Monetary Policy Transmission in Segmented Markets[*]

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December 2021

Abstract

We show that dealer market power impedes the pass-through of monetary policy in repo markets, which is an important first stage of monetary policy transmission. In the European repo market, most participants do not have access to trade on centralized exchanges. Rather, they rely on OTC intermediation by a small number of dealers that exhibit significant market power. As a result, the passthrough of the ECB's policy rate to repo markets is inefficient and unequal. Our estimates imply that a secured funding facility like the Fed's RRP can alleviate dealer market power and improve the transmission efficiency of monetary policy.

Keywords: Monetary policy, pass-through efficiency, repo market, market power

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1 Introduction

Repo markets are a crucial first stage of monetary policy transmission to the real economy. Following the disruptions in unsecured funding markets in the 2007/08 financial crisis, repos have become the dominant form of funding in money markets. Repos are short-term, commonly backed by government bonds, and often fully or over-collateralized. Nevertheless, the rates on these safe and short-term repos in the euro area have become increasingly dispersed and disconnected from the European Central Bank's (ECB) main policy rates. An important question is thus what frictions there are in the repo market and how they impede the efficient transmission of monetary policy.

In this paper, we show that *dealer market power* creates significant frictions for monetary policy passthrough in the European repo market. Prior literature on the European repo market has analyzed repos in a competitive market setting, where large dealer banks trade on centrally cleared e-trading platforms. However, we find that the majority of financial institutions trade identical repo contracts at substantially different prices.[1] We show that this rate dispersion arises from dealer market power in the over-the-counter (OTC) repo market because most market participants do not have access to the centralized trading platforms. Instead, they rely on OTC trades with a concentrated set of dealer banks.

Dealer market power has been studied in other contexts, such as markets for mortgage-backed securities (Schultz and Song, 2019), corporate bonds (Di Maggio, Kermani and Song, 2017; Hendershott et al., 2020), and municipal bonds (Li and Schürhoff, 2019). Dealer market power in repo markets is especially important because repo markets are an essential first stage of monetary policy transmission. For most financial institutions except large dealer banks, the OTC repo market remains the main source of short-term deposits and funding. It is also large and growing in size. In the euro area and the US, the OTC segment is estimated to be 30% and 50% of the total repo trading volume, respectively (ECB, 2018; Baklanova et al., 2019). As a result of dealer market power, our estimates show that only 53.3% to 70.7% of the inter-dealer repo rate passed through to

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[1]For example, the standard deviation in rates for customers lending cash to dealers against German government bonds was 11.1bps, compared to an average rate of -69.9bps, from February 2017 to February 2020.

OTC customers during the ECB's September 2019 rate cut. The transmission was also highly unequal across customers, with a standard deviation of between 24.5% to 41.7%. Our paper thereby provides the first systematic analysis of how dealer market power impedes the passthrough efficiency of monetary policy in repo markets.

Our results also provide insights on how regulatory interventions may alleviate frictions in the pass-through of monetary policy. First, we show that allowing OTC customers access to the inter-dealer repo market would improve pass-through by alleviating market power frictions. Under our estimates, pass-through efficiency would improve by 26% to 39%. Second, if the central bank made a secured deposit facility available to OTC customers, like the US Federal Reserve does with its Reverse Repo Facility (RRP), both market power and collateral scarcity frictions would be alleviated.

Our empirical analysis makes use of the ECB's Money Market Statistical Reporting (MMSR) dataset, which contains transaction-level data on all repo trades conducted by large euro area dealers. In the European context, the MMSR is the first dataset that records both inter-dealer and OTC trades made by dealers with various customers, such as non-dealer banks, pension funds, insurance companies, hedge funds, and other financial institutions. Outside of the euro area, transaction-level data on bilateral repos is generally difficult to find. In the US, for example, there are only three snapshots of data available for bilateral repo markets.

We begin by documenting a number of novel facts about the OTC segment of the European repo market. First, the vast majority of non-dealers do not have access to centralized trading platforms. Rather, they trade repos bilaterally with a concentrated set of dealers: the median customer in our data only ever trades with a single dealer. Second, there is substantial dispersion in OTC repo rates for observably similar loans backed by the same ISIN-level collateral. Third, dealers lend at higher rates than they borrow, so dealers attain a net interest margin in the OTC market. The magnitudes of dispersion and net interest margins are large: for German collateral-backed loans, the weighted standard deviation in customers' repo lending rates is 11.1bps, and dealers' average net interest margin amounts to 12.6bps. Moreover, neither effect is explained by heterogeneity in loan characteristics, such as terms, haircuts, and collateral ISINs. Rather, customers that can afford to form more links and that have larger trading volumes can improve their bargaining power and obtain more favorable repo rates. Together, these stylized facts

point to the presence of dealer market power.

We then develop a simple model to illustrate how dealer market power and collateral scarcity impede the transmission of monetary policy in repo markets. The repo market in our model has a core-periphery structure. The core consists of dealer banks, who can buy or sell secured funds in a competitive inter-dealer market. The periphery consists of dealers' OTC customers, who do not have access to the inter-dealer market and can only rely on dealers to conduct repo trades. In the baseline model, the central bank provides an unsecured deposit facility to dealer banks at a given Deposit Facility Rate (DFR).

In our model, collateral scarcity creates a spread between the DFR and inter-dealer repo rates. Collateral backing repo trades is scarce, so the equilibrium repo rate for a given collateral type can be lower than the DFR, and DFR rate changes will pass through imperfectly to inter-dealer repo rates. The novel feature of our model is that dealers' market power also constrains the pass-through of inter-dealer repo rates to OTC customer-facing repo rates. Formally, we assume repo rates in the OTC segment are set using Nash bargaining. Hence, dealers are able to partially price discriminate between customers with different willingness-to-pay for secured lending or borrowing. Our model matches the stylized facts that we document. Moreover, other potential mechanisms, such as dealer balance sheet costs, cannot explain all of these stylized facts.

Our model makes two testable predictions about how market power constrains the pass-through of DFR and inter-dealer rates into the OTC market. First, pass-through to the OTC market should be lower for collateral types with higher OTC rate dispersion. This is because higher rate dispersion indicates that dealers have more bargaining power over their customers, which leads to lower rate pass-through. Second, OTC pass-through should be lower for market participants who borrow from (lend to) dealers at higher (lower) rates. This is because a customer borrows from (lends to) a dealer at higher (lower) rates when the dealer has more bargaining power, and higher bargaining power also implies that inter-dealer repo rates will pass through less to customer-facing repo rates.

If net interest margins and rate dispersion are in fact a result of dealer market power, then the empirically observed pass-through of monetary policy should also align with our model predictions. To this end, we utilize the ECB's September 2019 DFR cut from -40bps to -50bps. This rate cut allows us to measure the pass-through of DFR rates to inter-dealer and OTC repo rates by dividing the change in observed inter-dealer and OTC

repo rates by the magnitude of the DFR rate cut. We can then back out pass-through from the inter-dealer market to the OTC market by comparing the relative magnitudes of DFR-inter-dealer and DFR-OTC pass-through. We measure OTC pass-through for different collateral types and different market participants, and we verify that both model predictions hold across a number of empirical specifications. We also ensure that our results are not driven by differences in collateral value, market participants' preferences, and maturities of the repos.

Our results bear important implications for how regulatory interventions can help improve the pass-through efficiency of monetary policy. We find that, if OTC customers had direct access to the inter-dealer repo market, they would no longer be subject to dealer market power in trading repos. Consequently, monetary policy pass-through to OTC customers would improve. Quantitatively, we find that inter-dealer market access would improve pass-through by 26% to 34% for OTC customers lending to dealers and by 31% to 39% for customers borrowing from dealers. Nevertheless, access cannot fully restore pass-through because collateral scarcity frictions remain.

Both market power and collateral scarcity frictions could be alleviated if the central bank provided a secured deposit facility for both dealers and customers, like the US Federal Reserve's RRP Facility. A secured deposit rate available to dealers behaves like a price floor. If it is binding, inter-dealer repo rates would be equal to the RRP rate, and some fraction of market participants would use the facility instead of trading in the inter-dealer market. If the RRP facility were available also to market participants in the OTC segment, however, the RRP rate would also affect OTC repo rates by changing customers' bargaining position. Even when the RRP rate is lower than the prevailing inter-dealer repo rate, it gives customers an additional outside option for borrowing funds, which they can use to negotiate better repo rates with dealers. Thus, the RRP facility can improve policy rate pass-through even if there is no actual take-up of the facility in equilibrium.

Finally, we use our model to infer the relative importance of dealer market power versus balance sheet costs in explaining the net interest margins in repo markets. Using variation in repo rates across dealers of the same customer and estimates of bargaining power uncovered from the September 2019 DFR rate cut, we find that dealer market power explains 41.9% of net interest margins.

Literature review. The main contribution of our paper is to improve the understanding the pass-through of monetary policy in money markets. Duffie and Krishnamurthy (2016) measure passthrough efficiency using rate dispersion across different money market instruments. Bech and Klee (2011) explain how differential access to central bank reserves has affected the spread between the IOER and the Fed funds rate after the 2007/08 financial crisis. Relatedly, Bech, Klee and Stebunovs (2012) examine the spread between repo rates and the Fed funds rate. While the literature so far has relied on aggregate time-series data to infer passthrough frictions, we use transaction-level data to directly measure these frictions within repo markets—dealer market power arising from market segmentation. This allows us to study how the interaction between market participants affects their passthrough efficiency. It also allows for policy counterfactuals on how policy actions can improve the passthrough to these market participants. Our specific estimates are based on the European setting, but our qualitative findings and predictions are applicable to all repo markets in which a large number of market participants depend on concentrated intermediation by a small set of dealer banks.

In the European context, the repo literature has mostly focused on understanding the resilience of repo markets (Mancini, Ranaldo and Wrampelmeyer, 2016) and the effect of collateral scarcity and specialness in inter-dealer repo rates (Buraschi and Menini, 2002; Ferrari, Guagliano and Mazzacurati, 2017; Brand, Ferrante and Hubert, 2019; Corradin and Maddaloni, 2020). Two recent papers that relate specialness to the transmission of conventional and unconventional monetary policy include Arrata et al. (2020), who study the effect of asset purchases on repo rates, and Ballensiefen, Ranaldo and Winterberg (2020), who examine the effect of deposit facility access and collateral eligibility for asset purchases.[2] Our paper complements the existing literature by showing that market power in the OTC segment is a significant determinant of repo rate variation in addition to repo specialness and that market power impedes the transmission of monetary policy. Our analysis is made possible by the new MMSR dataset that for the first time records repos in the OTC segment.

In the US context, most work has centered around strains in triparty repo markets

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[2]Other papers on European repo markets more broadly include Boissel et al. (2017), Schaffner, Ranaldo and Tsatsaronis (2019), Ranaldo, Schaffner and Vasios (2019), Bechtel, Ranaldo and Wrampelmeyer (2019), and Ballensiefen and Ranaldo (2019).

(Krishnamurthy, Nagel and Orlov, 2014; Copeland, Martin and Walker, 2014; Infante and Vardoulakis, 2018; Afonso et al., 2020).[3] In particular, Anbil, Anderson and Senyuz (2020) highlight how market segmentation in the triparty Treasury repo market can contribute to repo rate spikes. Copeland et al. (2012), Han and Nikolaou (2016), and Li (2021) analyze how trading relationships between dealers and money market funds affect prices and trade volumes in the US triparty repo market. Our focus is on how dealer market power frictions affect the passthrough of monetary policy. While our analysis draws on European data, our qualitative predictions may improve the general understanding of monetary policy passthrough in OTC repo markets. Our data also sheds light on the bilateral repo market, which accounts for half of the repo activity in the US but for which there is only very limited information. One exception is Baklanova et al. (2019), who analyze three snapshots of data on the US bilateral repo market from 2015Q1 with a focus on collateral.

