

# Why Do Dealers Buy High and Sell Low? An Analysis of Persistent Crossing in Extremely Segmented Markets

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## Abstract

Impediments to aggregating small positions in combination with investor suitability rules disproportionately affect retail-sized trading and cause persistent “crossing” of the agency MBS market. Retail buyers obtain 3%-8% lower prices than institutional sellers. 83% of small buy trades in the MBS market are crossed versus less than 1.5% of small buy trades in the corporate bond and agency debenture markets. We validate these unique MBS findings through out-of-sample real money purchases at an average discount of 8% relative to institutional sell prices. We develop a model showing that classic bond market frictions cannot produce such pricing patterns.

Keywords: agency mortgage-backed securities, corporate bonds, agency debentures, market frictions, market crossing, suitability, market fragmentation, volume imbalance.  
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## Abstract

Impediments to aggregating small positions in combination with investor suitability rules disproportionately affect retail-sized trading and cause persistent “crossing” of the agency MBS market. Retail buyers obtain 3%-8% lower prices than institutional sellers. 83% of small buy trades in the MBS market are crossed versus less than 1.5% of small buy trades in the corporate bond and agency debenture markets. We validate these unique MBS findings through out-of-sample real money purchases at an average discount of 8% relative to institutional sell prices. We develop a model showing that classic bond market frictions cannot produce such pricing patterns.

## 1. Introduction

Data on individual bond market transactions provide ample evidence that one trade size does not fit all customers. Differential preferences regarding trade size divide customers into retail and institutional investor segments. An extensive literature identifies frictions that operate differently in different trade size segments of corporate and municipal bond markets. Such frictions include transaction costs (Harris and Piwowar, 2006; Hong and Warga, 2004) and differential bargaining power due either to search costs (Green, Hollifield, and Schürhoff, 2007a; Feldhütter, 2012) or sophistication about value (Green, Hollifield, and Schürhoff, 2007b).

Trade size segmentation and size-based frictions in over-the-counter bond markets raise the potential for “fragmentation.” In a fragmented market, a buyer or a seller may not be able to obtain the best available price for her transaction across all segments (Lee, 1993). For example, the price that a trader of a small corporate bond position can achieve may not be the best available price per unit – it will typically be worse than the price available to a trader of a large position. However, as modeled by the existing literature, these traditional frictions produce arbitrage-proof prices in the sense that no market participant can profitably buy a security in one size segment and sell the same security in the other. In both models and practice, size segments never “cross” and small trade customer buy prices are always higher than concurrent large trade customer sell prices for the same corporate bond. Crossed trades do not occur because corporate bond dealers easily bridge the two segments through aggregating retail-sized or splitting up institutional-sized positions.

In this paper, we show that this traditional view of “uncrossed” bond markets is incomplete. Indeed, we provide evidence from the agency mortgage-backed securities (MBS) market that prices consistently cross and produce apparent violations of arbitrage conditions. We

attribute these unique pricing patterns to two frictions affecting MBS dealers (as well as dealers in many other structured products) – impediments to aggregating small positions and a suitability restriction on recommending small positions to retail customers. Our evidence on both the existence and persistence of market crosses is thus evidence not only of conditions that produce extreme market fragmentation, but also of barriers to arbitrage that limit MBS dealers’ ability to span trade size segments within a single security.

The agency MBS sector – comprised of MBS issued by the Federal National Mortgage Association (FNMA, “Fannie Mae”), the Federal Home Loan Mortgage Corporation (FHLMC, “Freddie Mac”), and the Government National Mortgage Association (GNMA, “Ginnie Mae”) – constitutes about one quarter of outstanding US debt securities and is second only to Treasuries in daily secondary market trading volume. Given the vast number of individual securities in this sector, the number of customers actively seeking to buy or sell a particular issue at a given point in time may be quite small. In such a product space, the aggregate-and-resell channel breaks down because it is unlikely that any dealer (or even the entire dealer community) will see a sufficient number of small sell trades in the same individual security over any reasonably short length of time. In a sense, dealers suffer a raw material shortage regarding the usual arbitrage process for bridging market segments even though accumulating multiple “cheap” small positions to form a single large block attractive to an institutional buyer would appear profitable. In contrast, given the limited number of individual securities per issuer in the corporate bond and agency debentures spaces, dealers in these markets can more easily aggregate small-sized trades into larger, institutional positions on a timely basis.

The suitability friction originates from the Financial Industry Regulatory Authority (FINRA) Suitability Rule that incentivizes broker-dealers to institute company-wide policies

against recommending complex securities that may not fit a retail investment profile. These policies impede some retail investors from learning about dealer inventories of certain securities. Suitability-driven policies create barriers to retail investor awareness in the spirit of Merton (1987), who states: “the existence of prudent-investing laws and traditions as well as other regulatory constraints can also rule out investment ... by some investors.” Agency MBS are among those securities that FINRA has deemed potentially unsuitable for retail investors because of the cash flow complexity derived from prepayment risk. The implementation of suitability rules may cause a persistent shortage of retail buyers for unsuitable securities such as MBS.

We look for evidence of size-based segmentation by examining TRACE data for three different debt markets – investment grade corporate bonds, agency debentures, and agency MBS. We confirm that observable market characteristics like customer buy/sell volume imbalance differ across the three markets in a way that is consistent with a differential effect of the suitability friction in the MBS market. We also verify that MBS dealers face a much lower probability of aggregating retail-sized customer sells into institutional-sized customer buys on the same day.

We then examine the relation between trade size and average customer buy and sell prices in the same security on the same day and find evidence of size-related fragmentation. Consistent with findings from previous studies, the prices of small trades differ significantly from the prices of large trades in all three markets. Our empirical investigation finds that small sell trades are priced at a discount relative to large trades in all three markets, but the discounts of MBS sells are much larger – 4%-10% in MBS versus 0.3%-0.6% in corporates and 0.2%-0.5% in agency debentures. Small buy trades in corporates and agency debentures are priced at a

premium to large trades (0.8%-1.6% in corporates, and 0.1%-0.3% in agency debentures). In sharp contrast, small customer buy trades in MBS occur at 3% to 8% discounts to large trades.

We also find that the MBS market is persistently crossed. Using a conservative filter that takes into account the daily high-low price range, we find that 83% of small buy trades occur at prices below the prices of large sells in the same security on the same day. Crossed markets can be viewed as violations of the law of one price. In contrast, prices of small trades are virtually arbitrage-proof in corporate bonds and agency debentures – the same filter identifies less than 1.5% of small buy trades occurring below the institutional sell prices. We investigate the MBS market opportunities for arbitrage profits based on these crossed prices. However, we find no practical opportunities for position aggregation arbitrage across the two trade-size segments. The flow of trading in individual securities is just too light to permit aggregation of multiple cheap small positions for timely resale in a large trade to an institutional investor. The apparently arbitrage-prone differential pricing in adjacent trade-size segments of the MBS market remains effectively arbitrage-proof due to this market's position aggregation friction.

To address any residual concerns about the new MBS TRACE data used in this study, we also implement a real-money buy-and-hold MBS investment program using a combination of personal and student investment fund monies. We execute 37 out-of-research-sample MBS transactions that conform to the standards of our research design. We capture an 8% average discount (net of all commissions) versus institutional sell prices, in line with the high end of the range that might be anticipated on the basis of our research sample's MBS customer buy trades results.

Finally, we examine the relative roles of the position aggregation and suitability frictions in generating crossed markets in a stylized model that also incorporates traditional size-related

frictions. The model shows that persistently crossed markets – in which small buy trades are executed at lower prices than large sell trades – can result from a combination of the small position aggregation and suitability frictions. We show that the literature’s traditional frictions alone cannot produce persistent market crossing. The results suggest that forms of our novel position aggregation and suitability frictions are not only sufficient, but may also be necessary, to explain persistently crossed markets.

## **2. Background**

In this section we first provide background information on trading in agency MBS, agency debentures, and corporate bonds. We then discuss market frictions that operate differently in small versus large trades and also develop testable hypotheses about the effects of these frictions on buy-sell volume imbalance and pricing patterns.

### *2.1 Trade and Position Sizes: Current Face versus Original Face Values*

Debt markets are segmented on trade size.<sup>1</sup> The Financial Industry Regulatory Authority (FINRA) classifies customer bond market trades as “retail” if transaction size is below \$100,000 and as “institutional” if transaction size is equal to or above \$100,000 (Ketchum, 2012).

Differences in observed “round lot” trade sizes across markets no doubt reflect cross-market differences in the retail versus institutional customer mix. For example, the mode size for customer trades in the mainly institutional specified-pool MBS market is \$1,000,000, one hundred times the \$10,000 mode size for customer trades in the more retail-oriented corporate bond market.

Obviously, an investor’s initial position size (in “face” or par value) is also determined by investor choice. For corporate bonds and agency debentures, the effective face value of an

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<sup>1</sup> Harris and Piwowar (2006), Hong and Warga (2004), Green, Hollifield, and Schürhoff (2007a, 2007b) and Feldhütter (2012).

investor's position remains constant through the security's redemption date. However, a special feature of conventional pass-through MBS is that, due to intervening principal repayments, the current face value of any specific MBS position shrinks over time relative to its original face value.<sup>2</sup> Position decay is a separate problem for an institutional MBS investor that is not confronted by investors in Treasuries, agency debentures, corporate bonds, or municipal bonds. For example, an institutional investor holding a \$1 million, 30-year MBS position for ten years may be left with a retail-sized position of only \$25,000 in current face value. Principal repayments often transform the originally large positions preferred and purchased by institutional investors into holdings too small in current face value to be of interest to the same investors.

## *2.2 Methods of Managing Position Decay in Structured Products*

While we highlight here its impact for agency MBS, position decay is a general concern for all structured products that have cash flows tied to a portfolio of individual loans such as private-label residential MBS, commercial MBS (CMBS), asset-backed securities (ABS), and collateralized loan obligations (CLOs). How position decay manifests itself within a given securitization depends both on attributes of the underlying loans and the structure that the securitizer chooses. In general, the industry manages decay at 1) the individual loan level using prepayment impediments; 2) the security/pool level via reinvestment periods; 3) the supra-security level using transaction bundling and security aggregation conventions; and 4) the enhanced supra-security level that both aggregate and tranche the cash flows from basic securities. The supra-security levels are the only features used to manage decay for agency MBS.

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<sup>2</sup> A pass-through MBS entitles its owner to a pro-rata share of all principal and interest payments made on a pool of residential property loans that conform to underwriting standards set by the sponsoring agency. Unscheduled principal prepayments may be to the economic disadvantage of the pass-through MBS investor, especially if they result from individual mortgage loan refinancings driven by a general decrease in interest rates. But both scheduled and unscheduled principal repayments reduce a position's current face value.



Design challenges to managing position decay begin at the loan level since these underlying assets may be amortizing or non-amortizing. ABS issuers generally securitize amortizing long-maturity assets, such as auto loans and student loans, as “liquidating pools.” These loans have little or no prepayment restrictions and are subject to position decay via principal amortization and prepayments as with agency MBS. In contrast, commercial mortgages typically have loan-level features such as balloon maturity provisions and impediments to prepayments such as lockout periods, prepayment points, yield maintenance provisions, and defeasance provisions. These features keep CMBS from suffering position decay to the same extent found in agency MBS.

ABS issuers generally securitize short-maturity assets, such as credit card and trade receivables, as “revolving pools.” Revolving pools directly offset principal repayments during an initial revolving or lockout period by reinvesting the repaid funds back into new assets. For example, during a typical credit card securitization’s revolving period, the collateral manager reinvests any principal payments made by the credit card borrowers into new receivables in order to maintain the original size of the pool. Similarly, CLOs typically use a reinvestment period to keep the underlying pool of bank loans at its full original size.<sup>3</sup>

Transaction bundling and security aggregation conventions are two supra-security channels through which the industry manages position decay in agency MBS. Contracting innovations like the highly successful “to be announced” (TBA) forward contract market provide a degree of fungibility to the universe of MBS useful in bundling positions in multiple pools into

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<sup>3</sup> This revolving period for credit card receivables can be as short as 18 months or as long as 10 years (Fabozzi, 2013). Prior to the 2008-2009 global financial crisis, the typical contractual maturity of CLO deals was between 12 and 15 years, with a reinvestment period spanning the first 5 to 7 years. More recently, the contractual maturity of deals have often been below 10 years and reinvestment periods have been trimmed to as short as 2 years (Federal Reserve Board, 2010).

single, large-sized trades (Vickery and Wright, 2013). These TBA contracts call for delivery of as yet unidentified agency pass-through securities on a deferred settlement date. Under this contract convention, liquidity that might otherwise fragment among any number of individual specified pools and settlement dates consolidates around a generic security for particular settlement dates. The majority of MBS trading takes place within this TBA channel, which has excellent pre-trade transparency and offers convenient execution via electronic platforms available to institutional traders.

Furthermore, security aggregation facilities sponsored by the issuing agencies (e.g., “megapools” for FNMA MBS) allow positions in individual MBS to be aggregated into new securities. Such bundling resets but does not eliminate the MBS decay problem.

Finally, securitizers routinely use enhanced supra-security measures such as cash flow restructuring to manage position decay in certain products. Time tranching of principal repayments via sequential pay rules is one way to help mitigate position decay. For example, Collateralized Mortgage Obligations (CMOs) with sequential pay rules can produce tranches that have much longer average lives than the original agency pass-through MBS collateral used to structure them. Sequential pay structures are also common for senior tranches of auto loan and lease ABS.<sup>4</sup> By directing principal repayments exclusively to the prepayment-subordinated tranches, more senior tranches remain at full face value until their protection is sequentially exhausted. For both CMOs and auto ABS, these sequential pay structures create some classes of securities that are unaffected by position decay for long periods of time.

While we restrict our empirical study here to agency MBS, the significant negative impacts of position decay on liquidity and value that we find highlight the incentives securitizers

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<sup>4</sup> These may include four AAA-rated tranches with different stated maturities, with the shortest tranche having an average life of around three months and the remaining tranches having average lives ranging from one to three years (Federal Reserve Board, 2010).

have to employ design features to manage such decay across the full universe of loan-based structured products.

### *2.3 Suitability*

FINRA requires that broker-dealers and their associated persons must have a reasonable basis to believe that any transaction or investment strategy involving securities that they recommend is suitable for the customer. The exact text of FINRA's Suitability Rule 2111(a) states:<sup>5</sup>

“A member or an associated person must have a reasonable basis to believe that a recommended transaction or investment strategy involving a security or securities is suitable for the customer, based on the information obtained through the reasonable diligence of the member or associated person to ascertain the customer's investment profile. A customer's investment profile includes, but is not limited to, the customer's age, other investments, financial situation and needs, tax status, investment objectives, investment experience, investment time horizon, liquidity needs, risk tolerance, and any other information the customer may disclose to the member or associated person in connection with such recommendation.”

Typically, both investment grade corporate bonds and agency debentures are deemed suitable asset classes for retail investors. However, the inherent cash flow complexity and the illiquidity of small positions increase the likelihood that FINRA-member broker-dealers will deem agency MBS unsuitable for retail investors, the natural potential buyers of small positions. Two specific criteria of Rule 2111(a) affect broker-dealer suitability policies regarding agency MBS: 1) the timing of anticipated cash flows should be harmonized with investor time horizons

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<sup>5</sup> Suitability rules date to at least the 1960s, at the time separately applied by NASD, NYSE, AMEX, and SEC to their respective constituent broker-dealers (Cohen, 1971).

and 2) retail investors who have strong liquidity needs should avoid investments lacking a deep secondary trading market. Regarding the first criteria, while the agency's credit guarantee shields an investor from default risk, an investment advisor has no clear way to match the random prepayment-driven cash flow profile of an MBS to a given investor's preferred investment time horizon. Regarding the second criteria, the lack of institutional interest in small positions relegates retail sellers into an illiquid segment of the market and therefore makes MBS investments hard to justify for investors who may experience a future need to sell. The suitability rule impedes information flow from dealers to retail investors and leaves a significant percentage of the potential buyers of small positions unaware of MBS products. The suitability rule is much less likely to impede any broker-dealer communications with institutional investors.

#### *2.4 The Securities Universe*

MBS markets also differ significantly from corporate bond and agency debentures markets in terms of the outstanding universes of individual securities. About \$5.6 trillion of agency MBS were outstanding as of mid-2012, which is similar to the outstanding amount of corporate debt. However, hundreds of thousands of individual MBS exist, dwarfing the raw number of individual US corporate or municipal securities. FNMA alone had about 500,000 single-family and multi-family pools (484,022 individual MBS and 17,296 Mega "pool of pools" securities) outstanding as of year-end 2012.

