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Automation versus Intermediation: Evidence from Treasuries Going Off the Run

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ABSTRACT

This paper examines the choice of trading venue by dealers in U.S. Treasury securities to determine when services provided by human intermediaries are difficult to replicate in fully automated trading systems. When Treasury securities go "off the run" their trading volume drops by more than 90%. This decline in trading volume allows us to test whether intermediaries' knowledge of the market and its participants can uncover hidden liquidity and facilitate better matching of customer orders in less active markets. Consistent with this hypothesis, the market share of electronic intermediaries falls from 81% to 12% when securities go off the run.

ELECTRONIC TRADING SYSTEMS HAVE BEEN steadily increasing their share of securities trading in almost all financial markets. As the amount of automation in financial markets increases, it is natural to ask what services human intermediaries provide that are difficult or impossible to replicate in a fully automated trading system. Existing theory suggests that human intermediaries play at least two important functions. First, an intermediary's knowledge of the market and its participants may uncover hidden liquidity that facilitates quicker and more efficient matching of customer orders (Grossman (1992)). The value of this matching function is greater when trading volume is low and matches are difficult to find. Second, when information asymmetry is high, the repeated interaction between an intermediary and its customers allows the intermediary to protect itself against informed trades and offer better prices to its customers (Seppi (1990)). These two factors explain, for example, why electronic communications networks (ECNs) have a greater market share for the largest and most actively traded Nasdaq stocks while Nasdaq market makers have a larger share in smaller, less liquid stocks characterized by greater information asymmetry (Barclay, Hendershott, and McCormick (2003)), and why NYSE specialists have higher participation rates in smaller, less liquid stocks (Madhavan and Sofianos (1998)).

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The ability of human intermediaries to match buyers and sellers and the ability to manage the adverse selection problem typically reinforce each other. Stocks of smaller companies generally have lower trading volume, greater information asymmetry, and more adverse selection. The greater adverse selection drives liquidity traders out of the market, which makes the security even more thinly traded. Because these two factors usually go hand in hand, prior research has not attempted to separate these two sources of value created by human intermediaries.

In this paper, we examine the choice of trading venue by dealers in U.S. Treasury securities. When the U.S. Treasury issues a new security, the new security is said to be "on the run" and is very actively traded. Together, the 2-year, 5-year, and 10-year on-the-run Treasury notes have an average daily trading volume comparable to all U.S. common stocks combined. As a new security goes on the run, the previously issued security of the same maturity goes "off the run" and its trading volume drops by more than 90%. Because there are no significant differences in the payoff-relevant information asymmetry between the new on-the-run note and the just off-the-run note, U.S. Treasury securities allow us to isolate the importance of the matching function of human intermediaries across active and less active markets.[1]

Almost all interdealer trades in U.S. Treasury securities are conducted through interdealer brokers (IDBs). Several IDBs operate automated electronic trading systems while other IDBs operate voice-based systems. Electronic brokers provide open limit order books with a variety of features that traders can access directly.[2] Voice brokers also provide open limit order books. However, with voice brokers, orders are placed and trades are executed over the telephone. Voice interaction adds to cost of the trade. However, by requiring the dealer to speak with the broker over the telephone, the broker is able to collect additional information and offer additional services to the dealer.

In an active market, finding a match is quick and easy. Therefore, supplying liquidity by placing a limit order is not very costly in an active market because the maturity of the option embedded in the order is very short.[3] In less active markets, finding a match is more difficult and time consuming. Traders may be reluctant to place limit orders in less active markets because the orders will be exposed for longer periods of time, increasing the value of the option given up at the time of the order. Although traders may be reluctant to place firm limit orders in less active markets, they might be willing to disclose qualitative information about their trading demands if the trader believes that this information

[1] Information asymmetry concerning nominal cash flows does not change when a Treasury security goes off the run. Nonpayoff-relevant information, such as dealer inventories or other market conditions, can be affected (Cao, Evans, and Lyons (2006)). What we refer to as the search and matching function provided by brokers includes possible assistance with nonpayoff-relevant information.

[2] Electronic trading systems typically allow bilateral negotiation of quantity, but not price (see, e.g., Boni and Leach (2004)).

[3] The cost of placing a limit order to buy or sell can be analyzed as the cost of the put or call option that is given up when the order is placed (Copeland and Galai (1983)).

will only be revealed to a natural counterparty. Voice interaction between a broker and its customers allows the broker to collect this additional qualitative information and find matches in less active markets. By examining dealers' trading venue choices, we are able to document the importance of these services and to determine when they are most valuable.

When a Treasury security goes off the run, its trading volume declines by more than 90%. This large shock to trading volume, which is not accompanied by any significant shift in payoff-relevant information, is associated with a similar decline in the market share of electronic brokers: Electronic brokers' market share falls from 81% when a Treasury security is on the run to only 12% when the security goes off the run. Larger trades, trades by dealers with large daily order imbalances, and trades on low volume days are less likely to be executed by electronic brokers. These results indicate that voice brokers' services are most valuable for more difficult trades in less active markets. These results also hold for repos on Treasury notes and for Treasury bills.

The remainder of this paper is organized as follows. Section I provides an overview of interdealer trading in the U.S. Treasury market. Section II reviews the related literature. Section III provides a general description of our data. Section IV documents the changes in trading volume and electronic brokers' market share that occur when Treasury securities go off the run. Sections V and VI analyze the choice of trading venue for Treasury notes. Section VII discusses Treasury bills and repos on Treasury notes and Section VIII concludes.

I. Interdealer Brokerage and Trading in U.S. Government Securities

Securities dealers provide liquidity in financial markets by standing ready to buy or sell a security at any time. In the Treasury market, primary dealers purchase the securities directly from the Treasury and resell them to investors. Dealers also make a secondary market in these securities by buying and selling them both before and after they are issued.

Through the normal course of market making and/or proprietary trading, a dealer's inventory of a particular Treasury security may become more or less than that desired. In these circumstances, dealers often trade with each other. Interdealer trades of Treasury securities almost always occur though an interdealer broker or IDB. During our 2001 to 2002 sample period, there were more than 30 active IDBs (Bond Market Association (2001)).