We relate to a growing literature on the Fed's RRP facility. Anderson and Kandrac (2018) and Anbil and Senyuz (2018) empirically show that the intoduction of the ONRRP partially crowded out MMFs's repo lending to banks. Macchiavelli (2019) and Infante (2020) analyze the implications of the RRP facility as new source of safe asset. Most closely related to us, Klee, Senyuz and Yoldas (2016) document that the RRP contributed to stronger co-movement among money market rates, while Duffie and Krishnamurthy (2016) point out that the improved passthrough to wholesale rates may be accompanied by a reduced passthrough to bank deposit rates. Our findings support the view that the RRP can improve monetary policy passthrough to repo rates. Importantly, we find that the RRP facility can improve passthrough through a bargaining power channel even without there being any actual take-up.

Our model builds on two groups of papers: a literature studying collateral scarcity and repo specialness,[4] and a literature analyzing trading on exogeneous networks.[5] Colliard,

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[3]Other papers studying US repo markets include Vandeweyer (2019), Anderson, Du and Schlusche (2019), Baklanova et al. (2019), Correa, Du and Liao (2020), Hu, Pan and Wang (2021), Copeland, Duffie and Yang (2021) and d'Avernas and Vandeweyer (2021).

[4]See, for example, Duffie (1996), Fisher (2002), Bottazzi, Luque and Páscoa (2012), Huh and Infante (2018), Infante (2019), and Nyborg (2019).

[5]See Gofman (2014), Malamud and Rostek (2017), Eisfeldt et al. (2018), Babus and Kondor (2018), and Colliard and Demange (2019). Our theoretical extension in Internet Appendix IB.2 is related to models of endogenous network formation, such as Farboodi (2014), Wang (2017), Craig and Ma (2018), Chang

Foucault and Hoffmann (2021) study trade in a core-periphery OTC network, in which trade in the core is competitive, but trade in the periphery is frictional and set through Nash bargaining. We develop a simple core-periphery OTC framework, which focuses on the implications of OTC frictions on the passthrough efficiency of monetary policy.

The paper proceeds as follows. Section 2 describes institutional features of the European repo market, and the data we use. Section 3 shows stylized facts about the OTC repo market. Section 4 presents our model, and section 5 presents empirical tests of the model's predictions. Section 6 discusses our policy counterfactuals. We conclude in section 7. All proofs are in the appendix, and supplementary theoretical and empirical results are contained in an online appendix.

2 Institutional Setting and Data

2.1 The European Repo Market

The smooth functioning of short-term funding markets is essential for the effective transmission of monetary policy. Since the 2007/08 financial crisis, conventional monetary policy in the euro area has been conducted through setting the rate on banks' deposits with the ECB's Deposit Facility. The DFR is an unsecured policy rate available to European banks, similar to the IOER set by the Federal Reserve on excess reserves by US depository institutions. How well this policy rate available to banks transmits to funding costs available to general market participants in money markets depends on the type of transactions between banks and money market participants and the market structure of their trading.

In the euro area, repos have become the predominant form of short-term funding after the 2007/08 financial crisis. Daily turnover in the secured segment has doubled from around 250 billion in 2007Q2 to around 500 billion in 2020Q2, while daily turnover in the unsecured segment has shrunk from around 170 billion to 20 billion (ECB, 2018). A repo

and Zhang (2018), Dugast, Üslü and Weill (2019). More broadly, our paper relates to models of search and random matching in OTC markets, such as Duffie, Gârleanu and Pedersen (2005), Duffie, Gârleanu and Pedersen (2007), Zhu (2012), Afonso and Lagos (2014), Hugonnier, Lester and Weill (2014), Armenter and Lester (2017), Babus and Hu (2017), Afonso, Armenter and Lester (2019).

is a trade in which a cash borrower sells a security, most commonly a sovereign bond, to a cash lender, with an agreement to buy them back after a set period of time at a set price. The repo lender is promised an interest rate and also benefits from having access to the collateral during the repo transaction. The security and convenience of collateral typically imply that repo rates are below unsecured market rates and the degree of deviation from unsecured rates depends on the value of the collateral pledged.

Repos are backed by a specific collateral (SC repo) or a pool of collateral (GC repo). In GC repo, any asset from a predefined basket of assets is accepted as collateral. In SC repo, the specific security used as collateral is known to both counterparties when entering the contract. Although SC repos have been characterized as relatively more collateral-driven than GC repos, they nevertheless serve as a secured source of deposits for lenders and as a source of funding for borrowers (Ballensiefen and Ranaldo, 2019). SC repos have also become increasingly important relative to GC repos. Using data from Brokertec, Eurex, and MTS Repo, Schaffner, Ranaldo and Tsatsaronis (2019) estimate that turnover in the SC segment is around five times higher than turnover in the GC segment. For completeness, our analysis will include both GC and SC repos and we treat each GC country basket as an individual collateral-ISIN. In Internet Appendix IA.1, we analyze the GC and SC subsamples separately, and show that our empirical findings about dealer market power hold in both subsamples.[6]

Repo contracts are traded either through centralized e-trading platforms, or over-the-counter. There are three main centralized platforms for trading repos in Europe: BrokerTec, Eurex Repo, and MTS Repo. These platforms are centralized markets, organized as limit-order books, and repo transactions are centrally cleared through various clearinghouses. While previous studies have focused on the inter-dealer repo market, little is known about the OTC segment because of data limitations. Our data uniquely allows us to shed light on the functioning of the OTC repo market and its role in the

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[6]It is sometimes thought that GC trades are primarily driven by funding demand, and SC trades by collateral demand. However, this is unlikely to be a complete description of the European repo market over this time period. Inter-dealer GC repo rates are mostly lower than the deposit facility rate over this time period, suggesting that GC trades are also partially collateral-driven; see Arrata et al. (2020) and Corradin and Maddaloni (2020) for a discussion of how collateral demand influences European repo rates. Moreover, OTC depositing customers do not have access to the ECB's deposit facility, and some customers have specific institutional requirements for collateral backing their deposits, so customers' trades with dealers could plausibly be driven by funding demand as well as collateral demand.

transmission of monetary policy.

The OTC repo market is economically important. Participation in the inter-dealer market is largely limited to dealer banks (ICMA, 2019). The vast majority of non-dealer repo market participants, including non-dealer banks and non-bank financial institutions, do not have direct access to inter-dealer markets. As a result, they rely on OTC intermediation by dealer banks to access repo markets.[7] The OTC market is also large in size. The ECB's 2018 European Money Market Study reports dealer-customer trades to be 30% of the inter-dealer volume (ECB, 2018). In addition, the economic significance of the OTC market is understated by the relative volumes, because dealers may use centralized platforms not only to meet their own trading needs but also as part of their intermediation of customers' demand to borrow or lend, so some fraction of inter-dealer repo volume may be generated by demand from the OTC market.

2.2   The MMSR Data

The primary dataset we use is the Money Market Statistical Reporting (MMSR) data from the ECB.[8] This dataset collects all repo transactions, both in the inter-dealer and in the OTC segment, made by 38 dealer banks, who are the main intermediaries in the European repo market.[9] Our dataset is at the transaction-level and covers the period from February 2017 to February 2020. For each loan, we observe the identity of the counterparty pair, the nominal amount, the interest rate, the collateral used (at the ISIN-level), the haircut, and the maturity. We match additional collateral characteristics such as residual maturity and outstanding volume using ISINs. Each transaction also includes information on the sector and location of the customer. We focus on all repos backed by German, French, Italian, and Spanish government collateral, which includes both GC and SC repos traded in OTC and inter-dealer markets. Throughout the paper, we will use "borrowing" to refer to the borrowing of cash backed by collateral and "lending" to refer to the lending of cash backed by collateral.

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[7]Recently, sponsored access programs, such as Eurex's ISA Direct facility, have begun to allow for on-dealer participation, but the scope remains very limited.

[8]The dataset is described in more detail here.

[9]The list of reporting agents is available here.

3 Stylized Facts

This section introduces a number of novel facts about the European repo market that jointly point to the presence of dealer market power.

3.1 Market Structure

Fact 1. *The majority of market participants do not have access to inter-dealer markets and rely on concentrated intermediation by dealer banks in the OTC market.*

The core of the European repo market consists of the inter-dealer market. Dealers trade repos with each other on trading platforms with centralized trading. As described in Section 2, access to the trading platforms, at present, is largely limited to large dealer banks. Most other repo market participants do not have direct access and rely on dealer banks to intermediate their repo trades.[10]

The periphery of the European repo market consists of the dealer-customer market. This is an OTC market in which dealers trade bilaterally with customers. We find that most OTC customers are only connected to a small number of dealers. Over our sample period, the median repo customer lends to only a single dealer, while the 75th percentile customer lends to only two dealers. Similarly, the median customer borrows from only a single dealer, while the 75th percentile customer borrows from two dealers. Even when we aggregate the number of connected dealers by the country-sector of customers, we find that the median country-sector transacts with only one to two dealers across our sample period. The segmented access to e-trading coupled with the concentrated access to OTC intermediaries are suggestive of high market power by dealers over their customers.

3.2 Inter-dealer Repo Rates and Collateral Scarcity

There is a large literature studying the inter-dealer segment of the European repo market that shows segmentation by collateral type (Duffie (1996), Fisher (2002), Ferrari, Guagliano and Mazzacurati (2017), Brand, Ferrante and Hubert (2019), Corradin and Maddaloni

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[10]For example, a list of agents eligible to participate in the Eurex GC pooling marketplace, which is one of the largest trading platforms, is available here.

(2020), Arrata et al. (2020), and Ballensiefen, Ranaldo and Winterberg (2020)). Our data corroborate the results from the literature. For different government collateral, we plot the notional-volume-weighted average of repo rates in Figure 1. We find that dealers' repo borrowing rates in inter-dealer markets are -62.4, -54.4, -44.5, and -46.6bps when backed by German, French, Italian, and Spanish government collateral, respectively. Their corresponding repo lending rates in inter-dealer markets are -61.9, -53.9, -45.0, and -46.0bps.

Importantly, notice that for a given type of collateral, there is almost no difference between the rates at which dealers lend and borrow in the inter-dealer market. This suggests that the dealer banks in our sample make up a dominant share of the trades in the various e-trading platforms. Otherwise, if trades focused on particular sets of collateral are by non-observed participants, the inter-dealer lend and borrow rates that are averaged over repo trades by dealers in our sample may diverge.

3.3 OTC Repo Rate Dispersion

Fact 2. *There is substantial repo rate dispersion in the OTC segment of the repo market that cannot be explained by observable collateral and loan characteristics.*

In contrast to the relatively competitive inter-dealer repo market, we find substantial rate dispersion in the OTC market segment. Rate dispersion suggests that dealers have market power in the OTC segment of the repo market. In particular, it indicates that dealers are able to partially price discriminate, charging customers different rates depending on their willingness-to-pay. One way to capture rate dispersion is through the weighted average dispersion of repo rates. Duffie and Krishnamurthy (2016) first used the weighted average dispersion across money market rates to measure pass-through efficiency. We extend the measurement to transaction-level data to capture dispersion in rates across different market participants.

Figure 2 shows the notional-volume-weighted standard deviation of repo rates for different government collateral. For example, the weighted standard deviation across market participants depositing and borrowing cash backed by German collateral are 11.1bps and 9.5bps, respectively. This is a sizeable magnitude given that the loan rates for depositing and borrowing cash backed by German collateral are -69.9bps and -57.3bps.

These magnitudes are also significant compared to the variation in repo rates stemming from collateral specialness. For example, recall that the difference in inter-dealer repo rates backed by German and Italian collateral is 16.9bps for borrowing cash from dealers. Dispersion in repo rates backed by other types of collateral is also significant and persistent. The weighted standard deviation in dealers' repo borrow rates for French, Italian, and Spanish collateral are 7.8, 4.7, and 6.4bps, respectively, while the standard deviation for dealers' repo lend rates are 5.8, 6.5, and 6.2bps.