#### *2.5 Limits to Arbitrage and Market Fragmentation*

Economic theory summarized by the Law of One Price predicts that identical securities must have identical prices if they sell in competitive markets with no transactions costs or barriers to trade. Any deviations from the Law of One Price should be reversed almost instantaneously for liquid securities. This prediction is consistent with Garvey and Murphy's

(2006) evidence that price crosses on twenty heavily traded Nasdaq-listed stocks are limited to about one cent for one second.<sup>6</sup> Lamont and Thaler (2003) review seemingly anomalous violations of the Law of One Price in financial markets. One reason for seemingly anomalous pricing outcomes is the existence of trading impediments that limit arbitrage activities of traders seeking to buy low in one market segment and sell high in another to capture any observed price difference.

The differences among MBS, corporate bonds, and agency debentures regarding position decay, the issue universe, impediments to position aggregation, and investment suitability suggest MBS to be the sector most likely to exhibit symptoms of fragmentation related to trade size segmentation. Recall that position size decay plays an important role in the generation of small MBS positions that many institutional investors find inconvenient. No such decay occurs in corporate bond and agency debenture markets. Furthermore, an MBS dealer's ability to make markets in specific issues is impeded since a given trading volume in the sector is split up across a vast number of securities. In contrast, the numbers of individual securities within both the corporate bond and agency debenture universes are significantly smaller. Finally, though not an issue for investment grade corporate bonds and agency debentures, investment suitability rules impede dealer turnover of any acquired small MBS positions since such positions are deemed unsuitable for retail investors. The natural retail buyers remain unaware of the opportunity even if sellers of small positions are willing to trade their securities at substantial concessions. Of course, if trading of small positions in specific issues were active enough, a dealer could profit by bundling small positions for resale to an institution. In that case, suitability *per se* would not matter and the Law of One Price (appropriately amended for the bid-ask spread) would be

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<sup>6</sup> Shkilko, Van Ness, and Van Ness (2008) suggest that crossed Nasdaq-listed stock quotes (asked quote lower than the current bid) arise from competitive trading practices.

respected. However, an MBS dealer who lacks the raw material to aggregate positions for resale has no effective way to link the retail and institutional segments of the market. Note that TBA contract fungibility does not provide direct relief to the problem of aggregating multiple small positions since the Securities Industry and Financial Markets Association (SIFMA) “Good Delivery Guidelines” make delivery of pools with small current face values inconvenient.<sup>7</sup>

From another perspective, due to limits to aggregation, a small position and a large position in one security can be viewed as two different assets with identical cash flows in the spirit of Vayanos and Wang (2007) and Vayanos and Weill (2008). In their models, two securities have identical cash flows but investors cannot convert them into each other. In equilibrium, trading concentrates in one of the assets and makes its search costs lower. As a result, the less-traded asset is priced at a discount to more liquid one. In our setting, limits to aggregation prevent dealers and arbitragers from combining multiple small positions into large ones. Institutional investors, who are the marginal holders of both position sizes due to suitability constraints, demand an additional return for small positions to compensate for their lower liquidity. As a result, both buy and sell prices of small positions are lower than those of large positions.

## *2.6 Hypotheses*

Our analysis suggests two testable hypotheses concerning the market impacts of MBS-specific frictions.

Hypothesis 1: Suitability rules combined with position decay should cause a volume imbalance between small-sized customer sell and buy MBS trades. This hypothesis suggests that

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<sup>7</sup> For example, small pools are not easily spliced into TBA contract deliveries. The maximum number of different pools that can be combined for delivery against a TBA contract is just one for trades with current face less than \$500,000, just two for trades between \$500,000 and \$1,000,000, and only three per \$million for trades above \$1,000,000. Furthermore, buyers can stipulate a maximum number of individual pools that will be acceptable on even the largest of trade sizes.

the ratios of both the volumes and numbers of sell trades versus buy trades will fall with trade size in the MBS market but show no such patterns in the agency debentures and corporate bond markets.

Hypothesis 2: Impediments to position aggregation by dealers and other would-be arbitragers should cause extreme market fragmentation and crossed prices such that prices that some retail customers pay on small buy trades are lower than prices that some institutional customers receive on large sell trades. Hypothesis 2 suggests that the frequency of crossed customer buy trades falls with trade size in the MBS market but shows no such pattern in the agency debentures and corporate bond markets.

Our empirical strategy is to test for the existence of differential size-based trading patterns across the three markets – agency MBS, agency debenture, and investment grade corporate bond markets. We test the first hypothesis by examining whether trade-size effects on buy/sell imbalances exist for both the volume of trading and the number of trades. We test the second hypothesis by examining the average price differences between small buy and large sell trades and tabulating the percentage of buy trades in different size categories that occur below the price of large sell trades on the same day in the same security.

### **3. Data**

On May 16, 2011, FINRA initiated TRACE reporting requirements encompassing all member firm trades for structured products, including agency MBS. FINRA provided these transactions data on all agency MBS for the period from May 16, 2011 to January 31, 2013.<sup>8</sup>

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<sup>8</sup> FINRA provided the same data to three other research teams producing the following papers: Bessembinder, Maxwell, and Venkatamaran (2013), Friewald, Jankowitsch, and Subrahmanyam (2014), and Hollifield, Neklyudov, and Spatt (2014).

FINRA did not publicly disseminate these MBS trade-by-trade results during our sample period.<sup>9</sup> FINRA began releasing weekly aggregated market activity summaries on October 18, 2011.

Secondary trading in specified-pool MBS takes place in an over-the-counter dealer market where the security exchanging hands is identified by CUSIP. We analyze TRACE transactions data for Federal National Mortgage Association (FNMA, “Fannie Mae”) MBS, the most prominent issuer in agency MBS. Each TRACE bond trade report includes a security identifier (CUSIP), date and time of execution, settlement date, size, and price, as well as codes for counterparty type. Reported prices incorporate any commissions. Each TRACE specified-pool MBS trade report uses the original face value of MBS traded as the size variable and includes a pool factor if the latter differs from the most recently published factor. The pool factor is the percentage of total original pool principal that has not yet been repaid.

To filter out duplicated, withdrawn, and corrected trade entries, we employ the procedures described in Dick-Nielsen (2009). Additionally, we drop trades under special conditions and all interdealer trades from our analysis. We check the resulting transaction data for discernible errors and drop several outliers.

FINRA also provided a securities database encompassing individual MBS terms and selected pool characteristics like issuer, collateral type, issue date, original balance, weighted-average loan balance, credit score, coupon, and factor as of month-end for May 2011 to May 2012. We obtain security-level data on investment grade corporate bonds and agency debentures from Thomson Reuters Eikon. We merge the TRACE trade data by CUSIP with the data on security characteristics and keep only trades with security-level data. This results in a usable

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<sup>9</sup> Because MBS TRACE data were not being disseminated during our sample period, we cannot examine any information effects of specific trade reports on MBS prices, similar to the effects of TRACE price dissemination documented for corporate bonds by Bessembinder, Maxwell, and Venkataraman (2006), Edwards, Harris, and Piwowar (2007), Goldstein, Hotchkiss, and Sirri (2007), and Cici *et al.* (2015).



sample period extending from May 16, 2011 to May 31, 2012, We also analyze TRACE transactions data for FNMA debentures and investment grade corporate bonds over the same sample period.

TRACE reports trade size in face value for agency debentures and corporate bonds, but caps the reported size at \$5 million regardless of the actual face amount traded. For MBS, FINRA provided us with actual trade size data without any size caps. MBS transaction size is measured in the market and in TRACE as original face value. We compute the current face value for each MBS trade equal to the reported face amount multiplied by the pool factor. We use the factor from the actual TRACE report, if available, and otherwise use the latest reported factor from the securities database.

For FNMA MBS, we focus on pass-through securities based on 30-year conventional fixed-coupon, single-family mortgages and their corresponding TBA contracts. The 30-year sector accounts for about 75% of all customer trading volume in specified-pool MBS and almost 85% of all customer volume in corresponding TBA contracts. Our sample of 30-year specified-pool trades includes securities with coupons ranging from 3% to 16%. However, we keep only specified-pool trades with coupons that match the actively traded TBA coupons during our sample period. These active coupon rates range between 3.5% and 6.5%. Institutional market participants view the TBA channel as an extremely liquid backstop when evaluating a prospective specified-pool transaction. As such, TBA prices provide an excellent valuation benchmark for specified-pool MBS trades.<sup>10</sup>

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<sup>10</sup> For studies of TBA contract pricing see Boudoukh *et al.* (1997) and Gabaix, Krishnamurthy, and Vigneron (2007).

We restrict our agency debentures sample to FNMA issues for comparability with FNMA-guaranteed MBS.<sup>11</sup> We restrict our corporate bond sample to investment grade issuers to limit the impacts of credit differences between the MBS, debentures, and corporate bonds samples. We define investment grade bonds as those rated investment grade by all three rating agencies throughout our entire sample period. Finally, the FNMA debentures and investment grade corporate bond samples include many callable issues. We restrict the FNMA debentures and investment grade corporate bond samples to just those issues with at least three years remaining until maturity or next call date to provide a more reasonable bond duration match to the MBS sample.

Table 1 presents trading statistics for the three markets over our sample period. Customers made about 178,000 buy and sell trades in 30-year FNMA MBS with an aggregated current face value of nearly \$1.1 trillion. More than 32,000 individual MBS traded at least once. Customers executed about 44,000 trades in FNMA debenture with an aggregated face value greater than \$33 billion. Exactly 362 individual debentures traded at least once. More than 2 million customer trades in investment grade corporate bonds were executed over the sample period with an aggregated face value greater than \$900 billion. Nearly 4,900 individual investment grade corporate bonds traded at least once. Volume data for FNMA debentures and investment grade corporate bonds are understated because the TRACE report masks trade sizes above \$5 million.

While the volume of trades in MBS is larger than that for investment grade corporate bonds and FNMA debentures, this volume is spread over a much larger number of securities. Table 1 also reports statistics on trades per day per security. The mean number of trades per day

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<sup>11</sup> However, an investor's loss given default by FNMA would likely be different in the case of FNMA debentures since the recovery value for FNMA-guaranteed MBS would be supported by the values of the homes pledged to secure the individual mortgages held by the trust that issues the MBS.

per security for MBS (just 0.02) is about one-twentieth that of FNMA debentures (0.45) and is less than one-seventieth that of investment grade corporate bonds (1.56). Thus, while MBS volume is the highest of the three sectors, its trading frequency per security is by far the lowest.

Table 1 also reports statistics on the percentage of days that a given security has at least one customer buy and one customer sell trade on the same day. This metric gives some initial insight into how much two-way customer flow exists in each market. The mean percentage of days that a given security has at least one buy and one sell on the same day for FNMA MBS (just 0.1% of days) is an order of magnitude less than that for FNMA debentures (5.2%) and two orders of magnitude less than that for investment grade corporate bonds (16.4%). Clearly, on a per security basis, MBS reveal basic differences versus agency debentures and investment grade corporate bonds regarding potential ease of inventory turnover by dealers.

<Insert Table 1>

Figures 1a-1c present separate histograms of trade size for buy and sell transactions for each of our three markets. Figure 1a shows that institutionally appropriate \$1-to-\$50 million trades to be the most frequently chosen sizes. About 15% of the trades are \$5 million or larger in current face value. The histogram for MBS customer sell trades displays a very different picture. Trade sizes in the \$5,000-to-\$10,000 range are almost as frequent as \$1 million trades. A comparison of buy-versus-sell histograms shows a region of “missing” small customer buy trades, especially below \$25,000.<sup>12</sup> The trade size data for FNMA debenture customer trades in Figure 1b shows reasonably symmetric results for buy and sell trades, with good representation of retail (\$100,000 and under) transaction sizes. Around 10% of the trades of each type are \$5 million or larger. Finally, the trade size data for customer trades in investment grade corporate

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<sup>12</sup> Note that the trade size histograms for MBS appear more fully populated and smoother than the corresponding histograms for FNMA debentures and corporate bonds. This difference reflects our choice of current face value (pool factor times original face value) as the appropriate measure of trade size.

bonds in Figure 1c shows reasonably symmetric results for buy and sell trades and much higher frequency of retail-appropriate sizes. Only about 5% of investment grade corporate bond trades of each type are \$5 million or larger.

Figure 1d presents separate histograms of trade size for buy and sell transactions for TBA contract trading of MBS. Consistent with the general interpretation of TBA trading as an institutional market, the mode trade size is \$1 million and there is only minor activity in trade sizes smaller than \$250,000. Indeed, there is substantially more activity in TBA trades sized above \$100 million than in “retail” trades sized below \$100,000.

<Insert Figures 1a-1d>

These trade size histograms suggest that MBS trading appears to lack balance between customer buy and sell volume, especially below \$25,000 in current face value. Table 2 presents a comparison of aggregate volumes and numbers of customer buy versus sell trades across seven size buckets in all three markets. Five of the seven buckets offer special granularity on retail trades up to \$100,000 in size. The results consistently show that specified-pool MBS trading exhibits unbalanced two-way customer flow for small transactions. For the three smallest size buckets, customer sell volume is from six to nine times larger than buy volume. Similarly, the number of sell trades exceeds the number of buy trades by six to eight times for trade size buckets below \$25,000 in current face value. In contrast, the large specified-pool trade segment exhibits a more balanced two-way flow that provides dealers adequate opportunities to turn over acquired inventories as they service their customers’ needs. For the largest trade-size bucket (trades above \$250,000 in current face value), customer sell volume is only 1.5 times as large as the corresponding buy volume and the number of sell trades is a little more than just twice the number of buy trades.

The results for buy and sell volumes in FNMA debentures and investment grade corporate bonds in Panels B and C of Table 2 are very different from those in MBS. If anything, there is evidence of more customer buys than sells. There is also little evidence that transaction size affects the buy-sell volume balance in these two markets in the way it impacts MBS. The estimated relative pattern of buy-sell volume imbalances in the FNMA MBS market versus the FNMA debenture and investment grade corporate bond markets is consistent with Hypothesis 1.

<Insert Table 2>

We further analyze the flow of trades and aggregation possibilities within a simplified framework that presumes a single dealer who coordinates all trading in a given security. Our dealer can offload a retail customer sell trade on the same day by (1) selling the full position to another retail customer on the same day; (2) splitting up or combining small trades in the same security to sell to other retail customers; or (3) aggregating multiple retail customer sell trades for sale in the institutional market (where single trade sizes equal or larger than \$100,000). As an illustration, consider a security for which three retail customer sell trades with volumes of \$2,000, \$4,000, and \$28,000 and two buy trades of \$4,000 and \$10,000 occur on a given day. For this day, the dealer first round-trips the \$4,000 sell and buy trades. The dealer next combines and partly resells the other two sell trades using the remaining buy volume of \$10,000 on this day to absorb 33.3% of the remaining \$30,000 sell volume ( $= \$2,000 + \$28,000$ ). The residual volume of \$20,000 ( $\$2,000 + \$28,000 - \$10,000$ ) is smaller than \$100,000 and thus cannot be aggregated for sale in the institutional market. Thus, 66.7% of both trades remain in the dealer's end-of-day inventory for this security.<sup>13</sup>

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<sup>13</sup> In contrast, had the three retail trades been sized at \$12,000, \$4,000 and \$98,000, the dealer end-of-day position would have been “flat” since \$10,000 of the \$12,000 would be used for the second retail buy trade and the residual \$2,000 piece would be combined with the \$98,000 trade and sold in the institutional market.

Table 3 presents statistics on the number of retail trades that fall within the three inventory management channels and shows that 88% of trades for less than \$5,000 in a given MBS cannot be unwound by our omniscient dealer within the same day. This percentage still exceeds 80% even for MBS trades of \$50,000 to \$100,000 in current face. In contrast, only 34% to 43% of retail sell trades in agency debentures and corporate bonds remain with the dealer at the end of the trading day. Moreover, these two markets exhibit no decreasing pattern in trade size for end-of-day dealer inventory.

<Insert Table 3>

## **4. Empirical Analysis**

### *4.1 Transaction Prices*

Table 4 provides regression evidence regarding size-based effects on customer buy and customer sell prices for FNMA MBS (Panel A), FNMA debentures (Panel B), and corporate bonds (Panel C). For each class of debt, we report results for three different subsamples. Results for the first subsample, labeled “One Security,” are based solely on data for the security with the largest number of trades in each market during the sample period. Results for the second subsample, labeled “Securities with a Trade in Each Bucket,” are based on data for just those securities that have at least one buy and one sell trade in each size category. Results for the third subsample, labeled “Entire Sample,” are based upon all available data for the securities constituting the given class of debt with occurrences of both small and large trades on the same day. Preference for any one of these three subsamples over another reflects a research design trade-off. For example, while using a single security provides a direct comparison of large and small trades keeping any security characteristics constant, the results may not be representative of the broader sample of less liquid securities. In contrast, using all available data as in “Entire

Sample” provides representative results and adds statistical power, but involves a comparison of trades across potentially very different securities within the same debt class. Finally, the “Securities with a Trade in Each Bucket” sample is a middle ground between the other two sample choices that adds observations beyond the most liquid security while maintaining at least some degree of security-by-security data coverage across all size categories.