Unlike dealers, IDBs generally do not buy or sell securities on their own account. They simply match dealers who want to buy with dealers who want to sell. Dealers can trade passively through an IDB by submitting a limit order, or they can trade aggressively by hitting an existing limit order. In either case, because the IDB simply matches the buyer with the seller, the IDB does not profit from the bid-ask spread. Instead, it profits by charging a commission on each trade it brokers.

Historically, the IDB market operated strictly over the telephone. If one dealer wanted to trade with another, it would pick up the phone and speak with an IDB. During this conversation, the dealer would learn about the limit orders held by the IDB and decide whether to accept one or more of these offers, place a limit order of its own, or do nothing. As technology improved, IDBs allowed subscribing dealers to continuously view the IDBs' limit order books directly on computer screens, reducing the need for dealers to call the IDBs on the telephone. In voice-based systems, however, even though a dealer can see the passive limit orders on its computer screen, it still must call the IDB on the telephone if it wants to trade.

Recently, several IDBs have developed platforms for pure electronic trading in Treasury securities. Cantor Fitzgerald's eSpeed executed the first purely electronic bond trades in March 1999 and BrokerTec followed in June 2000.[4] Garban (ICAP) also developed an electronic trading platform at this time, but it attracted very little trading volume. In May 2003, ICAP purchased BrokerTec, leaving two competing electronic trading systems.

In addition to providing a computer screen that displays the limit order book, the electronic trading platforms also provide a keyboard that dealers can use to enter limit orders or hit existing orders directly. On electronic platforms, buyers are matched with sellers and trades are executed with no human intervention by the IDB. Electronic trading platforms consequently have a lower marginal cost per trade and charge lower marginal commissions. However, when a dealer calls a voice broker, the voice broker may collect more information than just the price and quantity to which the dealer is willing to commit. This additional qualitative information, which is often referred to as "market color," can be valuable to the voice brokers' customers because it allows the broker to match natural counterparties that otherwise would have difficulty finding each other.

Market color can best be described as nonpayoff-relevant information about short-lived variations in supply and demand that voice brokers collect from interactions with their customers. For example, a trader with a large order to buy a particular Treasury security will not want to reveal the full size of the order because revealing this information will place him at a competitive disadvantage. Instead, the trader will break up the order, revealing only part of it at any given time. If the trader calls a voice broker to place a limit order, the voice broker will ask whether there is more size behind the original order. Although the trader still may not reveal all of his information, more information is likely to be conveyed (e.g., that there is substantial size behind this order). This additional information will be conveyed because there is repeated interaction between the broker and the trader, and the trader trusts that the broker will reveal the

[4] Cantor Fitzgerald differs from BrokerTec in several important respects. First, prior to September 11, 2001, Cantor Fitzgerald offered both voice and electronic brokerage services. Our data do not differentiate between voice and electronic trading within an individual IDB. However, our results are unchanged if we examine only the period from October 2001 to November 2002 when Cantor Fitzgerald offered only electronic brokerage services. Our results are also unchanged if we discard the week of September 11, 2001. Second, Cantor Fitzgerald operated as both an IDB and a securities dealer, and thus sometimes executed trades on its own account. If we observe a trade between Cantor and another dealer, we assume that Cantor was functioning as an IDB. If we observe a trade between Cantor and another IDB, we assume that Cantor was functioning as a dealer.

information only to a natural counterparty who has substantial size to sell. The broker, understanding the market and his customer, can interpret this qualitative information and bring together natural counterparties for difficult trades.

As the fully automated trading systems have evolved, they have added features that attempt to replicate the services supplied by voice brokers. For example, a trader with a large order to fill can use an auto-refresh feature to replace a limit order whenever it is executed, a reserve size feature to indicate additional demand, and a negotiation feature to directly negotiate large trades with or without anonymity. Nevertheless, the continued success of voice brokers in certain segments of the market indicates that the electronic systems have not yet been able to capture and exploit all of the market color that makes voice brokers successful. Traders still convey certain types of information to a voice broker over the telephone that they are unwilling or unable to convey in a fully automated trading system.

There are no significant differences in the payoff-relevant information about on- and recently off-the-run Treasury securities. However, because trading volume declines by more than 90% when a Treasury security goes off the run, market information about supply and demand is likely to be more valuable to dealers attempting to trade off-the-run securities. On-the-run Treasury securities trade every 10 to 20 seconds in the IDB market. The cost of placing a limit order on an electronic trading system is low in this environment because the option embedded in this order has a very short maturity and is not very valuable. Recently off-the-run Treasury securities trade about 20 times per day and far off-the-run securities trade even less. Matching buyers and sellers is more difficult in this environment and the cost of supplying liquidity by placing a limit order is much more costly. Because the implicit cost of placing a limit order on an electronic trading system increases significantly when the security goes off the run, traders are more likely to pay the voice brokers' higher commissions in exchange for the better matching services when trading these securities.[5] This leads to the first hypothesis we test in this paper.

HYPOTHESIS 1: *When Treasury securities go off the run, the market share of electronic IDBs will decline and the market share of voice IDBs will increase.*

The ease of matching buyers and sellers and the cost of supplying liquidity through firm limit orders will also vary across trades and across days for on- and off-the-run securities. Other things equal, matches will occur more quickly and the cost of supplying liquidity through firm limit orders will be lower for trades that are small and routine (given market liquidity), and for trades that occur on high volume days. This leads to the second hypothesis we test in the paper.

[5] Commissions are negotiated between brokers and their clients and are not publicly available. Although both voice and electronic commissions are small (generally in the range of 0.05 and 0.1 basis points), voice brokers' commissions are roughly double the commissions charged by electronic brokers.

