2 - 2S'(\beta) - S(\beta)S'(\beta)).$$

When $\mu \to \infty$, then the ratio $\beta \to \infty$, the slope $S'(\beta) \to 0$, and this equality yields

$$S''(\beta) \approx -\frac{2s'(\beta)}{\beta}.$$

Therefore using that $\beta_{\mathrm{N}} = \mu$, the approximation of $S_{\mathrm{N}} - S_{\mathrm{O}}$ becomes

$$S_{\mathrm{N}} - S_{\mathrm{O}} \approx S'_{\mathrm{N}}(\beta_{\mathrm{N}}) \frac{\theta + \gamma - 1}{\gamma} \mu - S'_{\mathrm{N}}(\beta_{\mathrm{N}}) \left(\frac{\theta + \gamma - 1}{\gamma} \right)^2 \mu = \left(1 + \frac{\theta + \gamma - 1}{\gamma} \right) \frac{\theta + \gamma - 1}{\gamma} S'_{\mathrm{N}}(\beta_{\mathrm{N}}) \mu.$$

becomes small, which limits the number of exiters.[17]

Altogether, the volume effect is weak with small mass of informed traders μ, it is strong with large informed mass μ, and the opposite is true of cheap substitution. Therefore, cheap substitution dominates the volume effect and welfare rises upon closing the OTC market if and only if the informed mass μ is small. The trade-off between cheap substitution and the volume effect persists for general distributions of hedging benefits, as we show in Section 3.3.

The volume effect

The aggregate volume always falls upon closing the OTC market and lowering the traders' label accuracy (Proposition 3). The entrants never outnumber the exiters, because the equilibrium spread $S(\beta)$ is *concave* in the ratio of informed to uninformed traders β. Figure 5 demonstrates how the concavity implies the average bid-ask spread $\bar{S}$ must rise—therefore the aggregate trade volume V must decline (see Equation (3))—upon closing the OTC market.

Why is the equilibrium spread $S(\beta)$ concave? Due to that the informed traders, by paying their bid-ask spreads, contribute towards the revenue the dealer or the market maker needs to break even $(2\alpha-1)^{+}\beta$.[18] Doing so, the informed traders subsidize the uninformed traders

Similar steps for $S_{\mathrm{E}} - S_{\mathrm{N}}$ give us, when $\mu \to \infty$,

$$\frac{m(\text{exiters})}{m(\text{entrants})} \approx \frac{1 + \frac{\theta+\gamma-1}{\gamma}}{1 - \frac{\theta+\gamma-1}{1-\gamma}} > 1.$$

[17]In the limit when $\mu \to 0$, we derive that $\lim_{\mu\to 0} m(\text{entrants})/m(\text{exiters}) = 1$ here. First, the absolute difference between the ratio of informed to uninformed traders who choose the OTC market $\beta_{\mathrm{O}} := (1-\theta)\mu/\gamma$ $(< \mu)$ versus the ratio for the exchange $\beta_{\mathrm{E}} := \theta\mu/(1-\gamma)$ $(> \mu)$ is nearly zero with a small informed mass μ. In this case, the ratio of changes in the bid-ask spreads $(S_{\mathrm{N}} - S_{\mathrm{O}})/(S_{\mathrm{E}} - S_{\mathrm{N}})$ upon closing the OTC market is

$$\frac{S_{\mathrm{N}} - S_{\mathrm{O}}}{S_{\mathrm{E}} - S_{\mathrm{N}}} \approx \frac{\beta_{\mathrm{N}} - \beta_{\mathrm{O}}}{\beta_{\mathrm{E}} - \beta_{\mathrm{N}}} = \frac{1-\gamma}{\gamma},$$

and the spreads S_{O} and S_{E} are both near the No-OTC spread S_{N}. Then, the mass ratio becomes

$$\frac{m(\text{exiters})}{m(\text{entrants})} = \frac{\gamma\,(S_{\mathrm{N}} - S_{\mathrm{O}})}{(1-\gamma)\,(S_{\mathrm{E}} - S_{\mathrm{N}})} \approx 1.$$

[18]The break-even revenue is the gross value of the informed traders' private information in a market,

$$\underbrace{(2\alpha-1)^{+}}_{\substack{\text{Expected value}\\ \text{of each signal}}} \cdot \underbrace{\beta}_{\substack{\text{Ratio of}\\ \text{informed to}\\ \text{uninformed}\\ \text{traders}}} \quad ; \quad \beta \in \{\beta_{\mathrm{E}}, \beta_{\mathrm{O}}, \beta_{\mathrm{N}}\}.$$

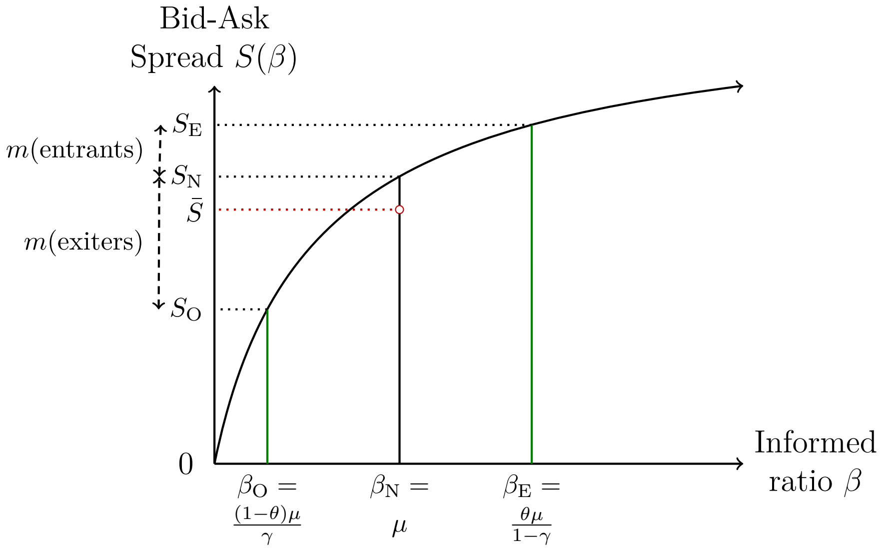

Figure 5: Equilibrium spread is concave

and reduce the elasticity of spreads to the break-even revenue $(2\alpha-1)^+\beta$. This elasticity to break-even revenue is falling in the informed ratio β, whereas the break-even revenue itself is increasing in β. The latter causes the equilibrium spread $S(\beta)$ to be increasing, and the former ensures that $S(\beta)$ is concave.

3.3 General Distributions

Our welfare implications are remarkably sharp: Closing the OTC market or less accurate labels always reduce aggregate volume, while their effect on welfare hinges on a single cutoff μ^* over the mass of informed traders. Crucial for the result is the rate of endogenous entry versus exit, which plainly depends on the distribution of hedging benefits. In this section, we show that our welfare implications are robust to most economically relevant distributions.

To do so, we assume that the hedging benefits follow a generic distribution F, $b_i \overset{iid}{\sim} F$, whose support is $[0,1]$ with a pdf $f(s)$. Such a distribution is "regular" in that its pdf $f(s)$ is differentiable in some neighborhoods of 0 and $2\alpha-1$ (the lower and upper bounds of the

It is the exogenous part of the zero-profit condition (1).

bid-ask spread) and that the limits $\lim_{s\downarrow 0} f'(s)$ and $\lim_{s\uparrow 2\alpha-1} f'(s)$ exist.[19] With a general distribution F, the zero-profit condition (1) becomes

$$\underbrace{s \cdot (1 - F(s))}_{\substack{\text{Profit from} \\ \text{uninformed traders}}} = \underbrace{(2\alpha - 1 - s)^{+} \cdot \beta}_{\text{Loss to informed traders}}. \tag{5}$$

The left-hand side is changed from $s \cdot (1 - s)$ to $s \cdot (1 - F(s))$ while the right-hand side is unchanged.

Two measures fully characterize the effects of closing the OTC market or less accurate labels on volume and welfare under this general framework. *Marginal volume* Δ_V is the decrease in the proportion of uninformed traders who trade when the informed ratio β marginally increases,

$$\Delta_V(\beta) := \underbrace{S'(\beta)}_{\substack{\text{Increase} \\ \text{in spread}}} \cdot \underbrace{f(S(\beta))}_{\substack{\text{Decrease} \\ \text{in trades}}}. \tag{6}$$

Marginal welfare Δ_W is the decrease in welfare per unit mass of uninformed traders when the informed ratio β marginally increases. It is equivalent to the marginal volume Δ_V weighted by the hedging benefit of the marginal uninformed trader $b = S(\beta)$:

$$\Delta_W(\beta) := \underbrace{S(\beta)}_{\substack{\text{Benefit} \\ \text{lost}}} \cdot \underbrace{S'(\beta) f(S(\beta))}_{\Delta_V}. \tag{7}$$

We show in Appendix A.2 that both the marginal volume Δ_V and the marginal welfare Δ_W are well defined.

The following proposition says our welfare implications hold under any distribution that

[19] These limits can be, but need not be, infinite. Most economically relevant pdfs for f are regular. For example, any pdf f continuously differentiable in the support $[0, 1]$ and any beta distribution are regular.

admits an “n-shaped” marginal welfare Δ_W. We sketch an example in Figure A.11.

$$\text{Marginal welfare } \Delta_W \text{ is } \textit{n-shaped} \text{ if } \Delta_W \text{ is strictly increasing below a cutoff in the ratio } \beta \text{ of informed to uninformed traders who choose the market and strictly decreasing beyond the cutoff.} \tag{8}$$

Proposition 4. *We let F be any regular distribution with support $[0,1]$ and each uninformed trader's hedging benefit $b_i \overset{iid}{\sim} F$. For any triple (α, θ, γ) and any constants $\theta_0, \theta_1 \in (1-\gamma, 1), \theta_1 > \theta_0$:*

(a) There exists two cutoffs $\bar{\mu}$ and $\underline{\mu}$, $\bar{\mu} > \underline{\mu} > 0$, such that closing the OTC market strictly raises welfare W across all mass of informed traders $\mu < \underline{\mu}$ and strictly lowers W across all $\mu > \bar{\mu}$.

(b) There exists two cutoffs $\bar{\mu}(\theta_0, \theta_1)$ and $\underline{\mu}(\theta_0, \theta_1)$, $\bar{\mu}(\theta_0, \theta_1) > \underline{\mu}(\theta_0, \theta_1) > 0$, such that lowering the traders' label accuracy θ from θ_1 to θ_0 raises W across all $\mu < \underline{\mu}(\theta_0, \theta_1)$ and strictly lowers W across all $\mu > \bar{\mu}(\theta_0, \theta_1)$.

(c) If the marginal welfare Δ_W is n-shaped (defined in (7)-(8)), the cutoffs $\bar{\mu} = \underline{\mu}$ and the cutoffs $\bar{\mu}(\theta_0, \theta_1) = \underline{\mu}(\theta_0, \theta_1)$.

(d) If the marginal volume $\Delta_V(\beta)$ (defined in (6)) is decreasing, closing the OTC market or lowering θ from θ_1 to θ_0 strictly lowers the aggregate trade volume V and widens the average bid-ask spread $\bar{S}$ across all $\mu > 0$.

