Does the Federal Reserve Obtain Competitive and Appropriate Prices in Monetary Policy Implementations?*

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Abstract

The Federal Reserve's (Fed) monetary policy implementations often involve extremely large trades within a short time frame. We show that dealers strategically manage inventory and charge uncompetitive pricing to the Fed in the agency MBS market: (1) dealers accumulate MBS inventory before Fed purchases and several large dealers acquire most inventory; (2) the same (large or small) dealer charges discriminatorily higher prices to the Fed than to non-Fed customers; (3) large dealers charge higher prices than small dealers when selling to the Fed, but the contrary is true when selling to non-Fed customers; and (4) the uncompetitive pricing worsens when the Fed increases purchase amounts.

Keywords: Inventory, Market power, Monetary policy, MBS, Primary dealer

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1 Introduction

> ***"The first objective is to obtain the securities at competitive and appropriate prices for the Federal Reserve, as doing so will ultimately benefit the U.S. taxpayer."***
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> — Brian Sack, Executive Vice President of the Federal Reserve Bank of New York, at the Global Interdependence Center Central Banking Series Event, Feb. 2011

The U.S. Federal Reserve (Fed) implements many monetary policies through trading with a group of around 20 primary dealers appointed by the Federal Reserve Bank of New York. For example, in implementing its conventional monetary policies that involve adjusting the federal funds rate, the Fed buys or sells Treasury securities with primary dealers as direct trading counterparties. During the Great Financial Crisis, the Fed implemented unconventional monetary policies that included purchasing Treasury securities and agency mortgage-backed securities (MBSs), known as quantitative easing (QE) in practice, also with primary dealers as direct trading counterparties. During the COVID-19 pandemic, the Fed again bought Treasury securities and agency MBSs, and also for the first time bought agency commercial MBSs and corporate bonds, still with primary dealers as the main direct trading counterparties.[1]

Do primary dealers exert strong market power against the Fed and extract large rents? On the one hand, the privilege of being able to trade directly with the Fed gives primary dealers a strategic advantage, which naturally makes the Fed susceptible to their market power and price discrimination. On the other hand, the Fed uses a range of strategies to reduce dealers' market power. For example, to induce competition, the Fed solicits bids (or offers) from multiple dealers for each trade. The Fed may also "threaten" to punish dealers for unreasonable and unfair pricing. Hence, it is unclear whether dealers can extract rents in the Fed's monetary policy implementations and what strategic behaviors they feature.

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[1] The specific arrangements have some variations across different asset purchase programs. For details, see https://www.newyorkfed.org/markets/domestic-market-operations and https://www.newyorkfed.org/markets/domestic-market-operations/monetary-policy-implementation/agency-commercial-mortgage-backed-securities/agency-commercial-mortgage-backed-securities-faq.

In this paper, we empirically show that dealers strategically manage inventory and extract large rents in trading with the Fed. Our analysis focuses on the agency MBS market, not only because of its importance and constant involvement in the Fed's policies,[2] but also because we are able to access detailed data on this market, making such an analysis feasible. In particular, we use two main datasets: supervisory-level MBS transactions data from the Trade Reporting and Compliance Engine (TRACE), as used in Gao, Schultz, and Song (2017) and Schultz and Song (2019); data of the Fed's trading records that are disclosed in accordance with the transparency requirements of the Dodd-Frank Act. Both datasets include dealer names, which allow for precise matching. The resulting merged data enable us to measure each primary dealer's market activities (e.g. market share, inventory change, and trading price), study heterogeneity across various dealers' transactions with the Fed, and compare dealers' pricing scheme to the Fed with that to other customers.[3]

The sample period for our analysis runs from October 2011 through March 2014, a period for which the two main datasets are available. In this period, the Fed conducted around 9,000 trades with an aggregate purchase amount of about $1.5 trillion involving 15- and 30-year MBSs issued by Fannie Mae, Freddie Mac, and Ginnie Mae. Before each purchase, the Fed announces a pre-determined transaction day and size; on the trading day, the Fed solicits offers from multiple primary dealers to induce price competition. Despite the Fed's efforts to stimulate competition, our analysis provides a number of results showing primary dealers' strategic inventory buildup and uncompetitive pricing to the Fed.

We first show that dealers strategically build up MBS inventory well ahead of the Fed's

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[2] Serving a critical role in facilitating mortgage borrowing by U.S. households, the agency MBS market is one of the largest fixed-income markets in the U.S., with an outstanding volume of about $8.8 trillion as of December 2019, according to the Securities Industry and Financial Markets Association (https://www.sifma.org/resources/research/us-mbs-issuance-and-outstanding/).

[3] Similar types of datasets can potentially be used to tackle our main research question in markets for Treasury securities, agency CMBSs, and corporate bonds, but are less readily available as of now. For example, TRACE data on Treasury transactions have been collected only since July 2017 and have not been made available to the public (https://libertystreeteconomics.newyorkfed.org/2018/09/unlocking-the-treasury-market-through-trace.html). TRACE data on corporate bonds and agency CMBSs are readily available, but the Fed's purchases in these two markets began only with the COVID-19 pandemic and involved small amounts. Instead, the Fed's agency MBS purchase has been large and regular before the COVID-19 pandemic, and further escalated greatly since the pandemic. See Section 3 for details.

trade date. By summing over the daily net order flows, we find that dealers begin accumulating MBS inventory around two months before the Fed's scheduled trade day and continue doing so until the Fed's trade day. On average, a dealer builds up about $300 million in MBS inventory.[4] In a placebo test, we do not find inventory run-ups before the Fed's purchase programs begin, supporting the conclusion that the dealers' inventory buildup is a strategic response to trading with the Fed.

Dealers differ dramatically in inventory capacity. We measure the inventory capacity of a dealer by her fraction of the aggregate trading volume from May 2011 through September 2011, during which no MBS purchase was conducted by the Fed. Remarkably, the top five dealers (out of about 200), which are all primary dealers, account for about half of the aggregate trading volume.[5] We define these top five dealers as large primary dealers and remaining primary dealers as small primary dealers. We find that this small number of large dealers control the bulk of the MBS inventory before the Fed's trade. On average, a large primary dealer builds up about $600 million in inventory before a Fed purchase, while a small primary dealer builds up only about $200 million in inventory.

How does dealers' inventory buildup, especially by large primary dealers, help them to extract rents? The key is to note that the Fed's purchase amount in a single operation (about $3,700 million on average) dwarfs any *individual* dealer's inventory capacity, which can enable dealers to exert market power. We demonstrate the economic mechanism through the framework of the Bertrand-Edgeworth price competition with constrained capacities (Tirole (1988)). Adapting from Kreps and Scheinkman (1983) specifically, we assume that the Fed aims to buy a fixed amount of MBSs from two dealers. The two dealers compete by their offering prices to the Fed, at which they would sell MBSs up to their respective inventory capacities. If the Fed purchase amount is lower than both dealers' inventory capacity, standard

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[4] To be precise, the order flows used are those of the so-called to-be-announced (TBA) forward contracts, which account for more than 90% of the agency MBS trading volume (Gao, Schultz, and Song (2017)). The Fed's purchases are implemented in the TBA market exclusively. See Section 2 for details.

[5] Similar heterogeneity and concentration are documented for other fixed-income markets such as corporate bonds, municipal bonds, and asset-backed securities (Di Maggio, Kermani, and Song (2017); Hollifield, Neklyudov, and Spatt (2017); Li and Schürhoff (2019)).

Bertrand outcome with competitive pricing arises. However, as long as the Fed buys more MBSs than either dealer's inventory capacity, the other dealer effectively monopolizes the Fed's residual demand, leading to uncompetitive prices. Such uncompetitive pricing is particularly acute when the two dealers have uneven inventory capacities: intuitively, the higher the discrepancy of their capacities, the closer the scenario to a monopolist dealer.

We empirically test two effects of this market power mechanism on primary dealers' pricing to the Fed. First, the *same* dealer sells at higher prices to the Fed than to non-Fed customers, which we call the *discriminatory pricing* effect. Indeed, we find that the same primary dealer on average sells MBSs to the Fed at a higher price, about 2 cents per $100 in par value, than she charges non-Fed customers. Second, compared with a small dealer, a large dealer with greater inventory capacity can exert stronger market power, thereby charging higher prices and selling more MBSs to the Fed, which we call the *differential pricing* effect. We regress Fed purchase prices on primary dealers' inventory capacity (measured by the market share of trading volume, as discussed above) and show that a dealer with a one-standard-derivation greater inventory capacity charges the Fed a price that is about one cent higher per $100 in par value. Meanwhile, a dealer with a one-standard-deviation greater inventory capacity sells 4.8% more MBSs as a fraction of the Fed's total purchase amount.[6]

Inventory costs, which can arise from either standard inventory risk (Ho and Stoll (1981)) or balance sheet regulations implemented since the 2008 crisis (Bao, O'Hara, and Zhou (2018); Bessembinder, Jacobsen, Maxwell, and Venkataraman (2018)), are clearly a potential alternative channel that might explain our empirical findings presented so far.[7] In particular, dealers

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[6] As argued by O'Hara, Wang, and Zhou (2018), the approach of comparing prices directly taken in these baseline analyses obviates the need to measure trading costs against a benchmark and subsumes the myriad effects that could affect bond trading in general. That being said, we do examine dealers' gross profit margins or markups charged to the Fed, which are measured as differences between dealers' selling prices to the Fed and the average buying price in a time window leading up to a Fed trade. A dealer with a one-standard-deviation greater inventory capacity charges the Fed a markup that is about 1.8 cents higher. This translates into about $300 million in gross profits from the $1.5 trillion total purchase in our sample period.

[7] Other related studies of dealers' inventory in OTC markets include empirical studies by Schultz (2017), Dick-Nielsen and Rossi (2019), An (2020), and Goldstein and Hotchkiss (2020), and theoretical studies by Weill (2007), Randall (2015), and Colliard, Foucault, and Hoffmann (2020), to name a few. Most of these studies focus on dealers' inventory costs, with the exception of An (2020) who studies dealers' strategic benefits in building inventory of heterogeneous assets.

may build up MBS inventory in order to avoid incurring excessive costs of scrambling for inventory near the Fed's trade day. Further, a convex inventory cost, i.e. the per-unit inventory cost increases with the inventory level, can explain both the discriminatory and differential pricing effects. However, we find that on the same days when the Fed buys MBSs, large dealers charge *lower* prices to non-Fed customers than small dealers do. That is, using MBSs from the same inventory, large dealers charge higher prices to the Fed than small dealers do, but offer lower prices to non-Fed customers. This contrasting pricing pattern is inconsistent with the story of inventory cost alone, given that the MBSs sold to the Fed and non-Fed customers are from the same inventory and should incur the same cost. Instead, dealers' market power can account for the contrast: large dealers exert greater market power than small dealers do in trading with the Fed, whose purchase size is high, but the difference in their market power is likely small for non-Fed customers, whose purchase is low.

We then exploit a variation in the size of the Fed's purchase program to further confirm that dealers' market power is associated with the large purchase size. Specifically, the QE3 program starts in September 2012, increasing the monthly purchase from about \$30 billion to roughly \$65 billion. Cast within our economic framework, the higher purchase amounts lead to even greater market power for large primary dealers and less competitive pricing to the Fed. Empirically, we indeed find that, after the beginning of QE3, the magnitudes of both differential and discriminatory pricing increase significantly.

Overall, our evidence reveals a significant dealer rent component in the higher price the Fed pays relative to what non-Fed customers pay. Several other components may also be present. In particular, an inventory cost component is likely in place, which should also be positively associated with the Fed's purchase size, as does dealer rent. We hence term the sum of the dealer rent and inventory cost components as the *trade-size markup*. This is in sharp contrast to the *trade-size discount* that has been observed in dealer-intermediated markets (Bernhardt, Dvoracek, Hughson, and Werner (2004); Bessembinder, Spatt, and Venkataraman (2020)). Further, in addition to making large-size purchases, the Fed differs from non-Fed customers in terms of *operational flexibility*. In particular, the Fed publicly releases and commits to a trading schedule that is fixed well ahead of the trade execution day, while non-Fed customers can adjust their trading schedule more flexibly. Non-Fed customers can also solicit offers from a more diverse pool of dealers. Although such setup provides transparency, the Fed's inflexible operational setup constrains its outside options, which can lead to higher purchase prices.[8]

Our final empirical analysis attempts to systematically assess various effects—trade-size markup, trade-size discount, and operational flexibility—on the prices that the Fed pays relative to what non-Fed customers pay. We document two findings. First, by comparing the same dealers' selling prices to the Fed with selling prices to non-Fed customers for trades of similarly large size, we find that the operational inflexibility accounts for less than half of the discriminatory pricing to the Fed, so the trade-size markup accounts for over half. Second, by examining non-Fed customers' trades of different sizes, we find that on days when the Fed does not trade (so dealers have enough inventory capacity to accommodate customers' demand), trade-size discount dominates for trades of all size ranges. Yet, on days when the Fed trades (so dealers may not have enough inventory capacity left for non-Fed customers), trade-size discount is observed for small trades but trade-size markup is observed for large trades. This pattern delivers a more refined picture of the trade-size effect that is consistent with our simple economic framework: customers receive execution-cost discounts for relatively small trades but pay markups for relatively large trades.