HYPOTHESIS 2: *For both on- and off-the-run Treasury securities, the market share of voice IDBs will be greater (and the market share of electronic IDBs will be smaller) for trades that are larger, for trades that are part of a larger effort to consistently buy or consistently sell throughout the day, for trades that occur on low volume days, and for trades that occur when the cost of supplying liquidity through firm limit orders is high.*

II. Related Literature

Several recent studies examine the microstructure and price formation process of the U.S. Treasury market. For example, Fleming and Remolona (1999), Huang, Cai, and Wang (2002), and Green (2004) examine the effect of public announcements on trading volume and information asymmetry. Brandt and Kavajecz (2004) examine price discovery on days with no public announcements. Krishnamurthy (2002) and Goldreich, Hanke, and Nath (2005) examine the relations among bond prices, bid-ask spreads, and changes in liquidity when Treasury securities go off the run. Vayanos and Wang (2003), Weill (2005), and Duffie, Garleanu, and Pedersen (2004) model price formation and trading in bargaining markets with search.

Because this paper focuses on traders' trading venue choices, it is more closely related to the literature on multimarket trading. Easley, Kiefer, and O'Hara (1996) and Bessembinder and Kaufman (1997) find that the regional exchanges skim off the least informed and most profitable trades from the primary exchange. Barclay, Hendershott, and McCormick (2003) find the reverse, however, when the secondary market is purely electronic. Barclay, Hendershott, and McCormick find that traders of Nasdaq stocks are more likely to use electronic platforms (ECNs) than traditional market makers for high-volume stocks and when trading volume, stock-return volatility, and information asymmetry are high. Our results for the Treasury market are consistent with the finding that electronic markets are most effective for high-volume securities, and on high-volume days.

Because we examine a brokered market, our results also relate to the upstairs and off-exchange brokered markets for equities. These markets have been modeled by Grossman (1992) and Seppi (1990) and studied empirically by Keim and Madhavan (1996), Madhavan and Cheng (1997), Smith, Turnbull, and White (2001), Booth et al. (2002), and Bessembinder and Venkataraman (2004). Bessembinder and Venkataraman show how upstairs brokers uncover hidden liquidity by getting block traders better prices than are available via the Paris Bourse's electronic limit order book. Because the upstairs market is used almost exclusively by large institutional traders who trade liquid stocks in large companies, prior papers have been unable to characterize the market-wide costs and benefits of fully automated electronic markets compared to markets with human intermediaries.

The interdealer Treasury market is most similar to the interdealer foreign exchange (FX) market, which also has both voice and electronic IDBs (see Lyons

(2001) for a detailed overview of the FX market). While there is no comprehensive FX trading data set with which to examine the choice between voice and electronic trading, what is known about the growth of electronic interdealer trading in FX is consistent with our results: Active currencies, such as the dollar–euro and dollar–yen, appear to have gone almost completely electronic while the less active currencies have not (Rime (2003)).

Studies of intermediation in equity markets typically focus on trading by a specialist or dealer. Hasbrouck and Sofianos (1993) and Madhavan and Sofianos (1998) find that specialists are more active in lower volume stocks. We use some of the empirical methods employed in these papers, but focus on the choices of traders rather than intermediaries. Reiss and Werner (1998, 2005) analyze interdealer trading in equity markets using the now defunct London Stock Exchange's IDB market and find that risk sharing motivates interdealer trading and that dealers send their less-informed orders to the anonymous IDBs.

III. Data and Descriptive Statistics

Our data are derived from clearing records submitted to the Fixed Income Clearing Corporation (FICC).[6] The FICC provides trade comparison, netting, and settlement of transactions between member firms in eligible Treasury bills, notes, bonds, and zero-coupon securities. The data contain all transactions between member firms from January 2001 through November 2002, and include the identities of the buyer and seller, the identity, amount, and price of the traded security, the trade date, the settlement date, and other miscellaneous transaction information.[7]

Each trade appears twice in our data, once as a trade between the buyer and the broker and once as a trade between the seller and the broker. To avoid double counting, we discard trades for which the reported seller is an IDB. The FICC does not accept trade records larger than $50 million par traded. Thus, if two dealers trade $150 million of a given Treasury security, the trade will be reported to the FICC as three trades of $50 million each.[8] Consequently, if on a given day we see multiple $50 million trades of the same security at the same price between the same buyer and seller, we cannot determine whether these represent one large trade or multiple smaller trades. In our analysis, we

[6] The FICC, which began operations on January 1, 2003, was formed by the merger of the Government Securities Clearing Corporation (GSCC) and the MBS Clearing Corporation (MBSCC). There are 127 FICC members in our database, including all major government bond dealers and some other large institutions such as Fannie Mae and Freddie Mac.

[7] Because we use settlement records, we do not have bid and ask quotations and we do not know the time of day when the transactions occurred. The FICC data contain records for transactions between closely related entities, which we discard. We also discard a small fraction of transactions for which there is no broker. The fraction of FICC transactions that we exclude is roughly constant on and off the run, and the paper's results are not sensitive to whether we exclude these transactions.

[8] About 7% of our trade records indicate a trade of exactly $50 million.

treat these observations as one large trade. However, none of our results are sensitive to this assumption.

Table I summarizes the daily interdealer trading activity in 2-year, 5-year, and 10-year U.S. Treasury notes. We focus on these securities because each of them was issued by the Treasury on a regular schedule during our sample period. The monthly issue of 2-year notes and the quarterly issue of 5-year and 10-year notes provide a large number of days on which these securities were both on and off the run. The combined trading volume in the 2-year, 5-year, and 10-year notes is greater than $88 billion per day, which is comparable to the total trading volume in all U.S. equity markets. Trading is heavily concentrated in the on-the-run notes, with the three on-the-run notes accounting for $74.6 billion of the $88.4 billion daily trading volume and the approximately 59 off-the-run securities trading each day accounting for the remaining $13.8 billion of aggregate daily trading volume. The average trading volume per security that is off the run is less than 1% of the trading volume of the on-the-run security. The pattern of trading volume for on- and off-the-run securities is similar for the 2-year, 5-year, and 10-year notes. While trading volume declines dramatically as securities go off the run, they still trade roughly 10 times per day (compared with over 2,000 trades per day for the on-the-run notes), with an average volume just over $200 million per day.