Proposition 4 parts (a) and (b) say, under *any* regular pdf f, closing the OTC market or less accurate labels raise welfare for low mass of informed traders μ and lowers welfare for high informed mass μ. Part (c) sharpens our policy guidance to a single cutoff on the informed mass μ, around which the effect on welfare hinges. Precisely, whenever marginal welfare Δ_W is n-shaped, closing the OTC market or less accurate labels raise welfare if and only if the informed mass $\mu < \hat{\mu}$. Part (d) emphasizes how the measures of liquidity are poor indicators for welfare: under a sufficient condition, closing the OTC market or less accurate labels always lower aggregate volume and widens the average spread.

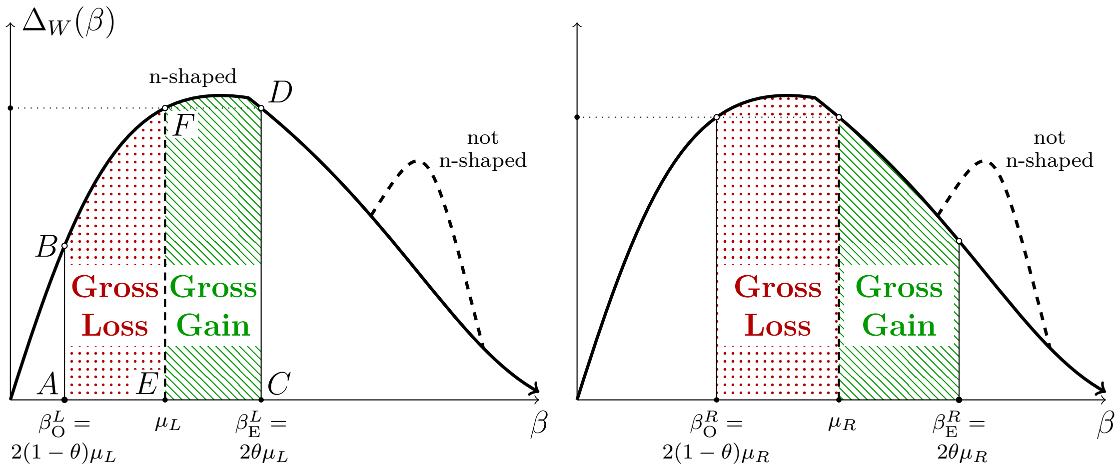

Figure 6: The Effect of Closing the OTC Market on Welfare ($\gamma = 1/2$)

We now outline the proof of Proposition 4 parts (a)-(c), then argue that most relevant distributions for F would result in an n-shaped marginal welfare Δ_W. We consider the simplest example where the label accuracy $\gamma = 1/2$ and the marginal welfare Δ_W is n-shaped. Figure 6 plots the marginal welfare Δ_W upon closing the OTC market in this example. We first focus on the left panel. Here both the mass of informed traders μ and the informed ratio β without the OTC market are equal to the constant μ_L. With the OTC market, the informed ratio is $\beta_O^L = 2(1-\theta)\mu_L < \mu_L$ over the counter and $\beta_E^L = 2\theta\mu_L > \mu_L$ on the exchange. As the informed ratio without the OTC market μ_L is larger than the ratio β_O^L over the counter, the LU-traders would pay a higher spread without the OTC market. The resulting exit by uninformed LU-traders creates a gross welfare loss marked by the red-dotted area between the points $\beta = \mu_L$ and $\beta = \beta_O^L$. Symmetrically, the gross welfare gain from the entry of uninformed LI-traders is marked by the green-lined area between the points $\beta = \mu_L$ and $\beta = \beta_E^L$.

We use Figure 6 to summarize our three-step proof of Proposition 4 parts (a) and (c). (We generalize this proof in Appendix A.2 to prove part (b).) First, we show that under any regular pdf f, the marginal welfare $\Delta_W(\beta)$ is increasing over low informed ratio β and decreasing over high β. Intuitively, the marginal welfare Δ_W is small if either the hedging benefit of a marginal uninformed trader is small or if few uninformed traders remain at the margin. When the informed ratio β is small enough, the quoted spread is near zero. Hence, the marginal uninformed trader's hedging benefit is small, which implies that the marginal welfare Δ_W is small. When the informed ratio β is large enough, the spread is wide and very few uninformed traders still trade, meaning the marginal welfare Δ_W is again small. Altogether, the marginal welfare Δ_W must be increasing from zero around the informed ratio $\beta = 0$ and decreasing to zero over high enough ratio β (regardless of whether Δ_W is n-shaped).

Second, we set the constants μ_L, μ_R such that marginal welfares $\Delta_W(\mu_L) = \Delta_W(\beta_{\text{E}}^L)$ and $\Delta_W(\mu_R) = \Delta_W(\beta_{\text{O}}^R)$, and show that closing the OTC market causes a net gain in welfare if the informed mass $\mu \leq \mu_L$ and a net loss if the mass $\mu \geq \mu_R$. From the left panel of Figure 6, because the gross welfare gain is uniformly "taller" than the gross welfare loss, the area of gross welfare gain is larger than the area of loss. (The base lengths of the gain and the loss are equal when the label accuracy $\gamma = 1/2$.) This remains to be true if we shift the constant μ_L leftwards, and thus closing the OTC market generates a net welfare gain for all mass $\mu \leq \mu_L$. Similarly on the right panel, the gross welfare loss is uniformly "taller" than the gross welfare gain, which would remain so as we shift the constant μ_R rightwards, thereby closing the OTC market would cause a net welfare loss for all mass $\mu \geq \mu_R$. We do not require marginal welfare Δ_W be n-shaped in this argument to establish part (a).

Third, the net welfare gain is increasing in the mass of informed traders μ between the constants μ_L and μ_R if marginal welfare Δ_W is n-shaped, which proves part (b). From both panels of Figure A.11, when the informed mass μ moves from the lower constant μ_L towards the higher one μ_R, the derivative of the net welfare change with respect to μ is, written geometrically,

$$\underbrace{\left(\theta \cdot ||\overline{CD}|| - \frac{1}{2} \cdot ||\overline{EF}||\right)}_{\text{Derivative of the gross welfare gain}} - \underbrace{\left(\frac{1}{2} \cdot ||\overline{EF}|| - (1-\theta) \cdot ||\overline{AB}||\right)}_{\text{Derivative of the gross welfare loss}}.$$

The derivative is negative for any informed mass μ between μ_L and μ_R, as both segments $\overline{AB}$ and $\overline{CD}$ are shorter than $\overline{EF}$. Thus, increasing the informed mass μ from μ_L to μ_R monotonically reduces the net change in welfare, which ensures a unique cutoff $\hat{\mu} \in (\mu_L, \mu_R)$, establishing part (b).

In the complete proof in Appendix A.2, we let the label accuracy γ be any value, not 1/2. For any accuracy $\gamma \neq 1/2$, the base lengths of the losses and the gains in Figure 6 differ from one another. It happens that, in calculating welfare, the relative weights on the gross loss and the gain change inversely to keep their base-times-weight equal. Therefore, our comparison of the lengths $\{||\overline{AB}||, ||\overline{CD}||, ||\overline{EF}||\}$ continues to work in establishing Parts (a)-(c) for all values of label accuracy γ.

How general are the conditions in Proposition 4? Most economically relevant distributions would result in an n-shaped marginal welfare Δ_W. Proposition 5 states the necessary and sufficient conditions on the distribution F for the resulting marginal welfare Δ_W to be n-shaped and marginal volume Δ_V to be decreasing.

Proposition 5. *(i) Marginal welfare Δ_W is n-shaped if and only if the function*

$$\frac{(2\alpha-1)(1-F(x))}{xf(x)(2\alpha-1-x)^2} - \frac{1}{2\alpha-1-x} \quad \textit{is U-shaped in } x \in (0, 2\alpha-1). \tag{9}$$

In particular, any beta distribution Beta(a, b) satisfies condition (9) for all $a, b > 0$.

(ii) Marginal volume Δ_V is decreasing if and only if the function

$$\frac{(2\alpha-1)(1-F(x))}{f(x)(2\alpha-1-x)^2} - \frac{x}{2\alpha-1-x} \quad \textit{is increasing in } x \in (0, 2\alpha-1). \tag{10}$$

Any beta distribution Beta(a, b) with parameters $a \leq 1, b \leq 1$ satisfies condition (10).

Using Taylor expansion around $2\alpha - 1$, one can verify that the uniform distribution $\mathbb{U}([0, 1])$ and the beta distributions—for all parameter values—satisfy condition (9) and thus have n-shaped marginal welfare Δ_W.[20] To interpret condition (9), we note that it holds at the extremes under *any* distribution F: the equation goes to infinity as s approaches 0 or $2\alpha - 1$. Condition (9) only rules out the distributions whose pdf f oscillates over moderate values of the support $(0, 2\alpha - 1)$.

[20]The beta distribution Beta(a, b) (pdf $f(s) = \frac{s^{a-1}(1-s)^{b-1}}{B(a,b)}$) is a highly general class of bounded distributions that embeds the uniform distribution when $a = b = 1$. One can also numerically verify that common unbounded distributions—Normal, Chi-squared, and Gamma—satisfy condition (9) when truncated on $[0, 1]$.

We can verify that (10) is satisfied for any uniform distribution and for beta distributions Beta(a, b) with parameters $a \leq 1, b \leq 1$. Such distributions starkly demonstrate the effect of cheap substitution. Because the entrants' hedging benefits are uniformly larger than the exiters' benefits, closing the OTC market can raise welfare—even as it reduces aggregate volume—for the assets that attract relatively few informed traders.

4 Optimal Pigouvian Tax

Our focus so far on closing the OTC market has two benefits. First, the focus reflects the aims of recent policies. Second, we can provide clear guidance for the assets that nearly always trade over the counter (close the OTC market) or are overwhelmingly traded on exchanges (do not close). However, closing the OTC market is a crude policy without clear guidance for the many assets whose OTC market shares are moderate.

In this section, we introduce a Pigouvian tax on OTC trades which *always* obtains a higher welfare than closing or keeping the OTC market. A positive OTC tax $t > 0$ subsidizes trades on the exchange with the revenue from OTC trades, while a negative tax $t < 0$ does the reverse. The OTC market share smoothly declines as the tax t increases. Moreover, policymakers can easily implement the socially optimal rate of the tax. We identify a simple test to determine if the current tax is too low, too high, or at the optimal rate: we can marginally increase the tax t, then measure the *weighted spread ratio* (Section 4.2 discusses how to estimate it)

$$WSR := \left| \frac{S_{\mathrm{O}} dV_{\mathrm{O}}}{S_{\mathrm{E}} dV_{\mathrm{E}}} \right|. \tag{11}$$

If the ratio $WSR > 1$, the current tax rate t exceeds the socially optimal rate, $t > t^*$. If the ratio $WSR < 1$, the tax t is below the optimal rate, $t < t^*$. In both cases, moving the tax t towards the optimal rate t^* raises welfare.

