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Information Asymmetries and Security Market Design: An Empirical Study of the Secondary Market for U.S. Government Securities

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ABSTRACT

This paper examines the empirical implications of an information asymmetry between primary and secondary dealers in the U.S. Government Securities market. This asymmetry arises because primary dealers are permitted to trade through *all* brokers operating in the marketplace while secondary dealers are restricted to trade through only a *subset* of brokers. Brokers distribute valuable information over video screens to their trading clients including dealers' up-to-date bid-ask spreads and recent transaction prices. As such, *all* brokers' video screen information is available to primary dealers, while only a *subset* of brokers' information is available to secondary dealers. Empirical analyses detect the resulting information asymmetry.

U.S. GOVERNMENT SECURITIES ARE traded in one of the largest and most efficient asset markets in the world; they are traded worldwide, 24 hours a day. Average daily volume exceeds $40 billion. Virtually continuous auction markets exist in the most active Government Securities issues.

The U.S. General Accounting Office (GAO) is currently evaluating the existing structure of the market for U.S. Government Securities in response to a mandate of the Government Securities Act of 1986. Efforts of the GAO have addressed concerns voiced by market participants regarding the efficiency and fairness of the existing market structure in light of the U.S. Government's desire to reduce the issuance costs of its growing debt burden.

The current debate largely focuses on an asymmetry inherent in the market structure. In particular, primary dealers currently enjoy access to *all* brokers arranging trades between government securities dealers while secondary dealers are restricted to trade through a *subset* of brokers. Brokers provide their trading customers with up-to-date video information which includes dealers' bid-ask spreads and recent transaction prices. Conse-

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quently, primary dealers have access to the video screen information of *all* brokers; secondary dealers only have access to the video screen information of a *subset* of brokers. The broker information available to secondary dealers is therefore a subset of the broker information available to primary dealers. This paper attempts to determine the empirical significance of the resulting information asymmetry.

My empirical methodology can be summarized as follows. If restricted access to broker video information provides primary dealers with superior information about upcoming changes in the value of traded government securities, then 1) price expectations of secondary dealers should lag those of primary dealers and 2) secondary dealers should widen their bid-ask spreads in response to efforts of primary dealers to exploit their superior information through arbitrage. I test these implications within the context of a simple model of intraday transactions prices which parameterizes the behavior of the bid-ask spread and the lag of secondary dealer price expectations behind those of primary dealers.

Analyses of intraday series of 566 2-year note and 1931 30-year long-term bond transactions detect information asymmetries between primary and secondary dealers. Point estimates indicate that secondary dealer price expectations lag those of primary dealers and that secondary dealers post wider bid-ask spreads.

Unfortunately, this paper does not address the case of *inactive* issues due to a lack of appropriate data. The set of inactive issues consists of all Treasury securities issued before the most recently executed Treasury auction that have yet to mature. Brokers' services are *completely unavailable* to secondary dealers in the case of inactive issues even though they are readily available to primary dealers. Given that I detect information asymmetries in trading of the two inactive issues examined in this paper, it is likely that even more substantial information asymmetries exist in the case of inactive issues.

The balance of the paper proceeds as follows. Section I describes the institutional structure of the secondary market for U.S. Government Securities and highlights issues of regulatory interest. Section II provides a model of transaction price behavior in a perfectly integrated market in which all primary and secondary dealers enjoy identical access to broker trading privileges and video screen information. Section III derives statistical properties of price changes in the presence of an information asymmetry between primary and secondary dealers. Section IV describes the data. Section V provides empirical results. Section VI provides concluding comments.

I. The Secondary Market for U.S. Government Securities

This section describes the institutional structure of the secondary market for U.S. government securities and highlights issues of regulatory interest.[1]

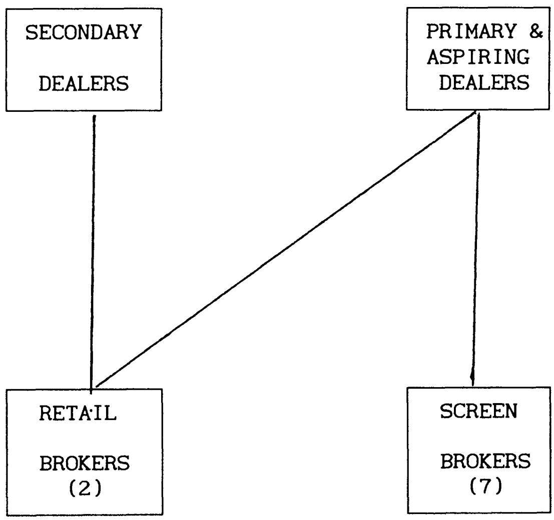
[1] This section borrows liberally from GAO (1987a).

The U.S. Treasury issues securities in the form of bills, notes, and bonds to refinance debt, to raise new funds to finance deficits, and to manage the Government's cash flow. As the fiscal agent of the Treasury, the Federal Reserve auctions Treasury securities to the public. The majority of initial purchasers of these securities are large banks and securities firms which operate as Government Securities dealers. These dealers purchase securities for their own portfolios, on behalf of their customers, or for resale in the secondary market. Dealers participating in issuance auctions are referred to as primary dealers.

Once purchased, Government Securities can be resold in the secondary market. The secondary market performs two basic functions. First, it distributes debt to private investors. These investors include state and local governments, insurance companies, banks, pension funds, other financial institutions, as well as individual investors. Second, the secondary market facilitates the resale of Government Securities when these investors decide to alter their Government Securities portfolios. See Figure 1.

Interdealer Broker Access in the

Secondary Market for US Government Securities



——— Denotes Trading / Screen Access

Figure 1.

Dealers

There are three categories of dealers participating in the secondary market for U.S. Government Securities—primary dealers, aspiring primary dealers, and secondary dealers. Primary dealers are dealers that participate in the issuance auctions in which Treasury securities are initially sold. Dealers volunteer to become primary dealers and in turn are required to meet certain financial standards as well as provide information to the Federal Reserve Bank of New York (FRBNY) needed to monitor compliance with these standards. To maintain their status as primary dealers, these dealers must also participate actively in issuance auctions and open market operations. There were in total 40 primary dealers when the data for this study were collected.

Aspiring primary dealers, the second category, are dealers undergoing FRBNY evaluation as potential primary dealers. This evaluation procedure typically lasts over a year, after which most aspiring dealers are granted primary dealer status. Aspiring primary dealers are not required to maintain any official FRBNY-mandated financial standards during the period of evaluation nor are they required to participate in Treasury securities issuance auctions. There were in total 13 aspiring primary dealers when the data for this study were collected.

Secondary dealers comprise the third category. For the purposes of this study, this category consists of all dealers that trade in the secondary market that are neither primary nor aspiring primary dealers. The category of secondary dealers thus includes securities firms, banks, pensions funds, state and local governments, financial institutions, and individual investors. There were several hundred secondary dealers when the data for this study were collected.

Brokers

Most trading in the secondary market does not occur in a centralized place such as a stock exchange. Rather, it occurs in a decentralized network of dealers and brokers connected by telecommunications systems. Dealers either negotiate trades directly or conduct them through brokers. Brokers do not buy securities for their own account but instead specialize in arranging trades for others. Roughly 50% of total secondary market trading volume is arranged by brokers. The remaining 50% of trading volume is exchanged in direct trade between dealers.

Brokered trading can be described as follows. Each brokerage firm installs video screens in customer offices which show for each security the firm handles: 1) the maximum bid and the minimum ask of the prices submitted by its customers and 2) the quantities that can be bought or sold at these posted prices. As such, each brokerage firm posts one bid and one ask price/quantity pair for each security it handles. When trades are executed at posted prices, brokers flash transaction prices and quantities on their screens to alert customers.