The electronic brokers' market share is much higher for on-the-run securities than for off-the-run securities. The electronic brokers' market share is 80.7% for the on-the-run notes and only 11.7% for the off-the-run notes. This difference is consistent across the maturity spectrum. When the notes go off the run, the electronic brokers' market share falls from 75.2% to 9.9% for the 2-year notes, from 83.5% to 8.5% for the 5-year notes, and from 84.5% to 8.9% for the 10-year notes.[9] The average voice trade is about twice as large as the average electronic trade in all three notes, suggesting that the more difficult trades benefit more from the services provided by a voice broker.

Most recent studies of the Treasury market use data from GovPX that consolidates trade and quote information from a subset of the voice IDBs. Fleming (1997) reports that GovPX represents about two-thirds of the interdealer broker trades during his earlier sample period. Our data show that GovPX's coverage of interdealer trading is only 20% to 30% for all maturities in 2001 and 2002. Because GovPX currently reflects only a small and narrow segment of the Treasury market, it may no longer provide a representative picture of this market.

IV. The Choice of Trading Venue as Securities Go Off the Run

During our sample period, a new 2-year note was issued each month, which yields 23 events in which a 2-year note went off the run. The 5-year and 10-year

[9] Electronic market share is only defined on days with trading. Because off-the-run securities regularly do not trade, the overall average electronic market share for these securities need not be within the range of the market shares for each maturity.

Table I

Descriptive Statistics

Summary statistics for interdealer trading of 2-year, 5-year, and 10-year U.S. Treasury notes from January 2001 through November 2002. Standard errors of the means are in parentheses. A Treasury note is considered on the run until the auction date of the next note of the same maturity.

Security	Volume ($Billions)	Trades (000s)	CUSIPs	Electronic Market Share (%)	Trade Size ($Millions)	
					Elec	Voice
All notes	88.4	7.6	62	71.7	10.0	21.8
	(1.1)	(0.1)	(0.5)	(0.2)	(0.1)	(0.1)
On the run	74.6	6.9	3	80.7	9.9	20.4
	(1.0)	(0.1)	(0.0)	(0.2)	(0.1)	(0.2)
Off the run	13.8	0.7	59	11.7	14.1	24.1
	(0.5)	(0.0)	(0.5)	(0.7)	(0.4)	(0.1)
2-Year notes	36.1	2.0	18	69.4	16.1	27.4
	(0.6)	(0.0)	(0.1)	(0.4)	(0.2)	(0.3)
On the run	30.5	1.7	1	75.2	17.1	27.8
	(0.5)	(0.0)	(0.0)	(0.4)	(0.3)	(0.5)
Off the run	5.6	0.2	16	9.9	18.3	29.0
	(0.5)	(0.0)	(0.1)	(0.7)	(1.1)	(0.3)
5-Year notes	29.5	2.8	21	74.4	9.1	19.6
	(0.4)	(0.0)	(0.3)	(0.3)	(0.1)	(0.2)
On the run	25.5	2.6	1	83.5	9.3	17.5
	(0.4)	(0.0)	(0.0)	(0.3)	(0.1)	(0.3)
Off the run	4.1	0.2	20	8.5	13.4	23.6
	(0.2)	(0.0)	(0.3)	(0.4)	(0.4)	(0.2)
10-Year notes	22.7	2.8	23	71.9	7.0	17.4
	(0.3)	(0.0)	(0.2)	(0.3)	(0.1)	(0.1)
On the run	18.6	2.6	1	84.5	7.1	14.9
	(0.3)	(0.0)	(0.0)	(0.3)	(0.1)	(0.2)
Off the run	4.1	0.2	22	8.9	10.5	20.6
	(0.2)	(0.0)	(0.2)	(0.4)	(0.3)	(0.1)

notes were issued approximately once per quarter during our sample period. On eight occasions, the on-the-run 5-year or 10-year note was "reopened" and did not go off the run (see Fleming (2002) for a discussion of reopenings). Thus, we have five events in which a 5-year note went off the run and four events in which a 10-year note went off the run.[10]

Figure 1 shows the average daily trading volume for the 2-year, 5-year, and 10-year Treasury notes that went off the run during our sample period. We average the daily trading volume across securities with the same maturity on a given day in relation to the off-the-run day (the day after the auction date for the subsequent note with the same maturity). All three maturities

[10] During our sample period, only one 30-year bond was issued. The 30-year bond that went off the run has the same trading characteristics as 2-year, 5-year, and 10-year notes that go off the run during our sample period. Because there is only one such bond, however, we do not include it in the analysis that follows.

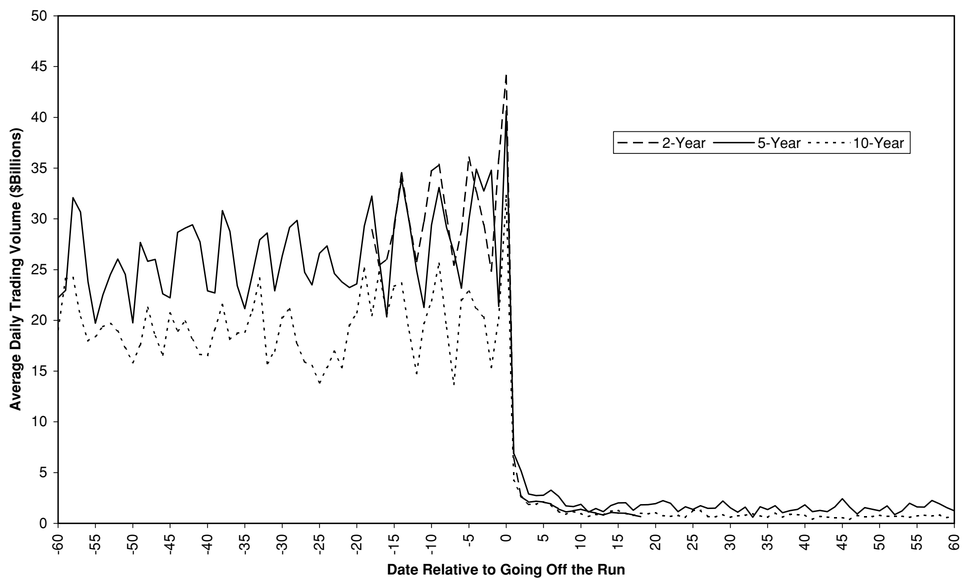

Figure 1. Trading volume for on- and off-the-run Treasury securities. Average trading volume is calculated for 2-year, 5-year, and 10-year U.S. Treasury notes that go off the run between January 2001 and November 2002.

trade between $20 and $30 billion per day while they are on the run. Trading volume appears to have a day-of-the-week effect that could be induced by the schedule of government macroeconomic announcements. On the day that these securities go off the run, trading volume falls by over 90%.[11] Thereafter, trading slowly declines with the far off-the-run securities trading infrequently.