Putting all evidence together, we show that the Fed paid large rents in policy implementations due to a combination of large purchase size, large dealers' control of the bulk of MBS inventory, and primary dealers' privilege that allows them to be the exclusive intermediaries between the Fed and ultimate MBS sellers. This has important implications for policy design. For example, the Fed's policy execution efficiency may be improved by adjusting purchase speed in light of secondary market conditions. In addition, the Fed can open up direct trading

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[8] Preannouncing the trading schedule also reduces the information content of the trades, thereby lowering transaction costs (Admanti and Pfleiderer (1991)). This effect runs against our empirical finding that the Fed's operational inflexibility leads to higher purchase prices.

to more and diverse counterparties such as banks, funds, and insurance companies, which may not only promote further competition but also reduce the concentration of MBS inventory in several large primary dealers. Indeed, the Fed began adding new trading counterparties for some of its asset purchase programs recently.[9] Nevertheless, potential changes in operational design have to be comprehensively evaluated to avoid losing the benefits of policy implementation speed and of the primary dealer system.[10]

The focus of our analysis is distinct from those of existing studies of Fed purchase auctions (Bonaldi, Hortacsu, and Song (2015); Song and Zhu (2018)) and Treasury issuance and buyback auctions (Cammack (1991); Simon (1994); Nyborg and Sundaresan (1996); Goldreich (2007); Han, Longstaff, and Merrill (2007); Hortacsu, Kastl, and Zhang (2018)).[11] These studies focus mostly on the formats of auctions, such as comparing uniform-price auctions with multiple-price auctions (see Kastl (2020) for a recent survey). Instead, our results imply that the Fed's huge purchase amounts grant dealers significant market power, which is further amplified by large dealers' control of the bulk of the MBS inventory. Our point resonates with Milgrom (2004) (page 5 in Chapter 1) in the context of spectrum licenses auctions; in particular, Milgrom states that "... the auction game begins long before the auction itself. The scope and terms of spectrum licenses can be even more important than the auction rules for determining the allocation..."

Naranjo and Nimalendran (2000), Pasquariello (2007), Pasquariello (2017), and Pasquariello, Roush, and Vega (2020) study the effects of central banks' trading on market liquidity

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[9] See https://www.newyorkfed.org/newsevents/news/markets/2020/20201120 for detailed announcements. Relatedly, Treasury issuance auctions allow for direct bidders other than primary dealers (Fleming and Myers (2013)).

[10] For example, some studies show that the policies' effects arise mainly from the stock of assets that are expected to be in the Fed's ultimate holdings, rather than the flow of purchases (Gagnon, Raskin, Remanche, and Sack (2011); Krishnamurthy and Vissing-Jorgensen (2011)). Under this condition, purchasing at a lower speed can potentially reduce uncompetitive pricing.

[11] A set of empirical studies of government debt auctions in other countries also focus on aggregate auction outcomes based on bid-level data, including Umlauf (1993), Gordy (1999), Nyborg, Rydqvist, and Sundaresan (2002), Keloharju, Nyborg, and Rydqvist (2005), Hortacsu and McAdams (2010), Kastl (2011), and Hortacsu and Kastl (2012). Theoretical and experimental studies of Treasury issuance auctions include Bikhchandani and Huang (1989), Goswami, Noe, and Rebello (1996), Chatterjea and Jarrow (1998), Kremer and Nyborg (2004), and Boyarchenko, Lucca, and Veldkamp (2019).

and price informativeness. In these studies, central banks' trading reflects private information they hold. Our paper complements these studies but focuses on the importance of dealer inventory in central bank trading. Also related are O'Hara, Wang, and Zhou (2018), Griffin, Hirschey, and Kruger (2020), and Hendershott, Li, Livdan, and Schürhoff (2020), who document dealers' discriminatory pricing to various non-Fed customers in corporate and municipal bond markets.

2 Institutional Background and Economic Framework

In this section, we introduce some institutional background and then present a simple economic framework to guide our empirical analysis.

2.1 Institutional Background

Most agency MBSs are issued as pass-through securities in which interest payments (subtracting credit guarantee and mortgage service fees) and principal payments on underlying mortgages are passed through pro rata to MBS investors. Agency MBSs are effectively default-free, with credit guarantees from Fannie Mae, Freddie Mac, or Ginnie Mae, but subject to uncertainty regarding the timing of cash flows, which is known as prepayment risk. Trading in agency MBSs occurs via both the specified pool (SP) contract in which an individual MBS is traded and the TBA forward contract in which any MBS within an eligible cohort can be delivered (Vickery and Wright (2013)). A TBA contract specifies, for example, a Fannie Mae 30-year fixed-rate MBS with a 4% security coupon rate, but the particular MBS that a seller delivers needs to be identified only two days before the settlement day. TBA trading is remarkably liquid and incurs low transaction costs of only a few basis points (Gao, Schultz, and Song (2017)).

The Fed purchases agency MBSs exclusively through TBA contracts because of their great liquidity. One important feature of the Fed's asset purchases, not only in agency MBS markets but also more broadly in other markets, is the huge purchase amounts and rapid implementation speed. For example, in just 15 months, from January 2009 to March 2010, the Fed purchased \$1.25 trillion in agency MBSs, while in 8 months, from November 2010 to June 2011, the Fed purchased \$600 billion in Treasury securities. In the recent COVID-19 pandemic, the Fed purchased about \$75 billion in Treasury securities and \$50 billion in agency MBSs on each business day in the week of March 23. Another feature of Fed purchases is that the Fed discloses details of upcoming purchase operations to avoid potential adverse effects on market functioning (Potter (2013)). The Fed usually releases a detailed schedule including the date, the securities to be purchased, and the expected amount involved in each upcoming purchase operation.

The massive purchases, rapid implementation, and pre-announced operation schedules would conceivably give primary dealers—the exclusive direct trading counterparties—a strategic advantage that enables them to exert market power against the Fed. The Fed's operation mechanism, on the other hand, can counteract dealers' market power by stimulating competition. In particular, for each trade, the Fed solicits offers (or bids) from multiple dealers. For example, when purchasing Treasury securities, the Fed uses its own FedTrade system to request offers from all primary dealers for each trade (Song and Zhu (2018)). When purchasing agency MBSs, prior to 2014 Q1 the Fed used the request-for-quote (RFQ) algorithm on the Tradeweb electronic platform involving four dealers for each trade and has been using the FedTrade system involving all primary dealers ever since then. The Fed also has some flexibility regarding the specific amount involved in each purchase operation beyond the minimum purchase amount.

The extent to which the Fed's trading mechanism can stimulate competition among primary dealers depends on dealers' strategic behaviors. Given the large and well-anticipated purchases involved in each operation, dealers can strategically accumulate MBS inventories prior to the Fed's operation day. On the one hand, building up inventories in advance can reduce a dealer's cost for intermediating the movement of MBSs from investors to the Fed. On the other hand, inventory accumulation allows dealers to gain strategic advantage in competing against other dealers.

Dealers' capacities to accumulate inventory vary. For example, some dealers have broad customer bases, maintain large trading networks, have large balance sheet, and are associated with bank-holding companies that have large mortgage-lending businesses. Naturally, large dealers are able to acquire larger MBS inventories and also source them at lower cost. In fact, even among primary dealers, there is substantial heterogeneity regarding their shares of secondary market trading: the top five primary dealers account for 47% of the total trading volume, while the remaining primary dealers account for about 38% (see Table 2 for details). Significant dealer heterogeneity is also documented in markets for corporate bonds, municipal bonds, and asset-backed securities (Di Maggio, Kermani, and Song (2017); Hollifield, Neklyudov, and Spatt (2017); Li and Schürhoff (2019)). The potential concentration of the bulk of MBS inventories in the hands of only a few large dealers stifles competition and subjects the Fed to their market power. We now introduce a simple economic framework to demonstrate the specific channel through which dealers' market power arises when selling to the Fed.

2.2 Economic Framework and Empirical Design

Our simple economic framework is adapted from the classic Kreps and Scheinkman (1983) setup of Bertrand-Edgeworth competition with capacity constraints. In particular, a large dealer with high inventory capacity and a small dealer with low inventory capacity compete to sell MBSs to the Fed. The large and small dealers' inventories are x_1 and x_2, respectively, with both available as public information and $x_1 \geq x_2 > 0$. We take x_1 and x_2 as exogenously given, but they could be endogenized in the same manner as in the first-stage game in Kreps and Scheinkman (1983). We normalize dealers' reservation value of holding inventory to 0. The Fed seeks to buy some constant $D \in (0, x_1 + x_2)$ units of MBSs.[12] Each dealer $i = 1, 2$ submits an offer to sell up to x_i units of MBSs at price p_i. The Fed buys first from the lowest

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[12] We use constant demand D for ease of interpretation. Kreps and Scheinkman (1983) assume a general demand function $D(p)$, which needs to satisfy some additional technical conditions. The completely inelastic demand D in our setting can be approximated by a very inelastic demand function $D(p)$ that satisfies the technical assumptions of Kreps and Scheinkman (1983).

offered price, and if necessary then from the higher offered price, until purchase demand D is met.

The equilibrium has two cases.[13]

(i) If the Fed's purchase demand is small ($D \leq x_2$), dealers engage in standard Bertrand competition. They sell the same amount of inventory at the same competitive price to the Fed.

(ii) If the Fed's purchase demand is moderately large ($x_2 < D < x_1 + x_2$), both dealers employ a mixed strategy, randomizing the offer price p_i on a common interval that is above the competitive price level. The large dealer on average sells more inventory to the Fed than the small dealer.[14] Further, the large dealer's offer price stochastically dominates that of the small dealer.

Therefore, whether the Fed can obtain competitive prices depends on the magnitude of Fed purchases relative to dealers' inventory. When a Fed purchase is small, as in case (i), the Fed obtains competitive prices. As long as a Fed purchase exceeds the smaller dealer's inventory capacity x_2 in case (ii), both dealers exert market power and charge uncompetitive prices to the Fed. Intuitively, this happens because at least one dealer effectively monopolizes the residual demand from the Fed.

Moreover, although the existence of uncompetitive pricing does not depend on heterogeneity in dealers' inventory capacity, such heterogeneity tends to exacerbate uncompetitive pricing. For example, keeping the Fed's purchase demand D and the sum of dealers' inventory $x_1 + x_2$ constant, a greater discrepancy between x_1 and x_2 makes case (ii), with uncompetitive pricing, more likely to happen than case (i), with competitive pricing.

Guided by this simple economic framework, our empirical design for studying primary dealers' uncompetitive pricing to the Fed consists of two main components, as illustrated in Figure 1.

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[13] The equilibrium uniqueness is shown by Osborne and Pitchik (1986).

[14] This result is not shown in Kreps and Scheinkman (1983), but we show it in Appendix B.

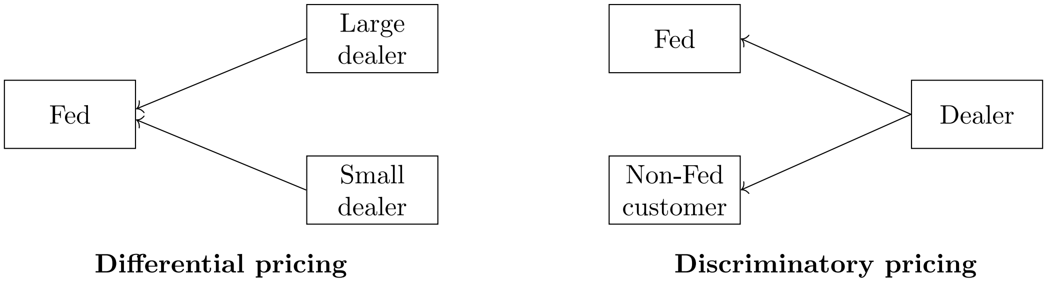

Figure 1. Illustration of the empirical design

In the left panel, we study large and small dealers' differential pricing and selling volumes to the Fed. In the right panel, we examine whether the same dealer charges a discriminatory selling price to the Fed relative to the price she charges non-Fed customers.

First, we study large and small dealers' differential pricing and selling volumes to the Fed, as illustrated in the left panel of Figure 1. The Fed's huge purchases, which on average account for half of new MBS issuance in each month (see Section 3.2), renders case (ii) the most likely scenario. In this scenario, the Fed's purchase exceeds the smaller dealer's inventory but is below the inventory of all dealers combined. Dealers with greater inventory capacity exert stronger market power against Fed.[15] We hence arrive at the following prediction.

Prediction 1 (Differential pricing)**.** *Compared with small dealers, large dealers on average sell larger quantities of MBSs at higher prices to the Fed.*

Second, the Fed is special in our model only because of the heavy demand involved. A non-Fed customer can also face uncompetitive pricing when her purchase amount is large relative to individual dealers' inventories. In general, however, non-Fed customers' purchase quantities are much lower than the Fed's and can be satisfied by most dealers' inventories. Hence, non-Fed customers likely obtain (more) competitive prices, as in case (i). Accordingly, we examine whether the same primary dealer charges a higher or discriminatory selling price to the Fed relative to the price she charges non-Fed customers, as illustrated in the right panel of Figure 1.