If a customer finds a price on a given broker's screen attractive, he can telephone the broker and communicate his desire to initiate trade. The broker will then telephone the customer posting this price and consummate the transaction. If a customer instead prefers to post his own price on a broker's screen, he can submit a price/quantity sale (ask) or purchase (bid) pair to the broker over the telephone. If a customer submits a sale order, the broker will post the customer's price/quantity pair as long his ask price is strictly less than the single ask price for the security in question which is already posted on the broker's video screen. Likewise, if the customer submits a purchase order, the broker will post the customer's price/quantity pair at the bid as long as the submitted bid price is strictly greater than the single bid price already posted on the broker's screen. Existing prices are dropped when new postings occur. The proposed volume plays no role in determining whether a price is posted.

Submitted price/quantity pairs which do not meet these criteria are held in queue until they expire. Price/quantity pairs, whether they are held in queue or posted on the broker's video screen, expire 2 minutes after they are submitted. If a posted ask order expires while on a broker's screen, the broker replaces the expired ask order with the ask order that has the lowest ask price in his queue. Likewise, if a posted bid order expires, the broker replaces the expired bid order with the bid order that has the highest bid price in his queue. (If two orders in queue have exactly the same price the broker posts the price/quantity pair of the order which arrived first.) Prices are therefore dropped due to the 2-minute rule to post inferior prices from time to time. Neither price expiration nor posting times are provided on broker screens, so traders do not necessarily know when prices will expire.

A quoted price on a broker screen represents 1/10,000 of the actual price at which the security in question will be exchanged in the event of a trade. The broker price grid is defined in increments of 1/32, although dealers are allowed to quote prices in finer increments of 1/64 and 1/128. The face value of all traded securities is $1 million. Dealers are required to post whole-number volumes. The minimum volume which dealers can post is therefore one. As an example, a quoted price at the bid of 99 + 16/32 with an associated volume of five represents an offer to purchase five government securities with a total face value of $5 million at a price of $995,000 per security.

It is important to discuss the nature of the trading mechanism employed by brokers. The dealer posting a price/quantity pair for which trade has been initiated has the right of first refusal for additional trades at the posted price. If this dealer prefers to increase the volume of the transaction, he can communicate a proposal for a larger volume to his trading partner via the broker arranging the transaction. If the trading partner (i.e., the dealer who initiated trade in the first place) agrees, the volume of trade at the posted price will be increased to the newly proposed volume. The broker will then post the new trading volume on his screen. If the trading partner chooses not to accept the proposal to increase the volume of trade, the broker will accept offers from other dealers for the additional volume at the posted price. This process continues until the trading needs of the dealer initially posting the price/quantity pair are satisfied or no new dealers contact the broker to exchange additional transaction volumes. The final transaction volume is then posted on the broker's screen, and all trade is consummated. Due to the nature of this mechanism, dealers quite often build up transaction volumes well above originally posted volumes. For example, it is not uncommon for dealers to build up to volumes of \$30 million in face value from initially posted volumes of \$5 million.

To illustrate how brokers employ this mechanism let us take the example in which a buyer "hits" a seller's posted ask price/quantity pair of five units at 99 + 6/16. Assume the seller hopes to sell 25 units, but the buyer only wants to purchase 15 units. As the initiator of trade the buyer is required to purchase the posted quantity of 5 units. Once the buyer has initiated trade, the broker asks the seller if he would like to increase the volume. The seller responds affirmatively and proposes to increase the volume to 10. The broker posts the volume of 10 on his screen and communicates this proposal to the buyer who accepts. The broker then asks the seller is he prefers a further increase in the volume of trade. Once again, the seller responds affirmatively, the broker posts the new volume on his screen and communicates the proposal, and the buyer accepts. The broker again asks the seller if he prefers another increase. The seller in turn proposes a volume of 25, so the broker posts the volume on his screen and communicates the proposal to the buyer. The buyer refuses to increase the volume since his needs have been met. At this point the first buy order to arrive is allocated the remaining 10 units at the posted price of 99 + 6/16. If no buy order arrives within 2 minutes of the refusal of the first buyer, the broker imposes the 2-minute rule and drops the sell order from his screen.

As compensation for his services, buyers and sellers each pay the broker 1/6400 of the face values of arranged transactions. Charges are levied only on transacted volumes; posting orders and placing orders in queue are free of charge.

All brokerage activity is *anonymous*. Brokers do not divulge the identities of dealers who have executed transactions, posted price/quantity pairs on video screens, or placed orders in queue. Dealers therefore remain uninformed of whom they've traded with until resettlement the day following the consummation of brokered transactions.

The feature of anonymity is designed to prevent strategic gaming which might otherwise arise in a transparent market in which market participants' identities are unveiled. For example, some argue that in a transparent market, participants could collectively force dealers constrained by inventory rebalancing requirements to trade at unfavorable prices.

Interdealer brokers adhere to the policy of restricting their customer bases exclusively to primary and aspiring primary dealers. The customer lists of interdealer brokers overlap considerably according to the GAO. There were in total seven interdealer brokers when the data for this study were collected.

Retail brokers serve secondary dealers as well as primary and aspiring dealers. Retail brokers indicate that secondary dealer transactions constitute the majority of their business activity.[2] There were in total two retail brokers when the data for this study were collected.

Interdealer brokers argue that they must restrict their customer base to primary and aspiring primary dealers due to the feature of anonymous trading. The argument is as follows. Interdealer brokers do not back the transactions which they arrange as principals. Individual dealers must therefore bear principal risk when they transact. This gives rise to an adverse selection problem which could lead to a breakdown of trade. In particular, due to the blind brokerage feature, dealers do not know the identities of their trading partners. They must have confidence, however, that their trading partners are creditworthy and are able to honor their trading commitments. Otherwise, in the worst case, dealers could suffer substantial losses if a trading partner were to go bankrupt and fail to honor his trades.

Interdealer brokers argue that restricting their customer base to primary and aspiring primary dealers eliminates this adverse selection problem. The financial stability of primary dealers is regularly monitored by the FRBNY in association with issuance auctions and open market operations. Although aspiring primary dealers are not formally required to meet the strict standards imposed on primary dealers, it is widely held that the FRBNY only grants aspiring primary dealer status to dealers maintaining financial standards similar to those of existing primary dealers.

Retail brokers, on the other hand, back the trades they arrange as principals. The issue of adverse selection of trading partners therefore does not arise in the case of retail broking. Of course, retail brokers attempt to limit their exposure to principal risk by restricting their customer base to dealers whom they regard as creditworthy.

Many secondary dealers maintain creditworthiness standards comparable to those of primary dealers but would find it against their interests to meet the auction participation requirements necessary to acquire primary dealer status. These dealers argue that they deserve access to interdealer broker services and that the risk of expanding interdealer broker access is minimal given how well retail broking currently functions.

Secondary dealers complain about the low quality of retail broker price information relative to interdealer broker price information. Some argue that retail broker prices fail to depict market conditions accurately due to the concentration of transacted order flows on interdealer broker screens. Others argue that transaction prices on retail screens are misleading because primary dealers "head and fake" and transact small volumes at off-the-market prices on retail screens in order to manipulate secondary dealers' price expectations. Secondary dealers also claim a disadvantage in grasping the overall market climate due to the heterogeneous information content of different brokers' video screen information.

[2] See GAO (1987a).

Furthermore, retail brokers do not arrange trades for *inactive* issues. Therefore, broker services are *completely unavailable* to secondary dealers in the case of inactive issues. The set of inactive issues consists of all Treasury securities issued before the most recently executed auction that have yet to mature.

Interdealer brokers, however, do arrange trades for inactive issues. The video screen information of the seven interdealer brokers is therefore available to primary dealers, while no broker video information is available to secondary dealers. Secondary dealers thus complain that information asymmetries between primary and secondary dealers are even larger in the case of inactive issues.

Proponents of the existing system argue against changing a stable, well-functioning market system. They argue that the quality of video screen information does not differ between interdealer and retail brokers. Some also suggest that primary dealers deserve special privileges with interdealer brokers as compensation for service as stable outlets for government debt.