The dramatic decline in trading volume for securities that go off the run provides a unique insight about the pure matching function of human and electronic intermediaries. In almost all financial markets, the level of trading volume and the level of information asymmetry are closely linked. Thus, in these markets, it is difficult, if not impossible, to separate the effects of information asymmetry from the pure matching function of the intermediary. In the Treasury market, there is no difference in the payoff-relevant information for on- and off-the-run securities. Therefore, we can hold the level of information asymmetry constant and focus on the matching function of voice and electronic brokers.

For the 2-year, 5-year, and 10-year notes depicted in Figure 1, Figure 2 graphs the average daily market share by trading venue and by day in relation to the off-the-run date. For all three notes, the electronic brokers' market share is between 80% and 90% when the security is on the run. When these

[11] Fleming (2002) shows that bid-ask spreads increase from roughly 0.5 to 2 basis points when Treasury securities go off the run.

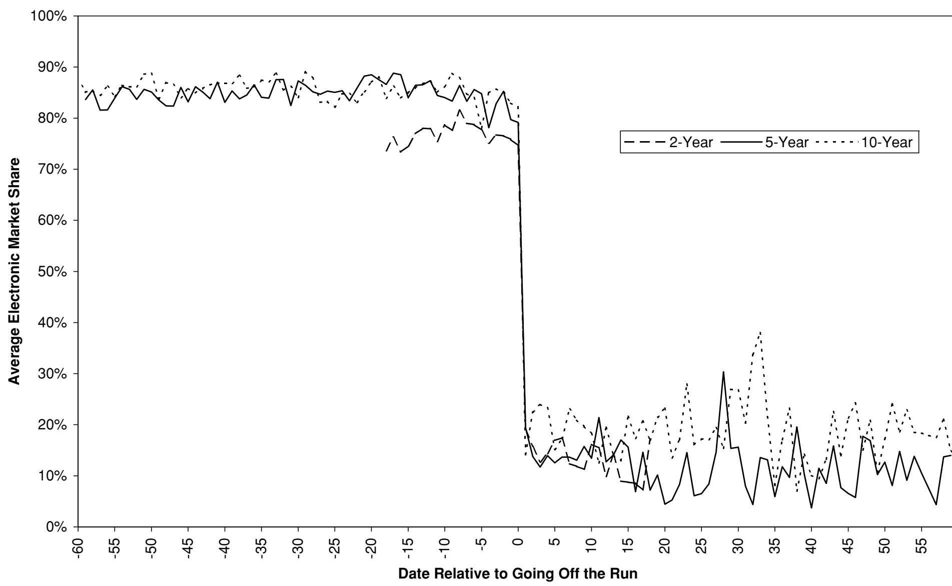

Figure 2. Electronic brokers' market share for on- and off-the-run Treasury securities. The electronic brokers' daily market shares are calculated for 2-year, 5-year, and 10-year U.S. Treasury notes that go off the run between January 2001 and November 2002.

securities go off the run, the electronic brokers' market share falls to about 10%. This shift in market share from electronic to voice brokers occurs immediately when the security goes off-the-run and is permanent, providing support for Hypothesis 1.

V. Market Share Regressions

Using a regression specification similar to that employed by Madhavan and Sofianos (1998) in their study of NYSE specialist participation rates, we examine the extent to which the observed shift in market share from electronic to voice brokers when Treasury securities go off the run can be explained by changes in market conditions that might affect the choice of intermediary. The dependent variable in these regressions is the percentage of the total trading volume in a given Treasury security on a given day that is executed by an electronic broker.

To test Hypothesis 1, we include a dummy variable as a regressor that indicates when the security is on the run. Hypothesis 1 predicts that the coefficient on this dummy variable will be positive and significant. To test Hypothesis 2, we include the average trade size (measured as the log of par traded) and an estimate of the cost of providing liquidity by submitting a firm limit order. Hypothesis 2 predicts that the coefficients on these two variables will be negative and significant. As control variables, we also include dummy variables for 5-year and 10-year notes, and a dummy variable for days on which there were public announcements of macroeconomic news.[12]

Following Bollen, Smith, and Whaley (2004), we estimate the expected cost of placing a limit order as the price of an at-the-money option with time to maturity equal to the average time between trades. Specifically, we calculate this option value as $S[2N(0.5\sigma\sqrt{t}) - 1]$, where S is the bond price, σ is the bond price volatility, N is the standard normal distribution function, and t is the average time between trades for that security on that day.

To calculate the bond price volatility, we follow the range-based estimation approach in Alizadeh, Brandt, and Diebold (2002). If the bond price follows a driftless Brownian motion such that $dS = \sigma\, dW$, then the log range, $[\ln(\max S(t) - \min S(t))]$, has a Gaussian distribution with mean $0.43 + \ln(\sigma)$. We use this relation to estimate the daily volatility for each security on each day as $\sigma = \exp[(\ln(\max S(t) - \min S(t))) - 0.43]$.[13]

As the expected time between trades increases, there is a greater likelihood that new information will arrive before a limit order executes. Unless traders placing limit orders constantly monitor the market, their orders can become "stale" and are more likely to be executed when prices move in an unfavorable direction. In our sample, the average time between trades is roughly 100 times longer for off-the-run securities than for on-the-run securities. The maturity effect is magnified when the bond price volatility is high. Using an option value to measure the cost of placing a limit order captures both of these effects. In our sample, the average cost of placing a limit order, as measured by this option value, is 0.24 basis points for the on-the-run securities and 1.73 basis points for the off-the-run securities.