However, rate dispersion could also be driven by heterogeneity in repo loans' characteristics like collateral ISINs and haircuts rather than dealer market power. To this end, we attempt to purge repo rates of variation arising from observable loan characteristics. Formally, let i index a given repo loan transaction in month t in the raw data, and let X_i be a vector of characteristics of loan i. We first pool all repo transactions in the same collateral-country segment, and use daily data to estimate the following pooled regression every month t:

$$r_{it} = \beta_t X_{it} + \varepsilon_{it}, \tag{1}$$

where X_i includes collateral ISIN, collateral haircut, and loan maturity. We then construct the residual $\hat{\varepsilon}_{it}$ from the predicted value for each transaction. This residual captures the component of r_{it} which is not predictable based on the vector of characteristics X_{it}. If all rate dispersion were explained by fundamentals, the residual $\hat{\varepsilon}_{it}$ should be 0. Thus, the amount of residual dispersion indicates the extent to which non-fundamental factors, such as dealer market power, influence repo rates.

We use the residualized rates to recompute dispersion in repo rates in each collateral segment. The results are shown in Table 2. From Table 2, we observe that 67% to 94% of the dispersion in repo rates is preserved after we residualize the repo rates. This confirms that a significant portion of the dispersion in repo rates is induced by dealers' ability to discriminate between market participants rather than differences in collateral.

3.4 OTC Net Interest Margins

Fact 3. *Dealers attain net interest margins in the OTC market by charging higher rates for lending funds than for borrowing funds. These net interest margins cannot be explained by observable*

collateral and loan characteristics.

In Figure 3, we plot the notional-volume-weighted average of OTC repo rates for transactions in which dealers lend to and borrow from customers. Figure 3 shows that dealers lend to OTC customers at an average rate that is systematically higher than the rate at which they borrow. From February 2017 to February 2020, the average value-weighted net interest margins for repos backed by German, French, Italian, and Spanish government bonds are 12.6, 7.5, 10.0, and 3.8bps, which are economically significant given that the average lending rates are -57.3, -48.6, -41.5, and -42.4bps, respectively.

One concern could be that dealers earn a net interest margin by lending and borrowing in repo markets using different types of collateral and loan terms. To rule out that differences in collateral and loan characteristics explain the net interest margins, we again use the residualized rates to recompute net interest margins and show the results in Table 2. We observe that the net interest margins for the residualized rates are slightly smaller at 9.9, 6.2, 7.6, and 3.5bps for German, French, Italian, and Spanish collateral, compared to the raw net interest margins of 12.6, 7.5, 10.0, and 3.8bps. Thus, accounting for repo characteristics decreases the size of net interest margins only slightly, implying that observable repo characteristics cannot explain a large share of dealers' net interest margins.

Nevertheless, the net interest margins of the residualized rates can still partially arise from dealer's balance sheet costs in addition to their market power. In Section 6.3, we show how, under the assumptions of our model, balance sheet costs can be empirically distinguished from market power, and we find that dealer market power accounts for a substantial portion of the net interest margins.

3.5 Customer Characteristics and Bargaining Power

Fact 4. *Forming more links and trading larger volumes can improve customers' bargaining power in the OTC market.*

To better understand the determinants of dealer bargaining power, we examine how repo rates vary with a range of customer and network characteristics. To this end, we first collapse the residualized repo rates obtained in Equation (1) across our sample period

to obtain residualized rates, Loan Rate$_{cdksn}^{resid}$, for repos between customer c and dealer d backed by collateral-ISIN k, where customer c belongs to sector s and is located in country n. Then, we run a cross-sectional regression of these averaged residuals on the average bilateral repo volumes between customer c and dealer d backed by collateral k, Bilateral Vol$_{cdk}$, customer c's total repo volume backed by collateral k, Total Vol$_{ck}$, and the number of connected dealers for customer c, RA Num$_c$. We also control for the sector and country of the customer using fixed effects δ_s and ω_d respectively. The results are reported in Table 1.

$$\text{Loan Rate}_{cdkns}^{resid} =$$
$$\alpha + \beta_1 \text{Bilateral Vol}_{cdk} + \beta_2 \text{Total Vol}_{ck} + \beta_3 \text{RA Num}_c + \eta_n + \delta_s + \omega_d + \varepsilon_{cdkns}. \quad (2)$$

From the first two columns in Table 1, we see that the coefficients on the bilateral loan volume and the number of RAs is positive and significant. This means that when lending to dealers, customers that have a larger trading volume and that are connected to a larger number of other dealer banks receive higher, i.e., more favourable rates. At the same time, customers with larger trading volumes and more connections also borrow at lower, i.e., more favourable, rates from dealer banks. All else equal, a one-standard-deviation increase in bilateral loan volume improves customer lending rates and lowers customer borrowing rates by 0.40 and 0.36bps, respectively. In comparison, connecting to an additional dealer bank increases customer lending rates and decreases customer borrowing rates by 0.80 and 0.44bps.

Our results are not driven by differences in loan characteristics across customers with different number of dealers and trading volumes because the residualized repo rates already purged out the time-varying effect of loan characteristics at the collateral-ISIN level. Our results are also robust to the inclusion of RA fixed effects as evident from columns (2) and (4). We further include country and sector fixed effects for each customer. Notice that money market funds seem to receive significantly less favorable rates than customers from other sectors for both lending and borrowing transactions.

Our findings are consistent with the presence of dealer market power in repo markets, where customers that trade larger volumes and that can afford to form a larger number of relationships with dealer banks enjoy a higher effective bargaining power. These results

are consistent with costly formation of new dealer relationships and trading costs that involve some overhead costs. Please refer to our model and Internet Appendix IB.2 for further details.

4 Model

We build a simple model to demonstrate how collateral scarcity and market power limit the pass-through of monetary policy to repo markets. Motivated by our stylized facts, the model has a two-tiered structure, depicted in Figure 4. Dealers lend and borrow from each other in a competitive inter-dealer market, and dealers trade with customers in an OTC market. We will show that *collateral scarcity* constrains pass-through from the DFR to the inter-dealer market, whereas *market power* constrains pass-through from the inter-dealer market to the OTC market.

Subsection 4.1 characterizes outcomes in the OTC market, taking the inter-dealer repo rate as given. Subsection 4.2 shows how the equilibrium inter-dealer repo rate is determined by the supply and demand for repo funding, from both dealers and OTC customers. Finally, Subsection 4.3 characterizes the pass-through from the Deposit Facility Rate to inter-dealer and OTC repo rates.

4.1 The OTC Repo Market

Our model of the OTC market is a simple bargaining model with an exogenous trading network. There are a finite number of dealers. Each dealer is linked to a continuum of infinitesimally small OTC customers. Motivated by the fact that links are very sparse and stable over time in our data, we assume that each customer is connected to a single dealer, and that customer-dealer links are exogenous. OTC customers do not have access to the inter-dealer market, so they can only conduct repo transactions by trading with dealers. Throughout this subsection, we take the repo rate in the inter-dealer repo market, r_{ID}, as given; we examine how r_{ID} is determined in equilibrium in the following subsection.

There are two types of customers: borrowers and depositors. Borrowers want to borrow a unit of cash from their dealer, and are willing to put up a unit of collateral to

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secure the loan. Each borrower is characterized by two parameters: v_B, the maximum rate she is willing to pay for borrowing secured, and θ_B, which is the dealer's bargaining power with the borrower. v_B and θ_B can be arbitrarily jointly distributed in the population of borrowers. Repo depositors wish to lend cash to dealers, secured by collateral. Each depositor has a minimum rate v_D that she is willing to accept from the dealer, and a parameter θ_D, which determines the dealer's bargaining power with the depositor. v_D and θ_D can be arbitrarily jointly distributed.

In the baseline model, we assume dealers have no costs for intermediating customers' repo trades. Thus, if a customer wishes to borrow secured, the customer's dealer borrows in the inter-dealer market at rate r_{ID} and lends to the customer. If a customer wishes to deposit secured, the dealer lends funds in the inter-dealer market at rate r_{ID}, receives collateral, and rehypothecates the collateral to the customer in exchange for cash. In both cases, the dealer makes exactly offsetting trades and takes on no net position in funds or collateral. Thus, the break-even rate to the dealer of either trade is r_{ID}. However, as we will detail, dealers have market power over their customers, allowing them to charge OTC repo rates that differ from r_{ID}.

The assumption that dealers face no intermediation costs is strong. We relax this assumption in Internet Appendix IB.1. We show that intermediation costs can explain net interest margins and OTC rate dispersion, but they cannot explain imperfect pass-through from inter-dealer repo rates into OTC rates, which is the main prediction of the model we bring to the data.

Price setting. We let dealers have bargaining power in the OTC market. Formally, when dealers trade with customers, repo rates are set through Nash bargaining. On the loan side, dealers lend to all borrowers with values higher than the inter-dealer rate, that is, $v_B > r_{ID}$. A dealer lends to a borrower with value v_B and bargaining power parameter θ_B at rate:

$$r_B\left(v_B, \theta_B, r_{ID}\right) = r_{ID} + \theta_B\left(v_B - r_{ID}\right). \tag{3}$$

That is, the OTC repo rate is set as the weighted average of the dealer's and customer's reservation values, with weight θ_B on the borrower's value, and $1 - \theta_B$ on the dealer's marginal cost. Thus, the dealer keeps a share θ_B of the total trade surplus.

Analogously, dealers borrow from all depositors with values lower than the inter-

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dealer rate, that is, with $v_D < r_{ID}$. A depositor with value v_D and bargaining power parameter θ_D receives rate:

$$r_D(v_D, \theta_D, r_{ID}) = r_{ID} - \theta_D(r_{ID} - v_D). \tag{4}$$

In words, analogous to (3), r_D is set so the dealer gets a share θ_D of the total trade surplus.

There are several reasons why dealers' bargaining power may differ across customers. Some customers may be more sophisticated and aware of market conditions, allowing them to negotiate better rates. Some customers may be connected to multiple dealers, allowing them to negotiate better prices with each dealer. Customers who trade larger volumes may also be able to negotiate better prices with dealers. We formalize these effects in Internet Appendix IB.2. Building on Stole and Zwiebel (1996), we construct a model in which customers can choose to form relationships with one or more dealers, and customers who connect to multiple dealers, and customers who trade larger volumes, trade at better rates.

Equilibrium outcomes. Our model can simultaneously rationalize the stylized facts we observe in the data: dealers' net interest margins and dispersion in OTC repo rates.

Claim 1. *Dealers' net interest margins are:*

$$E\left[r_B(v_B, \theta_B, r_{ID}) \mid v_B \geqslant r_{ID}\right] - E\left[r_D(v_D, \theta_D, r_{ID}) \mid v_D \leqslant r_{ID}\right] =$$
$$E\left[\theta_B(v_B - r_{ID}) \mid v_B \geqslant r_{ID}\right] + E\left[\theta_D(r_{ID} - v_D) \mid v_D \leqslant r_{ID}\right]. \tag{5}$$

Claim 1 shows that dealers make a net interest margin through their market power. Dealers' net interest margins are increasing in three quantities: the average bargaining power parameters θ_B, θ_D; the average values of borrowers and depositors relative to the inter-dealer rate; and the conditional covariance between these two terms. In words, the net interest margin attained by dealers in the OTC repo market depends on how high borrowers' values are (and how low depositors' values are) relative to the inter-dealer rate, how much bargaining power the dealer has, and the extent to which dealers have high bargaining power with high-value customers.