4.1 Characterizing the Optimal Pigouvian Tax

We take the general model of Section 3.3, keep the OTC market open, then introduce a Pigouvian transactions tax t on each trade of the OTC dealer. The tax revenue is transferred to the market maker on the exchange as a per-trade subsidy. We fix all parameters $\{\mu, \theta, \gamma, \alpha\}$ except the tax rate t. Under this setup, the dealer's zero profit condition becomes

$$(2\alpha - 1)\beta_{\text{O}} = \Big(S_{\text{O}}(t) - t\Big) \underbrace{\Big(\beta_{\text{O}} + 1 - F(S_{\text{O}}(t))\Big)}_{V_{\text{O}}(t)}, \tag{12}$$

and the market maker's zero profit condition is

$$(2\alpha - 1)\beta_{\text{E}} = \left(S_{\text{E}}(t) + \frac{V_{\text{O}}(t)}{V_{\text{E}}(t)} t\right) \underbrace{\Big(\beta_{\text{E}} + 1 - F(S_{\text{E}}(t))\Big)}_{V_{\text{E}}(t)}. \tag{13}$$

Increasing the tax t is equivalent to exogenously raising the OTC spread S_{O} and lowering the exchange spread S_{E}.

The *optimal Pigouvian tax* t^* is the Pigouvian tax t that maximizes welfare W. (14)

Proposition 6 says that the optimal Pigouvian tax t^* attains a strictly higher welfare than closing the OTC market. Similarly, the optimal tax t^* typically raises welfare above merely keeping the OTC market, because the tax can always be zero.

Proposition 6. *For any triple (α, θ, γ), there exists a unique optimal Pigouvian tax $t^*(\mu)$ as defined in (14). Welfare W is strictly higher under the optimal tax $t^*(\mu)$ than with a closed OTC market. Moreover, the optimal tax $t^*(\mu)$ is generically non-zero, in that the set $\{\mu : t^*(\mu) = 0\}$ is countable.*

How does the optimal Pigouvian tax t^* outperform closing the OTC market? To answer, we construct the Pigouvian tax equivalent to closing the OTC market:

Zero-OTC tax $\bar{t}$ is the smallest Pigouvian tax such that the OTC volume is zero.

We will show that the optimal tax is strictly below the Zero-OTC tax, $t^* < \bar{t}$, which implies welfare is strictly higher with the optimal tax than closing the OTC market. (Formal proofs are in Appendix A.3.)

At the Zero-OTC tax $t = \bar{t}$, each trader is indifferent between trading over the counter or on the exchange; in particular,

$$S_{\mathrm{O}}(t = \bar{t}) = S_{\mathrm{E}}(t = \bar{t}).$$

Doing so equalizes the hedging benefits of the marginal uninformed traders in each market. Therefore, a small cut in the tax t from the Zero-OTC level $\bar{t}$ creates entrants and exiters with the same hedging benefits, which shuts down cheap substitution. The lack of cheap substitution leaves the volume effect to entirely determine the change in welfare.

The volume effect happens to raise welfare upon the tax cut from $\bar{t}$. The intuition centers on how the informed traders absorb a portion of any tax change, mitigating its effect on the uninformed traders. Lower tax (or higher subsidies) in a market incentivizes more uninformed traders to participate. At the same time, a part of the lower tax is "wasted" on higher payoffs for informed traders, who always trade in equilibrium. Thereby a change in the tax induces a small response from uninformed traders where there is a greater share of informed traders. The Likely Informed traders comprise the relatively more informed traders and they trade on the exchange—the uninformed traders on the exchange respond more to the tax. Meanwhile, the tax cut widens the bid-ask spread on the exchange S_{E} and narrows the spread over the counter S_{O}. So, the exiters on the exchange outnumber the entrants over the counter. The optimal tax t^* must then be strictly below the Zero-OTC tax $\bar{t}$. Since $t^* \neq \bar{t}$, implementing the optimal tax obtains a strictly higher welfare than closing the OTC market.

4.2 Implementing the Optimal Pigouvian Tax

The optimal Pigouvian tax t^* can be implemented with the aid of a marginal policy experiment.

Proposition 7. *We suppose the initial Pigouvian tax rate is t, then we increase the rate by a small amount $dt > 0$. (a) The consequent weighted spread ratio $WSR > 1$ (defined in (11)) if and only if the initial tax is strictly greater than the optimal rate $t > t^*$, and $WSR < 1$ if and only if $t < t^*$. (b) Welfare W increases $dW/dt > 0$ if and only if $WSR < 1$, and $dW/dt < 0$ if and only if $WSR > 1$. (c) The weighted spread ratio WSR from a small change in the tax rate is strictly increasing in the initial rate t, $dWSR/dt > 0$.*

Proposition 7 spells out a simple procedure to conservatively implement the optimal Pigouvian tax.

Procedure

1. Introduce the Pigouvian tax at a rate near zero or marginally change the rate of the existing Pigouvian tax.
2. Calculate the weighted spread ratio WSR from the last change in the tax rate.
3. If WSR is sufficiently above 1, lower the tax rate; if WSR is sufficiently below 1, raise the tax rate; otherwise, do nothing.
4. If the tax rate was changed in step 3, return to step 2; otherwise, end this procedure.

Policymakers can set the range of WSR around 1 above or below which the tax rate is changed. We denote this range $R(WSR) := [\underline{R}, \bar{R}]$, $\underline{R} \in (0, 1)$, $\bar{R} > 1$. Part (c) of Proposition 7 says the ratio WSR moves farther away from 1 as the current tax rate t moves away from the optimal rate t^*. Therefore in our procedure, widening the range $R(WSR)$ increases gap between the current and the optimal tax rates before the tax rate is changed.[21] If the cost of changing the tax rate is high, one may set a wide range $R(WSR)$ and enlarge the size of the tax cut or raise in step 3. To be more conservative, one sets a wide $R(WSR)$ yet keep the size of the tax change in step 3 small.

Intuition behind WSR and step 3 in our procedure is comes from condition (4) under which closing the OTC market raises welfare. Upon a small increase in the Pigouvian tax, we

[21]A wider $R(WSR)$ also compensates for greater error in the estimation of WSR. We leave for future work the construction of confidence intervals around estimates of WSR.

can separate the weighted spread ratio WSR into the benefits and the mass ratios (defined in Section 3.2).

$$WSR = \left| \underbrace{\frac{S_{\mathrm{O}}}{S_{\mathrm{E}}}}_{\substack{\text{Inverse}\\ \text{benefits}\\ \text{ratio}}} \cdot \underbrace{\frac{dV_{\mathrm{O}}}{dV_{\mathrm{E}}}}_{\substack{\text{Mass}\\ \text{ratio}}} \right|$$

The benefits ratio $S_{\mathrm{E}}/S_{\mathrm{O}}$ captures cheap substitution, which raises welfare upon the tax increase. It arises because the marginal uninformed traders have larger hedging benefits on the exchange than in the OTC market (S_{E} versus $S_{\mathrm{O}} < S_{\mathrm{E}}$). The inverse of the benefits ratio $S_{\mathrm{O}}/S_{\mathrm{E}}$ measures how weak cheap substitution is: $S_{\mathrm{O}}/S_{\mathrm{E}}$ goes to 1 as cheap substitution vanishes and falls towards 0 as it strengthens. By contrast, the mass ratio $|dV_{\mathrm{O}}/dV_{\mathrm{E}}|$ captures the volume effect. The ratio $|dV_{\mathrm{O}}/dV_{\mathrm{E}}|$ is the size of the decline in OTC volume relative to the rise in exchange volume upon the tax increase. The product of the two ratios $|(S_{\mathrm{O}}/S_{\mathrm{E}})(dV_{\mathrm{O}}/dV_{\mathrm{E}})|$ exceeds 1 if the volume effect dominates cheap substitution, in which case a higher tax rate lowers welfare. The product is below 1 if cheap substitution dominates, where a higher tax raises welfare.

Estimating the Weighted Spread Ratio

The volume term of WSR $|dV_{\mathrm{O}}/dV_{\mathrm{E}}|$ is easily computed using trade volumes just before and just after the small change in the tax rate t. Already in the US and the EU, most trades must be reported in nearly real time, and must report whether it was executed on an exchange or over the counter. The spread term $S_{\mathrm{O}}/S_{\mathrm{E}}$ is empirically the ratio of average bid-ask spread over the counter to average spread on exchanges just before the tax change. To estimate it, the exchange spread S_{E} can be the best quoted offer minus the best quoted bid divided by the midpoint price. Effective spread from recent trades on exchanges can substitute for the quoted spread if no exchange has a bid or an offer. In the OTC market, binding quotes are not available. Moreover, effective spread cannot proxy for the OTC spread S_{O} if the asset is rarely traded over the counter. Instead, one may approximate S_{O} with the effective spreads of similar assets (e.g., corporate bonds at the same firm with similar maturity) or adopt benchmarks widely used among traders, such as MarketAxess' Composite+ or Bloomberg's BVAL.

Applicability of the Optimal Pigouvian Tax

The Pigouvian tax is not applicable to all assets. In particular, it cannot be implemented in any asset for which no pre-trade anonymous method of trading exist. Such methods include limit order books, batch auctions, dark pools, and all-to-all requests for quote we describe in Section 5.2. Most important asset classes are in fact actively traded via these methods: equities, their futures and options, Treasuries, corporate bonds, repurchase agreements (repos), and standardized swaps are actively traded in pre-trade anonymous markets (Footnote 1 lists examples).

5 Policy Implications

This section applies our results to recent policy debates.

5.1 Regulatory efforts to close OTC markets

Recent regulations in the US, EU, and Japan seek to push OTC trades onto exchanges. One might be tempted to exempt mostly OTC-traded assets, as the large OTC market share reflects a preference for OTC trading. However, we find that closing the OTC market would improve utilitarian welfare for precisely those OTC-dominated assets (Propositions 2 and 3). In general, leaving traders to freely choose between exchanges or the OTC market does not ensure efficient outcomes.

Case in point, the US Dodd-Frank Act sought to push the trades of swaps onto exchanges by ensuring *access* to exchanges. Dodd Frank establishes Swap Execution Facilities (SEFs), a form of automated trading platforms, and requires most swaps trades to be initiated in a SEF. Each SEF must offer a limit order book, and OTC dealers cannot own more than 40% of any SEF. In addition, a "fair access" rule restricts the conditions or fees that the SEFs can impose on their limit order books. As our model would predict, the access-based approach of Dodd-Frank failed to dislodge the OTC dominance in swaps—an asset class that our results imply should be traded on exchanges. Some 95% of swaps trades remain over the counter several years after the implementation of Dodd-Frank (Nagel, 2016).

Unlike the Dodd-Frank Act, the EU's Markets in Financial Instruments Directive II (MiFID II) *forces* certain trades onto exchanges. For instance, MiFID II requires all dealers to maintain public and binding quotes for any asset that meets a minimum liquidity requirement. All except large block trades must transact at those public quotes or on exchanges (Surowiecki, 2018). The MiFID II rules effectively ban price discrimination by OTC dealers on smaller trades. This mandate-based approach of MiFID II is more likely to shift trades onto exchanges than the access-based approach of Dodd-Frank. Nonetheless, in our model, the optimal Pigouvian tax (Section 4) would improve welfare upon both mandates to trade on exchanges as in MiFID II and merely ensuring access to exchanges as in Dodd-Frank.

5.2 Post-trade Name Give-Up

The US regulators adopted the mandate-based approach when they banned "post-trade name give-up" in 2020. Most swaps trades—over 80% for index credit default swaps and 45% for single-name CDS (Nagel, 2016)—are executed on SEFs, which offer two ways to trade: request-for-quote (RFQ) or all-to-all (A2A). In a RFQ, a trader simultaneously submits non-anonymous requests to trade a stated quantity to multiple dealers. Because the RFQ is pre-trade non-anonymous, a RFQ trade corresponds to an OTC trade in our model. An A2A trade either occurs on a limit order book or takes the form of a first-price auction open to all traders, which are both pre-trade anonymous. The A2A thus represents trading on the exchange in our model.