We estimate the regressions using the 2-year, 5-year, and 10-year notes depicted in Figures 1 and 2.[14] In our panel, correlated trading shocks may occur in multiple securities on the same day, causing contemporaneous correlation in the error terms across securities. Thus, to calculate standard errors controlling for both contemporaneous correlation and heteroskedasticity, we allow for arbitrary correlation across securities at each date. Let X_t, ε_t, and Ω_t denote a

[12] We use a subset of the macroeconomic announcements in Green (2004): monthly reports on employment, producer price index, consumer price index, durable goods orders, retail sales, housing starts, and U.S. exports and imports. At least one of these announcements occurs on approximately one-third of the days in our sample period.

[13] Differences in the frequency of trading and bid-ask spreads make calculating an equivalent measure of volatility for both on-the-run and off-the-run securities problematic. Because spreads are smaller and trading frequency is higher when a security is on the run, it is easier to estimate the volatility of the underlying value for on-the-run securities. We expect the underlying volatility for the on-the-run security and the just-off-the-run security of the same maturity to be essentially the same. Therefore, we use the daily estimates of volatility of the on-the-run security for both the on-the-run security and the just-off-the-run security of the same maturity. The paper's results are robust to using the estimated volatility for off-the-run securities and to using the Parkinson (1980) volatility estimate with or without a correction for the trading frequency.

[14] Specifically, the regressions include 2-year notes within 20 days before or after the off-the-run date and 5-year and 10-year notes within 60 days before or after the off-the-run date. Estimating the model on a larger sample of securities, including the far off-the-run securities, gives similar results.

Table II

Electronic Brokers' Market Share Regressions

The market share of electronic interdealer brokers (in percent) is calculated each day for 2-year, 5-year, and 10-year U.S. Treasury notes from January 2001 through November 2002 for the days prior and subsequent to the going-off-the-run event (20 days before and after for 2-year notes and 60 days before and after for 5-year and 10-year notes). These daily percentage market shares are regressed on the bond price volatility (*volatility*), the logarithm of the average trade size (*log(trade size)*), the square root of the average time between trades (*sqrt(time)*), the cost of placing a limit order (*option value*), and dummy variables indicating securities with a 5-year maturity (*5-year*), securities with a 10-year maturity (*10-year*), macroeconomic announcement days (*macro*), and securities that are on the run (*on-run*). The standard errors of the coefficients (in parentheses) control for heteroskedasticity and contemporaneous correlation within days. An asterisk (*) represents statistically significant coefficients at the 0.01 level.

Regression Number	(1)	(2)	(3)
Intercept	220.38*	235.28*	233.53*
	(28.10)	(29.08)	(28.48)
5-year	–0.77	–4.03*	–3.29
	(0.93)	(1.22)	(1.23)
10-year	4.07*	–0.67	1.02
	(1.17)	(1.52)	(1.60)
Macro	0.19	–0.23	0.01
	(0.60)	(0.55)	(0.56)
log(trade size)	–11.28*	–11.61*	–11.52*
	(1.59)	(1.60)	(1.56)
Option value	–5.29*		–2.61*
	(0.59)		(0.63)
Volatility		–7.32*	–3.27
		(2.16)	(2.01)
sqrt(time)		–163.32*	–119.72*
		(23.39)	(26.80)
On-run	45.58*	42.84*	40.94*
	(2.24)	(2.89)	(2.71)
Observations	1,986	1,986	1,986
R^2	0.888	0.892	0.894

single cross section of explanatory variables, the corresponding residual vector, and the associated error covariance matrix, respectively. Assuming independence over time, the ordinary least-squares estimator has a variance given by $(X'X)^{-1}\sum_t(X_t'\Omega_t X_t)(X'X)^{-1}$. Substituting fitted values, the asymptotic estimate of the variance–covariance matrix is $(X'X)^{-1}\sum_t(X_t'\hat{\varepsilon}_t\hat{\varepsilon}_t'X_t)(X'X)^{-1}$. Table II provides estimated regression coefficients and standard errors.[15]

Consistent with the results in Figure 2, the small coefficients on the 5-year and 10-year dummy variables in Table II indicate that the market share of electronic IDBs does not vary much across the maturity spectrum.

[15] If data were available for all securities that go off the run in our sample period, there would be 41 days (20 prior and 20 subsequent to going off the run) for each of the 23 2-year notes and 121 days (60 prior and 60 subsequent to going off the run) for each of the 9 5- and 10-year notes for a total of 2,032 security days. That number is reduced by notes that go off the run at the beginning or end of the sample period and holidays that shorten the on-the-run period.

In addition, the insignificant and small coefficients on the macro dummy variable indicate that the choice between voice and electronic IDBs is not affected by macroeconomic announcements after controlling for trading volume and volatility.

When a security goes off the run, its trading volume declines by more than 90%. This decline in trading volume makes it more difficult to match buyers and sellers, especially for large and difficult trades. The decline in trading frequency also increases the cost of supplying liquidity by placing a firm limit order because the lower trading frequency increases the effective maturity of the embedded option. Because voice brokers can use the qualitative information they collect over the telephone to mitigate this cost of trading in less active markets, we expect that the market share of voice brokers will increase as the cost of submitting a limit order increases. Regression (1) in Table II supports this hypothesis. The coefficient on the option value (the implicit cost of submitting a firm limit order) is negative and statistically significant.

As noted above, the cost of submitting a limit order is affected by both the expected time between trades and the bond price volatility. Regression (2) in Table II shows that each of these components is significantly negatively related to the electronic brokers' market share. When the cost of submitting a limit order and its components are both included in the regression (Regression (3)), the option value and the time between trades remain negative and statistically significant. The coefficient on the bond price volatility is negative, but not significant.

For both on- and off-the-run securities, all three regressions in Table II indicate that larger trades are more likely to occur with voice brokers. The fact that larger trades tend to be executed through voice brokers reinforces the notion that voice brokers are better able to match natural counterparties for difficult trades. Together, the negative and significant coefficients on the cost of submitting a limit order, the time between trades, the bond price volatility, and the trade size support Hypothesis 2.