For each trade, we define a “Large Trade Price Spread” to create a dependent trade price variable that removes any daily security-level variation. We calculate the Large Trade Price Spread as the difference between the price of each trade in a given security and the average daily price for all trades above \$100,000 in current face in that same security. This procedure is similar to adding fixed effects for all security/trade date combinations, but subtracts the (more relevant) mean daily price of large trades rather than the mean price of all trades to create the day-by-day price difference series. We run pooled regressions of the Large Trade Price Spread variable on a set of seven size bucket dummies interacted with transaction direction dummies (customer buy and sell).

The results in Panel A of Table 4 show that FNMA MBS customer sell trades in the smallest size bucket (below \$5,000 in current face) are priced 3.3 to 4.1 percentage points below trades in the largest size bucket (above \$250,000). The average prices of customer sell trades increase monotonically across size buckets. But, customer buys in the smallest size bucket are also priced below the largest size bucket, with discounts ranging from 3.2% to 4.9%. Customer buy prices also increase as trade size increases.

The results in Panel B of Table 4 for FNMA debentures also show that customer sell trades in the smallest size bucket (below \$5,000 in current face) are priced below trades in the largest size bucket (above \$250,000). However, the estimated sell price impacts for the smallest

debenture trades are just 0.29% to 0.37%. Importantly, the FNMA debenture customer buy trades do not display the same positive relation between trade size and customer buy prices found for FNMA MBS. Prices of FNMA debenture customer buy trades tend to fall as trade size increases. Moreover, there is some evidence that a \$100,000 trade size adequately defines the cutoff between retail and institutional market segments: buyers of positions in the \$100,000 to \$250,000 bucket pay prices that are only one to two cents higher than those for the largest trade bucket.

Finally, the results in Panel C of Table 4 also show that investment grade corporate bonds customer sell trades in the smallest size bucket are priced below trades in the largest size bucket. However, based on results of the two largest samples, the estimated sell price impact for the smallest investment grade corporate bond trades is roughly 0.5%. Again, the corporate bond customer buy trades do not display the same positive relation between trade size and customer buy prices found for MBS. Corporate bond customer buy trade prices tend to fall as trade size increases. Consistent with the results for FNMA debentures, there is some evidence that a \$100,000 trade size adequately defines the cutoff between the retail and institutional market segments for corporate bonds.

<Insert Table 4>

In Panel A of Table 4, the average prices of MBS buy trades below \$5,000 in current face are sometimes lower than the average prices of MBS sell trades. This apparent anomaly is explained by the fact that many MBS sell trades do not have matched offsetting customer buy trades. As a check, we “pair” each customer buy trade with a customer sell trade in the same CUSIP on the same date via the alternative matching procedures of Hong and Warga (2004) and Green, Hollifield, and Schürhoff (2007a). Hong and Warga (2004) match each customer buy



(sell) order with the closest-in-time customer sell (buy) order in the same security on the same date. Green, Hollifield, and Schürhoff (2007a) additionally require that the two trades have the same traded amount (an “immediate match”). We utilize both concepts, but also require that the two matched trades have the same settlement date.

Table 5 presents statistics on daily benchmark-adjusted prices of matched buy and sell trades for FNMA MBS, FNMA debentures, and corporate bonds. To adjust for security-level price level differences, we subtract a corresponding daily benchmark price from each reported trade price. We refer to the resulting price spread variable as “pay-up,” a term borrowed from MBS practitioners. We calculate pay-ups for MBS by first subtracting the TBA daily price benchmark from each reported price and then subtracting the mean pay-up of large trades in the same security over the entire sample period. We use the previously defined Large Trade Price Spreads as the pay-up for both FNMA debentures and investment grade corporate bonds.

We find negative average pay-ups for both customer buy and sell MBS trades in the first four size buckets. There is roughly a nine-point difference in the average pay-ups of specified-pool MBS sell trades between the largest and smallest size buckets. In sharp contrast to the MBS results, the corresponding matched buy and sell trades results for both agency debentures and corporate bonds show positive pay-ups for buy trades and negative pay-ups for sell trades. Both buy and sell pay-ups decline in magnitude with trade size.

<Insert Table 5>

Table 5 also provides estimates of the round-trip transactions costs of trading in agency MBS. The MBS round-trip costs are more than one price point (1.1%-1.6%) in the smallest size category and decline to 0.04% (a little more than 1/32nd of a price point) using the Green, Hollifield, and Schürhoff (2007a) measure for the largest category. This monotone decline of

round-trip costs with trade size has been well documented for municipal bonds (Hong and Warga, 2004; Harris and Piwowar, 2006; and Green, Hollifield, and Schürhoff, 2007a), for corporate bonds (Goldstein, Hotchkiss, and Sirri, 2007), and recently for non-agency structured products (Hollifield, Neklyudov, and Spatt, 2014). Note that the round-trip costs for agency MBS are roughly equal to those of corporate bonds for trade sizes below \$5,000, but then fall to much lower values than those for corporate bonds for larger trade sizes. For institutional-sized trades (greater than \$100,000), MBS roundtrip costs are similar to agency debentures.

Figure 2 presents a visual comparison of size-based average pay-ups of match customer buy and sell trades from FNMA MBS versus the pricing of FNMA debenture and corporate bond markets reported in Table 5.

<Insert Figure 2>

#### *4.2. Crossed Markets*

Our estimates in Tables 4 and 5 generate a size-to-value slope indicating that some customer buy prices for small trades (say, for \$1,000 current face) on average are lower than customer sell prices for larger trades (say, for either \$10,000 or \$250,000 of current face). Such an upward sloping size-to-value relation is indicative of a crossed market providing opportunities for traders to buy and bundle multiple small lots of one MBS for resale as a single larger lot.

Ideally, identifying a crossed trade requires the simultaneous occurrence of a small buy and a large sell in the same security. In practice, it is rare for such a small buy, large sell pair to occur within the same minute or even hour. As a result, we are left to identify crossed buys by comparing them to large sells or other relevant pricing benchmarks observed some time during the same day. Such a scheme could, however, generate false crosses since intraday movements in market prices could match small buys made at the daily low with large sells made at the daily

high. To reduce the occurrence of such false positives, we define crossed buys as buy trades occurring at prices lower than the difference between a large-sell price benchmark and the daily high-low price range.

We use the matched daily value-weighted average TBA price as the large-sell price benchmark for MBS. As previously discussed, the TBA price is a good lower bound for an institutional-sized sell price and is observable much more frequently than a large sell in a particular MBS. To estimate the daily high-low price range, we use the daily price range from the corresponding TBA contract.

We have larger samples for agency debentures and corporate bonds and use the daily average price of sell trades sized at or above \$100,000 in current face in the same security as the pricing benchmark. We compute the daily high-low price range using the Bloomberg BGN price benchmark. BGN is based on a composite of indicative quotes for institutional-sized trades contributed by broker-dealers on Bloomberg's electronic trading platform and is available several times a day.

Table 6 reports the incidence of apparent crossed buy trades in our sample and shows clear evidence that crossed buy trades occur frequently for small trade sizes in MBS. More than 82% of MBS customer buy trades below \$5,000 in current face value are crossed buys. The percentage of crossed buys falls sharply with trade size and shrinks to below 1% for trade sizes above \$250,000. Since we would not expect to see any crossed buys at all for large trades (e.g., trade sizes above \$250,000), we might attribute at most 1% of all measured crossed buys as arising from measurement error. This still suggests that at least 8 of 10 small-sized customer buy trades are crossed and provides strong support for Hypothesis 2. In contrast, we find little evidence of crossed buy trades arising in either FNMA debentures or investment grade corporate

bonds. In no case does the measured frequency of crossed buy trades exceed 2% and no simple size-based pattern is detectable.

<Insert Table 6>

#### *4.3. Are there easy arbitrage possibilities for dealers? No.*

We examine whether the frequent occurrence of crossed trades reported in Table 6 permits easy arbitrage profits in MBS by analyzing trades in the MBS with the largest number of trades. In this security, we could identify only five days (less than 2% of the sample trading days) on which a perfectly informed dealer (who sees *all* customer order flow over the course of a day) could purchase two or more small positions and then sell these combined positions at a higher price on the same day. Over these five days, the maximum profit this omniscient dealer could have made on any day was just \$200. We conclude that there is no practical way for a dealer to reliably and profitably aggregate small positions in a single security by waiting for repeated opportunities to buy a given specified pool and sell the aggregated larger position at a profit on the same day. This exercise confirms the basic conclusions of the aggregation analysis of Table 3.

#### *4.4. Do attractive investment opportunities exist for informed buy-and-hold retail investors? Yes.*

In spite of the lack of pure arbitrage opportunities for dealers, our empirical results imply that a retail investor could build an attractively priced buy-and-hold MBS portfolio by purchasing unsolicited (“reverse inquiry”) offerings from a broker-dealer. In the spirit of Scholes and Wolfson (1989), and to put to rest any concerns that our results are artifacts of data reporting errors, we implemented such a buying program using a combination of personal and student investment fund monies. We executed a series of small purchases in agency MBS positions during the period between January 12, 2012 and November 27, 2012. Appendix A

presents the details of our real money trading program. We executed 37 trades and captured a mean discount to TBA (“negative pay-up”) of 7.93 points after accounting for any and all commissions. Assuming that an institutional investor can typically sell a large position above the TBA price, this negative pay-up is equivalent to at least 8 points discount to institutional sell prices and is comparable to the 7.75 to 8.31 point discounts to large trades reported in Table 5 for the research sample’s trades sized below \$5,000 in current face. The trades in the highest coupon (6.5%) averaged the largest discounts (10.28 points). On the basis of these real money results, we conclude that self-educated retail investors can exploit the opportunity generated by size-related frictions in the MBS market.

## **5. Modeling Size-Related Frictions in Debt Markets**

We present a stylized theoretical bond market model that incorporates the standard frictions found in the previous literature. We calibrate this model to fit average transaction prices for different trade sizes in investment grade corporate bonds, agency debentures, and MBS. This calibration exercise shows that standard bond market frictions can explain the pricing patterns found in corporate bond and agency debentures markets, but not those found in MBS markets. We then extend the model to incorporate the MBS-specific position aggregation and suitability frictions. Accounting for these frictions dramatically improves the model fit of MBS prices and suggests that these frictions are sufficient to explain the unique pricing patterns in the MBS market.

### *5.1 A Stylized Model of Bond Trading*

Our basic model analyzes the interactions of institutional investors, retail investors, and bond dealers. The model is related to Green, Holifield, and Schürhoff (2007a), but also contains elements of Green, Holifield, and Schürhoff (2007b) and Feldhütter (2012). Figure 3 summarizes

the basic model's three-stage structure that begins with an initiating sale of a bond position by a customer to a dealer. Investors, who face per position holding costs, enter a Nash bargaining game with the dealer. The risk-neutral dealer can resell any acquired position by trading with a new customer in the second stage or in an interdealer market in the third stage. In the second stage, newly arriving potential buyers (both institutional and retail) face costs to become informed about the security and also enter a Nash bargaining game with the dealer. In the third stage, a dealer who did not sell an acquired position to another customer in the second stage can unload any remaining position in the interdealer market.

For convenience, we begin the exposition of the model with the third stage. A dealer who could not sell a bond to a newly arriving customer in the second stage can sell this bond in an interdealer market at price  $V$ . For this reason,  $V^D$ , the dealer's reservation value for customer trades in the first and second stages, equals  $V$ . In the second stage, if a dealer has acquired a bond in the first stage, he is contacted by an institutional (type I) and a retail (type R) buyer in arbitrary order. Potential buyers of either customer type (I/R) value the bond according to an intrinsic customer value equal to  $V$  plus an error term  $\varepsilon_b^{I/R}$  that is normally distributed with mean zero and standard deviation  $\sigma$ . Institutional investors additionally face fixed trade-specific information costs  $c_i^I$ . These costs reflect the institutional investors' opportunity cost of time and focus and bias them against buying small-sized positions. We assume information costs of retail investors to be zero, i.e.,  $c_i^R = 0$ .<sup>14</sup>

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<sup>14</sup> Positive information costs for retail investors do not change the results if  $c_i^R \ll c_i^I$ , reflecting the institutional investors' higher opportunity costs.

The investors' reservation buy price is defined by:

$$V_b^{I/R} = V + \varepsilon_b^{I/R} - \frac{c_i^{I/R}}{q}, \quad (1)$$

where  $q$  is the position size in current face value.

The retail customer may buy only if the position does not exceed a position limit that is exponentially distributed across retail customers with mean  $q_{max}^R$ .

The negotiation procedure to determine transaction prices is modeled with a Nash bargaining game (see, e.g., Green, Holifield, and Schürhoff, 2007a) subject to the participation constraint that the reservation value of a potential buyer  $V_b^{I/R}$  exceeds the reservation price of the dealer  $V^D$ . If both the retail and institutional investors are willing to buy the bond, the dealer sells to the one who arrives first. The transaction price is the outcome of the linear sharing rule:

$$P_b = \eta^{I/R} V^D + (1 - \eta^{I/R}) V_b^{I/R}, \quad (2)$$

where  $\eta^{I/R}$  is the institutional/retail investor's negotiation power. Relative bargaining power can be thought of as reflecting different levels of investor sophistication (Green, Hollifield, and Schürhoff, 2007a) or different search costs (Feldhütter, 2012). Institutional investors should be more sophisticated and be more likely to have efficient trading infrastructure than retail investors. For both reasons, we expect institutional investors to have higher bargaining power compared to retail investors,  $\eta^I > \eta^R$ .

In the model's first stage, initial security sales by some investors drive the model. Certain customers decide to sell because they have low intrinsic valuations of the bond. Additionally, institutional investors have fixed holdings costs per position similar to the type "low" investors in Feldhütter (2012). These costs reduce an institutional investor's reservation value for the security. Fixed holding costs per position can be interpreted as embodying the costs for an

institutional investor to manage a portfolio, keep records of principal repayments, distribute cash flows, and prepare financial statements. We expect them to be higher for securities with more complicated cash flow structures and longer maturities.<sup>15</sup>

Each possible seller thus values her position with a reservation value equal to the intrinsic value of the security to the customer minus the following fixed holding costs over the expected holding period:

$$V_s^{I/R} = V + \varepsilon_s^{I/R} - \frac{c_h^{I/R}}{q}, \quad (3)$$

where  $\varepsilon_s^I$  and  $\varepsilon_s^R$  are normally distributed error terms with mean zero and standard deviation  $\sigma$  and  $c_h^I$  are holding costs of institutional investors (defined on a per security basis). A customer facing large holding costs relative to a given position's size has a strong incentive to sell the bond. Retail investors do not face holding costs (i.e.,  $c_h^R = 0$ ).

In the model's first stage, a customer (either of type I or R) arrives at the dealer and considers selling an existing bond position. Denote  $\pi^I$  as the probability that the arriving seller is an institutional customer ( $\pi^R = 1 - \pi^I$ ). Sellers have positions of size  $q$  that we assume to be exponentially distributed with mean  $q^I$  or  $q^R$ , respectively.

Again, the investor and the dealer engage in a Nash bargaining game and the transaction price  $P_s$  is determined by the linear sharing rule

$$P_s = \eta^{I/R} V^D + (1 - \eta^{I/R}) V_s^{I/R}, \quad (4)$$

subject to the participation constraint  $V^D \geq V_s^{I/R}$ .<sup>16</sup>

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<sup>15</sup> Holding costs could also incorporate a component that is proportional to the position's volume, e.g., reflecting opportunity costs of a better investment opportunity or liquidity needs. A distinction between fixed and proportional holding costs is not relevant in Feldhütter (2012) because his investors either hold 0 or 1 unit of the security.