Claim 2. *Dispersion for borrower- and depositor-facing rates in the OTC market are, respectively,*

$$\mathrm{Var}\left[r_B\left(v_B, \theta_B, r_{ID}\right) \mid v_B \geqslant r_{ID}\right] = \mathrm{Var}\left[\theta_B\left(v_B - r_{ID}\right) \mid v_B \geqslant r_{ID}\right], \tag{6}$$

$$\mathrm{Var}\left[r_D\left(v_D, \theta_D, r_{ID}\right) \mid v_D \leqslant r_{ID}\right] = \mathrm{Var}\left[\theta_D\left(r_{ID} - v_D\right) \mid v_D \leqslant r_{ID}\right]. \tag{7}$$

Claim 2 shows that dispersion in OTC borrower (depositor) repo rates is generated by dispersion in θ_B (or θ_D) and dispersion in $v_B - r_{ID}$ (or $r_{ID} - v_D$). Dealers have high bargaining power when there is significant dispersion in customers' values, v_B and v_D, and when there is large dispersion in bargaining power among customers.[11]

Our model also shows that the passthrough of inter-dealer rates to OTC rates depends on bargaining power and provides two testable predictions regarding the variation in passthrough across markets and customers.

Claim 3. *The pass-through of inter-dealer rates to OTC rates (ID-OTC pass-through) for a borrower with value $v_B > r_{ID}$ and bargaining power θ_B is:*

$$\frac{dr_B\left(v_B, \theta_B, r_{ID}\right)}{dr_{ID}} = 1 - \theta_B. \tag{8}$$

The pass-through for a depositor with value $v_D < r_{ID}$ and bargaining power θ_D is:

$$\frac{dr_D\left(v_D, \theta_D, r_{ID}\right)}{dr_{ID}} = 1 - \theta_D. \tag{9}$$

Expressions (8) and (9) show that dealer bargaining power constrains pass-through: OTC repo rates do not move one-for-one with changes in inter-dealer repo rates r_{ID}. Rate pass-through is lower for customers with higher θ_B and θ_D, that is, customers against which dealers have more bargaining power.

Prediction 1. *Across collateral types, high rate dispersion is correlated with low ID-OTC pass-through.*

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[11]The literature has provided different microfoundations for price dispersion. For example, Colliard, Foucault and Hoffmann (2021) microfound price dispersion as arising from variation in how connected different parties in the periphery are, whereas price dispersion in our model arises from exogenous variation in OTC customers' values and bargaining power. Our empirical evidence supports the idea that there are differences in values and bargaining power, even among OTC customers who have the same number of connections to dealers.

Prediction 1 follows because, from claims 1 and 2, rate dispersion and pass-through are both affected by customers' bargaining power. Expressions (6) and (7) show that equilibrium rate dispersion is high when dealers' bargaining power is high, and expressions (8) and (9) show that ID-OTC pass-through is low when dealers' bargaining power is high.

Prediction 2. *Across OTC customers for a given collateral type, pass-through is lower for repo borrowers (depositors) who have ex-ante higher (lower) repo rates.*

Prediction 2 follows from combining the expressions for borrow and lend rates in expressions (3) and (4) with expressions (8) and (9) for ID-OTC pass-through. If a repo borrower has low bargaining power, dealers will both charge her higher interest rates and pass through inter-dealer rate changes to a lesser degree. Hence, we should observe lower ID-OTC rate pass-through for borrowers who face higher rates. Analogously, repo depositors who receive low rates are likely to have low bargaining power with dealers and should have relatively low ID-OTC rate pass-through.

4.2   The Inter-Dealer Repo Market

Next, we show how the interest rate r_{ID} is determined in the inter-dealer repo market when dealers can choose between lending repos and using the ECB's deposit facility. This allows us to describe how r_{ID} is affected by changes in the ECB's deposit facility rate.

We assume that, in addition to dealers' interactions with customers, dealers may have a fundamental demand for repo borrowing and lending, and that dealers can trade repo loans with each other in a competitive inter-dealer market. There are two kinds of dealers. There are N_L identical lending dealers who have excess cash they wish to lend out. These dealers can either deposit cash in the central bank's deposit facility at rate ρ (which is set by the central bank) or lend secured in the inter-dealer repo market. There are N_B identical borrowing dealers, who hold collateral and wish to borrow against it. For simplicity, we will assume that all lending dealers are identical, and all borrowing dealers are identical, in their preferences for cash and collateral, though this is not essential for the results. We will first examine dealers' own demand for repo borrowing and lending, then analyze the demand and supply from OTC customers that is passed on to the inter-dealer

market through OTC trades with dealers.

Each borrowing dealer has utility $W_B(q)$ for borrowing q units of cash, where $W_B(\cdot)$ is twice differentiable and strictly concave. Dealers behave competitively, taking the inter-dealer repo rate as given. Thus, if the equilibrium repo rate is r, borrowing dealers choose their borrowing quantity q to solve:

$$W_B'(q) = r. \tag{10}$$

Expression (10), summed across all dealers, defines an aggregate dealer demand function for repo funding, $Q_{B,Dealer}(r)$, satisfying:

$$Q_{B,Dealer}(r) = N_B q_{B,dealer}(r)$$

$$q_{B,Dealer}(r) = \{q : W_B'(q) = r\}.$$

Since $W_B(\cdot)$ is concave, $Q_{B,Dealer}(r)$ is decreasing in r: at higher rates, dealers demand less funding.

Lending dealers collectively have quantity L of excess funds to lend. They can use the central bank's deposit facility, but may prefer to lend in the inter-dealer market because they value the collateral they receive.[12] Lenders' valuation for collateral may arise from a number of sources: lenders may need collateral to cover short bond positions; lenders may want to preserve the option to rehypothecate collateral to other market participants; or lenders may simply have institutional constraints forcing them to lend collateralized.

Formally, lending dealers' utility for receiving q units of collateral is $W_L(q)$, which we assume is twice differentiable and strictly concave. Lending dealers also behave competitively; thus, if the repo rate is r, lending dealers choose q to maximize:

$$\max_q \rho(L - q) + rq + W_L(q). \tag{11}$$

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[12]Note that our model corresponds to an "excess funds" environment, where the supply of funds is large enough that the inter-dealer rate r_{ID} will tend to be below the deposit facility ρ, so that ρ is a binding outside option for at least some lending dealers. This is a reasonable assumption for the euro area during the time period in our sample. In an environment where funds were scarce, the inter-dealer rate r_{ID} may be well above ρ, in which case all dealers would strictly prefer to lend in the inter-dealer market, so the Deposit Facility Rate would not be binding. Our model abstracts away from this case for simplicity.

That is, lenders receive the Deposit Facility Rate ρ for the measure $L - q$ of funds they deposit in the facility, the repo rate r for the quantity q of funds they lend in the repo market, and utility $W_L(q)$ from the q units of collateral that they receive in the repo market. The solution to (11) is:

$$W'_L(q) = \rho - r. \tag{12}$$

Expression (12) defines an aggregate dealer supply function for repo funding:

$$Q_{L,Dealer}(\rho - r) = N_L q_{L,Dealer}(\rho - r) \tag{13}$$

$$q_{L,Dealer}(\rho - r) = \{q : W'_L(q) = \rho - r\}.$$

Note that the supply of repo funds is a function of $\rho - r$, the difference between the Deposit Facility Rate, ρ, and the repo rate r. Since $W_L(q)$ is concave, lending dealers' repo funding supply is decreasing in ρ and increasing in r.

Next, we characterize the total supply and demand of repo funding from OTC borrowers and lenders. In the previous subsection, we showed that all OTC borrowers with value $v_B > r$ will borrow. OTC customers borrow from dealers, who perfectly pass through all OTC quantities into the inter-dealer market. Let $M_{B,OTC}$ represent the total mass of OTC borrowers, and let $F_{v,B}(v_B)$ represent the CDF of v_B among borrowers. If the inter-dealer repo rate is r, the total quantity of repo funding demanded by OTC borrowers is:

$$Q_{B,OTC}(r) = M_{B,OTC} \int_{v_B > r} dF_{v,B}(v_B) = M_{B,OTC}(1 - F_{v,B}(r)),$$

thus, $Q_{B,OTC}(r)$ is decreasing in r. OTC depositors lend if their minimum acceptable value, v_D, is lower than the interest rate r. Let $M_{D,OTC}$ represent the mass of OTC depositors, and $F_{v,D}(v_D)$ represent the CDF of v_D among OTC depositors. The total quantity of repo funding supplied by OTC depositors, if the inter-dealer repo rate is r, is:

$$Q_{D,OTC}(r) = M_{D,OTC} \int_{v_D < r} dF_{v,D}(v_D) = M_{D,OTC}(F_{v,D}(r)),$$

thus, $Q_{D,OTC}(r)$ is increasing in r. The equilibrium inter-dealer repo rate, r_{ID}, must equate the supply and demand for repo funding from dealers and OTC customers. That

is, r_{ID} must satisfy:

$$Q_{B,OTC}(r_{ID}) + Q_{B,Dealer}(r_{ID}) = Q_{L,Dealer}(\rho - r_{ID}) + Q_{D,OTC}(r_{ID}). \tag{14}$$

Note that $Q_{B,OTC}(r)$ and $Q_{B,Dealer}(r)$ are both decreasing in r, whereas $Q_{L,Dealer}(\rho - r)$ and $Q_{D,OTC}(r)$ are increasing in r, so the supply and demand curves cross at most once, and there is a unique equilibrium rate r_{ID} in the inter-dealer market. By applying the implicit function theorem to (14), we can show how changes in the Deposit Facility Rate, ρ, affect the equilibrium inter-dealer repo rate r_{ID}.

Claim 4. *The pass-through of the Deposit Facility Rate to inter-dealer repo rates, which we call the DFR-ID pass-through, is:*

$$\frac{dr_{ID}}{d\rho} = \frac{Q'_{L,Dealer}(\rho - r)}{Q'_{B,OTC}(r) + Q'_{B,Dealer}(r) + Q'_{L,Dealer}(\rho - r) - Q'_{D,OTC}(r)}, \tag{15}$$

$\frac{dr_{ID}}{d\rho}$ *is always between 0 and 1.*

Claim 4 shows that the pass-through of ρ, to r_{ID} is always imperfect. This is because lending dealers value collateralized lending, and the market supply of collateral is not perfectly elastic. In the repo literature, this is often called the collateral scarcity effect. When the Deposit Facility Rate is increased, the equilibrium price of collateralized lending relative to the Deposit Facility Rate, $\rho - r_{ID}$, will increase, so the inter-dealer repo rate will rise by less than ρ. DFR-ID pass-through is higher when the slope of lending dealers' supply of funds, $Q'_{L,Dealer}(\rho - r)$, is large relative to the sum of the demand slopes of borrowing dealers, OTC borrowers, and OTC lenders. Internet Appendix IB.3 and Internet Appendix Figure IA.3 provide further intuition about the DFR-ID pass-through.

4.3   DFR to OTC Pass-through

By combining Claims 3 and 4, we can characterize the pass-through of the Deposit Facility Rate, ρ, to OTC repo rates.

Claim 5. *The pass-through of the Deposit Facility Rate to OTC rates (DFR-OTC pass-through)*

is:

$$\frac{dr_B\left(v_B,\theta_B,r_{ID}\right)}{d\rho}=\frac{dr_B\left(v_B,\theta_B,r_{ID}\right)}{dr_{ID}}\frac{dr_{ID}}{d\rho}, \tag{16}$$

$$\frac{dr_D\left(v_D,\theta_D,r_{ID}\right)}{d\rho}=\frac{dr_D\left(v_D,\theta_D,r_{ID}\right)}{dr_{ID}}\frac{dr_{ID}}{d\rho}. \tag{17}$$

In words, the pass-through of the Deposit Facility Rate ρ to OTC repo rates is simply the product of DFR-ID pass-through and ID-OTC pass-through. This decomposition is useful because it highlights two distinct pass-through frictions, which have different economic sources. Collateral scarcity in the inter-dealer market constrains the pass-through of the Deposit Facility Rate, ρ, to inter-dealer repo rates, r_{ID}. Market power in the OTC market constrains the pass-through of the inter-dealer rate, r_{ID}, to customer-facing rates in the OTC market, r_B and r_D.

5   Empirical Tests

In this section, we establish the presence of market power by empirically testing Predictions 1 and 2 in the data. Compared to Section 3 that documents general trends, our analysis in this section focuses on the cross-sectional variation in the response to monetary policy rate changes, which allows us to further distill the market power channel from potential confounding factors.