Most SEFs traditionally practiced post-trade name give-up (NGU), wherein parties to an A2A trade learn each other's identities after the trade. Buyside firms intensely opposed NGU since the "information leakage associated with sharing [their] trading activity" undermines A2A trading (Citadel LLC, 2020). The dealers claimed NGU helped to "tailor their pricing on requests-for-quote" and increase the liquidity they provide (JPMorgan Chase & Co., 2018). Such comments are consistent with NGU making the traders' labels more accurate (higher θ). A major argument used for NGU was that traders were "free to choose" whether or not to trade on SEFs with NGU. Moreover, the dealers cited research that RFQs have lower spreads and generate more volume than A2A to argue for the status quo with NGU

(Securities Industry and Financial Markets Association, 2018). Despite these claims, the Commodity Futures Trading Commission (CFTC) banned NGU in 2020.

Did the CFTC make the right call? Yes, in the light of our results. As swaps trades are OTC dominated (Nagel, 2016, Augustin, Subrahmanyam, Tang and Wang, 2016), Proposition 2 predicts the ban on NGU (lowering label accuracy θ) to raise welfare. Further, Proposition 2 undercuts a central argument for keeping NGU—that NGU may increase trade volume and reduce bid-ask spreads do *not* imply NGU improves welfare.

5.3 Permissioned Blockchain

We predict that the current plans to apply blockchain to financial markets would undermine exchanges in favor of OTC markets. Blockchain is an electronic recordkeeping procedure for a network of members, called "nodes". Each transaction between the nodes is broadcast to the other nodes in the network, and every node maintains a ledger of all such transactions. An algorithm periodically reconciles those ledgers, and the sequence of reconciled ledgers forms the 'official' record. Pseudonymity is crucial to generating trust in this record. Transactions on a blockchain includes the identifiers of counterparties involved in the trade: the reconciled record provides the complete trade history of every account on the blockchain. Any node can deduce what each account owns from the trade history, and thereby can detect attempts at fraud. However, pseudonymity violates anti-money-laundering rules (Elwell, Murphy and Seitzinger, 2013); most proposed blockchains for financial markets fully reveal traders' identities to their nodes.

Among the earliest such proposal is the Depository Trust & Clearing Corporation's (DTCC) plan to move the ownership records of most credit derivatives onto a blockchain (Irrera, 2017).[22] The DTCC plan, and its pilot run, envisions a "permissioned" blockchain in which 15 major dealers are the nodes—and no one else (DTCC, 2018). Soon thereafter, ICAP (the dominant interdealer broker) initiated a pilot of a permissioned blockchain for foreign exchange, and the DTCC proposed a permissioned blockchain for equities (DTCC, 2020).

[22] DTCC is the dominant clearhouse for most securities.

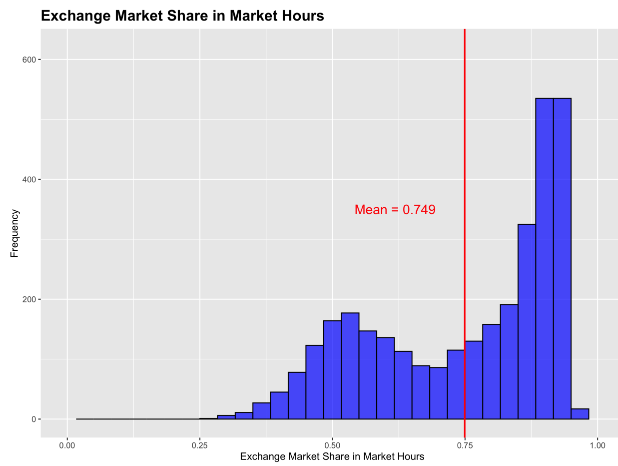

Figure 7: Exchange Market Share of Dollar Value of Trades in US-listed Equities

All three proposals would reveal all traders' transaction histories to the major dealers, allowing the dealers to better separate traders by their trading motives (higher label accuracy θ in our model). Then the dealers can cream-skim a greater share of uninformed traders, which worsens adverse selection risk on the exchanges and widens their bid-ask spreads (Proposition 0). The three proposed blockchains would therefore undermine liquidity on the exchanges, in contrast to the aim of policymakers to encourage trading on exchanges (as Dodd-Frank and MiFID II suggest).

6 Empirical Evidence

We use US equities data to document (1) substantial OTC market share in US-listed equities and (2) a positive correlation between the exchange market share and the exchange quoted spread predicted by Proposition 1. We then summarize the evidence related to our mechanism. The evidence is broadly consistent with our theory.

6.1 Exchange Market Share for US-listed Equities

Does OTC trading dominate only for historically OTC traded assets such as bonds? Figure 7 plots the average weekly exchange market share of US-listed equities from January

2, 2017 to March 5, 2021. It shows that even among US-listed equities, many are OTC dominated while much of the remainder exhibit large OTC market shares. We compute each ticker's weekly share of volume traded on exchanges ("exchange market share") by subtracting the (weekly) OTC trade volume reported by the Financial Industry Regulatory Agency (FINRA) from the aggregate trade volume by Trade-and-Quote (TAQ). We exclude exchange-traded funds and tickers that do not exist in both the first and the last weeks of the sample period. Only the trades during market hours are included to avoid an upward bias for OTC market share. (Results are nearly identical if all trades are included). The final data consists of 3,210 tickers observed over 218 weeks. Appendix B details the data and our variables, and presents the summary statistics.

6.2 Correlation between Exchange Market Share and Spread

Proposition 1 Part (c) predicts a positive correlation between exchange market share and the exchange quoted spread *if* the observations vary substantively in the mass of informed traders μ but not in label precision (θ, γ). We estimate the correlation within a narrow asset class, controlling for time fixed effects. Precisely, we partition US exchange-listed equities into quintiles by average weekly dollar volume and estimate the correlation within each quintile. Our empirical assumption is that across stocks within each dollar volume quintile in a given week, (i) the amount of available information about their individual traders (for example, the type of firm, reputation, past disclosures) is similar, so their label accuracies are also similar, and (ii) there is idiosyncratic variation in adverse selection risk (from, say, ticker-specific news).

We compute the percent quoted spread on exchanges ("quoted spread" or "percent quoted spread") as the time-weighted best bid-ask spread normalized by the contemporaneous mid-price for each ticker i in each week w from millisecond TAQ quotes. Table 1 presents the regression estimates for log exchange market share on log quoted spreads.[23] All regressions

[23] Bogousslavsky and Collin-Dufresne (2022) report a positive correlation between aggregate turnover and the bid-ask spread. We examine the intensive margin of *where* trades occur and necessarily distinguish between the trades on exchanges versus over-the-counter. They examine the extensive margin of *how much* trading occurs in the aggregate. In fact, we control for aggregate volume—we find a positive correlation between exchange market share and the quoted spread *conditional on* aggregate volume.

Table 1: Dependent Variable: log(Exchange Market Share)

Observations are weekly and include 3,210 non-ETF US-listed tickers that exist in both the first and the last weeks of the 218 weeks in the sample, from January 2, 2017 to March 5, 2021. Trades outside of market hours are excluded. Standard errors are clustered at the ticker level. Corresponding t-statistics are shown in parentheses. *, **, and *** denote significance at the 10%, 5%, and 1% level.

Independent Variables	Quintile 1			Quintile 2			Quintile 3		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
log(percent quoted spread)	0.074***	0.076***	0.072***	0.046***	0.144***	0.069***	0.061***	0.143***	0.077***
	(11.61)	(11.05)	(11.66)	(4.32)	(15.57)	(7.52)	(3.62)	(10.10)	(5.71)
log(dollar volume)		0.005			0.129***			0.125***	
		(0.89)			(24.39)			(18.90)	
log(number of trades)			0.029***			0.123***			0.150***
			(5.74)			(19.27)			(14.49)
Week FE	Yes								
R^2	0.059	0.059	0.068	0.027	0.168	0.182	0.029	0.140	0.208
N	137,453			139,184			139,010		

Independent Variables	Quintile 4			Quintile 5		
	(10)	(11)	(12)	(13)	(14)	(15)
log(percent quoted spread)	0.087***	0.131***	0.095***	0.028***	0.038***	0.044***
	(5.74)	(9.65)	(8.16)	(2.61)	(2.98)	(3.20)
log(dollar volume)		0.095***			0.014	
		(10.30)			(1.57)	
log(number of trades)			0.146***			0.034***
			(13.08)			(2.83)
Week FE	Yes					
R^2	0.074	0.146	0.273	0.051	0.056	0.078
N	139,273			139,383		

control for week fixed effects, thus our estimates capture cross-sectional variation. Standard errors are clustered at the ticker level. Under each quintile, the left-most regression has no controls. Consistent with Proposition 1 (c), for every quintile, the correlation between log exchange market share and log quoted spread is positive. Our results do not depend on covid or other time-varying shocks common across tickers, due to the week fixed effects.

We examine if our results are genuinely separate from the illiquidity explanation described in the introduction and, if so, whether the effect of our mechanism on exchange market share is in the same magnitude as the liquidity effect. To this end, the other regressions in Table 1 each controls for one of two proxies for liquidity, namely, log weekly total dollar volume (“dollar volume”) or log weekly total number of trades. It shows that the quoted spread is positively correlated with the exchange market share independently of liquidity—if anything, the coefficient estimates for quoted spread become larger once we control for liquidity. That is, our findings are not explained by more liquid tickers being easier to trade on exchanges. Furthermore, the coefficient estimates for the quoted spread and the liquidity proxies are in the same magnitude. These findings suggest that our mechanism (of venue choice driven by adverse selection risk) is not second order to the typical illiquidity explanation.

6.3 Further Evidence

Table 2: Asset Types by Primary Trading Venue

Primarily OTC Traded	**Primarily Exchange Traded**
Corporate bonds	Listed equities (Tuttle, 2014)
Municipal bonds	Equity options
Government bonds	(Nybo, Sears and Wade, 2014)
Credit default swaps	Government bond futures
(Riggs, Onur, Reiffen and Zhu, 2018)	Exchange-traded funds
Interest rate swaps (Nagel, 2016)	(Stafford, 2016)
Repos (Han and Nikolaou, 2016)	
Foreign exchange	

Asset types are categorized as in Duffie (2012, Chp. 1) unless followed by a citation. The latter are categorized as in the cited paper.