In Appendix B.1, we calculate expected sell prices  $E[P_s|q]$  and expected buy prices  $E[P_b|q]$  for a given position size  $q$ . We use these expected values to calibrate the model to the average empirical pay-ups derived from roundtrip trades using the Hong and Warga (2004) concept in Table 5. We exogenously fix the average position size of institutional sellers ( $q^I = 1,000,000$ ) and retail sellers ( $q^R = 10,000$ ). We fix the retail investor's average position limit  $q_{max}^R = 100,000$  and  $\pi^I = 0.3$ , a close match to the percentage of trades above \$100,000 for agency debentures and corporate bonds. We assume asset-specific standard deviations of the investors' intrinsic valuation:  $\sigma = 0.010$  for MBS, 0.005 for agency debentures, and 0.020 for corporate bonds.<sup>17</sup>  $V$  is set to 100 (% of face). We calibrate the model's free parameters by finding the parameter values that minimize the sum of squared differences between the transaction prices produced by the model and the empirically observed average prices for round-trip trades reported in Table 5. In particular, we solve the following minimization problem:<sup>18</sup>

$$\min_{\eta^I, \eta^R, c_i^I, c_h^I} \sum_{n=1}^7 (\Delta_s(q_n) - \hat{\Delta}_{s,n})^2 + (\Delta_b(q_n) - \hat{\Delta}_{b,n})^2, \quad (5)$$

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<sup>16</sup> In a previous version of the model, we also incorporated inventory holding costs à la Stoll (1978) as well as fixed transactions costs and adverse selection costs (Stoll, 1976). For any reasonable parameter selections, the predictions of the model do not change so we suppressed them in this version of the model.

<sup>17</sup> We assign the highest value of  $\sigma$  for corporate bonds and the lowest value for agency debentures. We use an intermediate  $\sigma$  value for MBS, reflecting the fact that investors are exposed to prepayment risks in addition to default on payment guarantees extended by the same agency that issued the debentures. Since both a lower negotiation power of investors and a higher standard deviation of investors' intrinsic valuation increase average bid-ask spreads, it is not necessary to leave both as free parameters (i.e., our different selected values for  $\sigma$  do not impact the overall fit of the model).

<sup>18</sup> Our qualitative results do not depend on the choices for the fixed parameters. In the numerical minimization problem, we constrain the parameters for information costs to be positive; negotiation power to be between 0 and 1; and holding costs of institutional investors to be at least \$50. Since the main purpose of information costs is to make institutional investors focus on larger positions and deter them from buying very small positions, we additionally constrain the probability that an institutional investor buys a position of \$100,000 to be at least 1% (if we do not implement this very conservative constraint, we sometimes run into corner solutions in which institutional buyers are completely excluded).

where  $Q_m = \{2,500; 7,500; 17,500; 37,500; 75,000; 175,000; 1,000,000\}$  is a vector of the midpoints of our seven trade size buckets,  $q_n$  refers to the  $n$ -th element of this vector,  $\Delta_{s/b}(q_n) = E[P_{s/b}|q_n] - V$  is the pay-up (i.e., the difference between transaction prices and benchmark value) for sell or buy trades of position size  $q_n$ , and  $\hat{\Delta}_{s,n}$  and  $\hat{\Delta}_{b,n}$  refer to the average pay-ups reported for the  $n$ -th bucket in Table 5.<sup>19</sup> Table 7 presents the results for the three markets.

<Insert Table 7 >

As Table 7 shows, our stylized model fits the typical shape of larger bid-ask spreads for smaller positions in the agency debentures and corporate bond market quite well. As anticipated, the calibrated parameter values for the negotiation power of institutional investors are higher than those of retail investors for both agency and corporate bonds.<sup>20</sup> Information costs  $c_i^I$  are much higher for corporate bonds than for agency debentures, perhaps reflecting the formers' more disperse and opaque default risks. Institutional seller's holding costs of  $c_h^I = \$455.51$  for agency debentures and  $c_h^I = \$152.03$  for corporate bonds are relatively small in relation to institutional investors' mean trade size of  $q^I = \$1,000,000$ . In contrast to agency debentures and corporate bonds, the model's fit is very poor for MBS, with a root mean squared error of more than 3% of face value and corner solutions for the parameter estimates. Importantly, the model does not produce the discounted buy and sell prices found empirically for small MBS positions.

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<sup>19</sup> For MBS, both the sell and the buy price have positive pay-ups in the largest bucket in Table 4. To eliminate a possible bias introduced by this result, we subtract the average pay-up in this bucket from all prices before calibrating the model.

<sup>20</sup> However, it is only possible to interpret the negotiation parameters relative to each other and not on an absolute value basis since they are only identified together with the dispersion of investors' intrinsic value  $\sigma$ .

## *5.2 An Extended Model Including Impediments to Aggregation and Suitability Frictions*

To explain discounted MBS buy and sell prices and the occurrence of crossed small-sized buy trades, we extend the model from Section 5.1 along two dimensions. First, we incorporate a suitability friction that prevents “uninformed” retail investors from participating in the market. Second, we introduce a size-related position aggregation friction that segments the interdealer market for certain securities by distinguishing markets that easily accept trades of all sizes from others where smaller positions are harder to trade. Although there has been a surge of new papers developing models for dealer intermediation, the position aggregation friction is new to the literature. Most papers instead restrict their models to a single trade size (see, e.g., Dunne, Hau, and Moore, 2015; Jankowitsch, Nashikkar, and Subrahmanyam, 2011; Neklyudov, 2014). An exception is Feldhütter (2012), who associates trade size with dealer sophistication, although he does not consider different trade sizes explicitly (his agents hold either zero or one unit). In his model, different interdealer prices arise simultaneously for trades with unsophisticated and sophisticated investors only during liquidity crises. The reason for the resulting market segmentation is Feldhütter’s (2012) assumption that sophisticated customers cannot trade via dealers with unsophisticated customers during crises.

In contrast to this literature, we directly assume that only “round lots” can be sold in the interdealer market. However, we introduce a set of odd lot traders who seek to buy small positions, aggregate them into round lot sizes, and sell the aggregated positions in the interdealer market. There is a certain probability that any position smaller in size than the market’s round lot acquired by a dealer from a customer must be held to maturity if it cannot be sold to these odd lot traders. Markets may differ in the intensity with which the trading flows in small positions support easy arbitrage by such aggregators. Polar cases include (1) markets where such arbitrage

is essentially costless, so that odd lot traders pay dealers  $V$  for small positions, the same price that these arbitragers themselves receive upon selling aggregated round lots in the interdealer market and (2) markets where trading in small positions is so light that no aggregation arbitrage is possible. The intermediate case is that dealers have some positive probability of selling a smaller-than-round lot position to an odd lot aggregator for  $V$ . All dealers face position holding costs and any position that the dealer fails to resell (either in the round lot interdealer market or to an odd lot aggregator) must be held to maturity.

We operationalize the size-related, position aggregation friction by specifying a size-specific probability  $\Omega(q)$  that the dealer is able to unload a position of size  $q$  for the round lot value  $V$  as:

$$\Omega(q) = 1 - e^{-k \cdot q}. \quad (6)$$

This function, which is close to 1 for large position sizes, captures the idea that the market may not easily aggregate small positions into larger, round lot positions. Should easy aggregation prove feasible, we expect the probability of accessing the interdealer market's price  $V$  for any sale across all trade sizes to be one. We expect that investment grade corporate bond and agency debenture markets would both be easy aggregation markets (i.e.,  $\Omega(q) = 1$  for all  $q$ ).

We compute the expected holding cost of dealers as the produce of the probability that the dealer cannot sell the position and the holding costs per position, i.e.,  $(1 - \Omega(q)) \cdot c_h^D$ . We also assume that holding costs of dealers equal those of institutional investors, i.e.,  $c_h^D = c_h^I$ .

The dealer's reservation value for the bond equals:

$$V^D = V - \frac{(1 - \Omega(q)) \cdot c_h^I}{q}. \quad (7)$$

Regarding the suitability friction, we assume that only some “informed” percentage  $\psi^R$  of retail investors are aware of bonds as an investible asset. We interpret suitability within the model via  $\psi^R$  and use it as the probability that, in stage two, a retail buyer appears (this probability is one in the basic model). Since for certain unsuitable bonds like MBS, the informed percentage of retail investors is low (only a small fraction of retail investors are sophisticated enough to invest in these bonds), we set the probability that a dealer attempting to resell a small-sized MBS position actually encounters an educated retail buyer to be  $\psi^R = 10\%$ .

Unsuitable bonds like MBS are held mainly by institutional investors. However, due to position decay, institutional investors hold legacy small positions that they might want to sell. Additionally, we assume that any retail investors in this market are buy-and-hold investors so that  $\pi^I$ , the probability that the arriving customer is an institutional investor in the first stage of the trading process equals one for all position sizes. Figure 4 provides a full description of the extended model.

In Appendix B.2, we also calculate expected buy and sell prices for a given position size  $q$  and employ them to calibrate the extended model to the average empirical pay-ups derived from roundtrip trades using the Hong and Warga (2004) concept in Table 5. We use the same predefined parameter values as in Section 5.1. As already noted, we additionally fix  $\psi^R = 10\%$ . We calibrate the model’s five free parameters –  $\eta^I, \eta^R, c_i^I, c_h^I, k$  – by minimizing the quadratic form given earlier by (5).

<Insert Table 8 >

Table 8 presents the results for fitting the extended model to the three markets. Although the extended model’s fit for both the FNMA debenture and investment grade corporate bond markets is similar to that of the basic model in Table 7, its goodness-of-fit dramatically improves

for the MBS data. The RMSE falls by an order of magnitude. Importantly, the extended model also produces negative pay-ups for both small buy and small sell trades.

Regarding the position aggregation friction, the parameter value of  $k = 0.000195$  for MBS implies that the probability of a successful aggregation of a position in the smallest bucket ( $q = 2,500$ ), is 38.6%. This probability increases quickly to 76.8% ( $q = 7,500$ ), in the second bucket, and 96.7% in the third bucket ( $q = 17,500$ ). For the fourth bucket ( $q = 37,500$ ), it is already very close to 100%. Our estimate of holding costs implies that an MBS institutional investor or dealer who is forced to hold a position until maturity incurs total costs of  $c_h^I = \$306.00$ . The estimated negotiation power is higher for retail than for institutional MBS buyers, implying that the small percentage of informed retail buyers have market power arising from the excess supply of small positions. For the agency debentures and corporate bond market, the large  $k = 0.02912$  and  $k = 0.001288$  imply that the position aggregation friction is practically turned off. The probability that positions in the smallest bucket ( $q = 2,500$ ) cannot be aggregated is 0 for agencies and only 4% for corporate bonds. For all other buckets, this probability is 0 for both agency debentures and corporate bonds.

Summarizing the results from this section, the calibration of the basic model in Table 7 clearly shows that the traditional size-related frictions cannot produce crossed customer buy trades. Due to the participation constraint in the Nash bargaining game, a buy will only happen if  $V_b^{I/R} > V^D = V$ . The linear sharing rule (2) then dictates buy prices  $P_b \geq V$ . The same bargaining mechanism also implies  $P_s \leq V$ . Intuitively, dealers never buy high and sell low when they can either aggregate small positions and sell them at the interdealer market at  $V$  or sell to an uninformed small buyer willing to pay above  $V$ . Once the position aggregation and suitability frictions are incorporated in the extended model, the calibration in Table 8 fits the observed

pricing patterns much better, because now the model allows for small buy trades to occur at prices well below the interdealer market value.

In the extended model that includes the position aggregation and suitability frictions, a dealer faces the likelihood of keeping an acquired small position to maturity and incurring significant holding costs. If the likelihood and/or costs are large enough, the dealer will be willing to sell the small position to an informed retail buyer at a significant discount to  $V$ . For an observer of trading across all sizes in the same security, the dealer community appears to indeed buy high (from institutional sellers) and sell low (to informed retail buyers).

## **6. Conclusion**

Dealers in over-the-counter bond markets serve a mix of retail and institutional customers who differ in preferences regarding trade size. An extensive literature has focused on disparate transaction costs, bargaining power, and position holding costs as the key drivers of trade size-based segmentation of corporate and municipal bond markets. However, for these markets, dealers and other arbitrage traders ensure that size segments never cross so that, for example, one customer's buy price for a small trade is always higher than another customer's sell price for a large trade in the same security at the same time. In both theory and reality, dealers profitably bridge the two segments either by aggregating multiple small positions purchased from retail customers for resale to an institutional customer or by splitting up a large position purchased from an institutional customer for resale to multiple retail customers.

In contrast, our paper provides strong evidence that agency MBS markets consistently cross, producing apparent violations of arbitrage conditions. Traditional frictions cannot explain these pricing patterns. We attribute the unique MBS pricing patterns to two additional frictions that affect bond dealers in the MBS but not in the corporate bond or agency debenture markets.

These frictions – impediments to aggregating small positions for resale to institutional customers and a suitability guideline against recommending MBS to retail customers – limit MBS dealers’ ability to unwind retail customer sell trades in either the retail or institutional trade size segments. The extreme market segmentation causes some dealers to buy a security at high prices from institutional investors while other dealers sell the same security at low prices to retail investors.

Our findings of steep price discounts for small trades versus large trades in MBS have important implications for proper marking of securities for investment portfolio valuation. The 1940 Investment Company Act requires a registered investment company to value securities using market quotations when they are readily available. For MBS, the most generally available market quotes would be those from trading screens for TBA contracts, which apply to institutional-sized trades. But the brokerage statements for newly acquired positions of retail investors are also marked off of such institutional-sized trade quotes. For example, the 37 retail-sized MBS trades executed with personal and student investment fund monies summarized in Table A.1 generated overnight “gains” of about 8% in their corresponding brokerage accounts. Obviously, such brokerage statements overstate the true realizable value of such positions, which could only have been sold at (more) heavily discounted prices. Our findings suggest that the SEC, brokerage firms, and pricing services should allow adjustments for position size when marking MBS for investor brokerage statement accounting purposes.

Again, while we limit our current study to agency MBS, similar frictions likely affect other structured products like ABS, CMBS, CMOs, CLOs, and private-label RMBS. If this is the case, then our recommendations for position-size adjustments to securities price marks will be relevant for a much wider set of assets.



## **Appendix A. Real Money Retail Investment Program**

We executed a series of small purchases in agency MBS positions during the period between January 12, 2012 and November 27, 2012.<sup>21</sup> Although we confined our research sample to Fannie Mae securities, the same forces should affect all agency MBS. Thus, we expanded our investment opportunity purview and entertained offerings for MBS issued by all three agencies.

On any given day, we telephoned a broker-dealer and asked for offerings of pass-through agency MBS. For the record, upon each of our reverse inquiries, our broker-dealer dutifully informed us that they “did not recommend this strategy.” However, we pushed past this message and inquired about any available offerings of small MBS positions. After about a one-to-three-minute delay to gain access to the firm’s current offering sheet, our broker-dealer gave us a verbal listing of the available securities, position sizes (original face values), and offering prices. The broker-dealer would not provide the entire listing to us in an electronic file or any other written format. In a world in which even retail accounts have instant and total access to brokerage firm inventories via screen-based trading platforms for Treasuries, corporate, and municipal bonds, this old-fashioned personal interaction seemed quaint. More importantly, this person-to-person platform emphasizes the costly nature of trading this product in terms of time expended by both the broker-dealer and the retail investor.

Next, we compared the broker-dealer’s offerings to the relevant Bloomberg TBA pricing screens to calculate price discounts to TBA. We typically looked for negative pay-ups (“price discounts to TBA”) of six or more points. In most cases we purchased securities only if offered at such price levels, but on some trading days for the student fund near the semester’s end, we purchased the cheapest position offered that day and waived the six-point discount criterion.

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<sup>21</sup> FINRA actually provided us with the research data in multiple batches. The first data sample we examined encompassed the period between May 16, 2011 and October 31, 2011. Thus, the trading program began a little more than two months after our initial examination of trading patterns based upon this first (short) research sample period.

In the beginning of the trading period, between January 12, 2012 and April 27, 2012, we asked for MBS offerings at least three times a week and traded about once a week. Typically, we purchased the entire size offered since the (small) dollar value of such offered positions suited our goal to diversify across a large number of individual securities. On two occasions, we asked and were able to trade a portion of the offered position. By the end, we executed 37 specified-pool transactions that conform to the standards of this paper's research design: 30-year, conventional agency MBS with coupon rates between 3.5% and 6.5%.

Table A.1 presents summary statistics for our trades. Out of the 37 transactions, 20 (54%) were for Fannie Mae, 15 (41%) were for Ginnie Mae, and two (5%) were for Freddie Mac pass-through MBS. The majority of the trades were in high-coupon, seasoned MBS with average (median) pool factors of 0.24 (0.17). The average (median) size of these trades was about \$2,100 (\$1,780) in current face value. The mean discount to TBA ("negative pay-up") was 7.93 points after accounting for any and all commissions. Assuming that an institutional investor can typically sell a large position above the TBA price, this negative pay-up is equivalent to at least 8 points discount to institutional sell prices and is comparable to the 7.75 to 8.31 point discounts to large trades reported in Table 5 for the research sample's trades sized below \$5,000 in current face. The trades in the highest coupon (6.5%) averaged the largest discounts (10.28 points). On the basis of these real money results, we conclude that self-educated buy-and-hold retail investors can exploit the opportunity generated by size-related frictions in the MBS market.