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[15] There are two granular cases within case (ii), depending on whether $D < x_1$ or not. With $D < x_1$, the small dealer can sell to the Fed only if her offer price p_2 is lower than that of the large dealer p_1. In consequence, the small dealer's transaction price with the Fed is stochastically dominated by her offer price p_2, which is in turn dominated by the large dealer's price p_1. If $D > x_1$, then the Fed buys from both dealers and the large dealer's transaction price with the Fed stochastically dominates the small dealer's.

Prediction 2 (Discriminatory pricing)**.** *The same primary dealer charges a higher selling price to the Fed than to non-Fed customers.*

We also explore variations in the Fed's purchase quantity D. When D is small, any dealer's inventory can satisfy the purchase demand, so case (i) of the equilibrium is likely to occur with competitive pricing. As D increases, case (ii) with uncompetitive pricing becomes more likely. We hence arrive at the following prediction.

Prediction 3 (Variation in the Fed's purchase amount)**.** *As the Fed's purchase increases, the magnitudes of differential pricing as in Prediction 1 and of discriminatory pricing as in Prediction 2 increase.*

Although not formally included in our simple economic framework, inventory costs are an important channel that drives dealers' pricing in classic microstructure models (Ho and Stoll (1981)). Balance sheet regulations implemented since the 2008 crisis, such as the Volcker Rule and supplementary leverage ratios, have also led to increases in dealers' inventory costs (Bao, O'Hara, and Zhou (2018); Bessembinder, Jacobsen, Maxwell, and Venkataraman (2018); Duffie (2018); He, Nagel, and Song (2020)). Indeed, inventory costs can potentially account for both the discriminatory and differential pricing effects.[16] However, one key difference between a dealer's inventory cost and marker power is that the former depends on the dealer exclusively while the latter is contingent on both the dealer and customer. We shall use this difference to distinguish between these two channels in our empirical analysis (in Section 5.2).

Finally, we discuss two additional issues related to dealers' inventory management and market power. First, while a dealer with higher inventory capacity on average acquires more inventory, the actual amount of inventory acquired can vary in practice. For example, a

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[16] Quadratic (or in general convex) inventory costs can explain differential pricing and selling amounts as follows. We assume that the large dealer's cost for holding x units of inventory is $\beta_1 x^2$ and the small dealer's cost is $\beta_2 x^2$, with $0 < \beta_1 < \beta_2$. Therefore, for any given level of inventory x, the large dealer's cost is lower than the small dealer's. Thus, the large dealer's equilibrium inventory level x_1 is greater than the small dealer's x_2 and the large dealer sells more MBSs to the Fed. The average per-unit inventory cost incurred by the large dealer is $\beta_1 x_1$ and that incurred by the small dealer is $\beta_2 x_2$. That $\beta_1 x_1 > \beta_2 x_2$ is possible, which implies that the large dealer needs to charge a higher price to the Fed than the small dealer does in order to break even.

dealer's affiliated mortgage loan desk may happen to receive a larger amount in loans, which are then issued as MBSs and sold to this dealer. A higher realized inventory leaves a given dealer with greater inventory risk, which may cause her to charge a lower selling price to the Fed in order to unload the inventory (see Table D.7 for supportive evidence). Note that this implication is about the varying inventory of a given dealer, which differs from both discriminatory pricing, where we vary customers, and differential pricing, where we compare various dealers.

Second, our simple economic framework abstracts away from inter-dealer trading, which can potentially affect dealers' trading strategies involving the Fed and equilibrium outcomes. For example, the small dealer may first win the trade with the Fed and then purchase the needed MBSs to deliver to the Fed. Moreover, inter-dealer trading can also facilitate "collusion" among dealers. These economic channels are more sophisticated but challenging to identify empirically, which we leave to future investigations.[17]

3 Data, Summary, and Measures

In this section, we introduce the data used in our empirical analysis, present summaries of the Fed's purchases and dealers' activities in MBS trading, and construct empirical measures.

3.1 Data and Cleaning

We use two main datasets. The first consists of the TRACE dataset of MBS transactions, while the second consists of purchase data that have been publicly released by the Federal Reserve Bank of New York. The sample period we choose runs from October 2011 through March 2014, a period for which both datasets are available (see Appendix A for details of the Fed's MBS purchase programs).

The TRACE data on agency MBS transactions that we use, which are also used in Gao,

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[17] Studies of how inter-dealer trading affects dealers' transactions with general customers include for example Viswanathan and Wang (2004) and Riggs, Onur, Reiffen, and Zhu (2020). Studies of dealer collusion against general customers include for example Christie and Schultz (1994) and Christie, Harris, and Schultz (1994).

Schultz, and Song (2017) and Schultz and Song (2019), contain all MBS trades that are intermediated by broker-dealers registered with the Financial Industry Regulatory Authority (FINRA). Each trade records the trade type, the agency involved, the loan term, the security coupon rate, the price, the par value, the trade date, and the settlement month, among other particulars. Both inter-dealer trades and customer-dealer trades are included. Importantly, dealer identifiers are included for each trade, which enables us to measure each primary dealer's market activities (e.g. market share, inventory change, and trading price) around the Fed's purchase.

We first apply the standard algorithm to correct trade revisions, cancellations, and reversals in the TRACE. We also account for the duplicated reports of inter-dealer trades. Because we measure the inventory of each individual dealer around the Fed's purchase, we address several issues regarding dealer identities. First, we assign a trade to the dealer who executed the trade rather than to the reporting dealer for give-up trades in which one reporting firm reports on behalf of one actual trading counterparty (e.g. a clearing firm reports on behalf of a correspondent firm) and for inter-dealer locked-in trades in which one reporting firm reports on behalf of both actual trading counterparties. Second, some dealers have multiple reporting identities in TRACE. We merge any multiple reporting identities that are tied to the same underlying dealer using the link table from the Depository Trust & Clearing Corporation.[18] Third, we exclude an inter-dealer broker who matches only dealers (see Appendix C for details).

To align with Fed purchases that are executed in the TBA market, we keep only regular good-delivery outright TBA trades with standard fixed coupon payments and without stipulations.[19] Furthermore, we keep only TBA contracts for 15- and 30-year MBSs issued by Fannie Mae, Freddie Mac, and Ginnie Mae. Some TBA trades have incorrect settlement dates, which we correct using the settlement schedule provided by the Securities Industry and Financial

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[18] By merging multiple reporting identities to the same dealer, we delete wash trades, in which a dealer trades with itself for bookkeeping purposes. These wash trades constitute 0.03% of the sample.

[19] Trades involving stipulated TBA contracts and dollar rolls as well as those not qualified for good delivery or with quarter or non-standard coupon rates, are hence excluded. Trades in specified pools are also deleted.

Markets Association (SIFMA). We also delete trades executed on weekends.[20] The resulting data contain 2,594,910 TBA trades, including trades between the Fed and primary dealers.

Turning to the Fed's purchase records, for every trade we obtain the transaction price, the counterparty identity, the principal amount, the date, and the TBA contract specification (agency, loan term, coupon rate, and settlement date) from the Fed's public website. We remove canceled transactions. We retain only outright purchases and exclude dollar rolls that the Fed uses to facilitate settlements (Song and Zhu (2019)). In addition, we exclude "small value exercises" that the Fed uses to test operational readiness.[21]

In total, we end up with 9,270 purchasing trades by the Fed. To measure changes in dealers' inventories related to Fed purchases, we separate dealers' trades with the Fed from other trades. Trades with the Fed are reported by dealers as customer-dealer trades in the TRACE with customers remaining anonymous, so we match these trades with the Fed's purchase records based on TBA contract specifications, trade dates, dealer names, trading quantities, prices, and directions. We identify 9,264 of the Fed's 9,270 trades and exclude the six unmatched trades.

3.2 Summary of Fed Purchases

We start by presenting a summary of the aggregate amounts of Fed MBS purchases. In our sample period, which runs from 2011 Q4 through 2014 Q1, the Fed maintains (1) the reinvestment program, which reinvests cash flows from agency MBSs and agency debts into agency MBSs and runs throughout our whole sample period, and (2) the so-called QE3 program, which runs from 2012 Q4 through the end of our sample period. Figure 2 plots the Fed's quarterly purchase amounts. For comparison, we also plot the quarterly issuance amounts of 15-year and 30-year agency MBSs, which the Fed purchases exclusively.

On average, the Fed purchases about $88 billion in agency MBSs per quarter from 2011

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[20] In the entire sample, fewer than 50 trades occur on weekends. Some are likely to be reporting errors, so we delete them.

[21] For more information on small value exercises, see the New York Fed website https://www.newyorkfed.org/markets/operational-readiness.

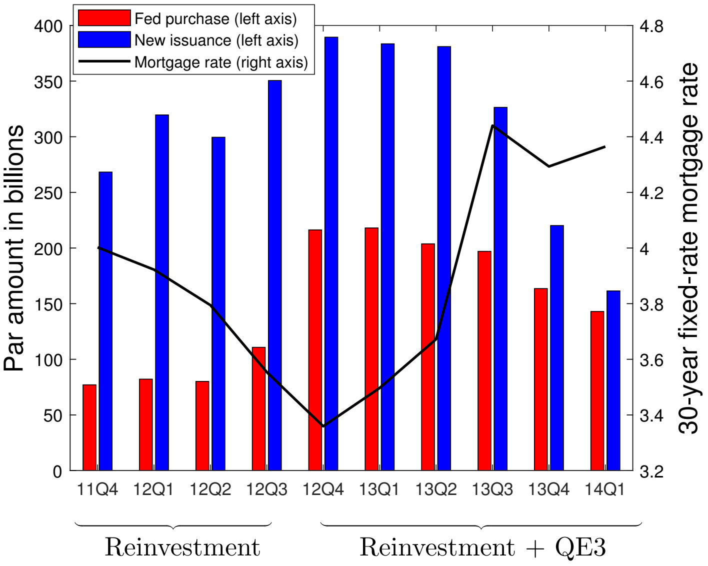

Figure 2. Quarterly agency MBS Fed purchase amounts, 15-year and 30-year agency MBS issuance amounts, and 30-year fixed-rate mortgage average rates

In this figure, we calculate the total agency MBS Fed purchase amounts for each quarter from 2011 Q4 through 2014 Q1. We obtain the 15-year and 30-year agency MBS issuance amounts from EMBS. We obtain 30-year fixed-rate mortgage average rates from FRED website https://fred.stlouisfed.org/series/MORTGAGE30US.

Q4 through 2012 Q3, and increases the purchase amounts to about $190 billion per quarter after the QE3 program starts. The Fed's purchases, which concentrate in newly issued MBSs, account for 28% of the quarterly total new issuance from 2011 Q4 through 2012 Q3. After QE3 starts, this fraction increases to 55% between 2012 Q4 and 2013 Q2. In 2013 Q3, the mortgage rate spikes, which dramatically reduces the new issuance amount so that the Fed purchases about 70% of the total new issuance in the last part of our sample period.

Table 1 provides a breakdown of the Fed's aggregate purchase amounts. We observe that almost all purchasing trades are executed at large-integer trade sizes of 50, 100, 150, 200, or 250 million par amounts. Second, the purchasing trades are concentrated in TBA contracts of 3%, 3.5%, and 4%, which are called "production coupons" and consist of the bulk of newly issued agency MBSs with coupon rates closely tied to concurrent primary mortgage rates. Third, the distribution of the Fed's overall purchase volume across agencies and loan terms is similar to that of the overall market balance, with more 30-year than 15-year MBSs and more involving Fannie Mae MBSs than Freddie Mac and Ginnie Mae MBSs.

Table 1. Summary statistics for Fed purchases

Purchase amount (million)	150	200	100	250	50	Other
Fraction (percentage)	30.0	29.0	25.0	12.6	2.7	0.7
Coupon rate (percentage)	3	3.5	4	2.5	2	4.5
Fraction (percentage)	33.2	31.5	22.0	9.9	2.0	1.5
Agency	Fannie Mae	Freddie Mac	Ginnie Mae			
Fraction (percentage)	50.1	27.8	22.1			
Loan term (year)	30	15				
Fraction (percentage)	81.4	18.6				

This table provides summary statistics for the 9,264 purchasing trades executed by the Fed from 2011 Q4 through 2014 Q1.

In addition, the Fed conducts multiple trades on different days under a given TBA contract, and these trades are settled together. In particular, the 9,264 trades in our sample represent 398 separate TBA contracts, so on average 23 trades are executed for each TBA contract. Trades under a given TBA contract are spread over about four weeks.

3.3 Summary of Primary Dealers' MBS Trading Activities

Over our 2.5-year sample period, there are 185 broker-dealers in total, among which 20 are primary dealers. Sixteen of these primary dealers made at least one sale to the Fed. The remaining four may have participated in the Fed's offer solicitations but never won a trade (they are small dealers on the agency MBS market and in total account for less than 1% of total MBS trading volume). Hence, we shall focus on the sixteen primary dealers who have traded with the Fed.