5.1   September 2019 DFR Rate Cut

To measure pass-through, we exploit the change in the Deposit Facility Rate from -40 to -50bps in September of 2019. This rate change did not coincide with other policy changes or major macroeconomic shocks, which makes it a relatively clean episode. Further, although there may be expectations of rate changes based on economic conditions, the very short maturity of repo contracts limits the effect of future expectations on rates and allows for a high-frequency analysis of the pass-through to OTC and inter-dealer markets.

Figure 5 plots the average daily repo rates in the inter-dealer and OTC market for repos backed by German, French, Italian, and Spanish collateral. The first vertical dotted line corresponds to the announcement of the rate change on September 12, whereas the

second dotted line corresponds to the implementation of the rate cut on September 18. To ensure that we capture the full extent of the pass-through to repo rates, we avoid the transition period between the announcement and the implementation. We treat the week before the announcement on September 12 as the pre-rate-cut period and the week after the implementation on September 18 as the post-rate-cut period.

The intuition for our empirical approach is straightforward for overnight and short-maturity repos. Each day, lending dealers can choose between lending overnight using the deposit facility and lending in the repo markets. Once the ECB implements a change in the deposit facility rate, lending dealers' substitution should cause rates in the inter-dealer repo market to shift in response. For short-maturity repo trades, knowledge that short rates will change in the future should not affect current rates: short rate changes should matter only once they have been implemented.[13] However, for longer-term repo loans, the rates at which dealer are willing to lend will also depend on expectations about future deposit facility rates. Thus, long-term repo rates prior to the September 12th rate change announcement could conceivably be affected by expectations about future deposit facility rate changes. This effect is unlikely to be a significant driver of our results because the vast majority of repo trades in our sample have short maturities.[14] In Internet Appendix IA.2, we test predictions 1 and 2 using only repo trades with maturities less than a week, and show that all results continue to hold.

5.2 Measuring Pass-through

Our model characterizes three different kinds of pass-through: DFR-ID pass-through, DFR-OTC pass-through, and ID-OTC pass-through. The 2019 policy rate cut allows us to measure DFR-ID and DFR-OTC pass-throughs for any segment of the repo mar-

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[13]The rate changes in Figure 5 appear to be somewhat gradual within the September 12 to September 18th window. These trends do not affect our estimates, because we use data before September 12th as the pre-period, and after September 18th as the post-period. Moreover, this pre-trend is not due to anticipation effects: rather, it is an artifact of money market timing conventions. Overnight repo trades arranged at date T may settle at time T, $T+1$, or $T+2$, corresponding respectively to O/N, T/N, and S/N trades. The DFR rate change will thus affect these three groups of trades differently. In Internet Appendix Figure IA.1, we show that the DFR rate change has a sharp cutoff effect on repo rates within the O/N, T/N, and S/N segments with no pre-trends.

[14]In our sample, O/N, S/N, and T/N repos make up 64.6% of total trades, and 80.6% of repos have maturities less than one week.

ket. For example, to calculate DFR-OTC pass-through for repos backed by collateral k, let Loan Rate$_k^{OTC,pre}$ represent the average OTC rates on repos backed by (ISIN-level) collateral k in the pre-rate-change period, and let Loan Rate$_k^{OTC,post}$ represent the corresponding rates in the post-rate-change period. We define DFR-OTC pass-through for collateral k, Passthrough$_k^{DFR-OTC}$, as:

$$
\text{Passthrough}_k^{DFR\_OTC} = \frac{\text{Loan Rate}_k^{OTC,post} - \text{Loan Rate}_k^{OTC,pre}}{-10}. \tag{18}
$$

In words, Passthrough$_k^{DFR-OTC}$ is the pre-post change in OTC rates for collateral k, divided by the size of the DFR rate change. It is thus the empirical counterpart of $\frac{dr_{ID}}{d\rho}$ in the model. Similarly, we can calculate DFR-ID pass-through for repos backed by collateral k using pre- and post-rate-cut average inter-dealer repo rates in (18). Based on expressions (16) and (17) of Claim 5, we can then calculate ID-OTC pass-throughs as the ratio of DFR-ID and DFR-OTC pass-throughs.

As an example, suppose we observe inter-dealer repo rates for a certain kind of collateral decrease from -60bps to -68bps, and average OTC depositor-facing repo rates decrease from -70bp to -76bp. DFR-ID pass-through is then the ratio $-8bps/-10bps$, which is 80%, and likewise DFR-OTC pass-through is 60%. We then infer that ID-OTC pass-through is 0.6/0.8, which is 75%.

We first examine our estimates for DFR-ID pass-through. While Subfigures (c) and (d) in Figure 5 show the average inter-dealer repo rates by collateral segment, significant variation in inter-dealer pass-throughs exists for repos backed by different ISINs. Figure 6 shows binned scatter plots of inter-dealer pass-throughs against pre-rate-cut loan rates within each collateral segment. From the Figure, we see that inter-dealer pass-throughs are not perfect, and they mostly range between 60% to 100%. Moreover, Figure 6 shows that pass-throughs are lower for ISINs with lower pre-cut loan rates, that is, repos backed by scarcer collateral. Claim 4 suggests that for these ISINs, lending dealers' funding supply is relatively inelastic, and the net demand for funding is relatively elastic.

5.3 OTC Rate Dispersion and Pass-through by Collateral

We now use our pass-through estimates to test our main model predictions. Prediction 1 states that ID-OTC pass-through should be negatively correlated with OTC rate dispersion across collateral types. Intuitively, if dealers have more market power in the OTC market for a given kind of collateral, repo rates should be more dispersed and dealers should be passing through less of any changes in inter-dealer rates to customers.

To test Prediction 1, we estimate the following specification:

$$\text{Passthrough}_k^{\text{ID\_OTC}} = \alpha + \beta_1 \text{p75-p25 Loan Rate}_k^{\text{pre}} + \beta_2 \text{RA Lend}_k + \varepsilon_k. \qquad (19)$$

Each observation involves repo backed by the same ISIN-level collateral. The dependent variable, $\text{Passthrough}_k^{\text{ID\_OTC}}$, is the inter-dealer OTC pass-through for ISIN k, and the main explanatory variable, $\text{p75-p25 Loan Rate}_k^{\text{pre}}$, is the interquartile range in pre-rate-change OTC repo rates for ISIN k. A dummy variable distinguishing between dealer-lend and dealer-borrow transactions is also included.

Table 3 shows the results. We see that the coefficient on the OTC interquartile ranges are all negative and significant except for the Spanish collateral segment. This confirms that higher OTC rate dispersion is associated with lower pass-through efficiency. Notice that this finding does not stem from collateral scarcity because inter-dealer repo rates for the same ISIN-level collateral is conditioned on in the ID-OTC pass-through variable. Dealer balance sheet costs are also unlikely to determine the result unless balance sheet costs for intermediating repos backed by different ISIN-level collateral are differentially impacted by changes in monetary policy.

5.4 OTC Loan Rates and Pass-through by Customer

Another way to shed light on the presence of dealer market power is from OTC customers' perspective. According to Prediction 2, ID-OTC pass-through should be positively (negatively) correlated with the level of OTC rates for customers who lend to (borrow from) dealers. Intuitively, if a dealer has higher bargaining power with a customer that they borrow from, the dealer will be able to borrow at lower rates and pass-through changes in inter-dealer rates less. Similarly, if a dealer has higher bargaining power with a

customer that they lend to, the dealer will be able to lend at higher rates and pass-through changes in inter-dealer rates less.

One concern is that different customers may be trading repos with different characteristics in the pre- and post-rate cut periods, and variation in rates driven by characteristics may confound our estimates of pass-through. We address this problem by calculating pass-through using residualized rates from (1) in Section 3.3, which removes all variation in rates arising from changes in the composition of repos in the pre- and post-periods. Since the coefficients (1) vary monthly, and both the pre- and post-periods are in September, the effect of the rate cut remains in the residuals. We then use averages of these residualized rates in the pre- and post-periods, for OTC customer c trading repos backed by collateral from country m, to calculate OTC pass-through, $\text{Passthrough}_{cmns}^{\text{DFR\_OTC,resid}}$, and pre-period OTC loan rates, $\text{Loan Rate}_{cmns}^{\text{pre,resid}}$. To absorb systematic differences in pass-throughs by collateral country, we include fixed effects γ_m for the collateral country m, η_n for the customer's country n, and δ_s for the customer's sector s. Formally, we estimate the following specification:

$$\text{Passthrough}_{cmns}^{\text{DFR\_OTC,resid}} = \alpha + \beta \text{Loan Rate}_{cmns}^{\text{pre,resid}} + \gamma_m + \eta_n + \delta_s + \varepsilon_{cmns}. \qquad (20)$$

We report the results from specification (20) in Table 4. From the first three columns, we observe that the residualized OTC pass-through and OTC loan rates are positively correlated when dealers borrow from customers. That is, market participants who enjoy a higher rate when lending to dealers in the pre-rate-cut period also have more efficient pass-through to their repo rates following the rate cut. From the last three columns, we observe that pass-through is negatively correlated with pre-rate-cut loan rates when dealers lend to custimer. That is, market participants who borrow from dealers at a higher rate in the pre-rate-cut period also have less efficient pass-through to their repo rates following the rate cut. Both sets of results are consistent with Prediction 2. The results in columns (2) and (4) remain robust when comparing customers within each sector, which shows that potential changes in sector-level valuation for repos are not driving our results. Columns (3) and (6) further condition on both the country and the sector of the customer. The economic and statistical significance for dealer borrow trades remain but that for dealer lend trades decline, which may in part be due to the smaller sample size of the

latter group.

So far, we have shown that the relationship between pass-through and pre-rate-cut rates are most likely due to dealer market power because they are not driven by collateral composition nor simultaneous changes at the sector or country level. Nevertheless, there is still the slight possibility that there are unobserved changed in repo valuation at the individual counterparty level that are not explained by their use of different collateral, sector- and country-level changes, and that induces the exact cross-sectional variation in repo rates and pass-through that we observe.

To address this potential confounding, we exploit within-customer across-dealer variation in rates with customer fixed effects ϕ_c. If we observe a customer trading with two dealers, one at worse rates and one at better rates, Prediction 2 states that pass-through should be lower for the dealer which offers the customer worse rates. Formally, we estimate the following specification for OTC customer c and dealer d, trading collateral from country m:

$$\text{Passthrough}_{cdm}^{\text{DFR\_OTC,resid}} = \alpha + \beta \text{Loan Rate}_{cdm}^{\text{pre,resid}} + \phi_c + \gamma_m + \varepsilon_{cdm}. \tag{21}$$

Table 5 shows the result from estimating specification (21). The first two columns correspond to transactions in which dealers borrow from customers. Here, we find that bilateral OTC pass-through and OTC loan rates are positively correlated when dealers borrow from customers. The economic and statistical significance remains even when comparing trades of the same customer with different dealers, which rules out that our results are driven by customer-specific changes in repo valuation correlated with the policy rate cut. The results in the last two columns correspond to trades in which dealers lend to customers. The signs of the point estimates are consistent with Prediction 2, though the coefficient is not statistically significant in the last column.

6 Policy Counterfactuals

In this section, we perform two policy counterfactuals and a quantification exercise. First, we consider the effects of allowing customers direct access to inter-dealer markets. Second, we consider the effects of providing Reverse Repo (RRP) Facilities in the inter-dealer and

OTC market segments. Third, we show how net interest margins can be decomposed into components attributable to market power and dealer balance sheet costs.

6.1 Access to Inter-Dealer Trading Platforms

If OTC customers had direct access to the inter-dealer centralized trading platforms, they could trade at the competitive inter-dealer repo rate r_{ID}. This would eliminate the market power component of pass-through frictions, as the following claim shows.