Informed trading and OTC dominance

The key intuition behind Proposition 1 is that a higher share of volume is traded over the counter if a lower fraction of traders pose adverse selection risk. We present here three bits of anecdotal evidence that broadly support our mechanism. First, a pattern emerges in which the more OTC-traded assets have less informative prices. Table 2 lists mostly OTC-traded assets on the left and mostly exchange-traded assets on the right. Evidence points to the right-side assets having more informative prices than the left-side assets. Trades are rarely informative in corporate bonds (Oehmke and Zawadowski, 2017) and repurchase agreements (Han and Nikolaou, 2016). Stock prices predict corporate bond prices more often than vice versa (Gebhardt, Hvidkjaer and Swaminathan, 2005, Downing, Underwood and Xing, 2009,

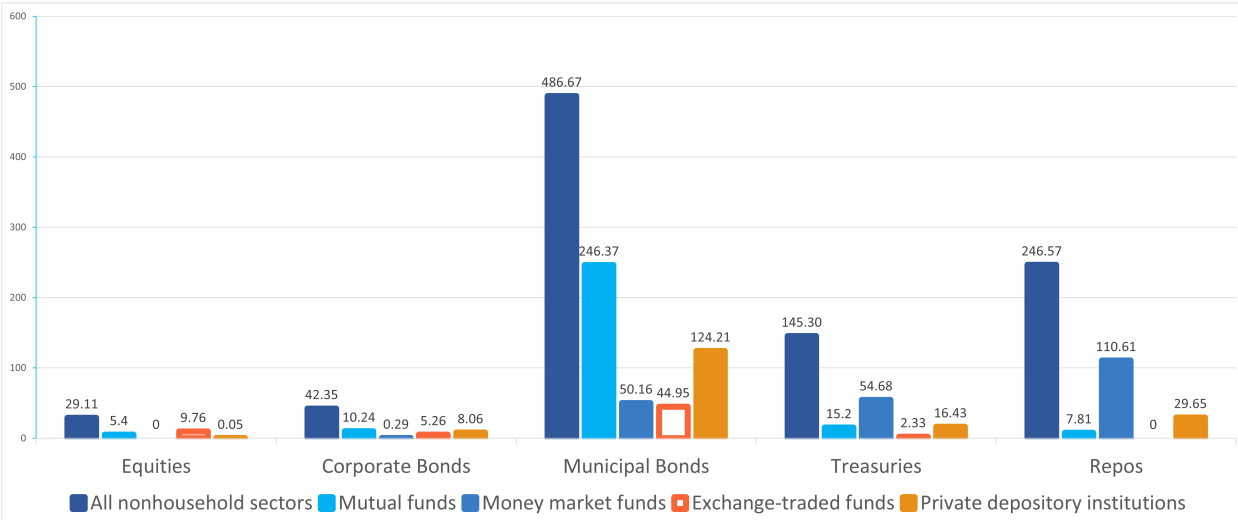

Figure 8: Ratio of Dollar Volume of given Type to Dollar Volume of Hedge Funds

Hong, Lin and Wu, 2012), and the bulk of price discovery in government bonds occur in the futures rather than the spot market (Upper and Werner, 2002, Campbell and Hendry, 2007, Mizrach and Neely, 2008). Further, equity options are more OTC-traded than equities (42% vs 17%; Tuttle, 2014, Nybo et al., 2014); and indeed, equity prices predict option prices and not the reverse, despite the larger trade volume of options (Chakravarty, Gulen and Mayhew, 2004, Muravyev, Pearson and Broussard, 2013). A caveat is that not all price discovery occurs through informed trading (Brogaard, Hendershott and Riordan, 2019). We complement the indirect evidence from price discovery with cross-asset observations on the amount of informed trading.

Figure 8 contains suggestive evidence that informed traders are less active in the more OTC-dominated assets. The US National Income Accounts report quarterly dollar value of trades by various types of institutions for US equities, corporate and municipal bonds, Treasuries, and repos. In Figure 8, each bar represents the ratio of the dollar volume by a given type of institution to the dollar volume by hedge funds in an asset class during the year from 2020Q4 to 2021Q3, the latest available quarter at the time of this analysis. We show all institutions ("All nonhousehold sectors") and the four largest institution types, and exclude households, who typically cannot access any asset beyond equities. Solid bars mark the institution types whose ratio to hedge funds is lower in equities than in each of the four OTC-dominated assets; the outlined bar marks otherwise.

Using hedge funds as a proxy for informed traders, taller bars indicate less informed trading. The dark blue bars (All nonhousehold sectors in Figure 8) suggest informed traders are proportionally far less active in OTC-dominated assets than in equities.[24] The other bars show mutual funds, money market funds, and deposit-taking banks driving this aggregate pattern. The latter two consist of uninformed traders, because money market funds and deposit-taking banks are tightly restricted from speculative trading by fiduciary duty and the Volcker Rule. The mutual funds' ratios to hedge funds in equities is not-so-decisively lower than the ratios in the OTC-dominated assets, especially for Treasuries and repos, perhaps since mutual funds include (likely informed) active funds and (likely uninformed) passive funds. Exchange-traded funds similarly include active and passive funds, and its ratio to hedge funds has a mixed pattern, where its ratio is lower in equities than in municipal bonds but higher than in other OTC-dominated assets. These patterns are broadly consistent with the OTC-dominated assets attracting relatively fewer informed traders than equities.

Third, the migration of most corporate bond trades from exchanges to the OTC market coincides with a sudden, exogenous halt to speculative trading. Biais and Green (2007) show that the proportion of corporate bond trading on NYSE falls sharply in the 1930s and 40s. Meanwhile, the proportion of corporate bonds held by institutions greatly increased, especially by insurance companies and pension funds. Homer (1975), a brokerage president in the 1930s, delivers a first-hand account of this transition. Pre-1930s, the corporate bond traders were primarily, "small, country investors or big-city investors," (Homer, 1975, p. 379) trading on the NYSE. Particularly active were sophisticated traders who often "grabbed up" new issues that, "if well priced they sold at quick premiums" (Homer, 1975, p. 379). The Great Depression pushed out such traders from the corporate bond market en-masse. It became instead, "almost wholly an institutional business," in which dealers bought at fire-sale prices from distressed investors then resold them to life insurance companies (Homer,

[24]Caution is in order: for each type of institution, within quarter and asset class, the National Income Accounts net out buys and sells. One concern is that the hedge funds' volume is especially underestimated, as they often keep little inventory. But this underestimation would merely scale down the bars in Figure 8 and leave our analysis intact. We believe it is unlikely that the netting introduces major systematic bias.

1975, p. 381). Unlike the previously dominant types of traders, these insurers preferred to trade over the counter although, "[t]he exchange tried hard to retain its bond business" (Homer, 1975, p. 381). On the whole, this history of corporate bond trading mirrors our mechanism that more uninformed trading (lower μ) leads to higher OTC market share.

Price discrimination by dealers

The driving mechanism in our model is that the dealer price discriminates in favor of those less likely to be informed. A testable implication is that OTC trades are less informative and less costly. Are they true? We find support in the large "upstairs" trading literature. (Upstairs trades are the OTC trades of stocks.) Rose (2014) compares limit order book (LOB) and upstairs trades on the Australian Stock Exchange, and finds that the LOB trades earn a profit on average while the upstairs trades make a loss. Moreover, loss-making traders are more likely than others to trade upstairs and pay a lower trading cost upstairs than on the LOB. The opposite holds for profitable traders. Others in the literature also find that upstairs trades are less informative and less costly (Madhavan and Cheng, 1997, Booth, Lin, Martikainen and Tse, 2002, Bessembinder and Venkataraman, 2004, Bernhardt, Dvoracek, Hughson and Werner, 2005), and more often come from uninformed traders (Smith, Turnbull and White, 2001, Westerholm, 2009). These results are not driven by larger traders, who may obtain better prices, concentrating in the upstairs market. In fact, the upstairs discount is decreasing in trade size (Westerholm, 2009) or is smaller for large orders than medium-sized ones (Bernhardt et al., 2005). As a direct evidence for our mechanism, Collin-Dufresne, Junge and Trolle (2020) finds substantial variation in dealers' index credit default swap pricing which is explained by the dealers charging higher spreads to traders who seem to be informed. The findings echo our mechanism that dealers price discriminate according to a trader's likelihood of being informed.

Liquid and standardized swaps

Collin-Dufresne et al. (2020) also documents the existence of informed trading in index CDS, an OTC-dominated asset class. This finding is consistent with our assumption of imperfectly informative labels. Without a comparison to another asset class, they cannot establish whether the level of informed trading is high or low in index CDS. Few studies do compare the information content of index CDS to other assets, and are divided on if index CDS prices lag behind (underlying) equity indices (Byström, 2006, Fung, Sierra, Yau and Zhang, 2008) or if the relationship is mixed (Procasky, 2020). Likewise, the evidence is split on whether interest rate swap (IRS) spreads lag interest rate future prices (Poskitt, 2007) or can lead during overnight trading (Frino and Garcia, 2018). Looking at (generally illiquid) single-name CDS, a large empirical literature remains divided on if CDS spreads lag equity prices (Hilscher, Pollet and Wilson, 2015, Zimmermann, 2021) or lead (Marsh and Wagner, 2016, Lee, Naranjo and Velioglu, 2018). Theory predicts index CDS trades to contain substantially less information than single-name CDS trades, due to the "information destruction effect" of pooling (DeMarzo, 2005). Broadly, it is an open question whether liquid, standardized, and OTC-dominated swaps (say, index CDS and IRS) attract mostly hedging-motivated traders as our theory predicts.

7 Conclusion

We show that closing the OTC market can improve utilitarian welfare, under the conservative setup of competitive pricing in the OTC market. In practice, search frictions and the dealers' market power hamper price competition in OTC markets. As OTC trading moves onto electronic platforms, such frictions are dissipating (Hendershott and Madhavan, 2015, O'Hara and Alex Zhou, 2021, Hau, Hoffmann, Langfield and Timmer, 2021). Price discrimination by the dealers remains a fundamental feature of OTC trading. We show this price discrimination leads to the OTC dominance of liquid and standardized assets that largely attract traders who pose a low adverse selection risk. However, for precisely those assets, closing the OTC markets would *raise* welfare due to cheap substitution.

While the competitive pricing assumption in the OTC market underlines the strength of our results, that our price on the exchange is competitive takes away from it. Our model misses out on some important sources of inefficiency on exchanges. For example, we do not consider how price impact (Vives, 2011) or sniping by fast traders (Budish, Cramton and Shim, 2015) might interact with the choice between trading over the counter or on the exchange. We view fixing the inefficiencies of exchanges as a separate question from whether the OTC market should be closed. Those inefficiencies can be addressed by improving the design of exchanges as several studies propose.[25] Moreover, these inefficiencies of exchanges dissipate when more low-(adverse selection)-risk traders participate. Our theory predicts most traders of OTC-dominated assets to be low-risk, and hence suggests that the exchanges for these assets would face minimal inefficiencies once their OTC markets are closed.

Previous work show that price discovery in secondary markets affect corporate investment decisions (for example, Goldstein and Guembel, 2008). We leave for future research the analysis of price discovery in the presence of an exchange and an OTC market for two reasons. In our model, a focus on price discovery *within* each market is an uninteresting one—higher the informed ratio β in the market, better is its price discovery. On the other hand, analyzing *aggregate* price discovery would require a stance on exactly how the quotes and transaction prices in the two markets are incorporated into the aggregate price discovery measure. For instance, specific price disclosure rules would determine the relative availability and importance of the trade prices over the counter versus those on the exchange.

[25] Malamud and Rostek (2017), Chen and Duffie (2021) show that optimal market fragmentation can address price impact, and Budish et al. (2015) proposes frequent batch auctions to resolve sniping by fast traders.

Appendix

A Proofs

A.1 Proofs for Section 2.3

Proof of Proposition 0. Part (a): It suffices to show that there exists at least one solution to the zero profit condition (5) so that $S(\beta)$ is well defined. We use Figure A.9, which plots the market maker's payoff $s[1-F(s)]-(2\alpha-1-s)^+\beta$ over the spread s. The payoff curve is continuous. Her payoff is negative at $s=0$, as she is adversely selected yet has no revenue. It is positive at $s=2\alpha-1$, as she breaks-even on the trades against the informed and profits on the uninformed. The Intermediate Value Theorem implies that there exists at least one solution to the zero profit condition. The smallest solution $S(\beta)$ is thus well defined.