We measure the inventory capacity of dealer i by the fraction of TBA trading volume (including both dealer-customer and inter-dealer trades) for which she was responsible among all 185 dealers from May 2011 (when the TRACE for agency MBSs became available) through September 2011, denoted as M_i. We do so to avoid the potential confounding effects of Fed purchases, which start in October 2011, on dealers' realized inventory. As shown in panel A of Table 2, the 16 primary dealers take a dominating market share of 85%. Furthermore, there is considerable heterogeneity among primary dealers: the top five primary dealers account for

Table 2. Summary statistics for primary dealers' trading activities

A: Primary dealers' market shares M_i from May 2011 through September 2011 (percentages)					
	Mean	Standard deviation	Top 5	Top 10	All 16
Primary dealers' market share M_i	5.3	3.8	47.4	77.2	85.1
B: Variations in primary dealers' market shares from 2011 Q4 through 2014 Q1 (percentages)					
	Mean	Standard deviation	Min	Max	
Top 5 primary dealers	45.0	17	42.0	48.3	
Top 10 primary dealers	80.3	2.1	77.2	83.3	
All 16 primary dealers	87.5	1.8	84.2	89.6	

This table presents summary statistics for primary dealers' trading activities. Panel A provides summary statistics for primary dealers' market shares M_i, which are calculated based on trading activities occurring from May 2011 through September 2011. Panel B provides time-series variations in primary dealers' market shares. We classify the top five and the top ten primary dealers using M_i. We measure these dealers' market shares for each quarter from 2011 Q4 through 2014 Q1 and then compute time-series variations.

47% of the market share while the top ten account for 77%.

The dealers' inventory capacity is also stable over time. To show this, we keep the classification of primary dealers as top five and top ten based on M_i. We then re-compute their market share for each quarter from 2011 Q4 through 2014 Q1 (including trades with the Fed). Panel B of Table 2 reports summary statistics for these quarterly time series for the groups of the top five, the top ten, and all 16 primary dealers, respectively. We observe that the time-series average market share is 45%, 80%, and 88% for the three groups, respectively, which is quite similar to those reported in panel A. Moreover, the time-series standard deviation and range are both tiny, confirming the remarkable stability of dealer inventory capacity.

4 Dealers' Strategic Inventory Buildup for Fed Purchases

In this section, we document dealers' strategic inventory buildup for Fed purchases.

As discussed in Section 3.2, the Fed conducts multiple trades on separate days of the same TBA contract, which are then settled together. Therefore, we calculate dealers' inventory as follows. First, for each trade n executed by the Fed of a given TBA contract m, we calculate the daily inventory change (= total purchase amount minus total sale amount on each day) for each primary dealer i for TBA contract m, excluding all trades with the Fed. We do this up to 60 weekdays before and after the day of trade n (these days are denoted in relative terms such that -1 and 1 mean 1 weekday before and after the day of trade n, respectively). Second, we take dealer i's average daily inventory change across trades n for each TBA contract m and each of the 121 days t, denoted as $\text{InvChg}_{i,m,t}$. Third, we subtract dealer i's total selling amount to the Fed under TBA contract m from $\text{InvChg}_{i,m,0}$, because dealers build inventory for the entire series of trades. Finally, we take the cumulative sum from day -60 to day t to measure dealer i's inventory buildup under TBA contract m on the t-th day relative to the Fed's purchase day, denoted as $\text{InvCum}_{i,m,t}$.

Figure 3A plots the average of $\text{InvCum}_{i,m,t}$ across TBA contracts m and dealers i against day t. We observe a remarkable increase in dealers' inventory prior to Fed trades. On average, a dealer builds up about \$300 million in inventory before the Fed's purchase, and sells \$234 million to the Fed on day 0. That is, although dealers in principle can first trade with the Fed and then scramble to replenish inventory afterwards, we find that they build up inventory mainly before a Fed purchase. As discussed in Section 2, this inventory buildup can not only reduce cost to dealers for intermediating the movement of MBSs from investors to the Fed (e.g. avoiding the risk of failure to deliver MBSs and related scrambling to replenish inventories), but also enable a dealer to gain a strategic advantage in competing against other dealers.

To provide further evidence that such an inventory buildup is a strategic response by dealers in anticipation of a Fed purchase, Figure 3B plots inventory changes under TBA contracts that settle in 2011 Q3, when the Fed purchase programs have not started. In particular, for each July, August, and September settlement months, we retain the top 10 TBA contracts in terms of total trading volume, which are comparable to those that are purchased by the Fed. The inventory calculation is the same as that for $\text{InvCum}_{i,m,t}$ except that day t is stipulated relative to the TBA settlement day. We observe that, in stark contrast to inventory buildups prior to Fed trades, dealers continue selling MBSs prior to the settlement date. Such selling before the settlement date likely reflects dealers' intermediation of new MBS issuance.[22]

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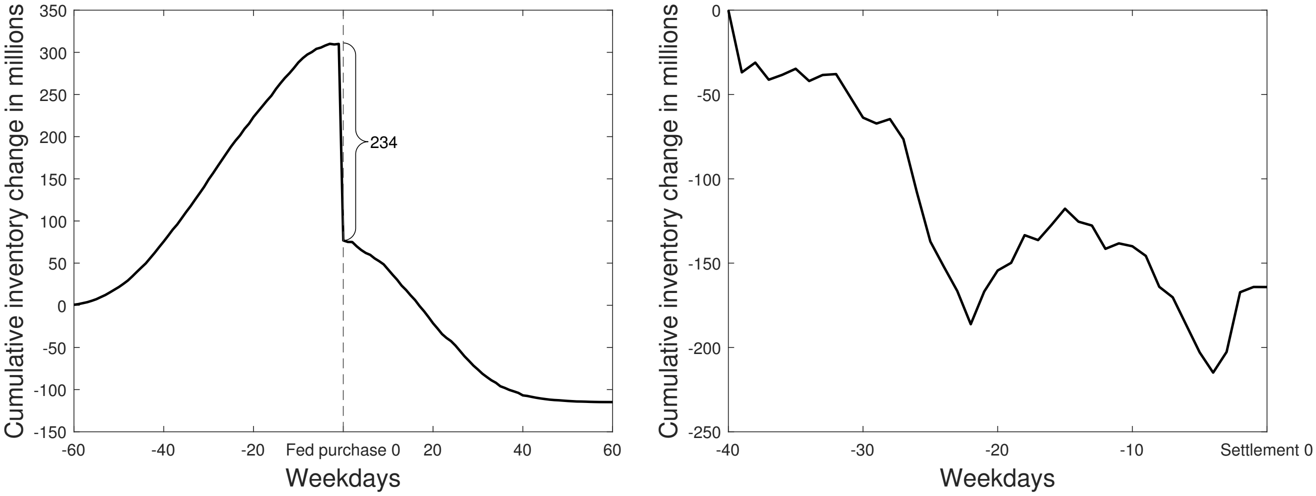
[22] The downward trend in dealer inventory prior to the TBA settlement day is closely related to the similar downward trend shown in Figure 3A after Fed trades. In fact, day 0 in Figure 3A is about 40 days prior to the TBA settlement day. Hence, the reduced dealer's inventory after Fed trades is likely associated with the usual practice of selling inventory before TBA settlement dates (Gao, Schultz, and Song (2017)).



(A) During a Fed purchase **(B) Before a Fed purchase**

Figure 3. Cumulative inventory change for an average dealer under an average TBA contract

In panel A we plot the cumulative inventory change for an average primary dealer under an average TBA contract that the Fed purchases from 2011 Q4 through 2014 Q1. Day 0 is the Fed's purchase date. On average, a dealer sells \$234 million under a TBA contract to the Fed. In panel B, we plot the cumulative inventory change for an average primary dealer under an average TBA contract that settles in 2011 Q3, when the Fed purchase programs have not started. Day 0 is the TBA contract settlement date.

Next, we show that a small number of large dealers acquire the bulk of MBS inventory. We categorize the top five primary dealers in terms of inventory capacity M_i as large dealers and the 11 remaining dealers as small dealers. Figure 4 plots the average $\text{InvCum}_{i,m,t}$ across m and i for the large and small dealer groups, respectively. Large dealers build significantly larger inventories than small dealers. An average large dealer builds up about \$600 million in inventory, while an average small dealer only builds up about \$200 million. That is, the bulk of MBS inventory is concentrated in the hands of only a few large dealers.

We further quantify the dependence of dealers' strategic inventory buildup on their inventory capacity. We regress $\text{InvCum}_{i,m,-1}$, the cumulative inventory change for dealer i under TBA contract m from 60 weekdays before to 1 weekday before a Fed purchase, on the Fed's total purchase amount for TBA contract m and report the results in column (1) of Table 3. On average, a dealer accumulates inventory equal to 6.83% of the Fed's total purchase amount. For column (2), we add the interaction term of the Fed's total purchase amount and dealer inventory capacity M_i to the regression. The coefficient is significantly positive, showing that,

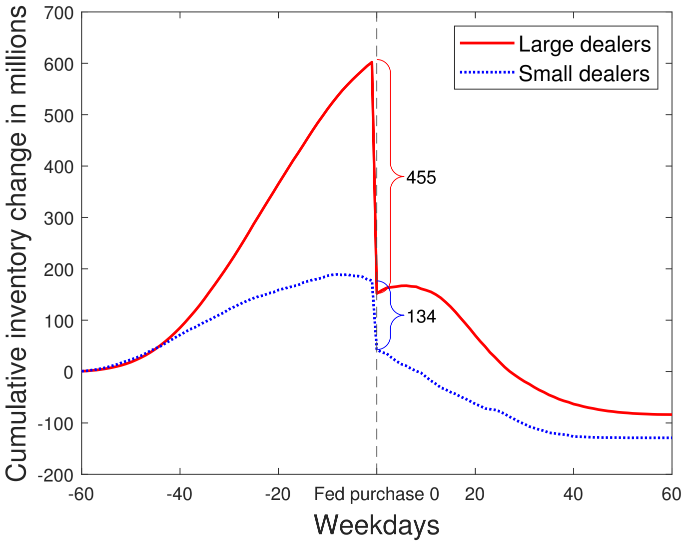


Figure 4. Cumulative inventory change for an average large dealer and an average small dealer under an average TBA contract

Based on primary dealers' market shares M_i from May 2011 through September 2011, we categorize the top five primary dealers as large dealers and the remaining dealers as small dealers. We plot the cumulative inventory change for an average large dealer and an average small dealer under an average TBA contract that the Fed purchases from 2011 Q4 through 2014 Q1. Day 0 is the Fed's purchase date. The numbers (455 and 134) in the brackets represent the total selling amount under a TBA contract to the Fed by an average large dealer and by an average small dealer, respectively.

quantitatively, a dealer with a one-percentage-point higher secondary market share accumulates 1.60% more inventory as a fraction of the Fed's total purchase amount. For column (3), we further add TBA contract fixed effects, and the coefficient remains unchanged.

Finally, it is worth discussing potential measurement issues with dealers' inventory buildup. First, the trading data, which measure flow changes in dealers' inventory, do not allow for precise measurement of dealers' inventory levels. Our focus is, however, on dealers' strategic inventory buildup in anticipation of a Fed trade, so the inventory change that is likely measured accurately using trading data suits our purpose. Second, although the Fed purchases MBSs exclusively through TBA contracts, dealers may deliver MBSs acquired on the SP market. However, MBSs in the SP market are usually higher in value, so it is suboptimal for dealers to accumulate a large volume of SP MBSs and deliver them to the Fed through TBA contracts. That being said, including SP trades in our analysis delivers similar results (see Table D.6). Third, dealers may acquire MBSs, especially new issuance, internally from their affiliated

Table 3. Inventory buildup

	(1)	(2)	(3)
Total Fed purchase amount	0.068***	-0.017***	
	(0.006)	(0.003)	
Dealer inventory capacity × total Fed purchase amount		1.598***	1.598***
		(0.104)	(0.108)
Intercept ($million)	58.16***	58.16***	
	(16.81)	(16.81)	
TBA contract FE			Yes
Observations	6,368	6,368	6,368
Adjusted R^2	0.148	0.318	0.428

We report the results obtained by analyzing factors driving $\text{InvCum}_{i,m,-1}$, the cumulative inventory change for dealer i under TBA contract m from 60 weekdays before to 1 weekday before a Fed purchase. We calculate the Fed's total purchase amount for TBA contract m and dealer inventory capacity M_i (market share from May 2011 through September 2011). Standard errors, clustered at the TBA contract level, are reported in parentheses. *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$. The sample period is from 2011 Q4 through 2014 Q1.

mortgage-lending and securitization branches. To the best of our knowledge, newly issued MBSs are sold mostly through TBA contracts that should show up in the TRACE data. Moreover, despite this concern, TBA market share is still a reasonable measure of dealer inventory capacity, because dealers who are large MBS issuers also tend to have large TBA market shares.

5 Dealers' Uncompetitive Pricing and Selling Amounts

The size of the Fed's purchases relative to dealers' inventory allows dealers to charge uncompetitive pricing, which is particularly acute given large dealers' essential control of the bulk of MBS inventory. As demonstrated in Section 2.2, the dealers' uncompetitive pricing to the Fed leads to two testable implications, differential pricing and selling amounts as in Prediction 1 and discriminatory pricing as in Prediction 2.