II. A Simple Model of Transaction Prices

This section provides a simple model of the behavior of price changes in a perfectly integrated market. My initial set-up resembles that of Garbade and Silber (1979) but also incorporates the insights of Glosten and Milgrom (1985) and Kyle (1985) on adverse selection in financial markets.

Throughout this section and the rest of this paper, I merge the categories of primary and aspiring primary dealers defined in the previous section into the category of "primary dealers" for convenience. Because primary and aspiring primary dealers possess exactly the same privileges with interdealer and retail brokers, no effective distinction exists between the two for the purposes of the remainder of this paper.

I use the term *market center* to distinguish between the broker access privileges of primary and secondary dealers. Primary dealers and interdealer brokers comprise the primary market center; primary dealers choosing to trade through retail brokers, secondary dealers, and retail brokers comprise the secondary market center. Note that because primary dealers enjoy access to both interdealer and retail brokers, the primary and secondary market centers are not composed of mutually exclusive sets of participants.

Assume all dealers transact in a costless, frictionless environment. Let E_k be the unobservable equilibrium value of the underlying asset at the time of the kth transaction in a given day (i.e., E_k is the expectation of the security's true value conditional on information available at the time of the kth transaction). Let T_k^a be the observed transaction price of the kth transaction initiated by a *purchaser* of the security (where the superscript a represents the ask side of the market). I assume that T_k^a is the sum of E_k and α_k^a, where α_k^a is a serially uncorrelated stochastic term with mean α, a lower bound of zero, and finite variance σ_α^2; α_k^a can be loosely interpreted as an inventory cost/monopoly power component of the spread. Thus, T_k^a is:

$$T_k^a = E_k + \alpha_k^a \quad \text{for} \quad \alpha_k^a \sim \left(\alpha, \sigma_\alpha^2\right) \geq 0. \tag{1a}$$

A symmetric model applies to transactions initiated by *sellers* in the perfectly integrated market center. Let T_k^b be the observed transaction price of the kth transaction initiated by a seller (where the superscript b represents the bid side of the market). Thus, T_k^b is:

$$T_k^b = E_k + \alpha_k^b \quad \text{for} \quad \alpha_k^b \sim \left(-\alpha, \sigma_\alpha^2\right) \leq 0. \tag{1b}$$

I assume changes in true value arise due to drift or due to the incorporation of information inherent in transacted volumes. Define r as the instantaneous rate of return and Δ_k as the elapsed time between the kth and $k-1$st trades. Also define V_k as the observed volume exchanged in the kth transaction. One thus has $V_k > 0$ if transaction k occurs at the ask and $V_k < 0$ otherwise. Thus, E_k is:

$$E_k = E_{k-1} + r * \Delta_k + \lambda * V_k + p_k, \qquad E(p_k) = 0, \quad \text{and} \quad E\left(p_k^2\right) = \Delta_k * \psi \tag{2}$$

where p_k is a normally distributed, serially uncorrelated stochastic innovation which I assume is uncorrelated with the α_k^as and α_k^bs; $\psi > 0$ is a constant which represents the variance of the drift term per unit of time (measured in minutes throughout this paper); it is assumed to be independent of Δ_k; λ represents the sensitivity of dealers' assessments of underlying asset values to transacted volumes.[3,4] Readers can interpret $\lambda * V_k$ as the volume-related adverse selection component of the bid-ask spread.[5,6]

The trading mechanism characterized by equations (2) is one in which the dealer posting the kth transaction price on a broker screen knows with perfect certainty the volume V_k which he will exchange in the kth transaction. Given V_k, the dealer is thus able to forecast perfectly his revised assessment of the true value E_k. Recalling discussion from Section I, how-

[3] Simplicity and the linear equilibrium of the Kyle (1985) model motivate the assumption that the true value varies linearly with transaction volumes.

[4] Regression results suggest that λ does not depend on Δ_k. In particular, the inclusion of the regressor $\Delta_k * V_k$ does not increase the explanatory power of the models discussed estimated in the empirical section of the paper.

[5] Admati and Pfleiderer (1988) and Foster and Viswanathan (1987) suggest that λ might exhibit patterns across trading periods. In exploratory regressions with my data, however, the estimated values of λ did not vary substantially across hours of the day or days of the week. I therefore assume λ is constant in the empirical analysis of this paper.

[6] Estimates of λ in the regressions with price changes presented later in this paper may incorporate inventory adjustment costs as well as adverse selection costs. For example, market makers' inventory costs may vary linearly with transaction volumes. Such inventory costs will not contribute to the formation of E_k but will be statistically indistinguishable from the adverse selection costs depicted in equations (2). All of the tests performed in this paper remain valid if such inventory costs arise, as long as their magnitudes do not differ between primary and secondary dealers.

ever, dealers are actually uncertain about the volumes they will transact in upcoming transactions when they post prices on broker screens. This is due to the uncertain nature of negotiations in which dealers build up ultimate transaction volumes above initially quoted volumes. In an ideal specification the dealer would post the kth transaction price based on the volume he *expects* to exchange in the kth transaction. Data on expected transaction volumes of dealers posting price/quantity pairs on broker screens are of course unavailable. To the extent that realized transaction volumes V_ks differ from dealers' ex ante expectations of volumes, the specification suffers from an errors-in-variables problem.

Taking the difference between prices of two transactions executed on the ask side of the market yields:

$$\begin{aligned} T_k^a - T_{k-1}^a &= \left(E_k + \alpha_k^a\right) - \left(E_{k-1} + \alpha_{k-1}^a\right) \\ &= r * \Delta_k + p_k + \alpha_k^a - \alpha_{k-1}^a + \lambda * V_k \end{aligned} \tag{3a}$$

where $E(T_k^a - T_{k-1}^a) = r * \Delta_k + \lambda * V_k$. If the kth and $k-1$st transactions are executed on the ask and bid sides of the market, respectively, one has:

$$\begin{aligned} T_k^a - T_{k-1}^b &= \left(E_k + \alpha_k^a\right) - \left(E_{k-1} + \alpha_{k-1}^b\right) \\ &= r * \Delta_k + p_k + \alpha_k^a - \alpha_{k-1}^b + \lambda * V_k \end{aligned} \tag{3b}$$

where $E(T_k^a - T_{k-1}^b) = 2 * \alpha + r * \Delta_k + \lambda * V_k$.

Now define the dummy variable $SIDE_k$:

$SIDE_k = 1$ if the kth transaction is executed on the ask side of the market.
$= -1$ if the kth transaction is executed on the bid side of the market.

One can estimate α and λ with the following regression model:

$$T_k - T_{k-1} = \alpha * \left(SIDE_k - SIDE_{k-1}\right) + r * \Delta_k + \lambda * V_k + \epsilon_k \tag{4}$$

where $\epsilon_k = (\alpha_k - SIDE_k * \alpha) - (\alpha_{k-1} - SIDE_{k-1} * \alpha) + p_k$ and $E(\epsilon_k) = 0$. Note that I drop the superscripts a and b.

One can estimate σ_α^2 and ψ with the following regression:

$$\hat{\epsilon}_k^2 = 2 * \sigma_\alpha^2 + \Delta_k * \psi + \xi_k; \quad E\left(\xi_k\right) = 0 \tag{5}$$

where $\hat{\epsilon}_k^2$ is the squared residual calculated with estimates of α and λ from model (4). (I employ heteroscedastic-consistent, MA(1)-consistent covariance matrices in all regressions in the empirical section of this paper. As such the heteroscedastic and MA(1) components in the error structures of models (4) and (5) do not invalidate hypothesis tests.)