Claim 6. *Suppose OTC customers had direct access to the competitive inter-dealer repo market. Then OTC market interest rates would be equal to the inter-dealer rate:*

$$r_B\left(\nu_B, \theta_B, r_{ID}\right) = r_D\left(\nu_D, \theta_D, r_{ID}\right) = r_{ID}. \tag{22}$$

DFR-ID pass-through is unchanged from (15):

$$\frac{dr_{ID}}{d\rho} = \frac{Q'_{L,Dealer}\left(\rho - r\right)}{Q'_{B,OTC}\left(r\right) + Q'_{B,Dealer}\left(r\right) + Q'_{Lj}\left(\rho - r\right) - Q'_{D,OTC}\left(r\right)}. \tag{23}$$

DFR-OTC pass-through would improve to be on par with DFR-ID pass-through:

$$\frac{dr_L\left(\nu_B, \theta_B, r_{ID}\right)}{d\rho} = \frac{Q'_{L,Dealer}\left(\rho - r\right)}{Q'_{B,OTC}\left(r\right) + Q'_{B,Dealer}\left(r\right) + Q'_{Lj}\left(\rho - r\right) - Q'_{D,OTC}\left(r\right)}. \tag{24}$$

In words, Claim 6 states that giving customers access would improve DFR-OTC pass-through to match DFR-ID pass-through. However, pass-through frictions from collateral scarcity remain, so that the pass-through to OTC and inter-dealer markets cannot be fully restored.

We then take our policy counterfactual to the data to quantify the improvement in pass-through from inter-dealer market access. For a given repo in the OTC segment, we calculate its counterfactual pass-through as the pass-through to repos backed by the same ISIN-level collateral in the inter-dealer segment following the September 2019 rate cut. That is, we let the pass-through to a given customer's repo loan backed by a given ISIN-level collateral take on the inter-dealer pass-through to repo rates backed by the

same ISIN-level collateral. Then, we compare this counterfactual passthrough to the observed passthrough in the data.

Figure 7 shows our results. Compared to the original OTC pass-throughs to dealer-borrow trades in the German, French, Italian, and Spanish segment of 63%, 49%, 61%, and 65%, we find that inter-dealer market access improves pass-through by 26%, 28%, 34%, and 30%, respectively. For dealer-lend trades in the German, French, Italian, and Spanish segment, the original pass-throughs of 45%, 47%, 57%, and 61% are improved by 39%, 32%, 35%, and 31%, respectively. The improvements in pass-through efficiencies are significant, indicating the importance of market power frictions. Nevertheless, the final pass-through efficiencies are below 100% because collateral scarcity frictions remain.

Another benefit of extending access to inter-dealer markets is to lower pass-through dispersion so that changes in the policy rate can transmit to market participants more equally. As Table 6 shows, pass-through dispersion for OTC market participants decreases substantially. For dealer-borrow repos, pass-through dispersion decreases from 24.5% to 13.6%, 41.7% to 14.9%, 30.1% to 9.4%, and 30.6% to 23.8% for the German, French, Italian, and Spanish segments, respectively. Pass-through dispersion of dealer-lend transactions is also improved from 36.5% to 19.6%, 37.5% to 23.0%, 31.2% to 23.6%, and 30.1% to 23.4% respectively. The reduction in dispersion arises from the elimination of market power frictions, whereas the remaining dispersion stems from the use of different collateral in backing repo trades.

6.2   Reverse Repo Facility (RRP)

If central banks offered a secured deposit rate, market participants would be able to lend cash to the central bank and receive securities in return. In the U.S., a secured deposit facility was made available to some non-bank market participants under the Federal Reserve's RRP Facility.

Within our model, we can explore how providing and setting policy rates on a secured deposit facility can affect monetary pass-through in the inter-dealer and OTC market segments. As the following claim shows, pass-through efficiency can be achieved in both inter-dealer and OTC market segments.

The inter-dealer market. First, suppose that the central bank conducts RRPs with

dealers but not directly with OTC customers. By providing a policy rate, r_{RRP}, at which repo depositors can deposit funds with the central bank backed by collateral, the central bank essentially introduces a floor to inter-dealer repo rates.

Claim 7. *With a reverse repo rate r_{RRP}, the inter-dealer equilibrium rate is:*

$$r_{ID} = \begin{cases} r_{RRP} & r_{nofloor,ID} \leqslant r_{RRP} \\ r_{nofloor,ID} & r_{nofloor,ID} \geqslant r_{RRP}, \end{cases} \tag{25}$$

where $r_{nofloor,ID}$ is the equilibrium rate which would prevail in the absence of the RRP facility. That is,

$$r_{nofloor,ID} = \{r : \ Q_{B,OTC}(r_{ID}) + Q_{B,Dealer}(r_{ID}) = Q_{L,Dealer}(\rho - r_{ID}) + Q_{D,OTC}(r_{ID})\}. \tag{26}$$

The pass-through of the RRP rate to inter-dealer rates is thus:

$$\frac{\partial r_{ID}}{\partial r_{RRP}} = \begin{cases} 1 & r_{nofloor,ID} \leqslant r_{RRP} \\ 0 & r_{nofloor,ID} \geqslant r_{RRP}. \end{cases} \tag{27}$$

Expression (27) characterizes the effect of changes in RRP rates on equilibrium rates. The top left panels of Figure 8 illustrate the results graphically. The RRP rate is binding if $r_{RRP} \geqslant r_{nofloor,ID}$. In this case, the market rate is the RRP rate, so changes in r_{RRP} pass on one-to-one to the market rate. If $r_{RRP} < r_{nofloor,ID}$, then the rate is non-binding, and changes do not affect the market rate.

Intuitively, the RRP rate acts as a price floor that is either binding or non-binding in a competitive inter-dealer market. Importantly, both the RRP rate and the inter-dealer rate are secured rates backed by collateral so that collateral scarcity frictions are alleviated and pass-through becomes efficient.

The OTC market. Instead, what would happen if non-dealer customers had direct access to the RRP? Recall from the baseline model that OTC customers do not have access to inter-dealer trading platforms and rely on intermediation by dealer banks, which subjects them to dealer market power. The following claim characterizes market outcomes, if OTC repo depositors as well as dealers were given access to the RRP facility.

Claim 8. *Suppose OTC depositors and dealers had access to the RRP Facility, paying rate r_{RRP}.*
The inter-dealer repo rate is identical to (25) of Claim 7:

$$r_{ID} = \begin{cases} r_{RRP} & r_{nofloor,ID} \leqslant r_{RRP} \\ r_{nofloor,ID} & r_{nofloor,ID} \geqslant r_{RRP}, \end{cases} \tag{28}$$

where $r_{nofloor,ID}$ is the equilibrium rate which would prevail in the absence of the RRP facility, as defined in (26). If $r_{RRP} \geqslant r_{nofloor,ID}$, then OTC depositors are indifferent between trading with dealers and using the RRP. If $r_{RRP} < r_{nofloor,ID}$, then the RRP Facility is not used, and all OTC depositors' repo trades are made with dealers. An OTC depositor with value v_D and bargaining power θ_D trades at rate:

$$r_D(v_D, \theta_D) = \begin{cases} r_{nofloor,ID} - \theta_D (r_{nofloor,ID} - v_D) & r_{nofloor,ID} < v_D \\ r_{ID} - \theta_D (r_{ID} - r_{RRP}) & v_D \leqslant r_{RRP} \leqslant r_{nofloor,ID} \\ r_{RRP} & r_{RRP} > r_{nofloor,ID}. \end{cases} \tag{29}$$

The pass-through of RRP rates to OTC depositors' rates is:

$$\frac{dr_D(v_D, \theta_D, r_{ID})}{dr_{RRP}} = \begin{cases} 0 & r_{RRP} < v_D \\ \theta_D & v_D \leqslant r_{RRP} \leqslant r_{nofloor,ID} \\ 1 & r_{RRP} > r_{nofloor,ID}. \end{cases} \tag{30}$$

The top-right and middle-right panels of Figure 8 illustrate Claim 8. Unlike in the inter-dealer market, the rate curve has three regions. When r_{RRP} is below v_D, it has no effect. When r_{RRP} is above $r_{nofloor,ID}$, OTC depositors are indifferent between using the r_{RRP} or trading with dealers, so r_{RRP} changes pass through one-to-one to customer-facing rates. However, in the intermediate region, changes in r_{RRP} partially pass through to customers' repo rates.

Intuitively, when r_{RRP} exceeds $r_{nofloor,ID}$, pass-through becomes perfectly efficient because both market power frictions and collateral scarcity frictions are eliminated. When r_{RRP} is between v_D and $r_{nofloor,ID}$, customers have an outside option of lending secured to the RRP Facility. In this range, the customer continues trading with dealers, but at

a rate that is affected by their outside option rate, r_{RRP}. Thus, offering the RRP rate, r_{RRP}, to market participants exerts competitive pressure on dealer rates and policy pass-through even without the central bank actually having to make any repo trades. Claim 8 implies that the range in which this bargaining power channel improves pass-through is heterogeneous, depending on the distribution of market participants' bargaining power and values. The aggregate effect is an average across customers, as shown in the bottom panel of Figure 8.

We note that our findings may apply to other settings in which market power affects money market outcomes. For example, Bech and Klee (2011) suggest that market power is one of the drivers of the IOER-Fed funds spread in the US money markets: GSEs do not have direct access to the IOER, and banks are able to charge GSEs a spread in the Fed funds market to intermediate access to the IOER. Our results imply that the Fed could potentially increase the Fed funds rate by giving GSEs access to a deposit facility with rates lower than the IOER, as this would exert competitive pressure on rates charged to GSEs in the Fed funds market.

6.3 Decomposing Net Interest Margins

Finally, we use our model and passthrough estimates to perform a simple decomposition of net interest margins into components attributable to market power and balance sheet costs. Formally, suppose dealers face balance sheet costs in intermediating repo trades: the cost to a dealer of making a repo loan is $r_{ID} + c_B$, and the cost for taking funds from depositors is $r_{ID} - c_D$. Using (3) and (4), and taking the expectations of rates across customers and dealers, we can express net interest margins as:[15]

$$\underbrace{E\left[r_B\right] - E\left[r_D\right]}_{\text{Net interest margin}} =$$

$$\underbrace{c_B + c_D}_{\text{Balance sheet costs}} + \underbrace{E\left[\theta_B\left(v_B - (r_{ID} + c_B)\right)\right] + E\left[\theta_D\left((r_{ID} + c_D) - v_D\right)\right]}_{\text{Market power}} \quad (31)$$

[15]Note that these are equivalent to (50) of Internet Appendix IB.1.2, specialized to the case of constant balance sheet costs.

In words, (31) states that the average net interest margin can be decomposed into a balance sheet cost component, $c_B + c_D$, and a component attributable to market power. In particular, let:

$$\phi \equiv \frac{E\left[\theta_B\left(v_B - (r_{ID} + c_B)\right)\right] + E\left[\theta_D\left((r_{ID} + c_D) - v_D\right)\right]}{E\left[r_B\right] - E\left[r_D\right]} \tag{32}$$

The parameter ϕ represents the fraction of net interest margins which is attributable to market power, as opposed to balance sheet costs. To estimate ϕ, note that we can write:

$$\phi = 1 - \frac{c_B + c_D}{E\left[r_B\right] - E\left[r_D\right]} \tag{33}$$

We observe the net interest margin $E\left[r_B\right] - E\left[r_D\right]$ in the data. In Appendix A.8, we show that balance sheet costs and, thus, ϕ are identified as long as we observe customers trading the same collateral with two or more dealers. Our estimates show that 41.9% of net interest margins are attributable to market power while the remaining 58.1% stem from dealer balance sheet costs. Thus, dealer market power accounts for a substantial portion of net interest margins, which ultimately impedes the pass-through efficiency of monetary policy.

7 Conclusion

In this paper, we have shown that market power is an important friction in the European repo market. Non-bank participants in the repo market cannot access the central bank's balance sheet or centralized trading platforms directly. They can only trade repos over-the-counter with dealer banks. Moreover, most market participants trade with a very small number of dealer banks. The presence of OTC repo rate dispersion and dealers' net interest margins confirm the market power of dealer banks over their OTC customers.