5.1 Baseline Evidence

We first test the discriminatory pricing effect. For each of the Fed's trades on day t under TBA contract m we look for primary dealers' selling trades to non-Fed customers on the same day t under the same TBA contract m. For 8,420 out of 9,264 Fed trades, we can find selling

Table 4. Dealers' discriminatory pricing

	(1)	(2)
Fed purchases	0.0203***	0.0189***
	(0.0018)	(0.0034)
Log(trade size)	-0.0182***	-0.0140***
	(0.0008)	(0.0024)
TBA contract × day FE	Yes	
TBA contract × day × dealer FE		Yes
Observations	132,420	22,137
Adjusted R^2	0.995	0.996
Number of matched Fed trades	8,420	4,780
Number of matched non-Fed customer trades	124,000	17,357
Average Fed trade size (million)	164.77	172.31
Average non-Fed customer trade size (million)	34.64	47.55

In this table we report the results of analyzing dealers' selling prices to the Fed and non-Fed customers. For columns (1) and (2) we run regressions (1) and (2), respectively. The dummy for Fed purchases equals one if dealers sell to the Fed and zero otherwise. The price unit is per \$100 in par value. Heteroscedasticity robust standard errors are reported in parentheses. $^*p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. We also report the average Fed and non-Fed customer trade size for the matched sample. The sample period is from 2011 Q4 through 2014 Q1.

trades to non-Fed customers by primary dealers, who could be different from dealers who sell to the Fed. For the matched sample, we consider the following regression:

$$P_{j,m,t} = \alpha\theta_{j,m,t} + \beta \ln\left(\frac{Size_{j,m,t}}{1,000,000}\right) + \gamma_{m,t} + \epsilon_{j,m,t}, \qquad (1)$$

where $P_{j,m,t}$ is the price of trade j on day t under TBA contract m. The dummy variable $\theta_{j,m,t}$ equals one if trade j is a sale to the Fed and zero if it is a sale to a non-Fed customer. We control for TBA contract×day fixed effects. We also control for the log of trade size $Size_{j,m,t}$ normalized to one million dollars because of the well-documented trade size discount in over-the-counter markets (Bessembinder, Spatt, and Venkataraman (2020)). This is because the average customer trade size is significant smaller than the average Fed trade size, as shown in the last two rows of Table 4. We report the results of regression (1) in column (1) of Table 4. The coefficient α is significantly positive, implying that on average primary dealers charge about 2 cents more per \$100 in par value to the Fed than to non-Fed customers.

Further, we restrict the sample to only 4,780 out of 9,264 Fed trades, each of which can be matched with a selling trade to a non-Fed customer by *the same dealer* who sells to the Fed. We then consider the following regression:

$$P_{j,m,t,i} = \alpha\theta_{j,m,t,i} + \beta \ln\left(\frac{Size_{j,m,t,i}}{1,000,000}\right) + \gamma_{m,t,i} + \epsilon_{j,m,t,i}, \tag{2}$$

where the transaction price of the j-th trade on day t of TBA contract m by dealer i is $P_{j,m,t,i}$. We now control for more refined TBA contract×day×dealer fixed effects $\gamma_{m,t,i}$. As can be seen in column (2) of Table 4, the coefficient remains roughly the same, confirming that a dealer charges 2 cents more to the Fed than to non-Fed customers.[23]

Turning to tests of the differential pricing between large and small dealers, we run the following regression:

$$P_n = \beta M_i + \kappa \log\left(\frac{Size_n}{1,000,000}\right) + \gamma_m + \psi_k Z_n^{\{x\}} + \epsilon_n, \tag{3}$$

where P_n is the Fed's price for purchase n and M_i is the inventory capacity measure of dealer i who sells to the Fed in purchase n. We control for the log of the Fed's purchase amount and also control for TBA contract fixed effects γ_m to compare individual dealers' selling prices to the Fed under the same TBA contract. Since different purchases n under the same TBA contract m can be executed on different days, we control for market conditions using the BBB spread,[24] 2-year and 10-year Treasury yields, and the VIX index. The coefficients ψ_k ($k =$ loan term×coupon of the TBA contract) allow for different loadings on the market-level variables for different types of TBA contracts. Standard errors ϵ_n are clustered at the TBA contract level.

In the first column of Table 5 we report the results for regression (3). The coefficient on

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[23] As shown in Table 1, the Fed allocates half of its agency MBS purchases to Fannie Mae MBSs and one quarter each to Freddie Mac and Ginnie Mae MBSs. In Table D.1 we show that dealers' price discrimination against the Fed is strongest for Ginnie Mae MBSs. That is, dealers' market power is strongest in the relatively small Ginnie Mae MBS market.

[24] We use the ICE BofA BBB US Corporate Index Option-Adjusted Spread from FRED, https://fred.stlouisfed.org/series/BAMLC0A4CBBB.

Table 5. Differential selling prices and amounts to the Fed

	Selling price	Selling amount
Dealer inventory capacity	0.242*	
	(0.137)	
Dealer inventory capacity × Fed purchase amount		1.27***
		(0.02)
Log(trade size)	0.089	
	(0.064)	
TBA contract FE	Yes	Yes
Loan term × coupon FE ×		
BBB spread	Yes	
2y Treasury yield	Yes	
10y Treasury yield	Yes	
VIX	Yes	
Observations	9,264	148,224
Adjusted R^2	0.975	0.041

In column (1), we report the results for regression (3). The price unit is per \$100 in par value. In column (2), we report the results for regression (4). Standard errors, clustered at the TBA contract level, are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

inventory capacity is positive and significant. Quantitatively, a dealer with a one-standard-derivation higher inventory capacity (3.8 percent from Table 2) charges the Fed a price that is about one cent ($= 0.24 \times 3.8$) higher per \$100 in par value. This is about 20% of an average primary dealer's gross profit margin when trading with the Fed.[25]

Finally, to test differential selling amounts between large and small dealers, we consider the following regression:

$$W_{i,n} = \beta M_i A_n + \gamma_m + \epsilon_{i,n}, \tag{4}$$

where A_n is the Fed's purchase amount in trade n, and $W_{i,n}$ is the selling amount to the Fed by dealer i (there is only one dealer for each purchase n such that $W_{i,n} = A_n$ when dealer i sells to the Fed in trade n and $W_{i,n} = 0$ otherwise). The key coefficient β is on the multiplicative term between the dealer inventory capacity M_i and the Fed's purchase amount A_n. The second column of Table 5 shows that the coefficient on inventory capacity is positive and significant. Quantitatively, a dealer with a one-standard-derivation higher inventory capacity (3.8 percent

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[25] In Table D.2 and Table D.3, we show that the average gross profit margin or markup charged by dealers to the Fed is about 5 cents, and larger dealers charge higher markups.

from Table 2) sells 4.8% (= 1.27×3.8%) more in MBSs as a fraction of the Fed's total purchase amount.

In sum, these baseline results provide significant empirical support for both the discriminatory and differential pricing effects.

5.2 Market Power Versus Inventory Cost

As discussed in Section 2.2, inventory cost can potentially account for both the discriminatory and differential pricing effects. To differentiate the market power channel from the inventory cost channel, we examine large and small dealers' differential pricing to non-Fed customers.

Specifically, we consider primary dealers' sell trades to non-Fed customers under the same TBA contracts on the same days when the Fed buys. Using these trades with non-Fed customers, we run regression (3) for the sample of trades of all sizes and of trades of at least \$1 million, \$10 million, or \$100 million, respectively. As can be seen in the first column of Table 6, which includes trades of all sizes, a dealer with a one-standard-derivation higher inventory capacity (3.8 percent from Table 2) charges non-Fed customers a price that is about 0.4 cents (= 0.106 × 3.8) lower per \$100 in par value. Further, the magnitude becomes larger for larger trades as reported in the next three columns, although the statistical significance becomes weaker, probably because there are fewer sampling observations.[26]

In sum, large dealers sell at *higher* prices to the Fed than small dealers do but sell at *lower* prices to non-Fed customers. This contrasting price pattern cannot be accounted for simply by reference to the inventory cost channel. The key in our analysis is the comparison of pricing to non-Fed customers on the *same* day as Fed trades under the *same* TBA contract. This ensures that dealers' selling should be based on the same inventory that incurs the same inventory costs. In a competitive pricing context, if larger dealers charge higher prices to the Fed because of their higher inventory costs, we should expect them to charge higher prices to non-Fed customers as well, which contradicts the results reported in Table 6. Instead, the

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[26] In Table D.4 we also show that large dealers charge lower markups to non-Fed customers than small dealers do.

Table 6. Dealers' differential pricing to non-Fed customers

	All	$\geq$ 1 million	$\geq$ 10 million	$\geq$ 100 million
Dealer inventory capacity	-0.106**	-0.122**	-0.206**	-0.183
	(0.053)	(0.061)	(0.086)	(0.210)
Log(trade size)	-0.009**	-0.005	0.013	0.013
	(0.003)	(0.004)	(0.009)	(0.014)
TBA contract FE	Yes	Yes	Yes	Yes
Loan term × coupon FE ×				
BBB spread	Yes	Yes	Yes	Yes
2y Treasury yield	Yes	Yes	Yes	Yes
10y Treasury yield	Yes	Yes	Yes	Yes
VIX	Yes	Yes	Yes	Yes
Observations	87,341	78,506	45,179	12,989
Adjusted R^2	0.983	0.983	0.981	0.977

We report the results for regression (3) using dealers' trades that sell to non-Fed customers, for the sample of trades of all sizes and of trades of at least \$1 million, \$10 million, or \$100 million. The price unit is per \$100 in par value. Standard errors, clustered at the TBA contract level, are reported in parentheses. $^*p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. The sample period is from 2011 Q4 through 2014 Q1.

contrasting pricing pattern is consistent with the market power channel. Specifically, larger dealers exert greater market power in trading with the Fed, whose purchases are larger, while the difference in market power between large and small dealers is likely negligible for non-Fed customers, whose purchases are smaller.

6 Variations in the Fed Purchase Amounts

In this section, we exploit a variation in the size of the Fed's purchase program. Specifically, the QE3 program starts in September 2012, which increases the monthly purchase amount from about \$30 billion to roughly \$65 billion (see Section 2 for details). Cast within our economic framework, this increase in purchase amount gives large primary dealers greater market power and exacerbates differential and discriminatory pricing to the Fed, as formulated in Prediction 3.

We define the pre-QE3 period as running from 2011 Q4 through 2012 Q3, and the QE3 period as running from 2012 Q4 through 2014 Q1, and provide three sets of supportive evidence. First, the larger Fed purchase amounts in QE3 may motivate dealers to acquire more inventory, so we ensure that dealers' inventory capacity remains stable and that large dealers

Table 7. Inventory buildup: pre-QE3 and QE3 periods

	Pre-QE3 (11Q4-12Q3)		QE3 (12Q4-14Q1)	
	(1)	(2)	(3)	(4)
Dealer inventory capacity	6,991***	6,991***	6,534***	6,533***
	(1,111)	(1,147)	(605)	(625)
Intercept	-26.08		-47.38***	
	(20.75)		(8.80)	
TBA contract FE		Yes		Yes
Observations	1,936	1,936	4,432	4,432
Adjusted R^2	0.072	0.282	0.083	0.357

We report the results obtained by analyzing factors driving $\text{InvCum}_{i,m,-1}$, the cumulative inventory change for dealer i under TBA contract m from 60 weekdays before to 1 weekday before a Fed purchase. In columns (1) and (2) we report results for the pre-QE3 period and in columns (3) and (4) we report results for the QE3 period. The coefficients unit is $million. Standard errors, clustered at the TBA contract level, are reported in parentheses. *$p<0.1$; **$p<0.05$; ***$p<0.01$. The sample period is from 2011 Q4 through 2014 Q1.

still acquire most of the MBS inventories. In columns (1) and (2) of Table 7 we report the results for regressions of the dealer inventory buildup measure $\text{InvCum}_{i,m,-1}$ on dealers' inventory capacity M_i for the pre-QE3 period, while in columns (3) and (4) we report those for the QE3 period. The coefficients on M_i are similar for both the pre-QE3 and QE3 periods. On average, a primary dealer with a one-percentage-point higher market share from May 2011 through September 2011 builds about $70 million higher inventories in both the pre-QE3 and QE3 periods.

Second, in columns (1) and (2) of Table 8 we report regressions of the Fed's purchase prices on dealer inventory capacity for the pre-QE3 and QE3 periods, respectively. The coefficient is larger in the QE3 period (0.271) than in the pre-QE3 period (0.146), showing that differential pricing to the Fed from large and small dealers indeed becomes more pronounced when the Fed's purchase amount is higher. In columns (3) and (4) of Table 8 we report regressions of dealers' selling amounts to the Fed for the pre-QE3 and QE3 periods, respectively. The coefficient on dealer inventory capacity is slightly larger in QE3. Together, the differential pricing and selling amounts from large and small dealers to the Fed increase after QE3 starts.[27]

Third, we report discriminatory pricing results in columns (1) and (2) of Table 9, for which

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[27] In Table D.5, we show that the differential markup also becomes slightly more pronounced after QE3 starts.