One interpretation of the model is as follows. Model (4) "purges" from price differences the effects of the bid-ask spread as well as the drift due to the interest rate. Policy makers can employ estimates of parameters of the bid-ask spread to assess the significance of adverse selection in the trading process. Estimates of the interest rate are less likely to be of interest, but failure to include Δ_k as a regressor could induce misspecification and contaminate regression results. Model (5) distinguishes variability in price changes attributable to the arrival of new information from that due to variation in the constant component of the spread.

If the primary and secondary dealer market centers are perfectly integrated, parameter estimates of models (4) and (5) should not depend on the market centers in which the kth and $k-1$st transactions employed to calculate $T_k - T_{k-1}$ are executed. If the market centers are unintegrated, the adverse selection parameter estimated in (4) will be larger in trades executed in the secondary market center due to the existence of wider information asymmetries. Also, the lag of secondary dealers' price expectations behind those of primary dealers will arise in estimation of (5).

Simultaneity bias may arise in models (4) and (5) due to the joint determination of trade times, prices, and volumes in the trading process. Also, as I indicated previously, measurement error exists in the V_k due to disparities between expected and realized transaction volumes. In the empirical section of this paper I address the issue of simultaneity bias in detail and discuss results of Hausman specification tests and instrumental variables estimation.

III. Testable Implications of Information Asymmetries

In this section I derive implications of information asymmetries between primary and secondary dealers for estimation of models (4) and (5) of the previous section. I assume throughout that the actual process of intermarket center adjustment is driven by 1) the dissemination of information from primary dealers to secondary dealers through direct (i.e., nonbrokered) primary-secondary dealer trade,[7] 2) intermarket center arbitrage performed by primary dealers trading through retail brokers, and 3) public announcements which reveal the private information of primary dealers.[8]

I assume that valuations of underlying assets of secondary dealers lag those of primary dealers deterministically:

$$E_k^s = E_k^p - p_k^\delta \tag{6}$$

where s and p distinguish between secondary and primary dealer valuations. The term p_k^δ denotes the *realized* drift in the primary dealer market center

[7] Recall that direct trade between dealers constitutes 50% of secondary market volume. In fact, several major securities firms have full-time sales/trading forces to execute direct trades over the telephone with other dealers. Most of these firms are primary dealers.

[8] A commonly used empirical methodology for examining lead-lag relationships such as that hypothesized between the primary and secondary market centers employs Granger-Sims causality tests. Granger-Sims causality tests per se are not statistically valid tests of lead-lag relationships. In particular, the fact that a series y_t displays a phase lead of a series x_t is neither a necessary nor a sufficient condition for current or lagged y_ts to be of use in predicting x_t. (See Sargent (1984).)

during the period beginning δ minutes before the kth transaction and ending at the time of the kth transaction; thus it represents the additional information incorporated into primary market center prices during the period beginning δ minutes before the kth transaction and ending at the time of execution of the kth transaction. I also assume the "true" value is determined in the primary market center and follows the same stochastic process posited in the previous section:

$$E_k^p = E_{k-1}^p + r * \Delta_k + \lambda_p * V_k + p_k \tag{7a}$$

if the kth transaction is executed in the primary dealer market center and:

$$E_k^p = E_{k-1}^p + r * \Delta_k + \lambda_s * V_k + p_k \tag{7b}$$

if the kth transaction is executed in the secondary dealer market center. The subscripts p and s distinguish the depth parameters of the primary and secondary dealer market centers, respectively. I make this distinction because the values of λ_p and λ_s will differ if primary and secondary dealers are indeed asymmetrically informed.

Now define the dummy variable $SIDE_k^P$ as follows:

$SIDE_k^P$ = 1 if the kth transaction is executed on the ask side of the market in the primary market center.
= -1 if the kth transaction is executed on the bid side of the market in the primary market center.
= 0 if the kth transaction is executed in secondary market center.

Define $SIDE_k^s$ similarly where the superscript s of course refers to the secondary market center.

Incorporating equations (6), (7a), and (7b) into model (4) from the previous section yields the following regression model:

$$\begin{aligned} T_k - T_{k-1} = {} & r * \Delta_k + \alpha_p * \left(SIDE_k^p - SIDE_{k-1}^p\right) + |SIDE_k^p| * \lambda_p * V_k \\ & + \alpha_s * \left(SIDE_k^s - SIDE_{k-1}^s\right) + |SIDE_k^s| * \lambda_s * V_k \\ & + \epsilon_k \end{aligned} \tag{8}$$

where $E(\epsilon_k) = 0$ and $|\ |$ denotes the absolute value operator. The dummies effectively select the proper parameters for model (8) according to the execution points of the kth and $k-1$st transactions.

Now define $\hat{\epsilon}_k^2$ as the squared residual calculated with the estimates of r, α_p, α_s, λ_p, and λ_s from model (8). Employing the fact that $\mathrm{Var}(p_k^\delta) = \delta * \psi$ yields the following regression models one can estimate $\sigma_{\alpha p}^2$, $\sigma_{\alpha s}^2$, ψ, and δ:

if $\delta < \Delta_k$,

$$\begin{aligned} \hat{\epsilon}_k^2 = {} & \left(|SIDE_k^p| + |SIDE_{k-1}^p|\right) * \sigma_{\alpha p}^2 \\ & + \left(|SIDE_k^s| + |SIDE_{k-1}^s|\right) * \sigma_{\alpha s}^2 \\ & + \left(\Delta_k + \delta/2 * \left(|SIDE_k^p| - |SIDE_{k-1}^p| - |SIDE_k^s|\right.\right. \\ & \left.\left. + |SIDE_{k-1}^s|\right) * \psi + \xi_k \right. \end{aligned} \tag{9a}$$

and if $\delta > \Delta_k$,

$$\begin{aligned}\hat{\epsilon}_k^2 = &\left(|SIDE_k^p| + |SIDE_{k-1}^p|\right) * \sigma_{\alpha p}^2 \\ &+\left(|SIDE_k^s| + |SIDE_{k-1}^s|\right) * \sigma_{\alpha s}^2 \\ &+\left(1 - D_k^{ps}\right) * \left(\Delta_k + \delta/2 * \left(|SIDE_k^p| - |SIDE_{k-1}^p|\right.\right. \\ &\left.\left.- |SIDE_k^s| + |SIDE_{k-1}^s|\right)\right) * \psi \\ &+ D_k^{ps} * \left(\delta - \Delta_k\right) * \psi + \xi_k. \end{aligned} \tag{9b}$$

Dummy D_k^{ps} takes on the value of 1 if $|SIDE_k^s| + |SIDE_{k-1}^p| = 2$ and 0 otherwise (i.e., $D_k^{ps} = 1$ if the dependent variable of model (8) used in the calculation of $\hat{\epsilon}_k^2$ is $T_k^s - T_{k-1}^p$, where the superscripts denote the execution points of transactions). The distinction between models (9a) and (9b) arises because $E(\hat{\epsilon}_k^2) = \sigma_{\alpha s}^2 + \sigma_{\alpha p}^2 + \text{Max}[\Delta_k - \delta, \delta - \Delta_k]$ for $\hat{\epsilon}_k^2$s corresponding to $T_k^s - T_{k-1}^p$ observations. One must determine whether $\Delta_k - \delta \geq 0$ or $\Delta_k - \delta < 0$ in order to avoid model misspecification for these $\hat{\epsilon}_k^2$s.

In the empirical section of this paper I first consistently estimate δ of models (9a) and (9b) exclusively with the squared residual series $\hat{\epsilon}_k^2$ from model (8) which correspond to $T_k^p - T_{k-1}^p$, $T_k^s - T_{k-1}^s$, and $T_k^p - T_{k-1}^s$ observations. I then compare Δ_k for each $\hat{\epsilon}_k^2$ which corresponds to a $T_k^s - T_{k-1}^p$ observation to this consistent estimate of δ to determine which of (9a) and (9b) applies. I then reestimate (9a) and (9b) by augmenting initial regressions with previously excluded $\hat{\epsilon}_k^2$s.