Furthermore, each trade produced an unusual overnight result for our brokerage statements. The 1940 Investment Company Act requires a registered investment company to value securities using market quotations when they are readily available. Unsurprisingly, the broker-dealer immediately marked all of the retail-sized MBS positions on the basis of the most

generally available market quotes, those from trading screens for TBA contracts. Obviously, these marks overstate the true value of the positions since selling out these positions would likely entail even larger discounts to TBA than those captured at purchase. No purchased MBS were sold. All of the investments were planned as “buy-and-hold” investments that would reinvest all MBS cash flows back into the strategy, especially relevant for the student fund’s endowment monies. However, our brokerage statements overstated the student fund’s true performance since its compound annual return jumped every time an MBS was purchased. Our statistical evidence and investment experience suggests that mark adjustments based on MBS position size would be appropriate for investor brokerage statement accounting purposes.

Finally, the hard-to-aggregate nature of the market evidenced itself in a simple fact: once an offered position in a particular security was purchased, the broker-dealer never showed another offering for that same CUSIP again.

<Insert Table A.1>

## Appendix B. Mathematical Derivations

In this appendix we provide detailed derivations for the expressions of expected sell and buy prices within our model.

### B.1 Sell and Buy Prices in the Basic Model of Bond Trading

#### B.1.1 Derivation of $E[P_s|q]$

We first need to calculate the probability that for a given position size  $q$ , the retail investor (R) is willing to sell. Using her participation constraint  $V^D \geq V_s^R$ , the fact that  $V_s^R$  is symmetrically distributed around  $V$  (see Equation (3)), and  $V^D = V$ , this probability equals  $\mathbb{P}(R \text{ sells}|q) = \frac{1}{2}$  and is independent of  $q$ . For an institutional investor (I), the same probability is given by

$$\mathbb{P}(I \text{ sells}|q) = \Phi\left(\frac{V^D - \left(V - \frac{c_h^I}{q}\right)}{\sigma}\right) = \Phi\left(\frac{c_h^I}{q \cdot \sigma}\right), \quad (\text{B.1})$$

where the mean of the institutional seller's intrinsic value now is  $V - \frac{c_h^I}{q}$  and  $\Phi$  is the standard normal cumulative distribution function. We can now calculate the conditional probability of a sell to a retail investor given that a sell to any investor occurs by using the overall proportion of institutional investors  $\pi^I$  as well as the density functions of the exponential distributions that determine the position size, i.e.,

$$\begin{aligned} & \mathbb{P}(R \text{ sells}|q, \text{any investor sells}) \\ &= \frac{(1 - \pi^I) \cdot \frac{1}{q^R} \cdot e^{-\frac{q}{q^R}} \cdot \mathbb{P}(R \text{ sells}|q)}{(1 - \pi^I) \cdot \frac{1}{q^R} \cdot e^{-\frac{q}{q^R}} \cdot \mathbb{P}(R \text{ sells}|q) + \pi^I \cdot \frac{1}{q^I} \cdot e^{-\frac{q}{q^I}} \cdot \mathbb{P}(I \text{ sells}|q)}. \end{aligned} \quad (\text{B.2})$$

The corresponding conditional probability of a sell to an institutional investor is then given by:

$$\mathbb{P}(I \text{ sells} | q, \text{any investor sells}) = 1 - \mathbb{P}(R \text{ sells} | q, \text{any investor sells}). \quad (\text{B.3})$$

For the calculation of the expected sell price, we first compute the expected sell price in the scenario when the dealer trades with a retail investor. We calculate this conditional expected value by taking expectations from Equation (4) as

$$E[P_s | q, R \text{ sells}] = \frac{\int_{-\infty}^{V^D} (\eta^R V^D + (1 - \eta^R)x) \cdot \frac{1}{\sigma} \cdot \phi\left(\frac{x-V}{\sigma}\right) dx}{\int_{-\infty}^{V^D} \frac{1}{\sigma} \cdot \phi\left(\frac{x-V}{\sigma}\right) dx} \quad (\text{B.4})$$

$$= V - \sqrt{\frac{2}{\pi}} \cdot \sigma(1 - \eta^R), \quad (\text{B.5})$$

where  $\phi$  is the probability density function of the normal distribution. Similarly, the expected sell price in a trade with an institutional investor is

$$E[P_s | q, I \text{ sells}] = \frac{\int_{-\infty}^{V^D} (\eta^I V^D + (1 - \eta^I)x) \cdot \frac{1}{\sigma} \cdot \phi\left(\frac{x - \left(V - \frac{c_h^I}{q}\right)}{\sigma}\right) dx}{\int_{-\infty}^{V^D} \frac{1}{\sigma} \cdot \phi\left(\frac{x - \left(V - \frac{c_h^I}{q}\right)}{\sigma}\right) dx} \quad (\text{B.6})$$

$$= V - \frac{c_h^I(1 - \eta^I)}{q} - \frac{\sqrt{\frac{1}{2\pi}} e^{-\frac{1}{2}\left(\frac{c_h^I}{q\sigma}\right)^2} \sigma(1 - \eta^I)}{\Phi\left(\frac{c_h^I}{q\sigma}\right)}. \quad (\text{B.7})$$

The expected sell price is then calculated as:

$$\begin{aligned} E[P_s|q] &= \mathbb{P}(R \text{ sells}|q, \text{any investor sells}) \cdot E[P_s|q, R \text{ sells}] \\ &+ \mathbb{P}(I \text{ sells}|q, \text{any investor sells}) \cdot E[P_s|q, I \text{ sells}]. \end{aligned} \quad (\text{B.8})$$

### B.1.2 Derivation $E[P_b|q]$

We first calculate the respective probabilities that a retail or institutional investor is willing to buy. Again, using the symmetric distribution of the retail buyer's intrinsic value (see Equation (1)), the probability that her participation constraint holds (i.e.,  $V_b^R \geq V^D$ ) is  $\frac{1}{2}$ . Given the probability that the position is smaller than the retail investor's exponentially distributed position limit, it follows that:

$$\mathbb{P}(R \text{ buys}|q) = \frac{1}{2} \cdot e^{-\frac{q}{q_{max}^R}}. \quad (\text{B.9})$$

Given the institutional buyer's participation constraint, the probability that he is willing to buy equals:

$$\mathbb{P}(I \text{ buys}|q) = 1 - \Phi\left(\frac{V^D - \left(V - \frac{c_i^I}{q}\right)}{\sigma}\right) \quad (\text{B.10})$$

$$= 1 - \Phi\left(\frac{c_i^I}{q \cdot \sigma}\right). \quad (\text{B.11})$$

The conditional probability of a retail buy trade is then given as:

$$\begin{aligned} & \mathbb{P}(R \text{ buys}|q, \text{any investor buys}) \\ &= \frac{\mathbb{P}(R \text{ buys}|q) \left[ \left(1 - \frac{1}{2} \mathbb{P}(I \text{ buys}|q)\right) \right]}{\mathbb{P}(R \text{ buys}|q) + \mathbb{P}(I \text{ buys}|q) - \mathbb{P}(R \text{ buys}|q)\mathbb{P}(I \text{ buys}|q)}, \end{aligned} \quad (\text{B.12})$$

where the numerator equals the sum of the probabilities that the retail investor buys and at the same time the institutional investor does not buy, i.e.,  $\mathbb{P}(R \text{ buys}|q)(1 - \mathbb{P}(I \text{ buys}|q))$  plus the probability that both investors are willing to buy but the retail investor arrives first, i.e.,  $\frac{1}{2} \mathbb{P}(R \text{ buys}|q)\mathbb{P}(I \text{ buys}|q)$ . The denominator equals the probability that the retail investor, the institutional investor, or both are willing to buy. The conditional probability of an institutional buy trade is then given as

$$\mathbb{P}(I \text{ buys}|q, \text{any investor buys}) = 1 - \mathbb{P}(R \text{ buys}|q, \text{any investor buys}). \quad (\text{B.13})$$

Taking expectations from Equation (2) delivers the conditional expected buy price if the dealer trades with a retail investor as:

$$\mathbb{E}[P_b|q, R \text{ buys}] = \frac{\int_{V^D}^{\infty} (\eta^R V^D + (1 - \eta^R)x) \cdot \frac{1}{\sigma} \cdot \phi\left(\frac{x-V}{\sigma}\right) dx}{\int_{V^D}^{\infty} \frac{1}{\sigma} \cdot \phi\left(\frac{x-V}{\sigma}\right) dx} \quad (\text{B.14})$$

$$= V + \sqrt{\frac{2}{\pi}} \cdot \sigma(1 - \eta^R). \quad (\text{B.15})$$

For a trade with an institutional investor, the expected buy price is given by:

$$E[P_b|q, I \text{ buys}] = \frac{\int_{V^D}^{\infty} (\eta^I V^D + (1 - \eta^I)x) \cdot \frac{1}{\sigma} \cdot \phi\left(\frac{x - \left(V - \frac{c_i^I}{q}\right)}{\sigma}\right) dx}{\int_{V^D}^{\infty} \frac{1}{\sigma} \cdot \phi\left(\frac{x - \left(V - \frac{c_i^I}{q}\right)}{\sigma}\right) dx} \quad (\text{B.16})$$

$$= V - \frac{c_i^I(1 - \eta^I)}{q} + \frac{\sqrt{\frac{1}{2\pi}} e^{-\frac{1}{2}\left(\frac{c_i^I}{q \cdot \sigma}\right)^2} \sigma(1 - \eta^I)}{1 - \Phi\left(\frac{c_i^I}{q \cdot \sigma}\right)}. \quad (\text{B.17})$$

We compute the expected buy price for a given position size  $q$  as:

$$\begin{aligned} E[P_b|q] &= \mathbb{P}(R \text{ buys}|q, \text{any investor buys}) \cdot E[P_b|q, R \text{ buys}] \\ &\quad + \mathbb{P}(I \text{ buys}|q, \text{any investor buys}) \cdot E[P_b|q, I \text{ buys}]. \end{aligned} \quad (\text{B.18})$$

## B.2 Sell and Buy Prices in the Extended Model

### B.2.1 Derivation of $E[P_s|q]$

Since only institutional investors sell bonds in MBS markets,  $E[P_s|q]$  equals  $E[P_s|q, I \text{ sells}]$ . Taking again expectations of Equation (4) delivers



$$E[P_s|q] = \frac{\int_{-\infty}^{V^D} (\eta^I V^D + (1 - \eta^I)x) \cdot \frac{1}{\sigma} \cdot \phi\left(\frac{x - \left(V - \frac{c_H^I}{q}\right)}{\sigma}\right) dx}{\int_{-\infty}^{V^D} \frac{1}{\sigma} \cdot \phi\left(\frac{x - \left(V - \frac{c_H^I}{q}\right)}{\sigma}\right) dx}. \quad (\text{B.19})$$

The final expression requires substituting the expression for  $V^D$  from Equation (7).

### B.2.2 Derivation of $E[P_b|q]$

Proceeding as in B.1.2, we first compute the probabilities that the retail or the institutional investor is willing to buy, respectively. Given the retail investor's participation constraint, the probability that the position is smaller than her position limit, and the probability that she is informed, it follows that:

$$\mathbb{P}(R \text{ buys}|q) = \int_{V^D}^{\infty} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-V}{\sigma}\right)^2} dx \cdot e^{-\frac{q}{q_{max}^R} \cdot \psi^R}, \quad (\text{B.20})$$

where we substitute Equation (7) for  $V^D$ . Since for institutional investors, only the reservation value of the dealer  $V^D$  has changed compared to the basic model, we can employ Equations (B.10) and (7). As before, Equations (B.12) and (B.13) deliver conditional probabilities that either the retail or the institutional investor trades with the dealer. Evaluating Equations (B.14) and (B.16), we can compute conditional expected buy prices given that the dealer trades with one of the two investors. Finally, we compute the expected buy price  $E[P_b|q]$  by employing (B.18).

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Table 1. Trading statistics of the three markets in our sample

The sample period is from May 16, 2011 to May 31, 2012. The FNMA MBS sample consists of 30-year conventional MBS pass-throughs. The FNMA debentures sample includes all FNMA debentures with more than 3 years remaining until maturity or next call date. The corporate bond sample includes all corporate bonds with more than 3 years left to maturity or next call date that were rated investment grade by all three rating agencies throughout our sample period. For corporate bonds and agency debentures total customer volume equals the sum of face amount of all customer trades during the period, but due to TRACE reporting restrictions, any trade for more than \$5 million face amount is reported as \$5 million. For MBS the customer volume equals the sum of current face (original face amount \* factor) of all customer trades during the period.

Measure	FNMA MBS	FNMA Debentures	Corporate Bonds
Total customer volume (\$ million current face)	1,073,941	33,882+	918,721+
Number of trades in sample	177,596	43,559	2,023,479
Number of securities in sample	32,393	362	4,886
Mean number of trades per day per security	0.02	0.45	1.56
Median number of trades per day per security	0.01	0.05	0.45
Max number of trades per day per security	8.43	12.86	70.06
Mean percent of days with at least one buy and one sell trade in a given security	0.1%	5.2%	16.4%
Median percent of days with at least one buy and one sell trade in a given security	0.0%	0.0%	4.9%
Max percent of days with at least one buy and one sell trade in a given security	86.4%	98.9%	99.2%

Table 2. Buy versus sell volume imbalance

The sample period is from May 16, 2011 to May 31, 2012. Volume amounts are in \$million of current face value. The FNMA MBS sample consists of 30-year conventional MBS pass-throughs. The FNMA debentures sample includes all FNMA bonds with more than 3 years remaining until maturity. The corporate bond sample includes all corporate bonds with more than 3 years left to maturity or next call date that were rated investment grade by all three rating agencies throughout our sample period. The Ratio of Volumes is calculated as (Sell Volume/Buy Volume). The Ratio of Number of Trades is calculated as (Number of Sell Trades/Number of Buy Trades).

Panel A. FNMA 30-year MBS

Trade Size (Current Face)	Buy Volume	Sell Volume	Ratio of Volumes	No. Buy Trades	No. Sell Trades	Ratio of No. Trades
Below \$5,000	8.251	70.122	8.5	4,917	34,307	7.0
\$5,000 to \$10,000	10.470	81.944	7.8	1,430	11,315	7.9
\$10,000 to \$25,000	32.003	199.142	6.2	1,908	12,336	6.5
\$25,000 to 50,000	58.868	283.650	4.8	1,620	7,963	4.9
\$50,000 to \$100,000	113.347	512.472	4.5	1,538	7,042	4.6
\$100,000 to \$250,000	384.967	1,507.879	3.9	2,298	9,065	3.9
Above \$250,000	423,935.958	646,742.048	1.5	26,238	55,619	2.1

Panel B. FNMA Debentures with 3+ Years to Maturity/Next Call Date

Trade Size (Current Face)	Buy Volume	Sell Volume	Ratio of Volumes	No. Buy Trades	No. Sell Trades	Ratio of No. Trades
Below \$5,000	8.109	13.713	1.7	2,545	4,331	1.7
\$5,000 to \$10,000	16.063	21.308	1.3	1,884	2,552	1.4
\$10,000 to \$25,000	57.262	63.781	1.1	3,020	3,457	1.1
\$25,000 to 50,000	96.238	85.590	0.9	2,416	2,172	0.9
\$50,000 to \$100,000	182.252	126.419	0.7	2,277	1,587	0.7
\$100,000 to \$250,000	396.451	242.631	0.6	2,249	1,394	0.6
Above \$250,000	19,112.240	13,460.220	0.7	8,258	5,417	0.7

Panel C. Investment-Grade Corporate Bonds with 3+ Years to Maturity/Next Call Date

Trade Size (Current Face)	Buy Volume	Sell Volume	Ratio of Volumes	No. Buy Trades	No. Sell Trades	Ratio of No. Trades
Below \$5,000	502.438	485.948	1.0	124,655	143,779	1.2
\$5,000 to \$10,000	1,763.035	952.533	0.5	186,999	105,295	0.6
\$10,000 to \$25,000	5,881.208	2,671.460	0.5	294,401	138,277	0.5
\$25,000 to 50,000	6,882.760	3,292.135	0.5	165,424	80,088	0.5
\$50,000 to \$100,000	10,007.037	5,438.314	0.5	114,405	63,239	0.6
\$100,000 to \$250,000	17,669.162	11,533.705	0.7	96,046	63,026	0.7
Above \$250,000	432,797.569	418,843.928	1.0	238,129	209,716	0.9

Table 3. The Importance of Different Dealer Channels for Unwinding Retail Sell Trades

This table presents the estimated probability for a trade of a given size to be unwound by a dealer using one of three possible channels – 1) Roundtripped corresponds to a matching buy trade in the same bond on the same day with the same volume; 2) Combined and Resold (as a whole or in parts) corresponds to non-round-tripped trades that can be sold against other buy trades of less than \$100,000 current face in the same bond on the same day; and 3) Aggregated to Institutional, which is triggered if the combined volume of remaining sell trades on that day is \$100,000 or more. If a trade cannot be sold or aggregated, the bond is left with the dealer. The sample period is from May 16, 2011 to May 31, 2012. The FNMA MBS sample consists of 30-year conventional MBS pass-throughs. The FNMA debentures sample includes all FNMA bonds with more than 3 years remaining until maturity. The corporate bond sample includes all corporate bonds with more than 3 years left to maturity or next call date that were rated investment grade by all three rating agencies throughout our sample period.