The coefficient on the on-the-run dummy variable indicates that when a security goes off the run, the electronic brokers' market share declines by 40 to 45 percentage points, even after controlling for the higher cost of submitting a limit order. The large shift from electronic to voice brokers when securities go off the run supports Hypothesis 1. This shift also suggests a potential liquidity externality. Traders benefit from concentrating their trades in the same trading venues. For the on-the-run securities, the preferred venue is electronic. When securities go off the run, the benefits of using a voice broker increase and, once a critical mass of traders leave the electronic IDBs, the majority of traders move to voice brokers.

Approximately 93% of the trades in our sample have one-day settlement. The majority of the trades with nonstandard (longer than 1 day) settlement occur during the when-issued trading period between the announcement of a new issue and its issue date. None of the results in this section, or elsewhere in the paper, are affected if we exclude trades with nonstandard settlement. It is interesting to note, however, that nonstandard trades during the when-issued period tend to be larger and are more likely to be executed through a voice broker than are other on-the-run trades.

The linear specification of the regressions in Table II provides coefficients that are easy to interpret. However, we also examine specifications that account for the fact that market shares are constrained between zero and one. Reestimating the daily market share regressions using a logistic specification provides coefficients with the same sign and similar statistical significance as reported in Table II and are not reported.

VI. Transaction-Level Regressions

The market-share regressions in Table II confirm our prediction that voice brokers are most valuable when trading volume is low and when trades are more difficult. To further explore these results and the predictions of Hypothesis 2, Table III reports the estimated coefficients from a probit regression estimated transaction-by-transaction, where the dependent variable is equal to one if an individual trade occurred on an electronic platform and zero otherwise. For the same sample as in Table II, we regress these indicators on dummy variables set equal to one if the security has a 5-year or 10-year maturity. We also include the daily measures of volatility, trading activity (*sqrt(time)*), and the cost of submitting a limit order (*option value*). Because the macroeconomic announcement variable had no impact on the market share regressions, we omit this variable from the probit regressions.

Because we estimate the probit regressions at the transaction level, rather than at the daily market share level, we replace the daily average trade size with the size of each individual trade (*log(trade size)*). We also include new information about the characteristics of the dealers. We add a fixed effect for each dealer, the logarithm of the total dollar trading volume by the dealer in that security on that day (*log(dealer volume)*), and the logarithm of the absolute value of the dealer's net volume (buy volume minus sell volume) in that security on that day (*log*(|*dealer net volume*|)). In addition to the coefficient estimates, Table III also reports the corresponding linear probability slopes and Chi-square statistics controlling for both heteroskedasticity and contemporaneous correlation within days.

Consistent with the results in Table II, the probit regressions indicate that trades are more likely to occur through electronic IDBs when the trade size is smaller, when trading activity in the security is more frequent, and when the security is on the run. These results confirm our previous conclusions that the services offered by voice brokers are most valuable when it is difficult to find a match because the trade is large or trading volume and liquidity are low.

In addition to controlling for market-wide effects, the transaction-level data also enable us to examine individual traders' motives for trading in a particular venue. In particular, we predict that dealers are more likely to use voice brokers when their trades are more difficult, either because the trades are larger or because the dealers want to trade a large quantity on one side of the market. Consistent with this prediction, trades are less likely to occur with an electronic

Table III
Probit Regressions for the Choice of Trading Venue

The dependent variable is equal to one for interdealer trades executed by an electronic broker and zero otherwise. Coefficient estimates are reported for the probit regression with the corresponding linear probability slopes and Chi-square statistics for 2-year, 5-year, and 10-year U.S. Treasury notes from January 2001 through November 2002 for the days prior and subsequent to the going-off-the-run event (20 days before and after for 2-year notes and 60 days before and after for 5-year and 10-year notes). Independent variables include the amount of par traded, (*log*(*trade size*)), the dealer's total dollar trading volume in that security on that day (*log*(*dealer volume*)), the absolute value of the dealer's net (buy minus sell) volume (*log*(|*dealer net volume*|)), the bond price volatility (*volatility*), the square root of the average time between trades (*sqrt(time)*), the cost of submitting a limit order (*option value*), and dummy variables indicating securities with a 5-year maturity (*5-year*), securities with a 10-year maturity (*10-year*), and securities that are on the run (*on-run*). Fixed effects for individual dealers are included where indicated, but not reported. The Chi-square statistics control for heteroskedasticity and contemporaneous correlation within days. An asterisk (*) represents statistically significant coefficients at the 0.01 level.

Regression Number	(1)	(2)	(3)	(4)	(5)	(6)
Fixed Dealer Effects	No	Yes	No	Yes	No	Yes
Intercept	1.650*		2.212*		2.085*	
	27		35		33	
5-year	0.293*	0.257*	0.174*	0.127*	0.203*	0.155*
	0.044	0.037	0.027	0.019	0.031	0.023
	32	28	16	12	19	15
10-year	0.452*	0.423*	0.257*	0.206*	0.287*	0.235*
	0.064	0.057	0.038	0.029	0.043	0.033
	44	41	18	14	20	17
log(trade size)	−0.286*	−0.282*	−0.284*	−0.281*	−0.282*	−0.279*
	−0.046	−0.042	−0.045	−0.042	−0.045	−0.042
	99	96	99	96	99	96
log(dealer volume)	0.207*	0.204*	0.190*	0.140*	0.189*	0.140*
	0.032	0.031	0.030	0.021	0.030	0.021
	77	30	89	27	90	28
log(|dealer net volume|)	−0.039*	−0.009*	−0.037*	−0.007*	−0.037*	−0.006*
	−0.006	−0.001	−0.006	−0.001	−0.006	−0.001
	30	6	29	4	29	4
Option value	−0.416*	−0.398*			−0.289*	−0.279*
	−0.066	−0.060			−0.046	−0.042
	26	25			10	9
Volatility			−0.010	−0.009	0.235*	0.229*
			−0.002	−0.001	0.038	0.035
			1	1	7	6
sqrt(time)			−13.175*	−14.150*	−6.530*	−7.719*
			−2.110	−2.142	−1.045	−1.167
			30	31	8	9
On-run	0.271*	0.278*	0.249*	0.246*	0.215*	0.213*
	0.051	0.049	0.046	0.043	0.039	0.037
	8	9	9	9	8	8
Observations	5,318,910	5,318,910	5,318,910	5,318,910	5,318,910	5,318,910
Pseudo R^2	0.138	0.138	0.140	0.170	0.140	0.171