The technique described in the preceding paragraph is legitimate as long as δ is truly a constant. If instead δ varies throughout my sample (but is positive so that my specification for the $\hat{\epsilon}_k^2$s corresponding to $T_k^p - T_{k-1}^p$, $T_k^s - T_{k-1}^s$, $T_k^p - T_{k-1}^s$ observations remains legitimate), initial estimates of δ will represent estimates of the *average* lag of secondary dealer valuations behind those of primary dealers. In such circumstances, my technique for categorizing the $\hat{\epsilon}_k^2$s corresponding to $T_k^s - T_{k-1}^p$ observations will lead to model misspecification.[9]

I estimate parameters of models (9a) and (9b) both with and without the $\hat{\epsilon}_k^2$s corresponding to $T_k^s - T_{k-1}^p$ observations in the empirical section of this paper. One must balance the benefits of increasing the power of parameter estimates with the potential cost of model misspecification when assessing the contribution of the introduction of the additional $\hat{\epsilon}_k^2$ observations to the estimation procedure. I employ all observations in the estimation of model (8) because in this case the preceding discussion of misspecification is irrelevant.

If the secondary market center lags the primary market center, one expects to estimate $\delta > 0$ and $\lambda_s > \lambda_p$. The first implication arises from the intermar-

[9] For example, assume that δ varies across my sample and that I estimate an average δ of 2.5 minutes with $\hat{\epsilon}_k^2$s which correspond to $T_k^p - T_{k-1}^s$, $T_k^s - T_{k-1}^s$ and $T_k^p - T_{k-1}^p$ observations. Now take a particular $T_k^s - T_{k-1}^p$ observation and assume for this observation $\Delta_k = 2$ minutes and the true value of δ during the period of execution of the two transactions used to calculate this observation is 1.5 minutes. Using the technique put forth in the previous paragraph I would make the mistake of applying model (9b) rather than (9a) to this observation.

ket adjustment between expectations of secondary and primary dealers posited in equations (6), (7a), and (7b). The second is based on the conclusions of the literature on adverse selection in financial markets. That is, one expects to observe larger adverse selection components in spreads posted on retail brokers' screens due to information asymmetries between primary dealers executing intermarket center arbitrage in trades with uninformed secondary dealers serving as market makers.[10]

IV. The Data

My data consist of transaction histories of 566 2-year note and 1931 30-year long-term bond (the long bond) transactions. Both the 2-year note and the long bond were issued in the May 1987 U.S. Treasury auction. The 2-year note was issued with a maturity of May 1989 while the 30-year long bond was issued with a maturity of May 2017. Both securities were *active issues* when these transaction histories were recorded. That is, these securities were the most recently issued Treasury securities with 2-year and 30-year maturities.

The data for the long bond were recorded over a period of 39 hours during the 6 trading days between July 17 and 24, 1987. The data for the 2-year note were recorded over a period of 34 hours during the 5 trading days between July 20 and 24, 1987. All data were recorded during active trading hours, i.e., between 9:00 A.M. and 4:00 P.M. Eastern Standard Time.

Recall that there were in total seven interdealer brokers and two retail brokers in the secondary market for U.S. government securities during the sampling period. The series I collected consist of transactions executed by *three* interdealer brokers (FBI, Garban, and RMJ) and one retail broker (Cantor-Fitzgerald).[11] These transaction series therefore do not include transactions executed by the three remaining interdealer brokers and the additional retail broker. Since FBI, Garban, RMJ, and Cantor-Fitzgerald arrange an estimated 80% of brokered 2-year note and long bond transactions, the exclusion of the four remaining brokers is not necessarily a major source of concern.

I created the data series by merging transaction histories which originate from two different sources. The first source, the source for the interdealer broker transaction information, is the Merrill-Lynch Bloomberg computer system. The Bloomberg system records the volume, price, side of the market

[10] If information asymmetries between different secondary dealers are more substantial than those between different primary dealers, trading in the secondary market center will be thinner than in the primary market center regardless of the existence of intermarket center arbitrage efforts of primary dealers. As such, strictly speaking, the result that $\lambda_s > \lambda_p$ is consistent with but does not necessarily confirm the alternative hypothesis.

[11] During the sampling period Cantor-Fitzgerald distributed its video screen information for a fee via Telerate to market observers. The Telerate information has no bearing on analyses conducted in this paper since it was available to primary and secondary dealers by virtue of their Cantor-Fitzgerald client status.

(i.e., whether the transaction occurred at the bid or ask), and the minute of execution of all transactions arranged by FBI, RMJ, and Garban. The system sequences transactions executed within the same minute. Bloomberg data are available only to Merrill-Lynch, a primary dealer.

The second source, the source of retail broker transaction information, is my manual transcription of Cantor-Fitzgerald video screen information. The transcription includes the volume, price, side of the market, and the minute of execution of transactions executed by Cantor-Fitzgerald. The timing mechanism, the clock on the Cantor-Fitzgerald screen, was synchronized with the timing mechanism of the Bloomberg system.[12]

Time pressure generally did not interfere with efforts to record data accurately. This is because transaction information is typically posted for a period of at least 20 seconds subsequent to the initiation of trade on Cantor-Fitzgerald's screen.

Unfortunately, however, during periods of very active trading it was impossible to transcribe volumes of four long bond and two 2-year note transactions. If the transaction for which the volume is unavailable is the last transaction executed in a pair used to calculate an observation, the observation is dropped from the sample in the empirical section of this paper. This is because the volume of the last transaction is an independent variable in regression models (8), (9a), and (9b).

The price of one long bond transaction was not transcribed. Obviously, no observations were constructed with this transaction.

Because the data originate from two sources and execution times are recorded in minutes, it is impossible to sequence transactions executed *within the same minute but in different market centers*. Since the actual sequence of transactions is the basis of the tests proposed in this paper, no observations calculated with such transactions are included in the regressions in the next section.

Lags equal to the average time required to execute a transaction in the primary market center exist in the data series. In particular, the data series of Cantor-Fitzgerald transactions include transaction *initiation* times while the FBI, Garban, and RMJ data series recorded by the Bloomberg system include transaction *completion* times. The duration of a typical 2-year note or long bond transaction (i.e., the amount of time which expires between the initia-

[12] A potential problem arises due to the fact that transaction times are recorded in minutes in the database. As an example, assume the recorded time of transaction T_k is 12:02 PM. while the recorded time of transaction T_{k-1} is 12:00 P.M. The corresponding measured value of Δ_k (i.e., the value which I would calculate for my regression) in this example would be 2 minutes. These recorded transaction times, however, would simply indicate that T_k occurred between 12:00 and 12:01 and T_{k-1} occurred between 12:02 and 12:03. As such, the true value of Δ_k would lie somewhere between one and 3 minutes.

Preliminary regressions indicated that measurement error attributable to the use of recorded execution times as opposed to actual execution times is not a serious source of concern. In particular, I assumed that measurement error in the Δ_ks adhered an i.i.d. triangular distribution on the interval $[0, 2]$ and altered estimators of parameters accordingly to remove the resulting statistical bias. Estimates changed only slightly.

tion and completion of a transaction) is roughly 30 seconds. Under the null hypothesis of perfect market integration one thus expects to estimate (roughly) $\delta = -0.5$ in both the long bond and 2-year note series.

Observations constructed with successive transactions spaced in time by more than 5 minutes are dropped from the sample. This is done because the analysis is designed to focus on short-run trading behavior. (The inclusion of observations calculated with transactions spaced in time by more than 5 minutes induces only minor changes in results.)

Table I provides summary statistics on my database of broker transactions. The table is divided into two sections. The first section provides summary statistics on the entire database. The second section provides summary statistics on the observations used in regressions in the next section of the paper.