Panel A. FNMA 30-year MBS

Trade Size (Current Face)	No. Sell Trades	No. of Sell Trades Roundtripped	No. Sell Trades Combined and Resold	No. Sell Trades Aggregated to Institutional Size	% Round-tripped	% Combined and Resold	% Aggregated to Institutional Size	% Left with the Dealer
Below \$5,000	34,402	1,214	1,661.6	1,197.2	3.5%	4.8%	3.5%	88.2%
\$5,000 to \$10,000	11,316	234	649.2	666.4	2.1%	5.7%	5.9%	86.3%
\$10,000 to \$25,000	12,339	303	573.8	845.4	2.5%	4.7%	6.9%	86.0%
\$25,000 to 50,000	7,961	243	329.6	659.9	3.1%	4.1%	8.3%	84.5%
\$50,000 to \$100,000	7,043	193	165.1	1,012.5	2.7%	2.3%	14.4%	80.5%

Panel B. FNMA Debentures with 3+ Years to Maturity/Next Call Date

Trade Size (Current Face)	No. Sell Trades	No. of Sell Trades Roundtripped	No. Sell Trades Combined and Resold	No. Sell Trades Aggregated to Institutional Size	% Round-tripped	% Combined and Resold	% Aggregated to Institutional Size	% Left with the Dealer
Below \$5,000	3,157	425	1,493.7	170.1	13.5%	47.3%	5.4%	33.8%
\$5,000 to \$10,000	2,713	212	1,304.7	218.6	7.8%	48.1%	8.1%	36.0%
\$10,000 to \$25,000	3,744	252	1,600.0	334.4	6.7%	42.7%	8.9%	41.6%
\$25,000 to 50,000	2,321	153	871.5	294.3	6.6%	37.5%	12.7%	43.2%
\$50,000 to \$100,000	1,722	72	527.3	389.3	4.2%	30.6%	22.6%	42.6%

Panel C. Investment-Grade Corporate Bonds with 3+ Years to Maturity/Next Call Date

Trade Size (Current Face)	No. Sell Trades	No. of Sell Trades Roundtripped	No. Sell Trades Combined and Resold	No. Sell Trades Aggregated to Institutional Size	% Round-tripped	% Combined and Resold	% Aggregated to Institutional Size	% Left with the Dealer
Below \$5,000	87,986	7,204	42,229.3	5,667.0	8.2%	48.0%	6.4%	37.4%
\$5,000 to \$10,000	92,415	11,499	34,101.4	8,125.2	12.4%	36.9%	8.8%	41.9%
\$10,000 to \$25,000	165,227	27,799	48,295.6	18,108.1	16.8%	29.2%	11.0%	43.0%
\$25,000 to 50,000	89,389	13,506	26,076.2	11,637.7	15.1%	29.2%	13.0%	42.7%
\$50,000 to \$100,000	63,623	9,335	16,185.1	11,625.7	14.7%	25.4%	18.3%	41.6%

Table 4. Regressions of large trade price spread on trade size bucket dummy variables

The sample period is from May 16, 2011 to May 31, 2012. The dependent variable, “Large Trade Price Spread,” is the price for each trade minus the average price of trades above \$100,000 in current face in the same security on the same day. The reported coefficients are for the interactions between dummies for each current face category and dummies for customer buys versus sells. The baseline category (captured by the constant) is customer sells with current face above \$250,000. The FNMA MBS sample includes 30-year conventional MBS pass-throughs. The FNMA debentures sample includes all issues with more than 3 years left to maturity or next call date. The corporate bond sample includes all corporate bonds with more than 3 years left to maturity or next call date that were rated investment grade by all three rating agencies throughout our sample period. *t*-statistics using standard errors clustered on securities are in parentheses. . \*, \*\*, and \*\*\* denote significance at 10%, 5%, and 1% level, respectively.

Panel A. FNMA 30-year MBS

Variable	One Security		Securities with a Trade in Each Bucket		Entire Sample	
	Buys	Sells	Buys	Sells	Buys	Sells
Below \$5,000	-4.877*** (-8.88)	-4.165*** (-16.97)	-4.357*** (-7.66)	-3.602*** (-19.81)	-3.178*** (-7.18)	-3.316*** (-20.75)
\$5,000 to \$10,000	0.525 (0.90)	-1.670*** (-5.91)	0.335 (0.85)	-1.365*** (-17.41)	0.308 (1.17)	-1.328*** (-24.03)
\$10,000 to \$25,000	0.465 (1.00)	-0.928*** (-3.28)	0.193 (1.55)	-0.787*** (-19.24)	0.151 (1.59)	-0.739*** (-23.57)
\$25,000 to \$50,000	0.284 (0.66)	-0.477 (-1.58)	0.231*** (3.46)	-0.449*** (-14.55)	0.121* (1.79)	-0.365*** (-12.29)
\$50,000 to \$100,000	0.345 (0.80)	-0.433 (-1.36)	0.296*** (4.04)	-0.334*** (-9.21)	0.206*** (3.78)	-0.216*** (-7.93)
\$100,000 to \$250,000	0.133 (0.33)	-0.133 (-0.41)	0.092*** (7.10)	-0.034** (-2.41)	0.037*** (7.10)	-0.009*** (-4.60)
Above \$250,000	0.064 (0.21)	baseline	0.067 (7.63)	baseline	0.011 (11.08)	baseline
Constant	-0.005 (-0.02)		-0.028*** (-4.25)		-0.003*** (-9.51)	
N observations	1,789		12,229		107,704	
R-squared	0.37		0.31		0.39	

Panel B. FNMA Debentures with 3+ Year to Maturity/Next Call Date

Variable	One Security		Securities with a Trade in Each Bucket		Entire Sample	
	Buys	Sells	Buys	Sells	Buys	Sells
Below \$5,000	0.137*** (8.44)	-0.289*** (-13.02)	0.257*** (4.54)	-0.355*** (-5.97)	0.257*** (4.63)	-0.367*** (-6.24)
\$5,000 to \$10,000	0.095*** (7.36)	-0.306*** (-11.57)	0.228*** (4.97)	-0.250*** (-7.00)	0.229*** (5.12)	-0.267*** (-7.16)
\$10,000 to \$25,000	0.088*** (7.16)	-0.122*** (-6.96)	0.146*** (5.88)	-0.177*** (-4.70)	0.147*** (6.05)	-0.183*** (-4.77)
\$25,000 to \$50,000	0.065*** (4.98)	-0.043** (-2.56)	0.133*** (4.96)	-0.126*** (-2.93)	0.136*** (5.16)	-0.130*** (-3.00)
\$50,000 to \$100,000	0.068*** (5.09)	0.003 (0.20)	0.130*** (5.85)	-0.105** (-2.26)	0.133*** (6.19)	-0.110** (-2.36)
\$100,000 to \$250,000	0.077*** (5.88)	-0.016 (-0.80)	0.117*** (7.46)	-0.020 (-1.38)	0.124*** (8.31)	-0.021 (-1.61)
Above \$250,000	0.067 (8.01)	baseline	0.103 (7.93)	baseline	0.102 (9.03)	baseline
Constant	-0.036*** (-5.63)		-0.052*** (-7.56)		-0.050*** (-8.56)	
N observations	3,345		35,163		37,443	
R-squared	0.26		0.14		0.14	



Table 4. (Cont.)

## Panel C. Investment-Grade Corporate Bonds with 3+ Year to Maturity/Next Call Date

Variable	One Security		Securities with a Trade in Each Bucket		Entire Sample	
	Buys	Sells	Buys	Sells	Buys	Sells
Below \$5,000	1.616*** (77.05)	-0.253*** (-5.75)	1.072*** (23.82)	-0.537*** (-29.63)	1.065*** (23.97)	-0.546*** (-30.06)
\$5,000 to \$10,000	1.670*** (96.04)	-0.392*** (-6.76)	1.323*** (31.42)	-0.562*** (-39.79)	1.318*** (31.81)	-0.574*** (-40.26)
\$10,000 to \$25,000	1.673*** (105.15)	-0.466*** (-12.86)	1.303*** (35.90)	-0.593*** (-46.16)	1.295*** (36.38)	-0.603*** (-46.82)
\$25,000 to \$50,000	1.599*** (84.96)	-0.502*** (-12.79)	1.167*** (34.23)	-0.525*** (-45.24)	1.158*** (34.88)	-0.531*** (-45.93)
\$50,000 to \$100,000	1.418*** (51.22)	-0.272*** (-4.69)	0.886*** (33.07)	-0.374*** (-37.11)	0.870*** (34.19)	-0.367*** (-36.28)
\$100,000 to \$250,000	0.925*** (20.63)	-0.150*** (-2.97)	0.432*** (33.58)	-0.042*** (-11.89)	0.418*** (35.82)	-0.043*** (-12.95)
Above \$250,000	0.286 (14.08)	baseline	0.252 (52.19)	baseline	0.246 (55.90)	baseline
Constant	-0.192*** (-15.51)		-0.143*** (-45.18)		-0.138*** (-48.39)	
N observations	18,546		1,493,488		1,595,951	
R-squared	0.44		0.40		0.39	

Table 5. Pay-ups of matched customer buy and customer sell trades

The sample period is from May 16, 2011 to May 31, 2012. Pay-up and spread are measured in price points. Under the Hong and Warga (2004, HW2004) concept, we match each customer buy trade to the closest in time customer sell trade in the same security, execution date, size category, and settlement date. Under the Green, Hollifield, and Schürhoff (2007a, GHS2007) concept, we start with the Hong and Warga (2004) pairing, but also require that the matched buy and sell trades have the same size. The MBS sample uses 30-year conventional securities with coupon rates between 3.5% and 6.5%. The FNMA debentures sample includes all bonds with at least 3 years left to maturity or next call date. The corporate bond sample includes all bonds with at least 3 years left to maturity or next call date that were rated investment grade by all three rating agencies throughout our sample period. We calculate pay-ups for MBS by first subtracting the TBA daily price benchmark from each reported price and then subtracting the mean pay-up of large trades in the same security over the entire sample period. The pay-ups for both FNMA debentures and corporate bonds are the previously defined Large Trade Price Spreads.

Trade Size	Statistic	MBS		Agency Debentures		Corporate Bonds	
		HW2004	GHS2007	HW2004	GHS2007	HW2004	GHS2007
Below \$5,000 in Current Face	Mean pay-up (Buys)	-7.75	-8.31	0.19	0.27	0.83	0.81
	Mean pay-up (Sells)	-8.84	-9.86	-0.34	-0.51	-0.61	-0.54
	Mean roundtrip spread	1.09	1.56	0.53	0.78	1.45	1.35
	Number of trade pairs	1,209	949	1,673	259	57,379	7,732
\$5,000 to \$10,000 in Current Face	Mean pay-up (Buys)	-0.65	-0.75	0.17	0.12	1.11	1.14
	Mean pay-up (Sells)	-1.78	-1.52	-0.30	-0.20	-0.66	-0.72
	Mean roundtrip spread	1.14	0.77	0.47	0.32	1.77	1.86
	Number of trade pairs	323	203	1,066	88	83,463	12,651
\$10,000 to \$25,000 in Current Face	Mean pay-up (Buys)	-0.28	-0.32	0.08	0.13	1.11	1.05
	Mean pay-up (Sells)	-1.46	-0.75	-0.25	-0.21	-0.65	-0.68
	Mean roundtrip spread	1.19	0.43	0.33	0.34	1.76	1.74
	Number of trade pairs	466	261	1,745	95	134,063	14,124
\$25,000 to 50,000 in Current Face	Mean pay-up (Buys)	-0.07	-0.14	0.04	0.07	1.02	0.84
	Mean pay-up (Sells)	-0.50	-0.51	-0.07	-0.13	-0.57	-0.54
	Mean roundtrip spread	0.43	0.37	0.11	0.19	1.60	1.38
	Number of trade pairs	320	212	961	74	56,202	9,895
\$50,000 to \$100,000 in Current Face	Mean pay-up (Buys)	0.07	0.04	0.06	0.27	0.75	0.61
	Mean pay-up (Sells)	-0.32	-0.20	-0.10	-0.18	-0.54	-0.41
	Mean roundtrip spread	0.39	0.24	0.16	0.45	1.29	1.02
	Number of trade pairs	275	177	832	41	39,388	10,998
\$100,000 to \$250,000 in Current Face	Mean pay-up (Buys)	0.02	0.03	0.07	0.07	0.37	0.20
	Mean pay-up (Sells)	-0.19	-0.14	-0.06	-0.06	-0.32	-0.16
	Mean roundtrip spread	0.21	0.17	0.13	0.13	0.69	0.36
	Number of trade pairs	404	251	1,365	66	52,230	8,707
Above \$250,000 in Current Face	Mean pay-up (Buys)	0.06	0.05	0.05	0.03	0.15	0.07
	Mean pay-up (Sells)	-0.03	0.01	-0.05	-0.04	-0.21	-0.12
	Mean roundtrip spread	0.09	0.04	0.10	0.07	0.36	0.19
	Number of trade pairs	3,841	2,792	5,421	1,079	148,834	48,090

Table 6. Crossed customer buy trades

The sample period is from May 16, 2011 to May 31, 2012. Crossed buys in each market are defined as customer buy trades occurring at prices lower than the difference between a pricing benchmark and the daily High-Low range. We use the volume-weighted average price of matched TBA trades on the same day as a pricing benchmark for MBS and the average price of large sell trades (above \$100,000 in current face) in the same security on the same day as a pricing benchmark for agency debentures and corporate bonds. For MBS, we define the daily High-Low range as the difference between the daily TBA Maximum Price and the daily TBA Minimum Price. We use the difference between the intraday maximum and minimum of the Bloomberg BGN benchmark, a composite indicative quote from contributing brokers on the Bloomberg electronic trading platform, as the daily High-Low range for agency debentures and corporate bonds. Sample definitions are the same as in Tables 1-4.

Trade Size (Current Face)	MBS			Agency Debentures			Corporate Bonds		
	Number of crossed buys	Number of buys	Pct. crossed buys	Number of crossed buys	Number of buys	Pct. crossed buys	Number of crossed buys	Number of buys	Pct. crossed buys
Below \$5,000	3,616	4,381	82.54%	11	1,210	0.909%	321	49,890	0.643%
\$5,000 to \$10,000	610	1,336	45.66%	2	823	0.243%	297	77,376	0.384%
\$10,000 to \$25,000	496	1,778	27.90%	4	1,441	0.278%	497	124,814	0.398%
\$25,000 to \$50,000	215	1,499	14.34%	6	1,276	0.470%	461	73,842	0.624%
\$50,000 to \$100,000	100	1,424	7.02%	3	1,138	0.264%	663	53,289	1.244%
\$100,000 to \$250,000	114	2,125	5.36%	2	1,289	0.155%	718	46,291	1.551%
Above \$250,000	220	25,061	0.88%	14	4,476	0.313%	1,834	125,058	1.467%

Table 7. Baseline model as calibrated to empirical pay-ups across trade size buckets

Sample period: May 16, 2011 to May 31, 2012. Pay-up is measured in price points. To calibrate the model, we use the Hong and Warga (2004) pay-ups from Table 5. For each market, we calibrate the model using Equation (5) to the average pay-up of buys and sells in the seven buckets and set  $q^I = 1,000,000$ ,  $q^R = 10,000$ ,  $q_{max}^R = 100,000$ ,  $\pi^I = 0.3$ ,  $\sigma = 0.01$  for MBS,  $\sigma = 0.005$  for agency debentures, and  $\sigma = 0.02$  for corporate bonds,  $c_h^I \geq 50$ , and  $V = 100\%$ .