We build a simple model to show how repo rates are affected by collateral scarcity and dealer market power. The model shows that market power reduces the pass-through of central bank policy rates to customer-facing repo rates and generates a number of predictions regarding monetary policy pass-through. We test and confirm these

predictions using the September 2019 monetary policy rate cut.

Our findings have important policy implications. Granting OTC customers access to inter-dealer repo markets would decrease dealer market power and improve the pass-through of the policy rate. Moreover, if the central bank gave OTC customers access to a secured deposit facility, like the Federal Reserve's RRP, policy rate pass-through could be further enhanced. Notably, the RRP can improve pass-through even without an actual take-up of the facility in equilibrium.

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Figure 1: Inter-dealer Repo Rates
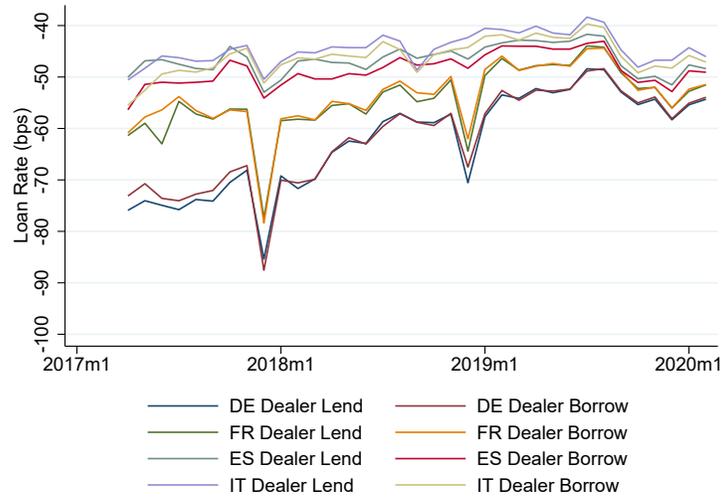
Notes. This figure shows the value-weighted average repo rates at which dealers borrow and lend in the inter-dealer market using German, French, Spanish, and Italian government collateral at a monthly frequency. The sample period is from February 2017 to February 2020.

Figure 2: Dispersion in OTC Rates

(a) DE   (b) FR

(c) IT   (d) ES
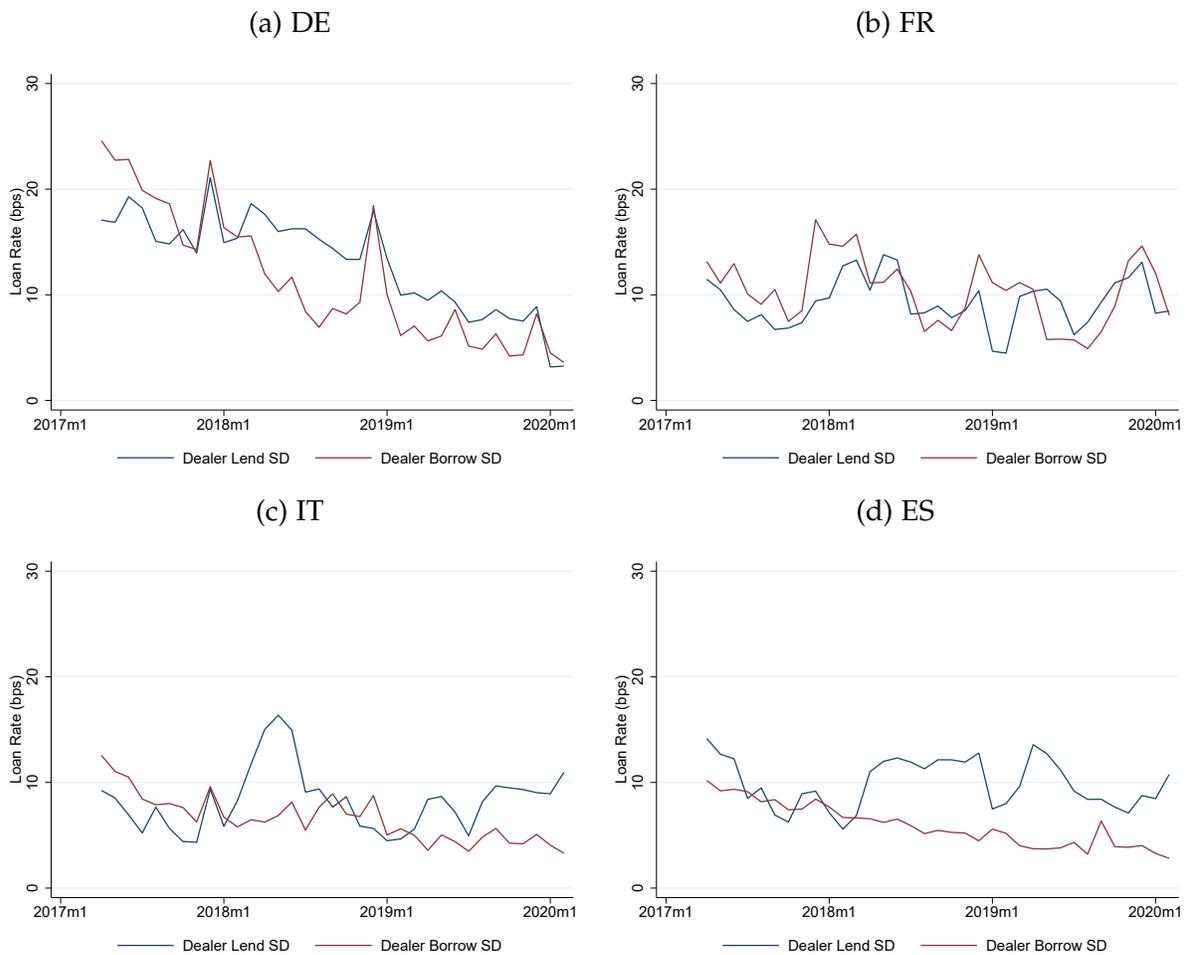
Notes. This figure shows the value-weighted standard deviation of repo rates at which dealers lend to and borrow from their customers in the OTC market at a monthly frequency. The four panels show rates on repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

Figure 3: OTC Dealer Lend and Borrow Rates
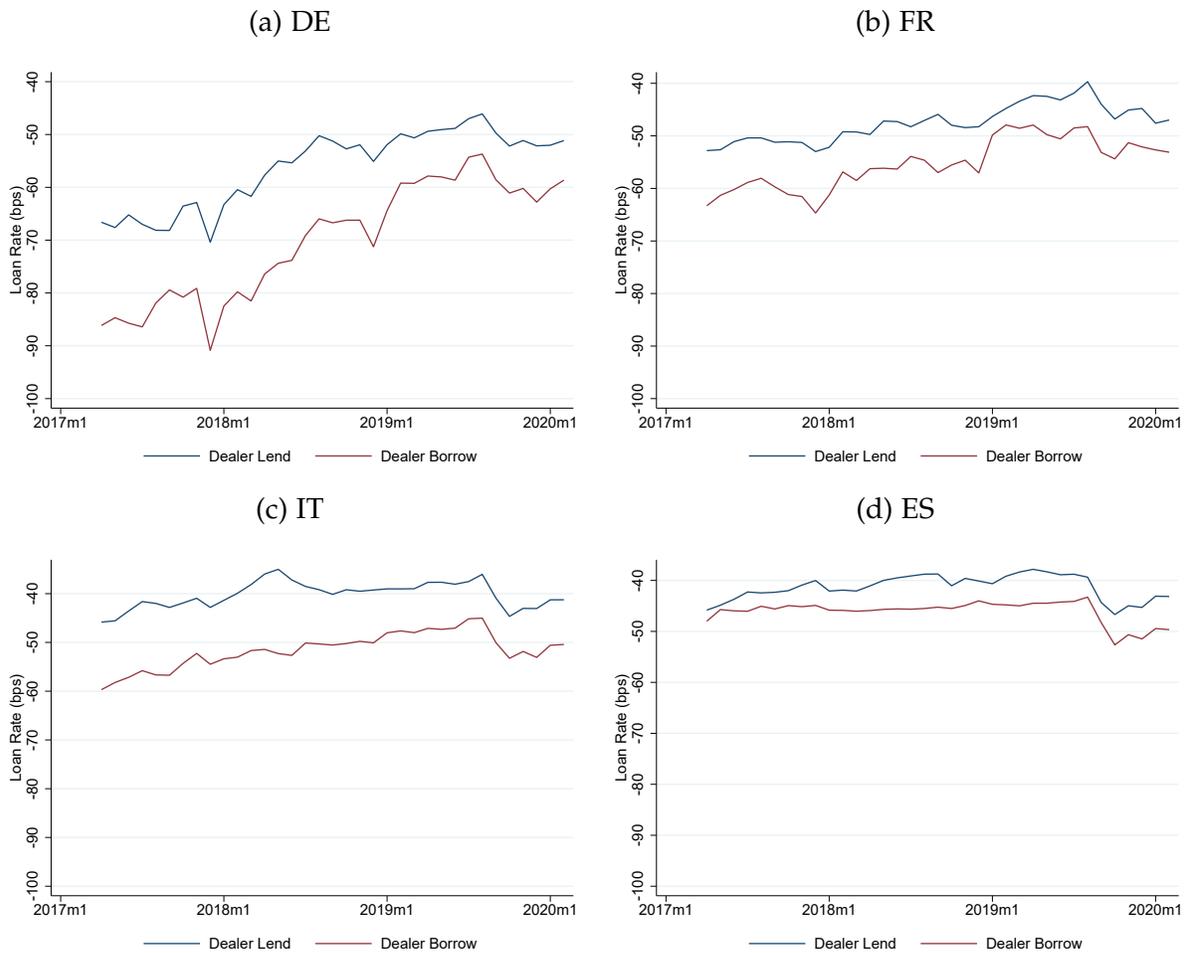
(a) DE

(b) FR

(c) IT

(d) ES

Notes. This figure shows the value-weighted average repo rates at which dealers lend to and borrow from their customers in the OTC market, at a monthly frequency. The four panels show rates on repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