Table 8. Differential pricing: pre-QE3 and QE3 periods

	Selling price		Selling amount	
	Pre-QE3	QE3	Pre-QE3	QE3
Dealer inventory capacity	0.143	0.271*		
	(0.215)	(0.144)		
Dealer inventory capacity × Fed's purchase amount			1.19***	1.29***
			(0.04)	(0.02)
Log(trade size)	0.059	-0.043		
	(0.128)	(0.061)		
TBA contract FE	Yes	Yes	Yes	Yes
Loan term × coupon FE ×				
BBB spread	Yes	Yes		
2y Treasury yield	Yes	Yes		
10y Treasury yield	Yes	Yes		
VIX	Yes	Yes		
Observations	2,238	7,026	35,808	112,416
Adjusted R^2	0.968	0.983	0.035	0.042

In columns (1) and (2), we report the results for regression (3) for the pre-QE3 and QE3 periods. The price unit is per \$100 in par value. In columns (3) and (4), we report the results for regression (4) for the pre-QE3 and QE3 periods. Standard errors, clustered at the TBA contract level, are reported in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. The sample period is from 2011 Q4 through 2014 Q1.

we add an interaction term to regressions (1) and (2) representing the relationship between Fed purchases and QE3 dummies. The coefficient on the interaction term, which captures dealers' discriminatory pricing in QE3 relative to pre-QE3, is positive and statistically significant when dealer fixed effects are included for column (2). The evidence suggests that primary dealers' discriminatory pricing against the Fed becomes more pronounced when the Fed makes larger purchases.

7 Decomposing Dealers' Pricing to the Fed

The evidence we have presented so far has pointed to the existence of a dealer rent component in the higher price the Fed pays relative to what non-Fed customers pay. Like inventory costs, this dealer rent component is also associated with the size of Fed purchases. Indeed, the Fed's trades are significantly larger than those of non-Fed customers, as shown in the last two rows of Table 4. We term this higher price associated with larger purchases a *trade-size markup*

Table 9. Dealers' discriminatory pricing: pre-QE3 and QE3 periods

	(1)	(2)
Fed purchases	0.0189***	0.0122***
	(0.0025)	(0.0041)
Fed purchases × QE3	0.0018	0.0087**
	(0.0028)	(0.0040)
Log(trade size)	-0.0182***	-0.0141***
	(0.0008)	(0.0024)
TBA contract × day FE	Yes	
TBA contract × day × dealer FE		Yes
Observations	132,420	22,137
Adjusted R^2	0.995	0.996

We analyze dealers' selling prices to the Fed and to non-Fed customers for the pre-QE3 and QE3 periods. For columns (1) and (2) we run regressions (1) and (2), to which we add an interaction term representing the relationship between Fed purchases and QE3 dummies. The dummy for Fed purchases equals one if dealers sell to the Fed and zero otherwise. The price unit is per $100 in par value. Heteroscedasticity robust standard errors are reported in parentheses. $^*p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. The sample period is from 2011 Q4 through 2014 Q1.

effect.[28]

In addition to the size of the purchases involved, the Fed differs from non-Fed customers in *operational flexibility* as well. In particular, the Fed publicly releases and commits to a trading schedule that is fixed well ahead of the trade execution day and also relies on the small set of primary dealers as direct trading counterparties. Although such arrangements allow for operational transparency, they sacrifice operational flexibility and constrain the Fed's outside options. In contrast, non-Fed customers can adjust their trading schedules more flexibly and solicit offers from a more diverse pool of dealers. The difference in operational flexibility can also lead to higher purchase prices to the Fed, which we call the operational inflexibility effect.

We decompose primary dealers' pricing to the Fed into the trade size markup effect and the operational inflexibility effect. Specifically, we match the Fed's trades with non-Fed customers' mega-sized trades, defined as trades of $100 million or above, given that the Fed's trades are usually numerated in several hundred millions of dollars (see Table 1). As shown in the last four rows of Table 10, we are able to match 5,120 of the Fed's trades if we include primary

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[28] Relatedly, O'Hara and Zhou (2020) find that customers pay higher execution costs in their larger selling trades in the corporate bond market during the COVID-19 crisis. They attribute this finding exclusively to dealers' costs.

Table 10. Dealers' discriminatory pricing for trades of mega sizes

	(1)	(2)
Fed purchases	0.0052**	0.0104**
	(0.0022)	(0.0042)
Log(trade size)	-0.0051	0.0281**
	(0.0078)	(0.0131)
TBA contract × day FE	Yes	
TBA contract × day × dealer FE		Yes
Observations	18,682	4,490
Adjusted R^2	0.992	0.996
Number of matched Fed trades	5,120	1,727
Number of matched non-Fed customer trades	13,562	2,763
Average Fed trade size (million)	175.40	184.89
Average non-Fed customer trade size (million)	216.46	205.16

In this table we report the results of analyzing dealers' selling prices to the Fed and non-Fed customers. For columns (1) and (2) we retain only mega-sized customer trades of at least \$100 million and run regressions (1) and (2), respectively. The dummy for Fed purchases equals one if dealers sell to the Fed and zero otherwise. The price unit is per \$100 in par value. Heteroscedasticity robust standard errors are reported in parentheses. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$. We also report the average Fed and non-Fed customer trade size for the matched sample. The sample period is from 2011 Q4 through 2014 Q1.

dealers who might differ from the one selling to the Fed and 1,727 trades if we restrict to the same dealer. For such samples, the average Fed and non-Fed trades are similar in size.

In Table 10 we report the results derived from regressions (1) and (2) for the two respective samples. The coefficients on the Fed dummy capture mainly the operational inflexibility component of discriminatory pricing to the Fed because the sample includes similarly large trades and we also control for log(trade size) for this matched sample. We observe that the coefficients on the Fed dummy are indeed positive and significant. The magnitude ranges from about 20% to 50% of the corresponding coefficients reported in Table 4. That is, less than half of the dealers' price markup charged to the Fed when compared with the price charged to non-Fed customers results from the Fed's inflexible operations design, while the remaining half of the difference in price reflects the size of Fed trades.

The trade-size markup effect contrasts sharply with the well-documented trade-size discount in dealer-intermediated markets (Bessembinder, Spatt, and Venkataraman (2020)). In particular, favorable pricing or lower transaction costs are usually charged to larger customers who trade larger orders and can provide more trading opportunities to dealers (Bernhardt,

Table 11. Trade-size effects

	Outside of Fed purchase dates		On Fed purchase dates	
	(1)	(2)	(3)	(4)
Micro [\$1,\$100,000)	0.3585***	0.3476***	0.2341***	0.1782***
	(0.0159)	(0.0262)	(0.0203)	(0.0315)
Odd-lot [\$100,000,\$1,000,000)	0.0366***	0.0270***	0.0233***	0.0153***
	(0.0015)	(0.0025)	(0.0024)	(0.0031)
Round-lot [\$1,000,000,\$10,000,000)	0.0258***	0.0104***	0.0167***	0.0076**
	(0.0012)	(0.0019)	(0.0022)	(0.0027)
Block [\$10,000,000,\$100,000,000)	0.0049***	0.0022	-0.0058***	-0.0051*
	(0.0012)	(0.0019)	(0.0022)	(0.0027)
Mega [\$100,000,000,∞) (control group)	0	0	0	0
TBA contract × day FE	Yes		Yes	
TBA contract × day × dealer FE		Yes		Yes
Observations	232,329	232,329	124,000	124,000
Adjusted R^2	0.995	0.996	0.995	0.995

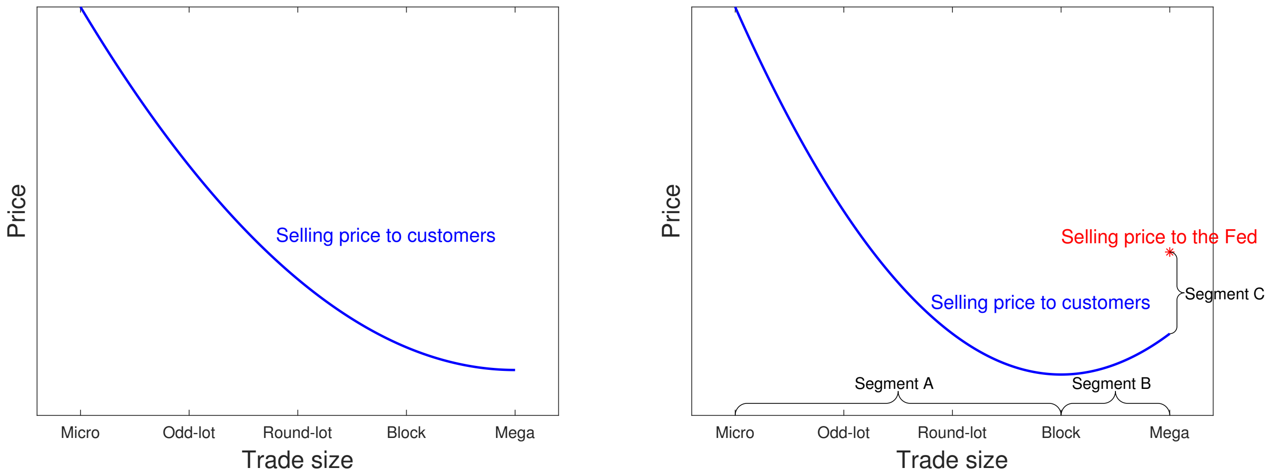
In this table we report the results for regression (5), which analyzes dealers' selling prices to non-Fed customers for various trade sizes. For columns (1) and (2) we use the sample of trades that occur on days when the Fed does not trade. For columns (3) and (4) we use the sample of trades that occur on days when the Fed trades. The price unit is per \$100 in par value. The control group for customers' trades consists of mega-sized trades ([\$100,000,000,∞)). Heteroscedasticity robust standard errors are reported in parentheses. *$p<0.1$; **$p<0.05$; ***$p<0.01$. The sample period is from 2011 Q4 through 2014 Q1.

Dvoracek, Hughson, and Werner (2004)). In fact, the significantly negative coefficients we report on log(trade size) in Table 4 are consistent with the trade-size discount. Hence, the inferior pricing to the Fed because of its large size as well as the positive coefficient on log(trade size) reported in column (2) of Table 10 point to a more refined picture of the trade-size effect: customers receive execution-cost discounts for moderately large trades, but pay rents for extremely large trades when few dealers have enough inventory to accommodate such buying demand.

To examine this conjecture, we consider days when the Fed trades, which constrains dealers' inventory, and days when the Fed does not trade. We run the following regression:

$$P_{j,m,t} = \alpha_1 \mathbf{1}_{\{j \in micro\}} + \alpha_2 \mathbf{1}_{\{j \in odd\}} + \alpha_3 \mathbf{1}_{\{j \in round\}} + \alpha_4 \mathbf{1}_{\{j \in block\}} + \gamma_{m,t} + \epsilon_{j,m,t}, \qquad (5)$$

where $P_{j,m,t}$ is a primary dealer's j-th sell trade to a non-Fed customer under TBA contract m on day t. We restrict the sample of TBA contracts to those that are purchased by the Fed.



(A) Outside of Fed purchase dates **(B) On Fed purchase dates**

Figure 5. Illustrations of the decomposition of discriminatory pricing

We illustrate the decomposition of discriminatory pricing on days when the Fed does not purchase MBSs (left panel) and on days when the Fed purchases MBSs (right panel). In the right panel, segment A represents the region where the trade-size discount effect is dominant. Segment B represents the region where the trade-size markup effect is dominant. Segment C represents the Fed's operational inflexibility effect.

The indicators of size groups are micro [\$1,\$100,000), odd-lot [\$100,000,\$1,000,000), round-lot [\$1,000,000,\$10,000,000), and block [\$10,000,000,\$100,000,000), with mega [\$100,000,000,∞) as the benchmark group.

In column (1) of Table 11 we report the regression results when controlling for TBA contract×day fixed effects and in column (2) we report the results when controlling for TBA contract×day×dealer fixed effects, in both cases using the sample of trades that occur on days when the Fed does not trade. We observe that the coefficients are all positive and decrease as trade size moves from small groups to large groups, consistent with the standard trade-size discount. In contrast, for columns (3) and (4), using the sample of trades that occur on days when the Fed trades, the coefficients are positive and decrease from micro to round-lot but turn negative for block trades. That is, dealers' selling prices to non-Fed customers show a trade-size discount as long as the trade is below block size, but then trend upwards into a markup for mega-sized trades, which are close in size to Fed trades.

We summarize the main qualitative findings in Figure 5. On days when the Fed does not purchase MBSs (left panel), customer demand can be satisfied by inventory held by various dealers, who compete for large order flows by giving discounts. On days when the Fed purchases MBSs (right panel), dealers face greater inventory constraints. Non-Fed customers' small trades still receive discounts (segment A) but their large trades can be satisfied only by dealers with large inventories, who charge a trade-size markup because of their greater market power and inventory costs (segment B). For similarly large trades, the Fed is charged a further markup as a result of its operational inflexibility (segment C).