Referring to the first section of Table I, Cantor-Fitzgerald, the retail broker isolated in this study, arranged almost half of the 1931 long bond transactions in the database but only 30% of the 566 2-year note transactions. The disparity in these proportions reflects the fact that Cantor-Fitzgerald is the dominant long bond broker in the market but is a somewhat weaker player in the case of the 2-year note. Transactions are essentially divided equally between hits and takes in both series.

Transactions prices vary more widely in the long bond series than in the 2-year note series. In particular, long bond prices vary between 98.97 and 102.77 (i.e,. 98 + 31/32 and 102 + 49/64, respectively, in terms of the market price grid) with a standard error of 1.02. Two-year note prices vary between 99.79 and 100.07 (i.e, 99 + 101/128 and 100 + 9/128, respectively, in terms of the market price grid) with a standard error of 0.07.

Now refer to the section of Table I which provides summary statistics on the observations for regressions in the next section. A total of 757 long bond and 281 2-year note price differences met the criteria established for the sample in this section. The standard deviation of the dependent variable $T_k - T_{k-1}$ is larger for the long bond series, reflecting the long bond's higher volatility. In the 2-year note series, the shortage of observations constructed with two successive secondary market center transactions reflects Cantor-Fitzgerald's weaker market position as a 2-year note broker.

The absolute value of the transaction volume regressor associated with the $T_k - T_{k-1}$ series, $|V_k|$, is on average larger as well as more variable in the 2-year note series; it averages 10.09 units in the 2-year note series and 5.93 units in the long bond series. Associated standard deviations are 12.63 and 6.62 units, respectively.

The regressor representing the amount of time elapsed between the execution of kth and $k - 1$st trades, Δ_k, is also on average larger and more variable in the 2-year note series; Δ_k averages 1.47 minutes in the 2-year note series and 1.01 minutes in the long bond series. Associated standard deviations are 1.12 and 1.45, respectively.

Readers should note that many dealers regard Cantor-Fitzgerald video screen information as the best information available in the market due to the

Table I

Selected Statistics on Data Series of Broker Transactions

The Complete Data Series[a]	Long Bond	2-Year Note
Division of Sample by Broker Type		
Retail Broker Transactions (i.e., Cantor-Fitzgerald)	929	171
Interdealer Broker Transactions (i.e., FBI, Garban and RMJ)	1002	395
Total	1931	566
Division of Sample by Transaction Type		
Hits (i.e., initiated by a seller	948	277
Takes (i.e., initiated by purchaser)	983	281
Total	1931	566
Transaction Prices		
Mean	100.38	99.28
Standard Error	1.02	.07
Minimum	98.97	99.79
Maximum	102.77	100.07
Observations Calculated for Empirical Estimation of Models (8), (9a), and (9b)[b]		
$T_k - T_{k-1}$		
Mean	0.0012	−0.0006
Standard Deviation	0.0206	0.0069
Minimum	−0.0781	−0.0023
Maximum	0.0938	0.0023
Transaction Pairs Used to Construct Observations		
T_k and T_{k-1} are primary and secondary market center transactions, respectively	152	51
T_k and T_{k-1} are secondary and primary market center transactions, respectively	141	50
T_k and T_{k-1} are both primary market center transactions	208	159
T_k and T_{k-1} are both secondary market center transactions	256	21
Total	757	281
$\lvert V_k \rvert$		
Mean	5.93	10.09
Standard Deviation	6.62	12.63
Minimum	1.00	1.00
Maximum	50.00	81.00
Δ_k		
Mean	1.01	1.47
Standard Deviation	1.12	1.45
Minimum	0.00	0.00
Maximum	5.00	5.00

[a] The price of one transaction in the long bond series was not transcribed. This transaction was dropped from the sample when these price statistics were calculated.

[b] These observations were constructed with transactions which: 1) were spaced in time by no more than 5 minutes and 2) were not executed during minutes in which transactions were executed in both the primary and secondary market centers.

high proportion of brokered long bond trades which Cantor-Fitzgerald arranges. As is reflected in my sample, Cantor-Fitzgerald arranges roughly 50% of brokered long bond transactions. As a result of this concentration of order flow, long bond bid-ask spreads and transaction prices are updated regularly on Cantor-Fitzgerald's video screen. Cantor-Fitzgerald's reputation as a broker of the 2-year note is less distinguished.

It is difficult, however, to predict whether statistical tests are more likely to detect information asymmetries between primary and secondary dealers in the long bond or the 2-year note series under the alternative hypothesis of imperfect market center integration. Based on the purported disparities in information quality between Cantor-Fitzgerald's long bond and 2-year note video information, one would expect more pronounced information asymmetries in the case of the 2-year note. On the other hand, due to the higher variability of the long bond prices, one might expect larger information asymmetries in the case of the long bond. In particular, more frequent price changes are likely to facilitate the exploitation of private information by primary dealers in trades with secondary dealers arranged by Cantor-Fitzgerald. The power of statistical tests is also likely to be greater in the case of the long bond due to the larger sample size as well as the wider variation in the dependent variable $T_k - T_{k-1}$.

V. Empirical Results

This section discusses estimation of models (8), (9a), and (9b). I first apply ordinary least squares to model (8) to estimate r, α_s, α_p, λ_s, and λ_p. I calculate the squared residual series $\hat{\epsilon}_k^2$ with these estimates and apply nonlinear least squares to models (9a) and (9b) to estimate $\sigma_{\alpha s}^2$, $\sigma_{\alpha p}^2$, ψ, and δ. To determine which of (9a) and (9b) applies to each of the $\hat{\epsilon}_k^2$s corresponding to $T_k^s - T_{k-1}^p$ observations, I first obtain nonlinear least squares estimates of δ exclusively employing the $\hat{\epsilon}_k^2$s corresponding to $T_k^p - T_{k-1}^p, T_k^s - T_{k-1}^s, T_k^p - T_{k-1}^s$ observations. I then compare observed values of Δ_k to estimates of δ for each of the $\hat{\epsilon}_k^2$s corresponding to $T_k^s - T_{k-1}^p$ observations. After determining which of (9a) and (9b) applies to these additional $\hat{\epsilon}_k^2$s, I run nonlinear least squares employing the entire $\hat{\epsilon}_k^2$ series. I postpone discussion of endogeneity of Δ_k and V_k until the end of this section.

As I explained in Section III, a potential problem of misspecification arises in regressions with the $\hat{\epsilon}_k^2$s corresponding to $T_k^s - T_{k-1}^p$ observations if δ varies throughout my samples. Readers must therefore balance the benefit of the gain in statistical power attributable to the inclusion of additional observations with the potential costs of introducing misspecification when assessing results. Regressions which exclude the additional $\hat{\epsilon}_k^2$s are not subject to such misspecification as long as δ remains positive throughout my samples.

Table II summarizes ordinary least squares estimates of the parameters r, α_s, α_p, λ_s, and λ_p of model (8). (In all regressions in this section I list heteroscedastic-consistent, MA(1) consistent t-statistics in parentheses.) Let

Table II

Ordinary Least Squares Estimation of Model (8)[a,b]
Null Hypothesis: $\lambda_s = \lambda_p$
Alternative Hypothesis: $\lambda_s > \lambda_p$

Estimated Parameters	2-Year Note	Long Bond
λ_s	1.4×10^{-4}	6.9×10^{-4}
	(2.19)	(6.62)
λ_p	4.5×10^{-6}	6.4×10^{-4}
	(0.20)	(4.25)
α_s	-1.0×10^{-5}	2.7×10^{-3}
	(0.01)	(2.99)
α_p	1.5×10^{-3}	5.8×10^{-3}
	(2.58)	(5.69)
r	-2.9×10^{-4}	6.3×10^{-4}
	(1.71)	(1.47)
Observations	281	757
R-Squared	0.04	0.17
Durbin-Watson	2.28	2.16
$\chi^2(2)$ Test of $\lambda_s = \lambda_p$	3.47	0.10
Significance Level of Test	0.06	0.75

[a] Observations for these regressions were constructed with transactions which: 1) were spaced in time by no more than 5 minutes and 2) were not executed during minutes in which transactions were executed in both the primary and secondary market centers.