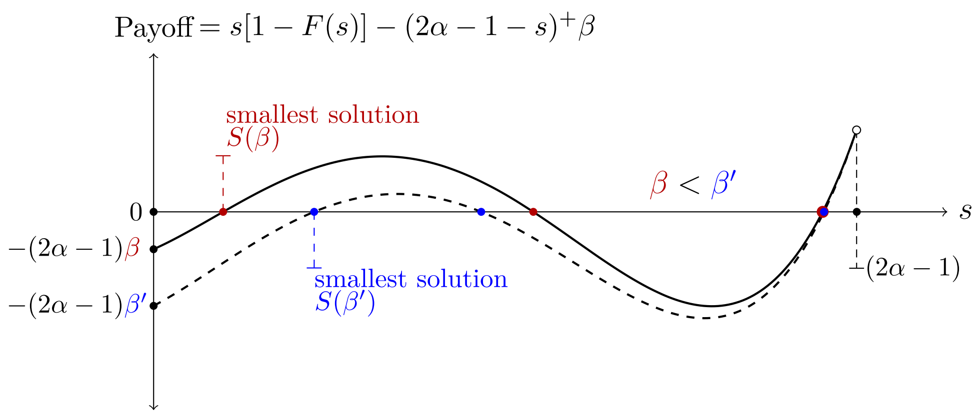

Figure A.9: Finding the equilibrium spread

Part (b): We proceed in three steps. First, we show that the spread function $S(\beta)$ is increasing in the informed ratio $\beta\in[0,\infty)$. We see this easily in Figure A.9: increasing β (to β') shifts the entire payoff curve downwards and the crossing point $S(\beta)$ to the right. Intuitively, as the informed traders impose losses on the market maker,more informed traders requires a higher spread for the market maker to break-even.

Second, we solve for the spreads in the OTC market. All traders with the same label share the same OTC spread, because they are indistinguishable to the dealer. For an LU-trader, the equilibrium OTC spread is $S(\beta_{\text{LU}})$, where β_{LU} is the informed ratio of the LU-traders. As LU-traders consist of $(1-\theta)\mu$ informed and γ uninformed traders, their OTC spread is $S\left(\frac{1-\theta}{\gamma}\,\mu\right)$. Similarly, the LI-traders' OTC spread is $S\left(\frac{\theta}{1-\gamma}\,\mu\right)$.

Third, we turn to the exchange spread S_{E}. If the market maker sets $S_{\text{E}} \in (S(\beta_{\text{LU}}), S(\beta_{\text{LI}})]$, all LU-traders choose the OTC market, whereas all LI-traders choose the exchange. Then the informed ratio on the exchange $\beta_{\text{E}} = \beta_{\text{LI}}$. The market maker thus earns zero profit if and only if she sets $S_{\text{E}} = S(\beta_{\text{LI}})$ in this case. If the market maker sets $S_{\text{E}} \le S(\beta_{\text{LU}})$, then every trader chooses the exchange, implying $\beta_{\text{E}} = \mu > \beta_{\text{LU}}$, and thus the market maker earns a non-zero profit. Therefore in equilibrium, *(i)* the exchange spread is $S_{\text{E}} = S(\beta_{\text{LI}}) = S\left(\frac{\theta}{1-\gamma}\,\mu\right)$, the lowest spread that earns the market maker a zero profit, and *(ii)* all LU-traders choose the OTC market, whereas all LI-traders choose the exchange. □

Proof of Proposition 1. We prove Parts (b) and (c), and use Part (c) to prove Part (a).
Part (b): The proof of Proposition 0 Part (b) showed that the spread function $S(\beta)$ is strictly increasing in the informed ratio β. Since $\beta_{\text{O}} < \beta_{\text{E}}$, then $S_{\text{O}} < S_{\text{E}}$.
Part (c): The ratio $V_{\text{E}}/V_{\text{O}}$ equals

$$\frac{V_{\text{E}}}{V_{\text{O}}} := \frac{(1-\gamma)(1-S_{\text{E}}) + \theta\mu}{\gamma(1-S_{\text{O}}) + (1-\theta)\mu}$$

The derivative of $V_{\text{E}}/V_{\text{O}}$ with respect to μ is positive if and only if

$$\frac{-\frac{\gamma}{1-\theta}\frac{\partial S_{\text{O}}}{\partial \mu} + 1}{\frac{\gamma}{1-\theta}(1-S_{\text{O}}) + \mu} < \frac{-\frac{1-\gamma}{\theta}\frac{\partial S_{\text{E}}}{\partial \mu} + 1}{\frac{1-\gamma}{\theta}(1-S_{\text{E}}) + \mu}. \tag{A.1}$$

It suffices to show that

$$\frac{\gamma}{1-\theta}(1-S_{\text{O}}) > \frac{1-\gamma}{\theta}(1-S_{\text{E}}) > 0, \tag{A.2}$$

$$\text{and} \quad \frac{1-\gamma}{\theta}\frac{\partial S_{\text{E}}}{\partial \mu} < \frac{\gamma}{1-\theta}\frac{\partial S_{\text{O}}}{\partial \mu} < 1. \tag{A.3}$$

Inequality (A.2) follows from $\gamma/(1-\theta) > (1-\gamma)/\theta > 0$ and $S_{\text{O}} < S_{\text{E}} < 2\alpha - 1 < 1$. One can show that $S(\beta)$ is strictly concave. Then (A.3) follows as

$$\frac{1-\gamma}{\theta}\frac{\partial S_{\mathrm{E}}}{\partial \mu} = S'\left(\frac{\theta}{1-\gamma}\mu\right) < S'\left(\frac{1-\theta}{\gamma}\mu\right) = \frac{\gamma}{1-\theta}\frac{\partial S_{\mathrm{O}}}{\partial \mu}$$
$$< S'(0) = 2\alpha - 1 < 1.$$

Part (a): We fix some $\underline{O} \in (0,1)$ and for any $\mu > 0$, we let

$$A(\mu) = \{(\theta,\gamma) : V_{\mathrm{O}}/V > \underline{O}\}.$$

There exists some (θ,γ) such that $\theta+\gamma > 1$, $\theta > 0$, $\gamma > 0$, and V_{O}/V is arbitrarily close to 0 or 1. For example, one can let $(\theta,\gamma) \approx (1,0)$, which results in $V_{\mathrm{O}}/V \approx 0$. Similarly, letting $(\theta,\gamma) \approx (0,1)$ would lead to $V_{\mathrm{O}}/V \approx 1$. By the Intermediate Value Theorem, there exists (θ,γ) such that the OTC market share V_{O}/V is equal to any arbitrary value in $(0,1)$. Thus, the set $A(\mu) \neq \varnothing$. Since the OTC market share V_{O}/V is strictly increasing as μ decreases for given (θ,γ), then the set $A(\mu)$ is strictly expanding as μ decreases. □

A.2 Proofs for Section 3

We proceed with the proofs in reverse order. We prove Proposition 4 for when the label accuracy θ falls, then show that closing the OTC market is equivalent to reducing θ to complete the proof. Applying Proposition 4 to the case $F = \mathbb{U}[0,1]$ proves Proposition 5.

The proof of Proposition 0 showed that the spread function $S(\beta)$ is increasing. As $S(\beta)$ is also left-continuous in β, then $S(\beta)$ is left differentiable. We let $S'(\beta)$ be the left derivative. Marginal volume Δ_V and marginal welfare Δ_W as in (6) and (7) are thus well defined.

Proof of Proposition 4. To prove Proposition 4 Parts (a) to (c), we first prove Part (d) which varies the label accuracy θ while the OTC market is open. Then we show that Proposition 4 (a)-(c) are a special case of Part (d).

Part (d): The change in aggregate trade volume V as the label accuracy θ falls from θ_1 to

θ_0 is

$$\underbrace{(1-\gamma)\int_{S\left(\frac{\theta_0}{1-\gamma}\mu\right)}^{S\left(\frac{\theta_1}{1-\gamma}\mu\right)} f(s)\,\mathrm{d}s}_{\substack{\text{Entry by uninformed}\\ \text{LI-traders}}} - \underbrace{\gamma\int_{S\left(\frac{1-\theta_1}{\gamma}\mu\right)}^{S\left(\frac{1-\theta_0}{\gamma}\mu\right)} f(s)\,\mathrm{d}s}_{\substack{\text{Exit by uninformed}\\ \text{LU-traders}}}$$

equal to

$$(1-\gamma)\int_{\frac{\theta_0}{1-\gamma}\mu}^{\frac{\theta_1}{1-\gamma}\mu} \Delta_V(\beta)\,\mathrm{d}\beta - \gamma\int_{\frac{1-\theta_1}{\gamma}\mu}^{\frac{1-\theta_0}{\gamma}\mu} \Delta_V(\beta)\,\mathrm{d}\beta. \tag{A.4}$$

Weighting (A.4) by the hedging benefit, we find the change in welfare

$$(1-\gamma)\int_{\frac{\theta_0}{1-\gamma}\mu}^{\frac{\theta_1}{1-\gamma}\mu} \Delta_W(\beta)\,\mathrm{d}\beta - \gamma\int_{\frac{1-\theta_1}{\gamma}\mu}^{\frac{1-\theta_0}{\gamma}\mu} \Delta_W(\beta)\,\mathrm{d}\beta. \tag{A.5}$$

The proofs are intuitive with the aid of graphs. Figure A.10 plots a generic Δ_W. We first show that Δ_W begins at $\Delta_W(0) = 0$ from which Δ_W strictly increases before eventually strictly decreasing to zero. When $\beta = 0$, $S(0) = 0$ and so $\Delta_W(0) = 0$. As β becomes large, $S(\beta)$ approaches $2\alpha - 1$, then

$$S'(\beta) = \frac{1}{\beta'(S(\beta))} = \frac{2\alpha - 1 - S(\beta)}{\frac{(2\alpha-1)[1-F(S(\beta))]}{2\alpha-1-S(\beta)} - S(\beta)f(S(\beta))} \xrightarrow{\beta\to\infty} 0$$

and thus $\Delta_W(\beta) \to 0$ as $\beta \to \infty$. One can verify that $\ln(\Delta_W)$ is differentiable in a neighborhood of $\beta = 0$ and

$$(\ln \Delta_W)'(\beta) = \left(\ln(S')\right)'(\beta) + S'(\beta)\left(\frac{1}{S(\beta)} + \frac{f'(S(\beta))}{f(S(\beta))}\right) \xrightarrow{\beta\downarrow 0} \infty.$$

Thus, $\ln(\Delta_W)$ is strictly increasing in a neighborhood of $\beta = 0$. That is, there exists some $\underline{\beta} > 0$ below which Δ_W is strictly increasing. By a similar argument, there exists some $\bar{\beta} > \underline{\beta}$, above which $\Delta_W(\beta)$ is strictly decreasing. Altogether, Δ_W begins at $\Delta_W(0) = 0$ from which Δ_W strictly increases before eventually strictly decreasing towards the lower limit of zero.