8 Conclusion

In this paper we provide empirical evidence on primary dealers' uncompetitive pricing to the Fed in its agency MBS purchases and examine dealers' strategic behaviors in doing so. We find that primary dealers accumulate MBS inventory over a period running from two months before a Fed purchase and, importantly, a few large dealers acquire the bulk of the MBS inventory. Large dealers charge higher prices than small dealers when selling to the Fed, but the opposite is true when selling to non-Fed customers. This price contrasting cannot be accounted for simply by reference to dealer inventory costs, but is consistent with a dealer rent story. We further show that a given dealer charges higher prices to the Fed than to non-Fed customers, and over half of the price difference results from the effects of large purchases. The uncompetitive pricing worsens when the Fed increases its purchase size after QE3 starts.

Our analysis shows that the Fed paid large rents due to a combination of the large purchases executed in a short period of time, large dealers' control of the bulk of the MBS inventory, and primary dealers' privilege of trading directly with the Fed. Hence, implementation of Fed purchase programs could be improved by adjusting purchase speed in light of secondary-market conditions and opening up direct trading to a more diverse pool of counterparties. Future research can address the tradeoffs in the design of the Fed's purchase operations in terms of reducing execution costs and reaping the benefits of fast execution and the primary dealer system.

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Appendices

The appendices provide additional results and details.

A Additional Institutional Background

Table A.1 lists the major events in the Fed's outright purchase and unwinding programs for agency MBSs. Before 2008, agency MBSs were involved only in the Fed's short-term financing or securities-lending operations. In response to the 2008 financial crisis, the Fed began conducting outright purchasing of agency MBSs in early 2009 for the first time in the history of U.S. monetary policy operations. After that, the Fed conducted multiple rounds of outright purchasing of agency MBSs until December 2014, when it began unwinding its MBS holdings. In March 2020, the Fed resumed purchasing agency MBSs in response to the COVID-19 pandemic.[29]

In terms of specific execution, before April 2014 the Fed conducted its agency MBS purchases on the Tradeweb electronic trading platform, which is a major trading platform for agency MBSs and accounts for about 40% of the dealer-client TBA trading volume (Schultz and Song (2019)). The Fed used this platform because it "did not have either the systems or the market knowledge needed to execute MBS purchases efficiently" (Potter (2012)) at that time when it traded on the secondary MBS market for the first time ever.[30] After April 2014, the Fed began purchasing agency MBSs using its own FedTrade platform (see Song and Zhu (2018) for an analysis of the Fed's purchasing programs on the FedTrade system for Treasuries).

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[29] In addition to outright purchasing, the Fed also includes agency MBSs in a number of other policy operations, such as repurchase agreements (repos) and reverse repurchase agreements (reverse repos). See https://www.newyorkfed.org/markets/domestic-market-operations/monetary-policy-implementation/repo-reverse-repo-agreements for details.

[30] The Fed at first used external investment managers from January 2009 through February 2010 and then switched to its own staff in March 2010.

Table A.1. Major events in the Fed's agency MBS purchasing/unwinding programs

2008	Nov	The Fed announces QE1, which can purchase up to $500 billion agency MBSs.
2009	Jan	QE1 purchase of agency MBSs officially starts.
	Mar	The Fed expands QE1 to allow for up to an additional $750 billion in purchases of agency MBSs.
2010	Mar	QE1 purchasing of agency MBSs ends.
2011	Sep	The Fed announces a reinvestment program, which reinvests cash flows from agency debt and agency MBSs into agency MBSs.
2012	Sep	The Fed announces QE3, which allows for purchases of agency MBSs at a pace of up to $40 billion per month.
2014	Oct	QE3 purchasing of agency MBSs ends.
		The Fed continues to reinvest agency debt and MBS cash flows into agency MBSs.
2017	Sep	Monthly reinvestment into agency MBSs is first subject to a size cap.
2020	Mar	The Fed restarts agency MBS purchasing "in the amounts needed to support smooth market functioning" in response to the COVID-19 pandemic.
		The monthly reinvestment cap on agency MBSs is removed.

This table lists the major events in the Fed's outright purchasing and unwinding programs for agency MBSs.

B Proof for Claims in Section 2.2

In case (ii) of the equilibrium discussed in Section 2.2, we claim that the large dealer on average sells more to the Fed than the small dealer does. In this proof, we use the equilibrium construction by Osborne and Pitchik (1986), which generalizes Kreps and Scheinkman (1983), to verify this claim. We use the notations of Osborne and Pitchik (1986).

In case (ii), we have $x_2 < D < x_1 + x_2$. Our x_1 and x_2 are equivalent to their notations of k_1 and k_2. By equation (2.2) of Osborne and Pitchik (1986), we have

$$L_1(p) = p \min(x_1, D), \tag{B.1}$$

$$M_1(p) = p \min(x_1, \max(0, D - x_2)) = p(D - x_2). \tag{B.2}$$

By their equation (3.1), we have

$$M_1^* = \max_{p \in [X(x), X(x_2)]} M_1(p) = X(x_2)(D - x_2). \tag{B.3}$$

By their equation (3.2), we have

$$Q_2(p; M_1^*) = \frac{L_1(p) - M_1^*}{L_1(p) - M_1(p)} = \frac{\min(x_1, D) - \frac{X(x_2)}{p}(D - x_2)}{\min(x_1, D) - (D - x_2)}. \tag{B.4}$$

Because $Q_2(p; M_1^*)$ is already nondecreasing in p, we do not need to construct the nondecreasing cover as in the general case of Osborne and Pitchik (1986). Let $\underline{p} = X(x_2)(D - x_2)/\min(x_1, D)$. By Theorem 1 of Osborne and Pitchik (1986), the small dealer's offer price p follows the C.D.F. $Q_2(p; M_1^*)$ on the interval $(\underline{p}, X(x_2)]$, and the small dealer's equilibrium revenue is $\underline{p}x_2$.

The small dealer's expected selling amount to the Fed is

$$\begin{aligned}
&\int_{\underline{p}}^{X(x_2)} \frac{x_2\underline{p}}{p}\, dQ_2(p; M_1^*) \\
=&\int_{\underline{p}}^{X(x_2)} \frac{x_2\underline{p}}{p}\, d\left(\frac{\min(x_1, D) - \frac{X(x_2)}{p}(D - x_2)}{\min(x_1, D) - (D - x_2)}\right) \\
=&\frac{x_2\underline{p}X(x_2)(D - x_2)}{\min(x_1, D) - (D - x_2)} \int_{-\frac{1}{\underline{p}}}^{-\frac{1}{X(x_2)}} -q\, dq \\
=&\frac{x_2(D - x_2)}{\min(x_1, D) - (D - x_2)} \frac{X(x_2)^2 - \underline{p}^2}{2\underline{p}X(x_2)} \\
=&\frac{x_2(D - x_2)}{\min(x_1, D) - (D - x_2)} \frac{\min(x_1, D)^2 - (D - x_2)^2}{2(D - x_2)\min(x_1, D)} \qquad \text{(B.5)} \\
=&\frac{x_2(\min(x_1, D) + (D - x_2))}{2\min(x_1, D)} \\
=&\frac{D}{2} - \frac{(D - x_2)(\min(x_1, D) - x_2)}{2\min(x_1, D)} \\
\leq&\frac{D}{2},
\end{aligned}$$

where in (B.5) we use the definition of $\underline{p}$. Since the total selling amount to the Fed is D in case (ii), the large dealer on average sells more to the Fed than the small dealer does.

C Algorithm for Cleaning Inter-dealer Broker Trades

In this appendix, we present our algorithm for cleaning trades that are intermediated by a large inter-dealer broker. This inter-dealer broker is a de facto exchange. For a given TBA contract at the same trading time (in seconds) and at the same trading price, 99.3% of trades intermediated by this inter-dealer broker are netted to 0. Our algorithm is as follows.

- For about two-thirds of the cases, this inter-dealer broker buys from some dealer A and sells to some dealer B the same TBA contract at the same time (in seconds) in the same quantity and at the same price. In this case, we delete the two trades that are intermediated by this inter-dealer broker and record the real transaction in which dealer A sells to dealer B.

- For the remaining one-third of cases, this inter-dealer broker splits trading volume across dealers for a given TBA contract at the same time (in seconds) at the same price. For example, dealer A sells \$10 million in MBSs, dealer B sells \$5 million in MBSs, and dealer C buys \$15 million in MBSs from this inter-dealer broker, all at the same time at the same price. In this case, we delete all three trades by this inter-dealer broker and record two trades: 1) dealer A sells \$10 million in MBSs to dealer C and 2) dealer B sells \$5 million in MBSs to dealer C.

- The above two cases cover 99.3% of trades intermediated by this inter-dealer broker. For the extremely rare cases in which this inter-dealer broker fails to net within the same second at the same price, we find that most of the time this inter-dealer broker either charges an explicit markup or holds inventory for a very short period of time, usually a few minutes. These trades are most likely executed by a separate dealer desk within this inter-dealer broker, outside of its main electronic matchmaking business. We leave these unmatched trades unchanged.

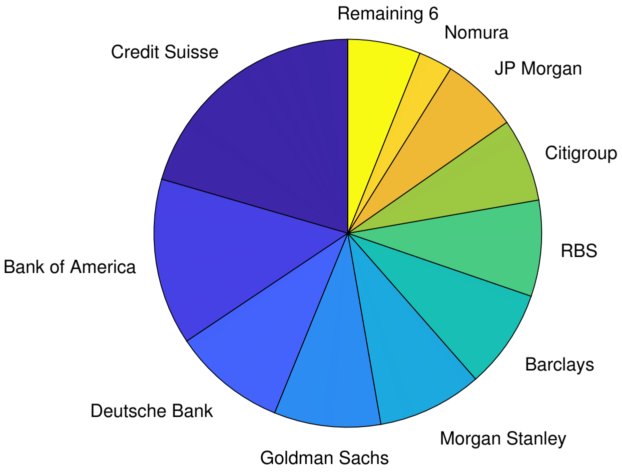

Figure D.1. Fractions of total volumes of MBS sales to the Fed

This figure plots the fractions of total dollar amounts of MBSs sold to the Fed for each dealer from 2011 Q4 through 2014 Q1. The remaining 6 dealers are BNP Paribas, Daiwa, UBS, RBC, Mizuho, and Jefferies.

D Additional Empirical Results and Robustness Checks

In this appendix, we present additional empirical results and robustness checks that are not included in the main text.

First, in Figure D.1 we plot the shares of various primary dealers in the Fed's $1.5 trillion total purchase amount in our sample. Out of the 16 primary dealers, the top four dealers account for over half of the purchase volume, suggesting that large dealers sell more to the Fed than small dealers do.

Second, we study differences between dealers' selling prices to the Fed and non-Fed customers for different MBS-issuing agencies and report the results in Table D.1. Compared with the baseline results reported in Table 4, we interact the Fed dummy with the MBS-issuing agency. We find that dealers' price discrimination against the Fed is most pronounced for MBSs that are issued by Ginnie Mae. This is consistent with the idea that Ginnie Mae MBSs are the least liquid among all agency MBSs and inventory constraints are more securely binding for such MBSs.

Table D.1. Dealers' discriminatory pricing: various agencies

	(1)	(2)
Fed purchases × Fannie Mae	0.0184***	0.0174***
	(0.0020)	(0.0035)
Fed purchases × Freddie Mac	0.0192***	0.0193***
	(0.0029)	(0.0057)
Fed purchases × Ginnie Mae	0.0265***	0.0284***
	(0.0038)	(0.0072)
Log(trade size)	-0.0182***	-0.0141***
	(0.0008)	(0.0024)
TBA contract × day FE	Yes	
TBA contract × day × dealer FE		Yes
Observations	132,420	22,137
Adjusted R^2	0.995	0.996

We analyze dealers' selling price to the Fed and non-Fed customers for various agencies. For columns (1) and (2) we run regressions (1) and (2), to which we add interaction terms representing the relationship between Fed purchases and MBS-issuing agencies. The dummy for Fed purchases equals one if dealers sell to the Fed and zero otherwise. The price unit is per $100 in par value. Heteroscedasticity robust standard errors are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

Third, we also show that, in addition to charging higher selling prices, large dealers obtain higher gross profit margins in trading with the Fed than small dealers do. To measure gross profit margins, we use a standard measure in the literature—the price markup. For each purchase n the Fed executes, we calculate counterparty dealer i's volume-weighted average buying price (including both dealer-customer and inter-dealer trades) from t weekdays and 1 weekday before the purchase n, denoted as $\tilde{P}_n^{\{-t\}}$ (index i is not added explicitly because there is only one counterparty dealer i for each purchase n). We do this for various time windows up to 60 weekdays before the purchase date, given that dealers accumulate inventory prior to a Fed trade, as documented in Figure 3A. We compute the price markup to the Fed as:

$$\text{Markup}_n^{\{-t\}} = P_n - \tilde{P}_n^{\{-t\}}. \tag{D.1}$$

Table D.2 provides summary statistics for the markup measure. We observe that the average markup ranges from 3.8 cents to 5.9 cents per $100 in par value for various window lengths t.