[b] Heteroscedastic-consistent, MA(1)-consistent t-statistics are listed in parentheses.

us first discuss 2-year note results. The estimate of α_s is negative, a result which is not consistent with the predictions of the model. The estimate, however, is insignificant and very small in magnitude. The inaccuracy of the estimate is probably attributable to the scarcity of secondary market center transactions in the 2-year note series. The estimate of α_p of 1.5×10^{-3} is economically plausible and has a t-statistic of 2.58. In particular, the magnitude of the estimate represents roughly 0.0015% of the average recorded transaction price in the 2-year note series.[13] The estimate of λ_s of 1.4×10^{-4} is accurate (with a t-statistic of 2.19) and economically plausible as well. The estimate indicates that each additional unit of a buyer-initiated 2-year note trade on average induces an upward revision in secondary market center prices of 0.00014%. The estimate of λ_p of 4.5×10^{-6} is smaller in magnitude, a result which is consistent with the alternative hypothesis. The restriction that $\lambda_s = \lambda_p$ is rejected at the 6% level of significance. (The test statistic is

[13] Two-year note spreads typically ranged between 0% (i.e., a locked market in which bid and ask prices did not differ) and 0.031% (i.e., 1/32 in terms of the market price grid) of outstanding 2-year note prices during my sampling period.

distributed $\chi^2(2)$.) The estimate of r of -2.9×10^{-4} arises due to the price decline of the 2-year note during the sampling period. The inaccuracy of the estimate is not surprising as intraday transaction price series are typically noisy due to factors such as price discreteness. The Durbin-Watson statistic exceeds 2 due to the negative serial correlation induced by the MA(1) in the error structure.

The model more accurately estimates parameters in the case of the long bond. Surprisingly, the estimate of α_p of 5.8×10^{-3} is twice as large as the estimate of α_s of 2.7×10^{-3}. T-statistics for estimates of α_p and α_s are 5.69 and 2.99. The estimate of λ_s of 6.9×10^{-4} exceeds the estimate of λ_p of 6.4×10^{-4}, but the difference between these estimates is neither economically nor statistically significant. T-statistics for estimates of λ_s and λ_p are 6.62 and 4.25, respectively. The positive estimate of r arises due to the increase in long bond prices during the sampling period. As in the case of the 2-year note, however, the estimate is insignificant. The Durbin-Watson statistic again exceeds 2 due to the negative serial correlation induced by the MA(1) in the error structure.

Let us now turn to nonlinear least squares estimation of models (9a) and (9b) in Table III. I first discuss results of the regression for the 2-year note which excludes $\hat{\epsilon}_k^2$s corresponding to the 51 $T_k^s - T_{k-1}^p$ observations in the series. This model estimates a value of δ of 4.31. The estimate differs significantly from -0.5, the value of δ under the null hypothesis. The model's estimate of $\sigma_{\alpha p}^2$ of 8.4×10^{-6} is substantially larger than its estimate of $\sigma_{\alpha s}^2$ of 0.8×10^{-6}. The estimate of $\sigma_{\alpha s}^2$, however, has a very large

Table III

Nonlinear Least Squares Estimates of Models (9a) and (9b)[a]
Null Hypothesis: $\delta = -0.5$
Alternative Hypothesis: $\delta > -0.5$

	2-Year Note		Long Bond	
	$\hat{\epsilon}_k^2$s for $T_k^s - T_{k-1}^p$ Obs. Excluded	$\hat{\epsilon}_k^2$s for $T_k^s - T_{k-1}^p$ Obs. Included	$\hat{\epsilon}_k^2$s for $T_k^s - T_{k-1}^p$ Obs. Excluded	$\hat{\epsilon}_k^2$s for $T_k^s - T_{k-1}^p$ Obs. Included
δ	4.31	6.91	1.75	0.39
	(1.83)	(2.02)	(0.70)	(0.43)
$\sigma_{\alpha s}$	0.8×10^{-6}	0.8×10^{-5}	1.8×10^{-4}	1.8×10^{-4}
	(0.13)	(1.24)	(4.71)	(5.77)
$\sigma_{\alpha p}$	8.4×10^{-6}	1.2×10^{-5}	1.2×10^{-4}	1.2×10^{-4}
	(2.64)	(3.92)	(4.81)	(5.55)
ψ	1.0×10^{-5}	6.5×10^{-6}	3.4×10^{-5}	4.4×10^{-5}
	(2.90)	(2.05)	(1.20)	(2.07)
R^2	0.07	0.05	0.01	0.01
Durbin-Watson	1.81	1.83	1.78	1.73
Observations	230	281	605	757

[a] Heteroscedastic-consistent, MA(1)-consistent t-statistics are listed in parentheses.

standard error. Again, this inaccuracy is probably attributable to the scarcity of secondary market center transactions in the 2-year note series. The estimate of ψ of 1.0×10^{-5} has a t-statistic of 2.90. This result suggests a dependence between price variability and the elapsed time between trades. The Durbin-Watson statistic is less than 2 due to the positive serial correlation induced by the MA(1) in the error structure.[14]

I next augment the sample for the regression discussed in the immediately preceding paragraph with the $\hat{\epsilon}_k^2$s corresponding to 51 2-year note $T_k^s - T_{k-1}^p$ observations. I apply models (9a) and (9b) to observations for which $\Delta_k \geq 5$ and $\Delta_k \leq 4$, respectively. Results suggest that the introduction of these observations induces model misspecification due to stochastic behavior in the parameter δ. In particular, the estimate of δ increases to 6.91 minutes and moves outside of the interval of 4–5 minutes employed to categorize the $T_k^s - T_{k-1}^p$ observations in the first place. Estimates of $\sigma_{\alpha p}^2$ and $\sigma_{\alpha s}^2$ increase to 1.2×10^{-5} and 0.8×10^{-5} while the estimate of ψ decreases by a third to 6.5×10^{-6}.

I now turn to the long bond regression which excludes the $\hat{\epsilon}_k^2$s corresponding to 152 $T_k^s - T_{k-1}^p$ observations in the long bond series. The estimate of δ is positive, as the alternative hypothesis would suggest, but does not differ significantly from -0.5. Estimates of $\sigma_{\alpha s}^2$ and $\sigma_{\alpha p}^2$ of 1.8×10^{-4} and 1.2×10^{-4} are very similar. Both estimates achieve high levels of statistical significance. The estimate of ψ of 3.4×10^{-5} is not significant, suggesting that the dependence between price variability and time is weak in the long bond series. The Durbin-Watson statistic is again less than 2 due to the positive serial correlation induced by the MA(1) in the error structure.

Results from the regression which includes the $\hat{\epsilon}_k^2$s corresponding to 152 $T_k^s - T_{k-1}^p$ observations suggest the introduction of misspecification but to a lesser extent than in the case of the 2-year note. The estimate of δ falls to 0.39 minutes and lies outside of the 1–2 minute interval employed to categorize the $T_k^s - T_{k-1}^p$ observations in the first place. The inaccuracy of the estimate precludes rejection of the null hypothesis that $\delta = -5$. Estimates of $\sigma_{\alpha s}^2$ and $\sigma_{\alpha p}^2$ are very similar to those in the regression discussed in the immediately preceding paragraph. The significance levels of these estimates rise, largely due to the introduction of the additional observations. The estimate of ψ increases to 4.4×10^{-5} and becomes statistically significant.

I now proceed to diagnostic tests of exogeneity of V_k and Δ_k. Potential sources of simultaneity bias include measurement error in the V_k series due to disparities between actual and expected volumes as well as the joint determination of prices, quantities, and trades in the trading process.