We define $\underline{\mu}$ such that $\frac{\theta_1\mu}{1-\gamma} = \underline{\beta}$ (see Figure A.10). If $\mu = \underline{\mu}$, the second term in (A.5)

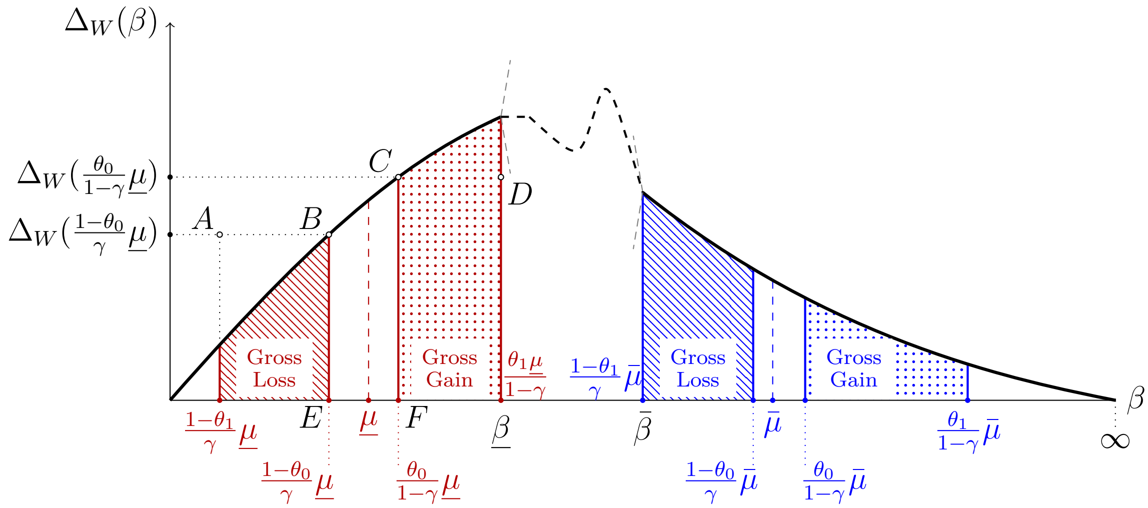

Figure A.10: Generic Δ_W

(marked "Gross Loss" in red) has a strict upper bound

$$\gamma \cdot \left(\frac{1-\theta_0}{\gamma}\underline{\mu} - \frac{1-\theta_1}{\gamma}\underline{\mu} \right) \cdot \Delta_W \left(\frac{1-\theta_0}{\gamma} \right) = (\theta_1 - \theta_0) \cdot \underline{\mu} \cdot ||\overline{BE}|| > 0,$$

which corresponds to the area ABE in Figure A.10 scaled by the mass γ of uninformed LU-traders. The first term in (A.5) (marked "Gross Gain" in red) has a strict lower bound

$$(\theta_1 - \theta_0) \cdot \underline{\mu} \cdot ||\overline{CF}||$$

marked by the area CDF. Since the segment $\overline{CF}$ is longer than $\overline{BE}$ (because Δ_W is strictly increasing in $\beta \in [0, \underline{\beta}]$), the Gross Gain in welfare is strictly larger than the Gross Loss. The same argument applies to any $\mu < \underline{\mu}$, so that closing the OTC market raises welfare if the informed mass μ is small. Likewise, we choose $\bar{\mu}$ such that $\frac{(1-\theta_1)\bar{\mu}}{\gamma} = \bar{\beta}$ and follow analogous steps to show that the Gross Loss in welfare (in blue) is larger than the Gross Gain if the informed mass μ is large $\mu \geq \bar{\mu}$.

We next show that if Δ_W is n-shaped, there is a single cutoff on μ denoted μ^* above which a decrease in θ strictly reduces welfare and below which it strictly raises welfare. To prove this, we choose two constants $\mu_R > \mu_L > 0$ as shown in Figure A.11. We set μ_L to be the highest μ such that $\Delta_W\left(\left(\frac{(1-\theta_0)\mu}{\gamma}\right)^-\right) \leq \Delta_W\left(\left(\frac{\theta_1\mu}{1-\gamma}\right)^-\right)$ and μ_R to be the highest μ such that $\Delta_W\left(\left(\frac{(1-\theta_1)\mu}{\gamma}\right)^-\right) \leq \Delta_W\left(\left(\frac{\theta_0\mu}{1-\gamma}\right)^-\right)$, where $\Delta_W(\beta^-)$ is the left limit of Δ_W at β. For the ease of exposition only, Figure A.11 illustrates the case where Δ_W is continuous in which case $\Delta_W\left(\frac{1-\theta_0}{\gamma}\,\mu_L\right) = \Delta_W\left(\frac{\theta_1}{1-\gamma}\,\mu_L\right)$ (line $\overline{BD}$) and $\Delta_W\left(\frac{1-\theta_1}{\gamma}\,\mu_R\right) = \Delta_W\left(\frac{\theta_0}{1-\gamma}\,\mu_R\right)$ (not shown). The same proof works if Δ_W is not continuous. As Δ_W is n-shaped, we know that such μ_L and μ_R exist, and that $\mu_L < \mu_R$. We proceed in two steps: *(i)* we show that the change in welfare (A.5) is strictly positive for all $\mu < \mu_L$ and strictly negative for all $\mu > \mu_R$; and *(ii)* that (A.5) is strictly decreasing between μ_L and μ_R. Together, *(i)* and *(ii)* establish the existence of the single cutoff μ^*. For *(i)*, we only show the case where $\mu \leq \mu_L$ since the argument is symmetric in the case where $\mu \geq \mu_R$. Setting $\mu = \mu_L$, an upper bound of the second term in (A.5) ("Gross Loss" in Figure A.11) is

$$(\theta_1 - \theta_0) \cdot \mu_L \cdot \Delta_W\left(\left(\frac{(1-\theta_0)\mu_L}{\gamma}\right)^-\right) = (\theta_1 - \theta_0) \cdot \mu_L \cdot ||\overline{BE}||$$

marked $ABEJ$ in Figure A.11. This upper bound is equal to the strict lower bound—marked $CDFH$—on the first term of (A.5) ("Gross Gain"). Hence (A.5) is strictly positive. To prove *(ii)* that (A.5) is strictly decreasing over $\mu \in (\mu_L, \mu_R)$, the derivative of (A.5) with respect to μ is, written geometrically,

$$\underbrace{\left(\theta_1 \cdot ||\overline{DF}|| - \theta_0 \cdot ||\overline{GH}||\right)}_{\text{Derivate of the gross welfare gain}} - \underbrace{\left((1-\theta_0) \cdot ||\overline{BE}|| - (1-\theta_1) \cdot ||\overline{IJ}||\right)}_{\text{Derivate of the gross welfare loss}}. \tag{A.6}$$

Due to Δ_W being n-shaped and how μ_L and μ_R are chosen, both $||\overline{BE}||$ and $||\overline{GH}||$ are strictly greater than $||\overline{DF}||$ and $||\overline{IJ}||$. Then (A.6) is strictly negative. In sum, as θ decreases from θ_1 to θ_0, the change in welfare is strictly positive if $\mu \leq \mu_L$, strictly negative if $\mu \geq \mu_R$, and strictly decreasing across $\mu \in (\mu_L, \mu_R)$, which together imply that a single cutoff μ^* exists.

Lastly, we show that if Δ_V is strictly decreasing, the change in volume (A.4) is strictly negative. Figure A.12 plots a decreasing Δ_V. The second term of (A.4) ("Exiters" in

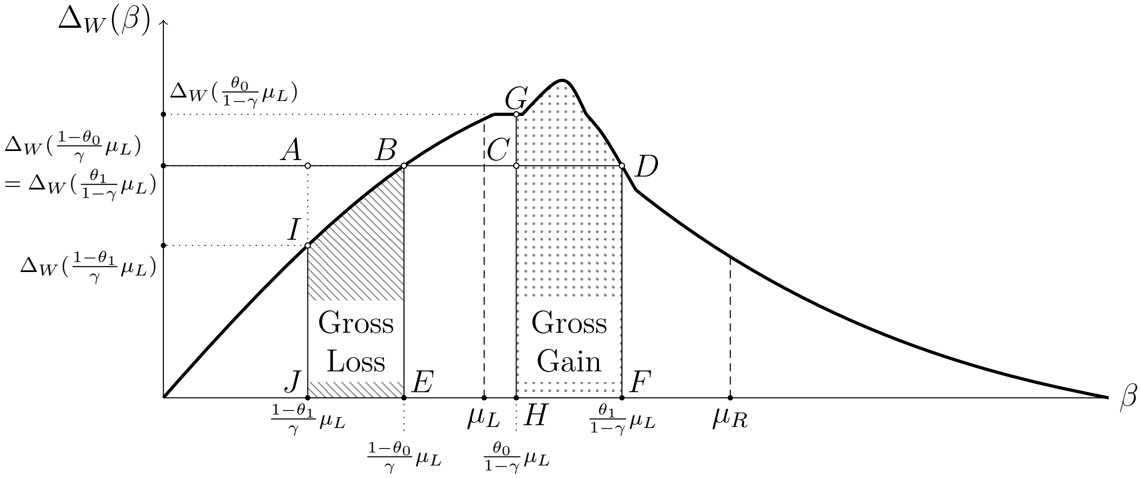

Figure A.11: "n-shaped" Δ_W

Figure A.12) has a strict lower bound

$$(\theta_1 - \theta_0)\,\mu \cdot ||\overline{BE}||$$

marked ABE, which is larger than the first term's strict upper bound ("Entrants")

$$(\theta_1 - \theta_0)\,\mu \cdot ||\overline{DF}||$$

marked CDF, and thus (A.4) is strictly negative.

Parts (a)-(c): We show that Parts (a)-(c) are a special case of Part (d). This is because Parts (a)-(c) compare the effects on welfare and on volume of closing the OTC market, which is equivalent to reducing the label accuracy θ from some level $\theta_1 > 1 - \gamma$ to the uninformative level $\theta_0 = 1 - \gamma$. $\square$

Proof of Proposition 5. The marginal welfare Δ_W can be written as

$$\Delta_W(\beta) = S'(\beta)S(\beta)f(S(\beta)) = \frac{S(\beta)f(S(\beta))}{\beta'(S(\beta))}.$$

Since the spread function $S(\beta)$ is strictly increasing in β, then $\Delta_W(\beta)$ is n-shaped if and only