Trade Size	Statistic	MBS		Agency Debentures		Corporate Bonds	
		Data	Model	Data	Model	Data	Model
Below \$5,000 in	Mean pay-up (Buys)	-7.75	0.39	0.19	0.19	0.83	0.84
Current Face	Mean pay-up (Sells)	-8.84	-0.79	-0.34	-0.26	-0.61	-0.84
\$5,000 to \$10,000 in	Mean pay-up (Buys)	-0.65	0.38	0.17	0.15	1.11	0.84
Current Face	Mean pay-up (Sells)	-1.78	-0.79	-0.30	-0.25	-0.66	-0.83
\$10,000 to \$25,000 in	Mean pay-up (Buys)	-0.28	0.35	0.08	0.13	1.11	0.84
Current Face	Mean pay-up (Sells)	-1.46	-0.77	-0.25	-0.24	-0.65	-0.83
\$25,000 to 50,000 in	Mean pay-up (Buys)	-0.07	0.31	0.04	0.11	1.02	0.84
Current Face	Mean pay-up (Sells)	-0.50	-0.67	-0.07	-0.20	-0.57	-0.75
\$50,000 to \$100,000 in	Mean pay-up (Buys)	0.07	0.23	0.06	0.09	0.75	0.76
Current Face	Mean pay-up (Sells)	-0.32	-0.09	-0.10	-0.07	-0.54	-0.35
\$100,000 to \$250,000 in	Mean pay-up (Buys)	0.02	0.10	0.07	0.06	0.37	0.37
Current Face	Mean pay-up (Sells)	-0.19	0.00	-0.06	-0.04	-0.32	-0.28
Above \$250,000 in	Mean pay-up (Buys)	0.06	0.00	0.05	0.03	0.15	0.26
Current Face	Mean pay-up (Sells)	-0.03	0.00	-0.05	-0.03	-0.21	-0.27
Root Mean Squared Error			3.10		0.05		0.16
Parameter Values							
Institutional Investor's Negotiation Power $\eta^I$			1.00		0.92		0.83
Retail Investor's Negotiation Power $\eta^R$			0.00		0.39		0.47
Institutional Buyer's Information Cost $c_i^I$			0.00		10.60		2717.49
Institutional Seller's Holding Cost $c_h^I$			50.00		455.51		152.03

Table 8. Extended model incorporating position aggregation and suitability frictions as calibrated to empirical pay-ups across trade size buckets

Sample period: May 16, 2011 to May 31, 2012. Pay-up is measured in price points. To calibrate the model, we use the Hong and Warga (2004) pay-ups from Table 5. For each market, we calibrate the model using Equation (8) to the average pay-up of buys and sells in the seven buckets and set  $\psi^R = 10\%$ ,  $q_{max}^R = 100,000$ ,  $\sigma = 0.01$  for MBS,  $\sigma = 0.005$  for agency debentures, and  $\sigma = 0.02$  for corporate bonds,  $c_h^I \geq 50$ , and  $V = 100\%$ .

Trade Size	Statistic	MBS		Agency Debentures		Corporate Bonds	
		Data	Model	Data	Model	Data	Model
Below \$5,000 in	Mean pay-up (Buys)	-7.75	-7.52	0.19	0.18	0.83	0.97
Current Face	Mean pay-up (Sells)	-8.84	-9.01	-0.34	-0.40	-0.61	-0.74
\$5,000 to \$10,000 in	Mean pay-up (Buys)	-0.65	-0.95	0.17	0.17	1.11	1.03
Current Face	Mean pay-up (Sells)	-1.78	-1.94	-0.30	-0.15	-0.66	-0.49
\$10,000 to \$25,000 in	Mean pay-up (Buys)	-0.28	-0.06	0.08	0.08	1.11	1.03
Current Face	Mean pay-up (Sells)	-1.46	-0.62	-0.25	-0.11	-0.65	-0.44
\$25,000 to 50,000 in	Mean pay-up (Buys)	-0.07	0.00	0.04	0.07	1.02	1.03
Current Face	Mean pay-up (Sells)	-0.50	-0.37	-0.07	-0.09	-0.57	-0.43
\$50,000 to \$100,000 in	Mean pay-up (Buys)	0.07	0.00	0.06	0.08	0.75	0.75
Current Face	Mean pay-up (Sells)	-0.32	-0.30	-0.10	-0.09	-0.54	-0.42
\$100,000 to \$250,000 in	Mean pay-up (Buys)	0.02	0.03	0.07	0.08	0.37	0.31
Current Face	Mean pay-up (Sells)	-0.19	-0.27	-0.06	-0.08	-0.32	-0.42
Above \$250,000 in	Mean pay-up (Buys)	0.06	0.21	0.05	0.08	0.15	0.39
Current Face	Mean pay-up (Sells)	-0.03	-0.26	-0.05	-0.08	-0.21	-0.42
Root Mean Squared Error			0.27		0.06		0.14
Parameter Values							
Institutional Investor's Negotiation Power $\eta^I$			0.68		0.80		0.74
Retail Investor's Negotiation Power $\eta^R$			1.00		0.54		0.35
Institutional Buyer's Information Cost $c_f^I$			4652.70		103.98		3409.78
Institutional Seller's/Dealer's Holding Cost $c_h^I$			306.00		50.00		50.00
Position Aggregation Parameter $k$			0.000195		0.02912		0.001288

Table A.1. Summary statistics of MBS trades executed with personal and student investment fund monies

We select only trades in 30-year MBS with coupons between 3.5% and 6.5%. The trades were executed over the period from January 12, 2012 to November 27, 2012.

Coupon	Statistic	Issuer			Total
		Fannie Mae	Freddie Mac	Ginnie Mae	
3.5	Mean pay-up	-7.17			-7.17
	Mean current face value	975			975
	Mean factor	0.98			0.98
	Number of trades	1			1
4.5	Mean pay-up	-6.09			-6.09
	Mean current face value	2,393			2,393
	Mean factor	0.81			0.81
	Number of trades	2			2
5.0	Mean pay-up	-8.02			-8.02
	Mean current face value	1,002			1,002
	Mean factor	0.32			0.32
	Number of trades	5			5
5.5	Mean pay-up	-6.00	-8.02		-6.51
	Mean current face value	2,539	2,481		2,525
	Mean factor	0.31	0.17		0.27
	Number of trades	3	1		4
6.0	Mean pay-up	-6.83	-2.48	-7.71	-7.01
	Mean current face value	1,410	2,405	2,747	2,189
	Mean factor	0.19	0.30	0.09	0.14
	Number of trades	6	1	8	15
6.5	Mean pay-up	-10.01		-10.39	-10.28
	Mean current face value	3,264		2,025	2,397
	Mean factor	0.39		0.06	0.16
	Number of trades	3		7	10
Total	Mean pay-up	-7.42	-5.25	-8.96	-7.93
	Mean current face value	1,832	2,443	2,410	2,099
	Mean factor	0.37	0.23	0.08	0.24
	Number of trades	20	2	15	37

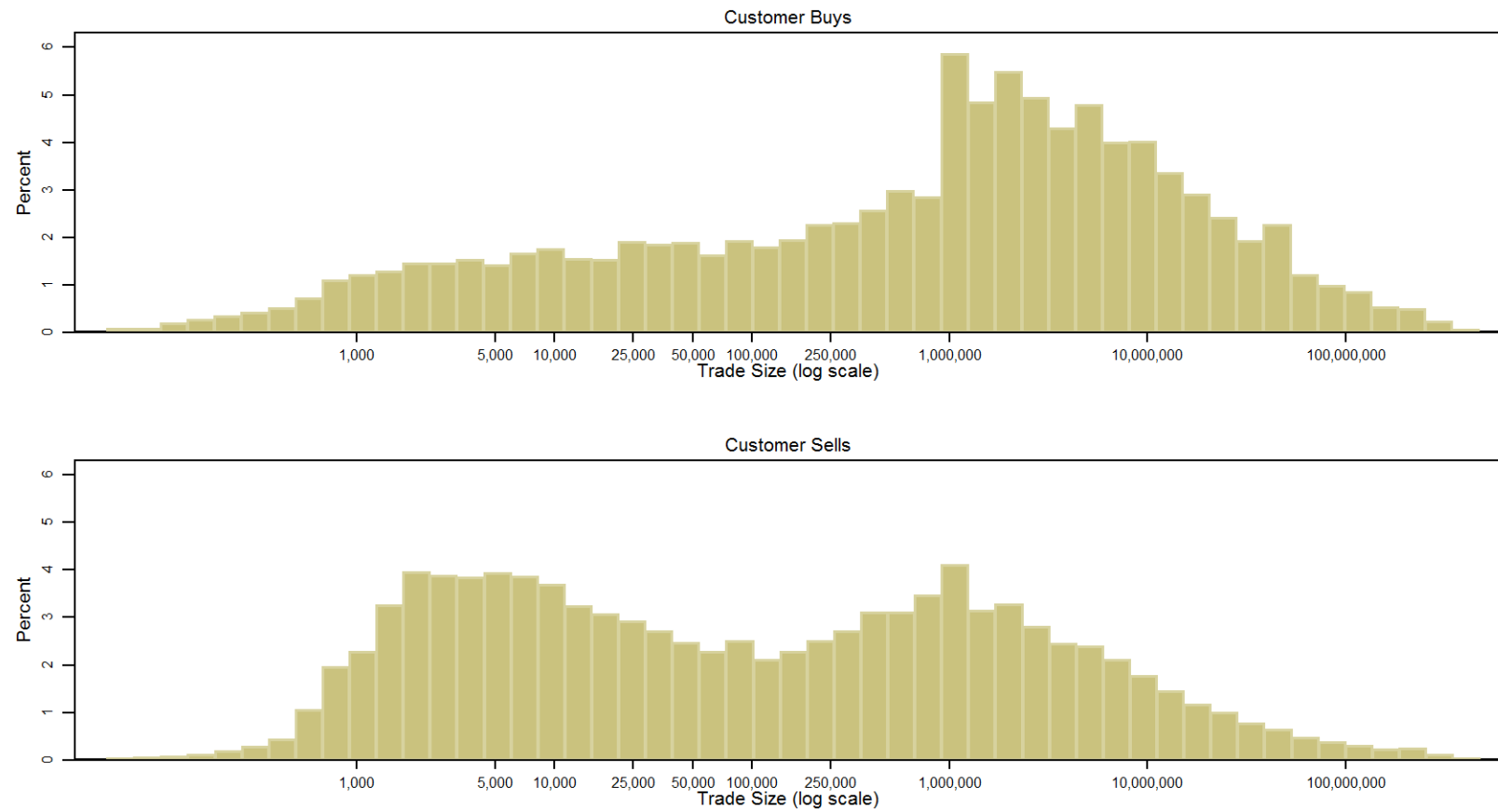


Figure 1a. Histogram of trade size for FNMA 30-year conventional pass-throughs

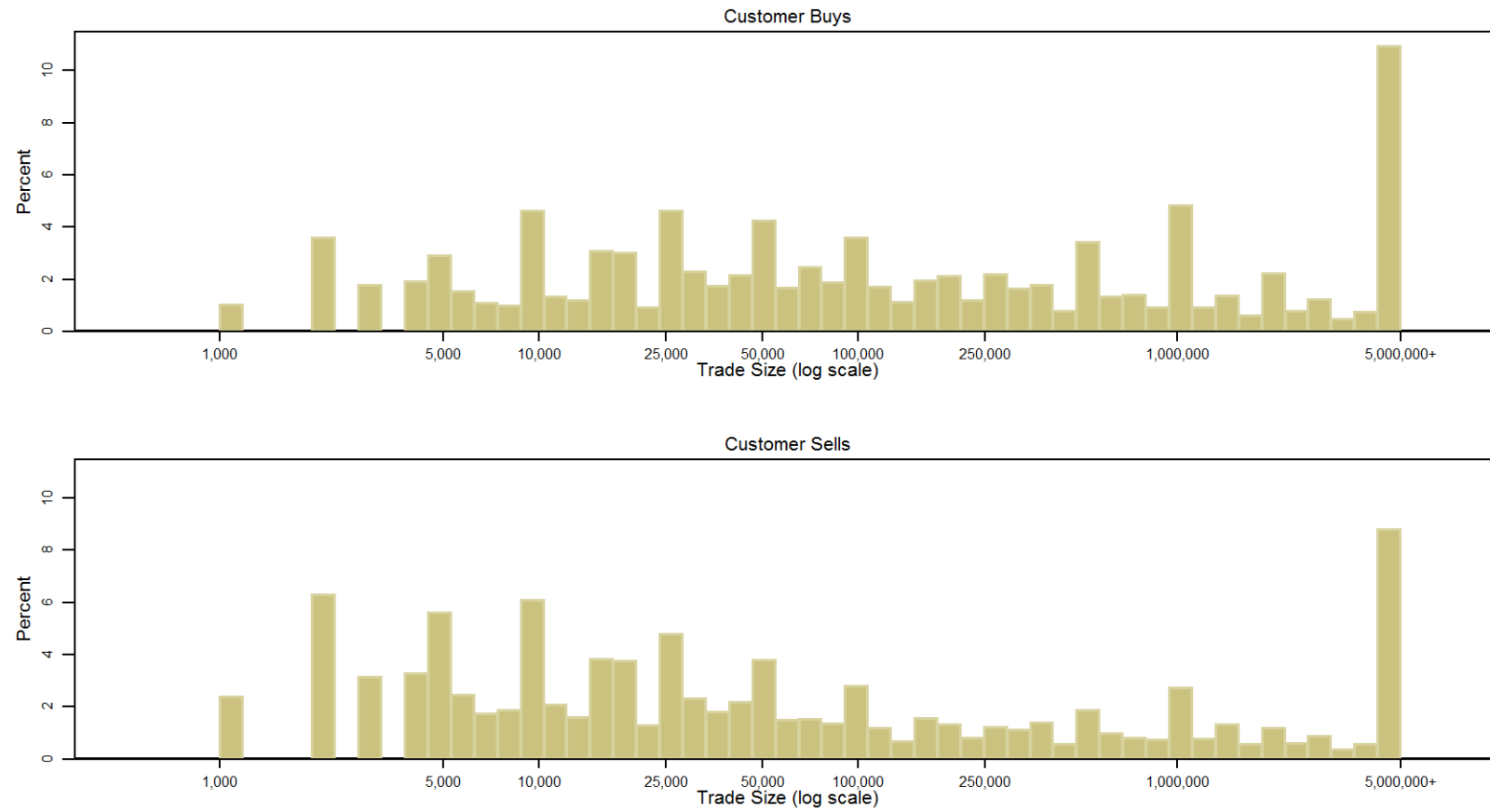
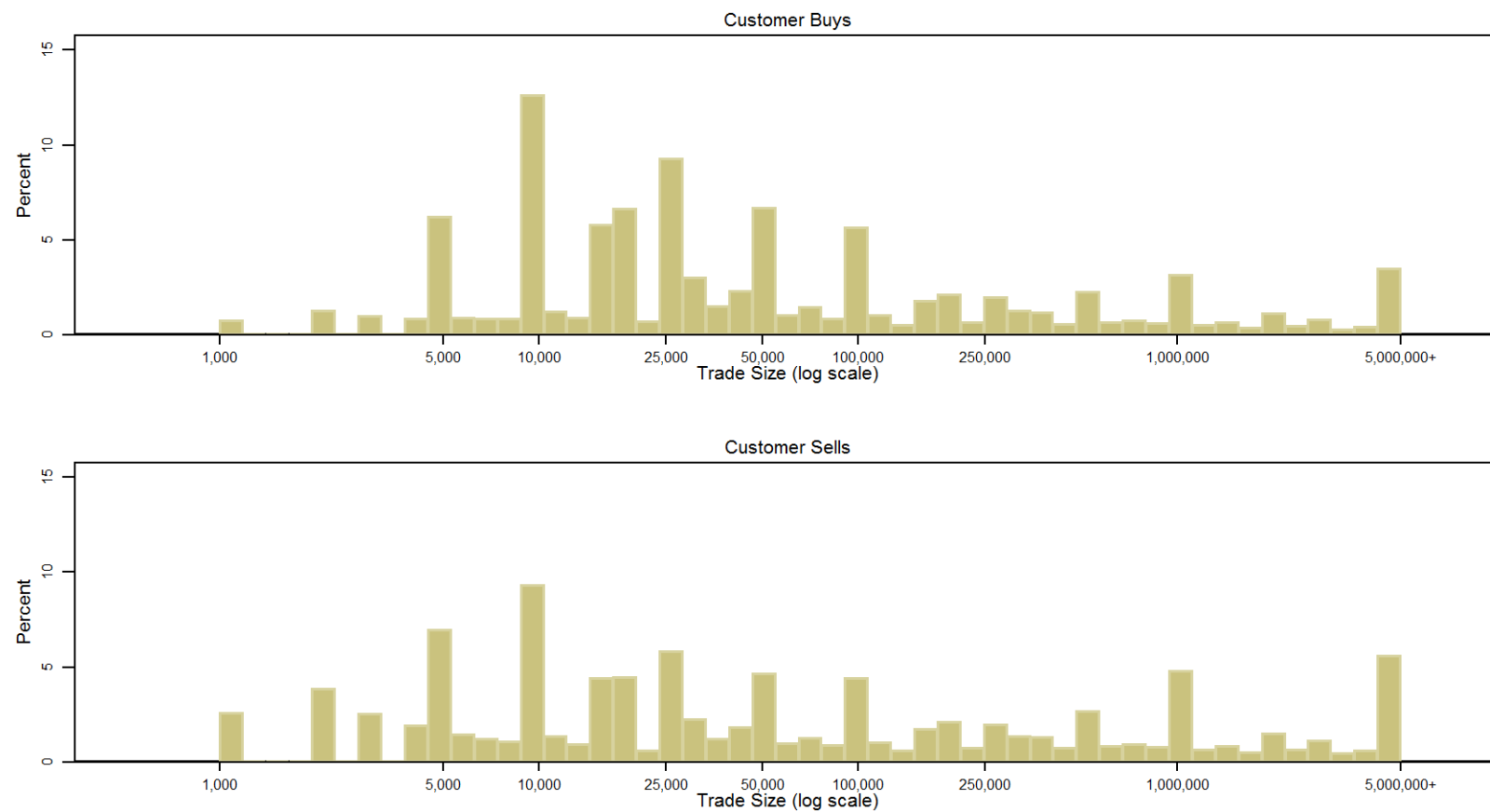