IDB when the trade is larger and when the dealer has a larger imbalance between buying and selling volume on a given day. Individual dealers can attempt to replicate some of the services provided by voice brokers by monitoring the market and gathering information about supply and demand beyond what is reported at any one time in the limit order book. In effect, such dealers internalize the brokers' services and consequently are less willing to pay the higher voice commissions. Dealers are more likely to closely monitor the market when they are more active in a given security on a given day. Consistent with this, higher dealer trading volume in a security leads to greater use of electronic IDBs: The coefficient on *log(dealer volume)* is positive and significant with or without the dealer fixed effects. This suggests that larger and more active dealers are more likely to trade through electronic brokers. Finally, we include dealer fixed effects to control for any systematic preferences of individual dealers. The coefficients on the other variables in the regressions are not affected significantly by the inclusion of dealer fixed effects. Thus, our results do not appear to be affected by a shift in trader clienteles when the securities go off the run.

VII. Repos on Treasury Notes and Treasury Bills

To further test the robustness of our results, we examine Treasury securities that are actively traded through repurchase agreements or "repos" and the trading of 13-week and 26-week Treasury bills.[16] In a repurchase agreement, one investor sells a security to another investor and agrees to repurchase it at a specified price on a specific future date, making a repurchase agreement essentially a collateralized loan with the traded security serving as the collateral. From the perspective of the buyer of the security, the identical transaction is referred to as a reverse repurchase agreement or "reverse repo." Repos typically are overnight agreements, but they can have terms as long as 30 days or more.

While they are on the run, the 2-year, 5-year, and 10-year notes are each used as collateral for $10 to $20 billion of repo transactions per day. When they go off the run, the repo volume declines gradually over the course of several weeks to approximately $5 to $10 billion dollars per security per day. Although the repo volume is significantly lower than the cash-market volume reported in Figure 1, the trade sizes tend to be significantly larger. When the securities are on the run, the electronic market share for repos is about 40%. As predicted, because of the lower overall trading volume, the electronic brokers' market share for on-the-run repos is considerably smaller than the 80% to 90% market share in the cash market. Consistent with the behavior of the cash market, however, the electronic market share declines gradually to about 25% when the securities go off the run.

Treasury bills trade actively on only one electronic IDB. Because we agreed not to disclose information about any individual market participant (such as the market share of a single IDB), we do not report the Treasury bill results

[16] A more extensive analysis of the repo market was included in a previous version of the paper and is available from the authors upon request.

here. However, the event-study and regression results for the Treasury bills are qualitatively similar to the results for the repos. Both trading volume and the electronic trading market share drop significantly as the bills go off the run. However, because trading volume drops by only about 75% when Treasury bills go off the run (Fleming (2002)), as compared to the drop of over 90% when the notes go off the run, the drop in the electronic market share is not as large in Treasury bills as it is in Treasury notes.

Coefficients from market share regressions or transaction-level probit regressions in Tables II and III for the repo and bills sample (details omitted) have the same sign and statistical significance for the notes in Sections V and VI. These results confirm our previous conclusion that electronic brokers provide low-cost execution for routine trades when trading activity is high, and that voice brokers appear to provide additional services that are most valuable when markets are less active, and for larger and more difficult trades.

VIII. Summary

As electronic trading systems increase their share of securities trading in financial markets, the natural question to ask is what services, if any, human intermediaries provide that are difficult or impossible to replicate in a fully automated trading system. Theory and past research suggest that human intermediation is most valuable when trading is thin and when information asymmetry is high. Because these two factors are highly correlated, prior research has not attempted to separate these sources of value created by human intermediaries.

We examine the choice of trading venue by dealers in U.S. Treasury securities. Newly issued Treasury securities are very actively traded. When the Treasury issues a new security of the same maturity, the old security goes off the run and its trading volume drops by more than 90%. This exogenous shock to trading volume allows us to examine the matching function of human intermediaries across active and less active markets.

Interdealer trades in U.S. Treasury securities are conducted through interdealer brokers (IDBs). Some IDBs operate completely automated electronic trading systems while others continue to operate voice-based systems. Personal interaction with the dealers allows the voice broker to collect additional market information and provide additional services. Interaction with a voice broker is costly and voice brokers consequently charge higher commissions than electronic brokers.

When Treasury securities are on the run, the electronic brokers' market share is approximately 80% and when a security goes off the run electronic brokers' market share falls to 12%. On days when trading is less active, when it is more costly to supply liquidity by placing a firm limit order, when trades are larger, and when a dealer has a larger imbalance between buying and selling, trades are less likely to occur through electronic brokers. These results indicate the circumstances in which the value of a voice brokers' services are greatest.

Finally, when securities go off the run, there is a large shift from electronic to voice brokers that our regression specifications cannot explain (as captured by a large and significant coefficient on the on-the-run dummy variable). Traders benefit from a liquidity externality when they bunch their trades on a single trading platform. When Treasury securities are on the run, the preferred platform appears to be electronic. When these same securities go off the run, the benefits of using a voice broker increase and traders move to the alternate platform. Once a critical mass of traders leaves the electronic IDBs, the equilibrium is for almost all traders to move to the voice brokers. The large shift in the market share when securities go off the run suggests that this liquidity externality is likely to be important.

This paper suggests that there is an important role for human intermediation in relatively active securities, for example, Treasury securities that trade hundreds of millions of dollars per day, with little information asymmetry. However, as the trading activity increases in these same securities, completely automated systems dominate. If the trading volume in financial markets continues to increase, as it has for the past several decades, our results indicate that the role of human intermediation will continue to diminish.

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