The trading process is best described as a dynamic multiple-bid, multiple-unit double auction in which multiple brokers intermediate trades between

[14] I employ ordinary least squares estimates of models (9a) and (9b) as starting values for 2-year note and long bond nonlinear least squares regressions which exclude the $\hat{\epsilon}_k^2$s corresponding to the $T_k^s - T_{k-1}^p$ observations. I employ parameter estimates from these nonlinear regressions as starting values for regressions which include the $\hat{\epsilon}_k^2$s corresponding to the $T_k^s - T_{k-1}^p$ observations. Each of the four regressions of Table III convergenced in three iterations.

differentially and/or asymmetrically informed traders posting and hitting price/quantity pairs. Needless to say, neither of the double auction literature nor the market microstructure literature provides a model which approximates this process. Further, no research has attempted to address how trade times are determined in equilibrium. As such, it is difficult to address rigorously whether or how endogeneity arises in the model.

One can conceivably generate simplistic models in which trade times and volumes are endogenous by imposing restrictive assumptions regarding the distribution of private information among traders and the nature of the trading mechanism employed. Such models could in turn provide the basis for a simultaneous equations specification for estimation. The development of any tractable model would require ignorance of essential features of the market in question and could grossly mischaracterize the trading process. The reliability of any resulting econometric specification would be questionable.

Rather than develop and estimate a system of simultaneous equations based on such a model, I employ values of Δ_k and V_k lagged one period as instruments in two-stage least squares estimation and perform specification tests. The most significant requirement for validity of this strategy is that lagged values are valid instruments. (The inclusion of addition lags of V_k and Δ_k induces only minor changes in results.)

It is unclear how simultaneity bias would actually lead to invalid statistical conclusions (e.g., incorrect rejection of the null hypothesis of perfect market center integration) given the basic properties of the data and the nature of the issue examined. The basis of the employed approach is the common sense proposition that secondary dealers' prices will drift toward those of primary dealers if restricted access to interdealer brokers creates an information asymmetry. Identifying this lag does not necessarily require the estimation of an econometric model as it is manifest in the raw data.

The statistical properties of the data suggest that the underlying motivation of models (8), (9a), and (9b) of independent, randomly arriving trades reasonably approximates the trading process. One would arguably expect dynamic, endogenously determined trading strategies, for example, to induce serial correlation in the Δ_k and V_k series. Yet, the correlation coefficients for the 2-year note and long bond V_k and V_{k-1} series are only 0.30 and 0.19, while the coefficients for Δ_k and Δ_{k-1} series are only 0.13 and 0.08. Also, one might also expect large cross correlations between Δ_k and $|V_k|$ in the event of joint determination of trade prices, volumes, and times. The correlation coefficients, however, between Δ_k and $|V_k|$ in the 2-year note and long bond series are only 0.01 and 0.05.

Simultaneity bias resulting from endogeneity of Δ_k is arguably limited. Most Government Securities transactions are initiated either directly or indirectly by institutions unlikely to possess private information. Most primary dealer transactions are executed on behalf of such institutions. The likely fraction of strategically timed primary dealer information trades is thus small. On this basis I later discuss results of regressions under the assumption that Δ_k is exogenous but V_k is endogenous.

Let us now discuss instrumental variables procedures under the assumption of endogeneity of both V_k and Δ_k. I drop observations in which V_{k-1} and Δ_{k-1} and V_k and Δ_k are determined in transactions executed on different days (i.e., T_{k-1} is the previous day's closing transaction and T_k is the following day's opening transaction). I also drop observations for which I am unable to identify V_{k-1} due to my inability to sequence primary and secondary market center transactions executed within the same minute. Lastly, I drop the first observation in each series due to the lagging procedure. Thus, 240 and 576 2-year note and long bond transactions are available for instrumental variables estimation.

I employ heteroscedastic-consistent, MA(1)-consistent Lagrange multiplier Hausman specification tests of model (8) with techniques derived in Wooldridge (1990). I am unable to reject the null hypothesis of exogeneity in both the 2-year note and the long bond regressions as the $\chi^2(3)$ statistics of 0.97 and 0.95 fall far short of conventional levels of statistical significance. (The test statistics have three degrees of freedom because distinct instrument series are required for the primary and secondary market center transaction volume series. To illustrate, if T_k is executed in the secondary market center, one has $V_k^s = V_k$, $V_{k-1}^p = 0$, $V_{k-1}^s = V_{k-1}$, and $V_{k-1}^p = 0$.)

To conduct specification tests for models (9a) and (9b) I project the Δ_ks into the space spanned by the Δ_{k-1}s and the dummy variables which identify transaction sequences and the variance terms. I then include the fitted values from these regressions in the original nonlinear least squares regressions and examine the heteroscedastic-consistent, MA(1)-consistent t-statistics on the fitted values' coefficients. These t-statistics are 0.42 and 2.30 for models (9a) and (9b) in the 2-year note regressions and -0.45 and 0.06 in the long bond regressions. The t-statistic of 2.3 on the coefficient in the 2-year note of regression model (9b) is admittedly evidence against the exogeneity of Δ_k, but it is arguably attributable to misspecification due to variation in δ during the sampling period.

Results of two-stage least squares estimation are available upon request. Estimates of the δs in these regressions suggest similar conclusions to OLS estimates but are very inaccurate. The estimates of the δs in the 2-year note series are entirely unrealistic and have huge standard errors. The estimates of the λs, the αs and the rs are not inordinately different from OLS estimates but are also inaccurate. There is no evidence in these regressions, however, that $\lambda_p < \lambda_s$ as estimates are very similar. Inaccuracy probably arises due to the low levels of serial dependence in the Δ_k and V_k series. These low levels of serial dependence may also explain the small sizes of specification test statistics.

Let us discuss how results change when assuming Δ_k is exogenous but V_k is endogenous. (Details of these results are also available upon request.) Hausman specification test statistics are again very small in both the long bond and 2-year note regressions when employing lagged V_ks as instruments. Two-stage least squares estimates of the parameters of (8) resemble OLS estimates but are less accurate. The estimates of λ_s and λ_p are very similar in the long bond regression but λ_s exceeds λ_p in the 2-year note regression.

Nonlinear least squares estimates of (9a) and (9b) lead to similar conclusions, whether or not one instruments for the V_ks in equation (8).

VI. Concluding Remarks

Results suggest information asymmetries between secondary and primary dealers in the secondary market for U.S. Government Securities in the case of the two active issues I examine. Secondary dealers' price expectations lag those of primary dealers by an estimated 4.8 minutes in the 2-year note series and 2.3 minutes in the long bond series. Parameters of secondary dealer market center bid-ask spreads appear larger than those of primary dealer market center spreads, suggesting the presence of an information asymmetry. Statistical evidence against the null hypothesis is stronger in the case of the 2-year note. This is probably due to Cantor-Fitzgerald's weaker market position as a 2-year note broker.

Due to a lack of appropriate data I have been unable to address information asymmetries in inactive issue trading in this paper. In the case of inactive issues no broker video screen information is available to secondary dealers. Given that I detect information asymmetries in the two active issues examined in this paper, it is likely that substantial information asymmetries exist in the case of inactive issues.

One must ask how secondary dealers remain in business in the presence of these information asymmetries. Most secondary dealers perform other activities besides government securities trading. Also, in many trades secondary dealers serve as intermediaries for trading clients. They charge spreads and presumably profit in such trades.

Secondary dealers have the option to trade directly with primary dealers over the telephone. Presumably spreads for such trades are reasonably competitive given the ease of conducting telephone searches and the large number of primary dealers serving as market makers. That they often prefer to trade via Cantor-Fitzgerald suggests that the information lag they face may not be inordinately costly.

This paper addresses only one of the many idiosyncrasies of U.S. Treasury Security trading. Other examples include Treasury Security auction and resale procedures. Further research should examine such idiosyncrasies in light of their implications for the behavior of Treasury Security prices and the employment of these prices by financial economists in capital budgeting problems and tests of asset pricing models.

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