Figure 1b. Histogram of trade size for FNMA debentures





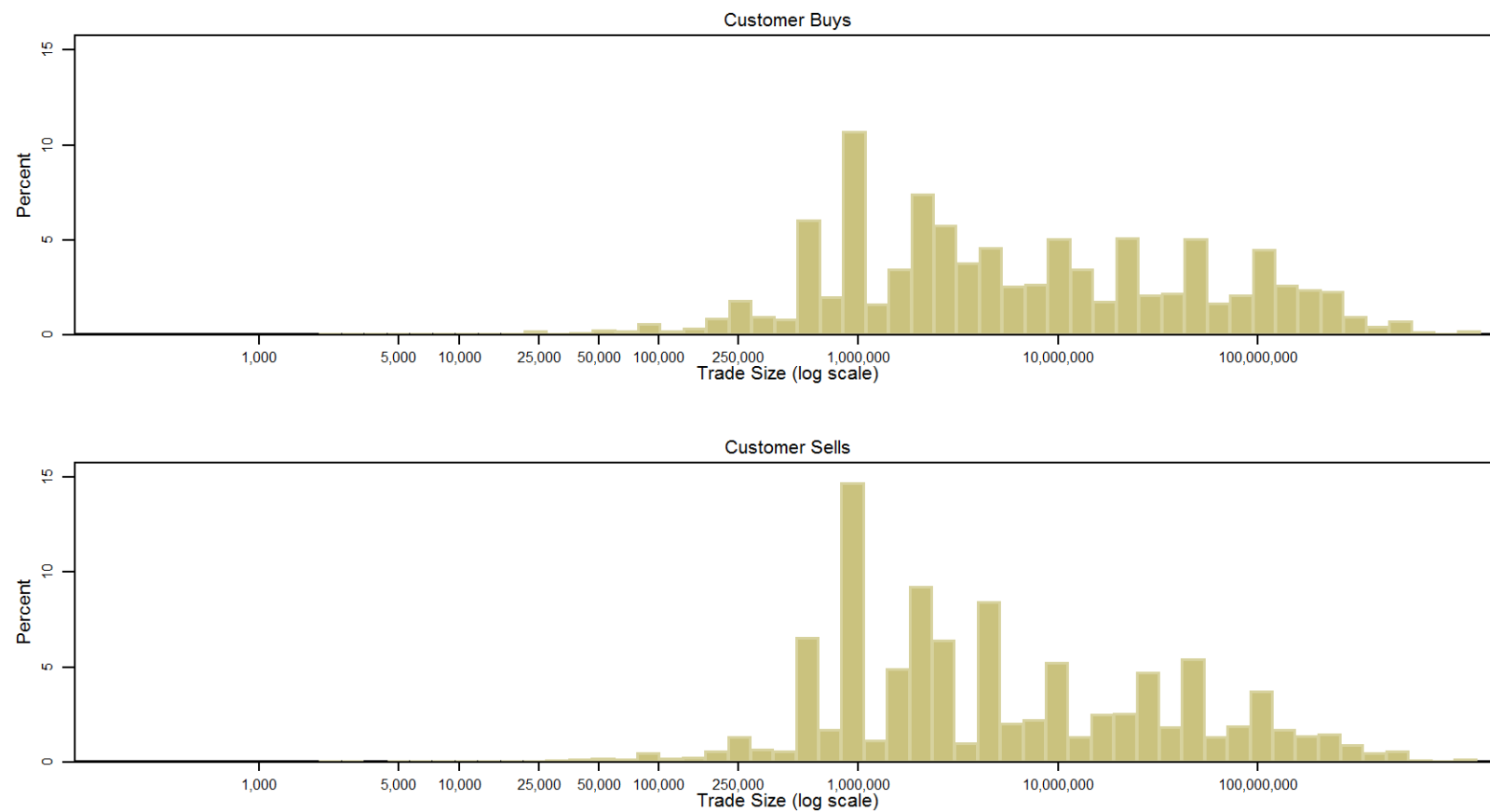


Figure 1d. Histogram of trade size for TBA contracts

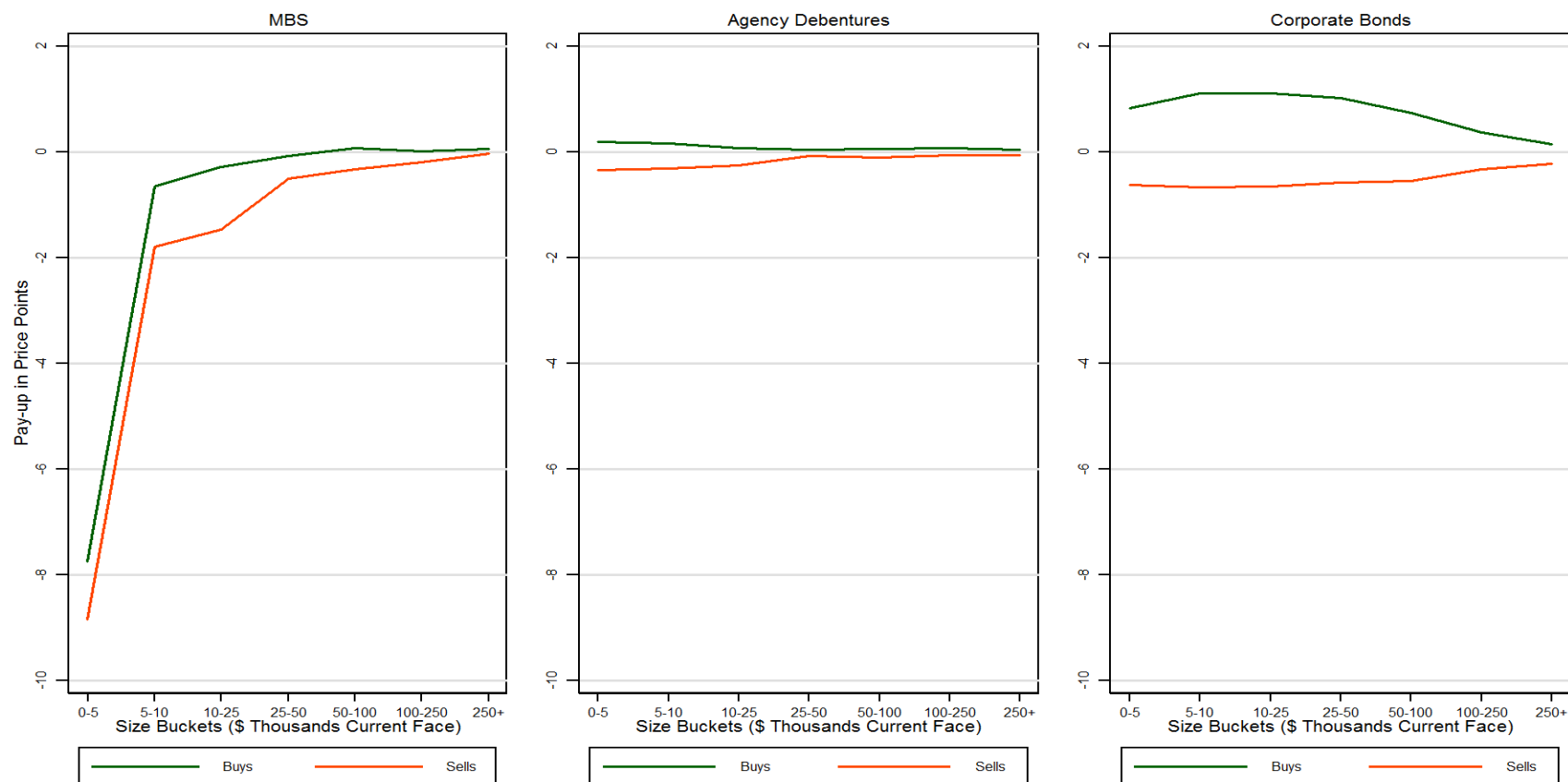


Figure 2. Average pay-ups of matched customer buy and sell trades grouped in trade-size categories

The plot shows the average pay-up of Hong and Warga (2004) matched customer buy and customer sell trades calculated the same way as in Table 5. The MBS sample is restricted to 30-year conventional securities with coupon rates between 3.5% and 6.5%. The Fannie Mae debentures sample includes all Fannie Mae bonds with more than 3 years left to maturity or next call date. The corporate bond sample includes all corporate bonds with more than 3 years left to maturity or next call date that were rated investment grade by all three rating agencies throughout our sample period.

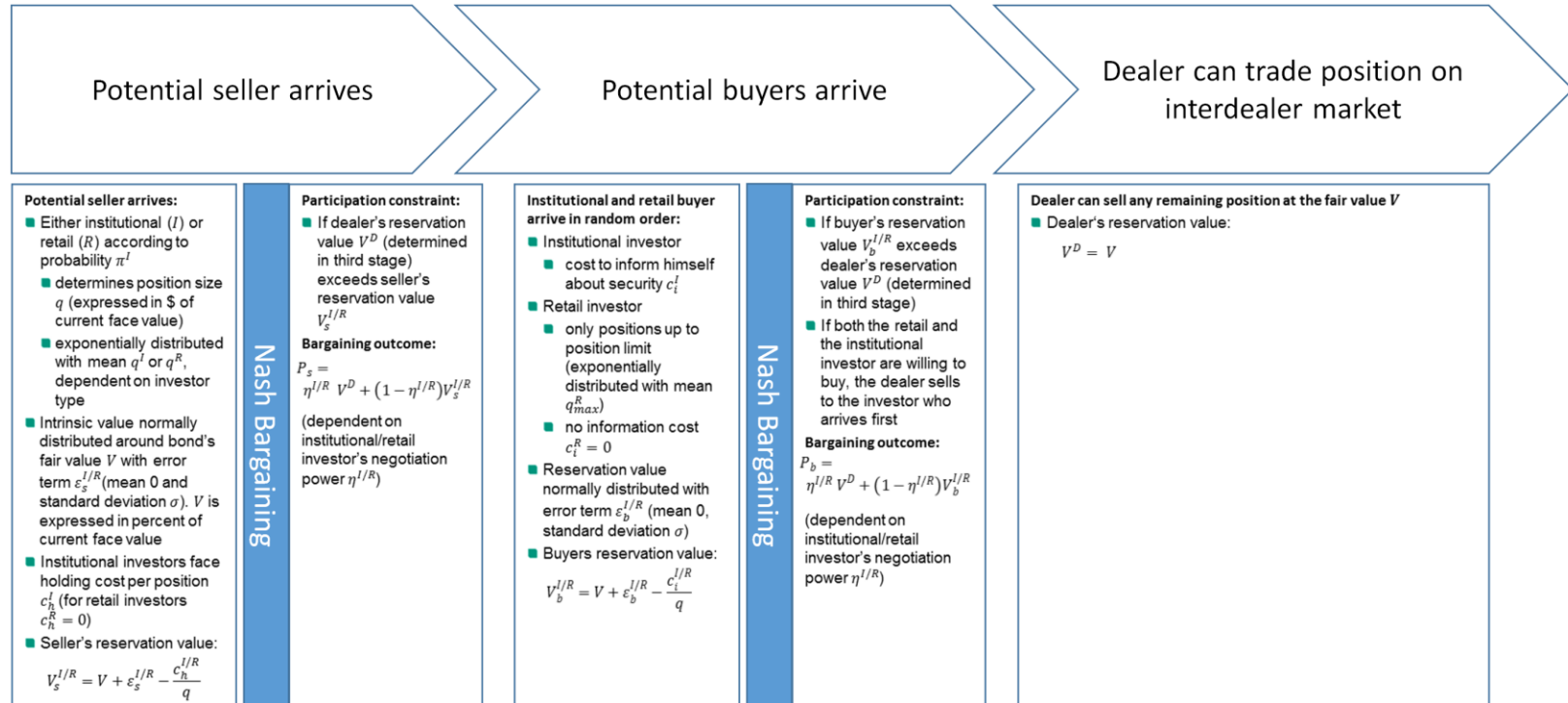


Figure 3. Description of basic model with traditional size-related frictions

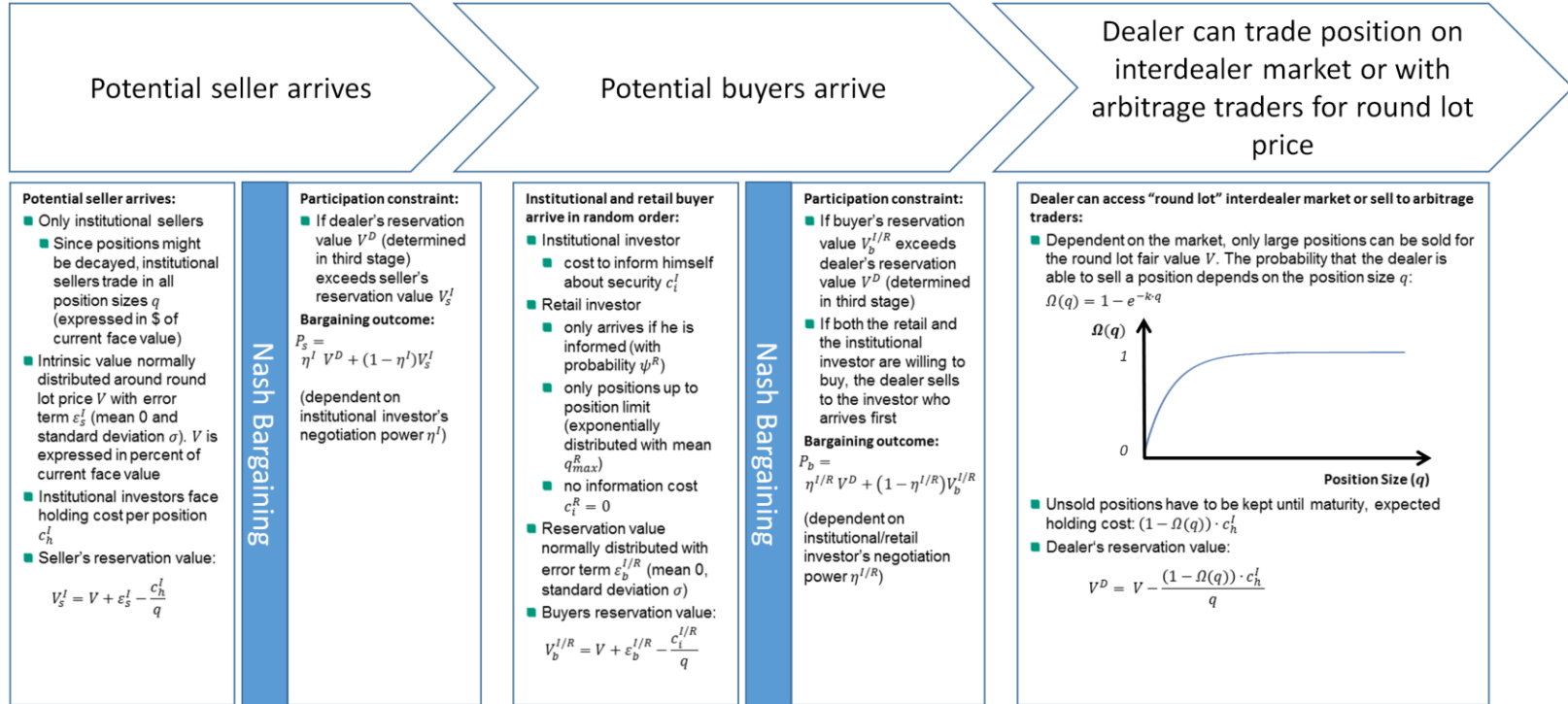


Figure 4. Description of extended model including position aggregation and suitability frictions