Table D.2. Summary statistics for dealers' markup to the Fed

Window length	[-5,-1]	[-10,-1]	[-20,-1]	[-30,-1]	[-45,-1]	[-60,-1]
Mean	0.038***	0.041***	0.055***	0.056***	0.059***	0.055***
	(0.005)	(0.006)	(0.008)	(0.009)	(0.010)	(0.010)
Observations	8,517	8,865	9,062	9,116	9,133	9,133

We report summary statistics for the dealer's markup $R_n^{\{t\}}$ for various window lengths $t = 5, 10, 20, 30, 45,$ and 60. The unit of markup is per \$100 in par value. Standard errors of means are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

Table D.3 reports the results of the following regression:

$$\text{Markup}_n^{\{-t\}} = \beta M_i + \kappa \log\left(\frac{Size_n}{1,000,000}\right) + \gamma_m + \psi_k \Delta Z_n^{\{x\}} + \epsilon_n, \tag{D.2}$$

where the changes in market variables $\Delta Z_n^{\{t\}}$ (with $t = 5, 10, 20, 30, 45,$ and 60) are controlled for because $\text{Markup}_n^{\{-t\}}$ is the difference between P_n and $\tilde{P}_n^{\{-t\}}$, which are calculated on different days. We observe that the β coefficients are positive and significant, implying that large dealers obtain higher markups than small dealers in selling to the Fed. Quantitatively, across various window lengths, the average coefficient β is about 0.48. A dealer with a one-standard-derivation higher inventory capacity (3.8 percent from Table 2) obtains a markup of about 1.8 cents (= 0.48 × 3.8) higher per \$100 in par value. This represents about one-third of the markup an average primary dealer charges the Fed. Moreover, the β coefficients are larger than those reported in the first column of Table 5, especially for long windows, implying that large dealers not only sell at higher prices to the Fed but also buy MBS inventories more cheaply.

Fourth, we study dealer markups to non-Fed customers by large and small primary dealers and report the results in Table D.4, using the indicator regression of Schultz and Song (2019):

$$\begin{aligned}\Delta P_{j,i} = {} & \alpha_0 + \alpha_1 \times \Delta Q_{j,i} + \alpha_2 \times \Delta Q_{j,i} \times \left(\ln\left(\frac{Size_{j,i}}{1,000,000}\right) + \ln\left(\frac{Size_{j-1,i}}{1,000,000}\right)\right) \\ & + \alpha_3 \times \Delta Q_{j,i} \times M_i + \psi_k \Delta Z_{j,i} + \epsilon_{j,i},\end{aligned} \tag{D.3}$$

Table D.3. Differential markups to the Fed

Window length	[-5,-1]	[-10,-1]	[-20,-1]	[-30,-1]	[-45,-1]	[-60,-1]
Dealer inventory capacity	0.260**	0.336***	0.442***	0.507***	0.631***	0.664***
	(0.120)	(0.130)	(0.157)	(0.163)	(0.172)	(0.176)
Log(trade size)	-0.028	-0.002	0.020	0.048	0.069	0.062
	(0.042)	(0.052)	(0.057)	(0.059)	(0.061)	(0.061)
TBA contract FE	Yes	Yes	Yes	Yes	Yes	Yes
Loan term FE × coupon FE ×						
Change in BBB spread	Yes	Yes	Yes	Yes	Yes	Yes
Change in 2y Treasury yield	Yes	Yes	Yes	Yes	Yes	Yes
Change in 10y Treasury yield	Yes	Yes	Yes	Yes	Yes	Yes
Change in VIX	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8,517	8,865	9,062	9,116	9,133	9,133
Adjusted R^2	0.678	0.756	0.829	0.874	0.899	0.903

We report the results of regression (D.2), for varying window lengths $t = 5, 10, 20, 30, 45$, and 60. The unit of markup is per \$100 in par value. Standard errors, clustered at the TBA contract level, are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

where $\Delta P_{j,i}$ is the price change between trades j and $j-1$ of dealer i. Each observation consists of two consecutive trades between non-Fed customers and the same dealer i under a given TBA contract. The term $\Delta Q_{j,i}$ equals 1 if customer sells in trade $j-1$ and buys in trade j, equals -1 if customer buys in trade $j-1$ and sells in trade j and 0 otherwise. The terms $Size_{j,i}$ and $Size_{j-1,i}$ represent the sizes of trades n and $n-1$. The term $\psi_k \Delta Z_{j,i}$ controls for changes in market variables in the time period between trade $j-1$ and trade j. We use only trades in the same set of 398 TBA contracts that the Fed purchases. We retain only trades between primary dealers and non-Fed customers and exclude trades under \$10,000.

In column (1) of Table D.4 we report the results of regression (D.3), excluding dealer inventory capacity M_i. The average markup charged by primary dealers to non-Fed customers, as captured by the coefficient on $\Delta Q_{j,i}$ is about 5.3 cents per \$100 in par value. Importantly, we can see that, in column (2), the coefficient on $\Delta Q_{j,i} \times M_i$ is significantly negative, showing that large dealers obtain lower markups than small dealers in trading with non-Fed customers, in contrast to the higher markups in trading with the Fed, as documented in Table D.3. Quantitatively, a dealer with a one-standard-deviation higher inventory capacity charges non-Fed customers about a one-cent lower markup ($= -0.25 \times 3.8$). The sharp contrast—larger dealers'

Table D.4. Differential markups to non-Fed customers

	(1)	(2)
ΔQ	0.0527***	0.0691***
	(0.0015)	(0.0037)
$\Delta Q\times$ Trade size	-0.0062***	-0.0058***
	(0.0002)	(0.0002)
$\Delta Q\times$ Dealer inventory capacity		-0.2507***
		(0.0413)
Constant	0.0003	0.0003
	(0.0005)	(0.0005)
Loan term FE × coupon FE ×		
Change in BBB spread	Yes	Yes
Change in 2y Treasury yield	Yes	Yes
Change in 10y Treasury yield	Yes	Yes
Change in VIX	Yes	Yes
Observations	589,405	589,405
Adjusted R^2	0.316	0.316

We report the results of regression (D.3). The unit of markup is per in \$100 par value. Heteroscedasticity robust standard errors are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

higher gross profit margins to the Fed but lower gross profit margins to non-Fed customers—which resembles the contrast in selling prices documented in Section 5.2, is inconsistent with the alternative interpretation based on a generic difference in intermediation costs between large and small dealers.

Fifth, in Table D.5 we report the results of regression (D.2) for the pre-QE3 and QE3 periods, respectively. For a short window length of $x \leq 20$, the coefficients on dealer inventory capacity in the QE3 period are significantly larger than those in the pre-QE3 period. For a long window length of $x \geq 30$, the coefficients for the two periods are similar, with those in the pre-QE3 period being slightly larger.

Moreover, in Table D.6 we replicate Table 3 by adding dealers' inventory buildups in corresponding specified pools to $\text{InvCum}_{i,m,-1}$. For each TBA contract m, we look for dealer i's transaction in TBA-eligible specified pools for MBSs that are guaranteed by the same agency, of the same maturity, and of the same security coupon rate. Since a specified-pool transaction can be matched to multiple TBA contracts, to avoid double counting we split dealers' inventory changes evenly for specified-pool transactions over the next four TBA contracts. For example,

Table D.5. Differential markups to the Fed: pre-QE3 and QE3 periods

A: Pre-QE3 (11Q4-12Q3)						
Window length	[-5,-1]	[-10,-1]	[-20,-1]	[-30,-1]	[-45,-1]	[-60,-1]
Dealer inventory capacity	-0.046	0.166	0.284	0.556**	0.626**	0.633**
	(0.193)	(0.213)	(0.253)	(0.257)	(0.276)	(0.281)
Log(trade size)	-0.038	0.067	0.171*	0.210*	0.208*	0.191*
	(0.067)	(0.082)	(0.100)	(0.110)	(0.118)	(0.117)
TBA contract FE	Yes	Yes	Yes	Yes	Yes	Yes
Loan term FE × coupon FE ×						
Change in BBB spread	Yes	Yes	Yes	Yes	Yes	Yes
Change in 2y Treasury yield	Yes	Yes	Yes	Yes	Yes	Yes
Change in 10y Treasury yield	Yes	Yes	Yes	Yes	Yes	Yes
Change in VIX	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,010	2,099	2,165	2,179	2,179	2,179
Adjusted R^2	0.634	0.727	0.760	0.777	0.784	0.789
B: QE3 (12Q4-14Q1)						
Window length	[-5,-1]	[-10,-1]	[-20,-1]	[-30,-1]	[-45,-1]	[-60,-1]
Dealer inventory capacity	0.231*	0.304**	0.387**	0.418**	0.532***	0.565***
	(0.135)	(0.141)	(0.171)	(0.178)	(0.185)	(0.190)
Log(trade size)	-0.002	-0.013	-0.024	-0.022	-0.029	-0.035
	(0.047)	(0.052)	(0.059)	(0.059)	(0.058)	(0.058)
TBA contract FE	Yes	Yes	Yes	Yes	Yes	Yes
Loan term FE × coupon FE ×						
Change in BBB spread	Yes	Yes	Yes	Yes	Yes	Yes
Change in 2y Treasury yield	Yes	Yes	Yes	Yes	Yes	Yes
Change in 10y Treasury yield	Yes	Yes	Yes	Yes	Yes	Yes
Change in VIX	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,505	6,766	6,897	6,937	6,954	6,954
Adjusted R^2	0.721	0.792	0.858	0.899	0.921	0.924

We report the results of regression (D.2) for varying window lengths $t = 5, 10, 20, 30, 45$, and 60. In panel A we report the results for the pre-QE3 period and in panel B we report the results for the QE3 period. The unit of markup is per $100 in par value. Standard errors, clustered at the TBA contract level, are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

if dealer A buys $4 million in MBSs through an SP transaction in February 01, 2013, we add $1 million in inventory changes each to the corresponding TBA contracts that settle in February, March, April, and May 2013. Compared with the results reported in Table 3, those reported in Table D.6 show that dealers build slightly larger inventories on average as a fraction of the total Fed purchases and the difference in inventory buildup between large and small dealers increases slightly. These results show that dealers indeed use specified pools to accumulate inventory when selling to the Fed, but specified pools are a minor channel compared with TBA contracts.

Table D.6. Inventory buildup with specified pools

	(1)	(2)	(3)
Total Fed purchase amount	0.082***	-0.013***	
	(0.006)	(0.003)	
Dealer inventory capacity × total Fed purchase amount		1.796***	1.796***
		(0.108)	(0.112)
Intercept ($million)	69.14***	69.14***	
	(18.80)	(18.81)	
TBA contract FE			Yes
Observations	6,368	6,368	6,368
Adjusted R^2	0.176	0.354	0.464

We report the results obtained by analyzing factors driving primary dealers' inventory buildup. We add dealers' inventory buildup in corresponding specified pools to $\text{InvCum}_{i,m,-1}$, the cumulative inventory change for dealer i under TBA contract m from 60 weekdays before to 1 weekday before a Fed purchase. We calculate the Fed's total purchase amount for TBA contract m and dealer inventory capacity M_i (market share from May 2011 through September 2011). Standard errors, clustered at the TBA contract level, are reported in parentheses. *p <0.1; **p <0.05; ***p <0.01. The sample period is from 2011 Q4 through 2014 Q1.

Finally, we study the effects of realized inventory buildups on selling prices and amounts to the Fed, as discussed in Section 2.2, and report the results in Table D.7. In column (1) we report the results for selling prices. The key right-hand side variable is dealer i's inventory buildup for a given TBA contract m, $\text{InvCum}_{i,m,-1}$ as defined in Section 4. We control for dealer fixed effects in the regression, so that the coefficients on $\text{InvCum}_{i,m,-1}$ measure the impact of varying inventory buildups for a given dealer. Other procedures remain the same as for Table 5. The actual realization of inventory buildup has a nonsignificant impact on the selling price to the Fed. In column (2) we report the results for selling amount, where each unit of observation is the total selling amount to the Fed by dealer i under TBA contract m. The significant coefficient 0.075 implies that if a given dealer builds $100 million in additional MBS inventory, she sells $7.5 million more to the Fed. Overall, the results show that, for a given dealer, the actual inventory buildup has a significantly positive effect on the quantity sold to the Fed but nonsignificant effect on prices charged to the Fed.

Table D.7. Effects of realized inventory buildup on selling prices and amounts to the Fed

	Selling price	Selling amount
$\text{InvCum}_{i,m,-1}$ ($billion)	-0.001	0.075***
	(0.004)	(0.016)
Log(trade size)	0.090	
	(0.064)	
Dealer FE	Yes	
Dealer FE × Fed purchase amount		Yes
TBA contract FE	Yes	Yes
Loan term × coupon FE ×		
BBB spread	Yes	
2y Treasury yield	Yes	
10y Treasury yield	Yes	
VIX	Yes	
Observations	9,264	6,368
Adjusted R^2	0.975	0.703

We report the effects of realized inventory buildup $\text{InvCum}_{i,m,-1}$, the cumulative inventory change for dealer i under TBA contract m from 60 weekdays before to 1 weekday before a Fed purchase, on selling prices and amounts to the Fed. Standard errors, clustered at the TBA contract level, are reported in parentheses. $^*p$ <0.1; $^{**}p$ <0.05; $^{***}p$ <0.01. The sample period is from 2011 Q4 through 2014 Q1.