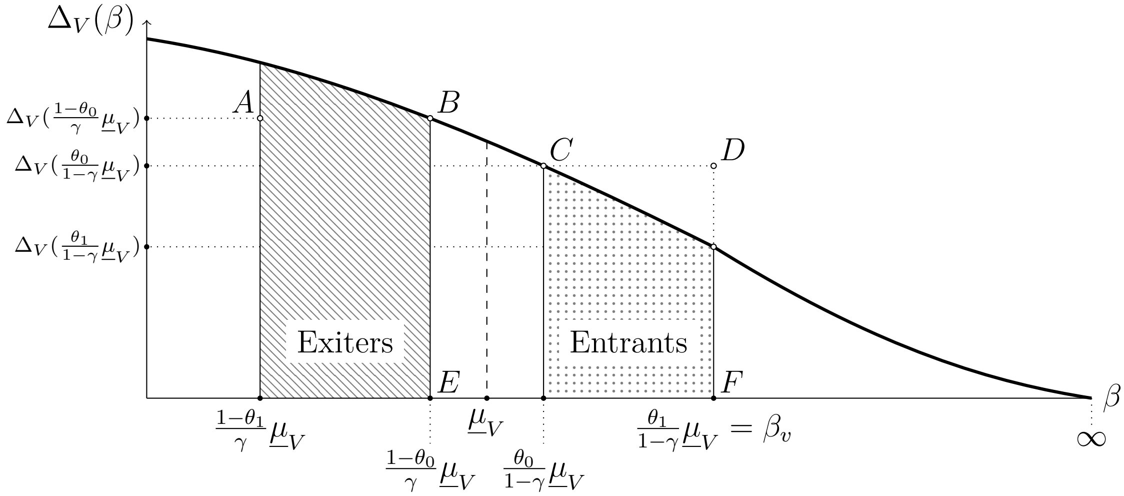

Figure A.12: Decreasing Δ_V

if $\beta'(s)/(sf(s))$ is U-shaped in $s \in (0, 2\alpha - 1)$. Differentiating (5) with respect to s yields

$$1 - F(s) + \beta - sf(s) = (2\alpha - 1 - s)\beta'(s),$$

which can be rearranged to

$$\beta'(s) = \frac{1 - F(s) + \beta - sf(s)}{2\alpha - 1 - s}.$$

From (5), we can express $\beta(s)$ as function of s:

$$\beta(s) = \frac{(1 - F(s))s}{2\alpha - 1 - s}.$$

Then marginal welfare $\Delta_W(\beta)$ is n-shaped if and only if condition (9) holds. Likewise, marginal volume $\Delta_V(\beta)$ is decreasing if and only if (10) is true. □

A.3 Proofs for Section 4

For a marginal decrease in the pigouvian tax $-dt$, the gains from trade realized in market m changes by $S_{\mathrm{m}}(t)dV_{\mathrm{m}}(t)$ ($m \in \{\mathrm{O,E}\}$). When the pigouvian tax $t = \bar{t}$, $S_{\mathrm{O}}(\bar{t}) = S_{\mathrm{E}}(\bar{t})$ by the definition of $\bar{t}$. Therefore, the net welfare change is positive if and only if the change in the aggregate volume of trade $dV_{\mathrm{O}}(t) + dV_{\mathrm{E}}(t)$ is positive. For a marginal decrease in the pigouvian tax $-dt$, the OTC volume changes by

$$dV_{\mathrm{O}}(t) = f(S_{\mathrm{O}}(t))S'_{\mathrm{O}}(t)dt,$$

and the OTC volume changes by

$$dV_{\mathrm{E}}(t) = -f(S_{\mathrm{E}}(t))S'_{\mathrm{E}}(t)dt,$$

It thus suffices to compare $S'_{\mathrm{O}}(t)$ with $S'_{\mathrm{E}}(t)$, that is to compare the sensitivity of the spreads $S_{\mathrm{O}}(t)$ and $S_{\mathrm{E}}(t)$ with respect to a change in the pigouvian tax t. Taking the derivatives in (12) and (13) with respect to t gives

$$1 = [\beta_{\mathrm{O}} + 1 - F(S_{\mathrm{O}}(t)) - S_{\mathrm{O}}(t)f(S_{\mathrm{O}}(t))]\, S'_{\mathrm{O}}(t),$$
$$1 = [\beta_{\mathrm{E}} + 1 - F(S_{\mathrm{E}}(t)) - S_{\mathrm{E}}(t)f(S_{\mathrm{E}}(t))]\, S'_{\mathrm{E}}(t).$$

When $t = \bar{t}$, $S_{\mathrm{O}}(\bar{t}) - S_{\mathrm{E}}(\bar{t})$. Since the informed ratio is higher in the OTC market than in the exchange market, $\beta_{\mathrm{O}} > \beta_{\mathrm{E}}$, thus $S'_{\mathrm{O}}(\bar{t}) > S'_{\mathrm{E}}(\bar{t}) > 0$. That is, the OTC spread $S_{\mathrm{O}}(t)$ is more sensitive than the exchange spread $S_{\mathrm{E}}(t)$ to a marginal change in the pigouvian tax around $\bar{t}$. Therefore, the aggregate volume increases $dV_{\mathrm{O}}(\bar{t}) + dV_{\mathrm{E}}(\bar{t}) > 0$ for a marginal decrease in the pigouvian tax $-dt$.

We work with the uniform distribution $f = \mathrm{Unif}[0, 1]$. We show that for a marginal decrease $-dt$ in the pigouvian tax, the marginal net change in welfare is positive when $t > t^*$ and negative when $t < t^*$ for some optimal level of tax $t^* < \bar{t}$. The marginal net change in welfare is positive if and only if

$$|\frac{S_O(t)dV_O(t)}{S_E(t)dV_E(t)}| > 1.$$

$$S_O(t)dV_O(t) = \frac{S_O(t)}{\beta_O + 1 - 2S_O(t)}dt = \frac{1}{\frac{\beta_O+1}{S_O(t)} - 2}dt.$$

$$\frac{1}{|S_E(t)dV_E(t)|} = \frac{\beta_E + 1 - 2S_E(t)}{S_E(t)}dt = \frac{\beta_E + 1}{S_E(t)} - 2dt.$$

Thus,

$$|\frac{S_O(t)dV_O(t)}{S_E(t)dV_E(t)}| = \frac{\frac{\beta_E+1}{S_E(t)} - 2}{\frac{1}{\frac{\beta_O+1}{S_O(t)}-2}} > 1.$$

Since the OTC spread $S_O(t)$ is increasing in t, $|S_O(t)dV_O(t)|$ is increasing in t. Likewise, $|S_E(t)dV_E(t)|$ is decreasing in t. Thus, the ratio of the two $|S_O(t)dV_O(t)/S_E(t)dV_E(t)|$ is increasing in t. Further, we showed that when $t = \bar{t}$, the ratio is larger than 1 because the cheapsubstitution effect is shut off and the volume effect is positive $|dV_O(t)/dV_E(t)| > 1$. Hence, there exists some optimal level of tax $t^* < \bar{t}$ such that the ratio is larger than 1 when $t > t^*$ and smaller than 1 when $t < t^*$.

To empirically verify whether a given tax level t is too high or too level, regulator could experiment with a local change dt in the tax, measure the volume effect $|dV_O(t)/dV_E(t)|$, and compare it against the cheapsubtitution effect $S_E(t)/S_O(t)$. If the volume effect is larger, then the tax t is too high. Otherwise, the tax is too low.

B Data, Variables, and Summary Statistics

We combine milisecond Trade-and-Quote (TAQ) quote and trade data sets with weekly OTC trade volumes from the Financial Industry Regulatory Agency (FINRA).[26] In the FINRA data, OTC volumes are separated into Alternative Trading Systems (ATS) versus Non-ATS OTC volumes. The ATS consists of dark pools, batch auctions, and limit order books that are not designated as "national securities exchanges" by the US Securities and Exchange Commissions. Since trading on the ATS is anonymous, and thus do not allow trader-specific price discrimination, the ATS correspond to the exchange in our model. The Non-ATS OTC refers to traditional bilateral and request-for-quote trades. Therefore, only the Non-ATS trades are counted as over the counter in our analysis.

The sample period is January 2, 2017–March 5, 2021, the available range of FINRA OTC data at the time of this analysis. We exclude all trades outside of market hours. Our sample consists of 3,210 US-listed non-ETF tickers that exist in both TAQ and FINRA data on

[26]FINRA data used here is available publicly at http://www.finra.org/industry/otc-transparency.

both the first and the last weeks of the 218 weeks in the sample period.

Exchange market share for ticker i and week w is 1 minus the ratio of week w OTC dollar volume of trades from FINRA to the week w aggregate dollar volume from TAQ. To compute *percent quoted spread* for ticker i and week w, we use the millisecond TAQ quotes to calculate the time-weighted percent best quoted spread, *(best offer - best bid) /midpoint*, for each day then we take the simple average across the number of days observed for ticker i in week w. The total *number of trades* and total *dollar volume* of trades are computed for each ticker i and week w from millisecond TAQ trade data. Table B.1 provides the summary statistics.

Table B.1: Summary Statistics

Each observation is one ticker for one week.

	Obs	Mean	SD	Min	25%	50%	75%	Max
	All Observations							
Exchange Market Share	694,305	0.750	0.198	0.000	0.597	0.828	0.914	1.000
Percent Quoted Spread	694,305	0.027	0.053	0.000	0.004	0.010	0.026	6.995
Dollar Volume of Trades	694,305	384.4M	2,752.6M	0.0M	3.3M	27.5M	187.2M	376,000.0M
Number of Trades	694,305	38,401	107,820	2	1,714	9,434	36,594	13,458,361
	Quintile 1 (by average weekly dollar volume of trades) Observations							
	Obs	Mean	SD	Min	25%	50%	75%	Max
Exchange Market Share	137,455	0.615	0.185	0.000	0.484	0.609	0.758	1.000
Percent Quoted Spread	137,455	0.067	0.086	0.001	0.016	0.042	0.089	6.995
Dollar Volume of Trades	137,455	1.6M	3.7M	0.0M	0.4M	0.9M	1.9M	543.8M
Number of Trades	137,455	997	3,495	2	189	474	1,027	491,416
	Quintile 2 Observations							
	Obs	Mean	SD	Min	25%	50%	75%	Max
Exchange Market Share	139,184	0.659	0.193	0.001	0.506	0.652	0.839	1.000
Percent Quoted Spread	139,184	0.037	0.055	0.001	0.011	0.022	0.044	4.943
Dollar Volume of Trades	139,184	8.3M	18.8M	0.0M	2.7M	5.4M	9.8M	1,570.1M
Number of Trades	139,184	5,240	14,348	7	1,345	2,815	5,745	950,784
	Quintile 3 Observations							
	Obs	Mean	SD	Min	25%	50%	75%	Max
Exchange Market Share	139,010	0.775	0.194	0.005	0.667	0.859	0.922	1.000
Percent Quoted Spread	139,010	0.018	0.033	0.000	0.007	0.012	0.019	3.687
Dollar Volume of Trades	139,010	37.6M	50.9M	0.0M	16.2M	27.8M	46.3M	4,236.7M
Number of Trades	139,010	14,577	25,721	5	5,120	9,755	17,342	1,986,649
	Quintile 4 Observations							
	Obs	Mean	SD	Min	25%	50%	75%	Max
Exchange Market Share	139,273	0.830	0.164	0.008	0.800	0.896	0.935	1.000
Percent Quoted Spread	139,273	0.008	0.012	0.000	0.003	0.005	0.009	0.487
Dollar Volume of Trades	139,273	153.5M	153.4M	0.0M	72.2M	119.7M	194.3M	14,100.0M
Number of Trades	139,273	32,783	36,820	59	14,249	25,524	41,738	3,485,211
	Quintile 5 Observations							
	Obs	Mean	SD	Min	25%	50%	75%	Max
Exchange Market Share	139,383	0.867	0.108	0.013	0.851	0.902	0.931	1.000
Percent Quoted Spread	139,383	0.003	0.005	0.000	0.001	0.002	0.004	0.226
Dollar Volume of Trades	139,383	1,714.1M	5,957.4M	0.3M	427.1M	726.2M	1,409.3M	376,000.0M
Number of Trades	139,383	137,773	206,702	1,161	51,324	86,649	153,925	13,458,361

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