Figure 4: Stylized Depiction of Model
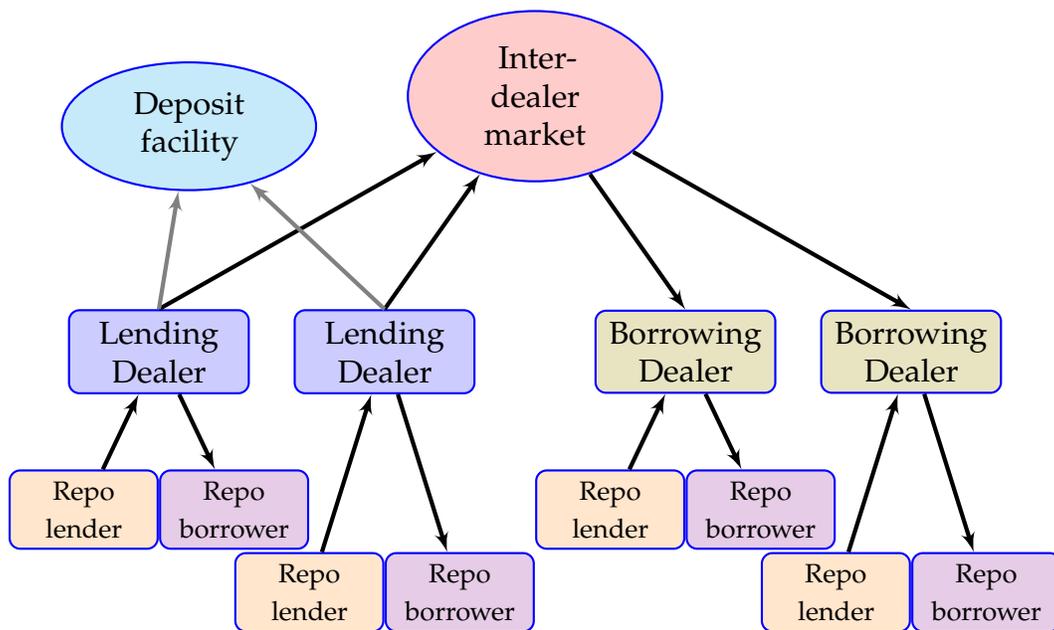
Figure 5: September 2019 Rate Cut
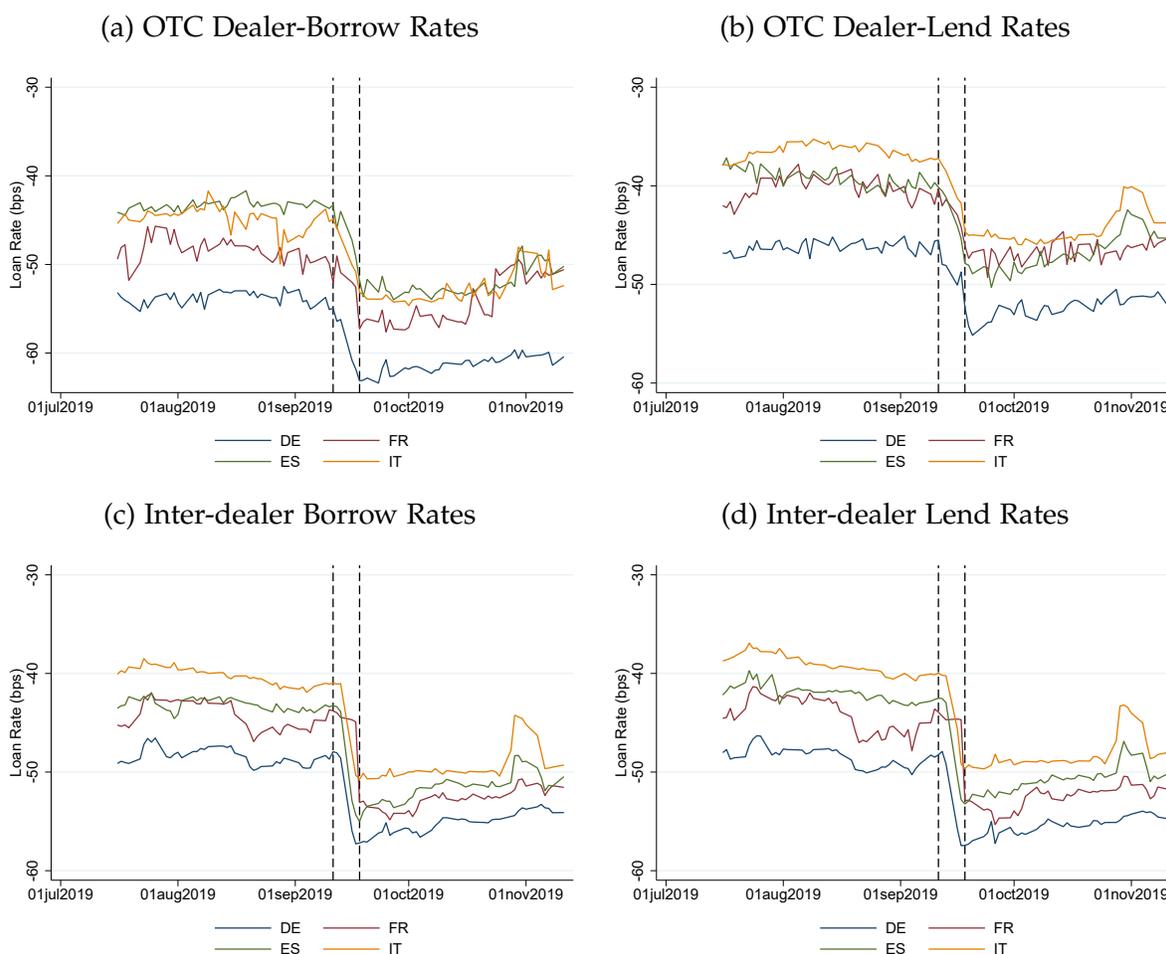
(a) OTC Dealer-Borrow Rates

(b) OTC Dealer-Lend Rates

(c) Inter-dealer Borrow Rates

(d) Inter-dealer Lend Rates

Notes. This figure shows the value-weighted average daily repo rates for German, French, Italian, and Spanish government collateral around the monetary policy rate cut in September 2019. Subfigures (a) and (b) correspond to the rates at which dealers borrow and lend in the OTC market, and subfigures (c) and (d) describe the inter-dealer repo market. The dotted vertical lines represent September 12, 2019, and September 18, 2019, which correspond to the announcement and implementation of a 10bps rate cut on the ECB's Deposit Facility Rate. Some data points have been omitted due to confidentiality reasons.

Figure 6: Inter-Dealer Pass-throughs

(a) DE

(b) FR

(c) IT

(d) ES
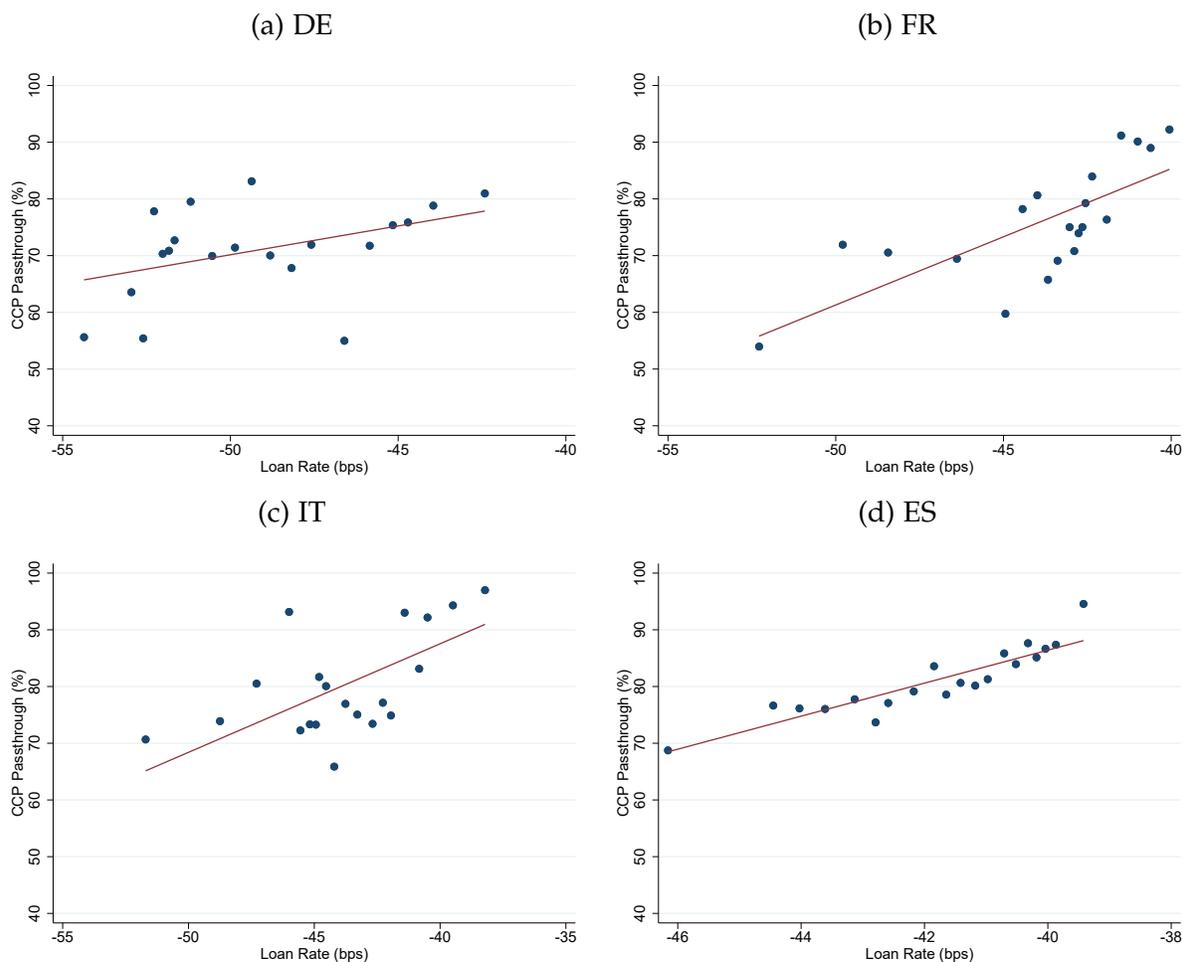
Notes. This figure shows binned scatterplots. The y-variable is DFR-ID pass-through, $\text{Passthrough}_k^{\text{DFR\_ID}}$, where k indexes collateral ISINs. As in specification (18), DFR-ID pass-through is calculated as the change in repo rates from the pre- to post-rate cut period, divided by the rate cut of -10bps. The x-axis is the pre-rate-change inter-dealer repo rate for ISIN k. The pre-rate-cut period refers the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019. Each collateral country is shown in a separate panel.

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Figure 7: Inter-Dealer Market Access and Pass-through

(a) Dealer Lend

(b) Dealer Borrow
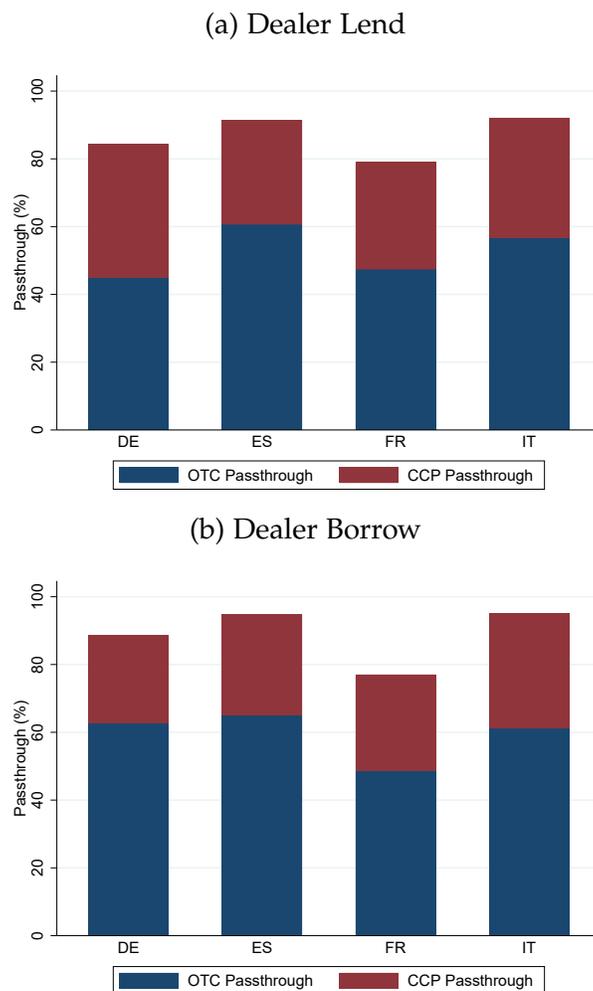
Notes. This figure plots the pass-through of the Deposit Facility Rate to repo rates in the OTC segment depending on market participants' inter-dealer market access. The observed pass-through to thet OTC market participants that do not have access to the inter-dealer repo market is indicated by the blue bar. The counterfactual pass-through to the current OTC market participants if they obtain access to the inter-dealer repo market is indicated by the red bar. Pass-throughs are calculated separately for each collateral country segment and for dealer-lend (Panel (a)) and dealer-borrow repos (Panel (b)).

Figure 8: The Effect of RRP on Inter-Dealer and OTC Pass-Through

(a) Inter-Dealer Rates

(b) OTC Rates

(c) Inter-Dealer Pass-Through

(d) OTC Pass-Through

(e) OTC Rates and Pass-Through (multiple customers)
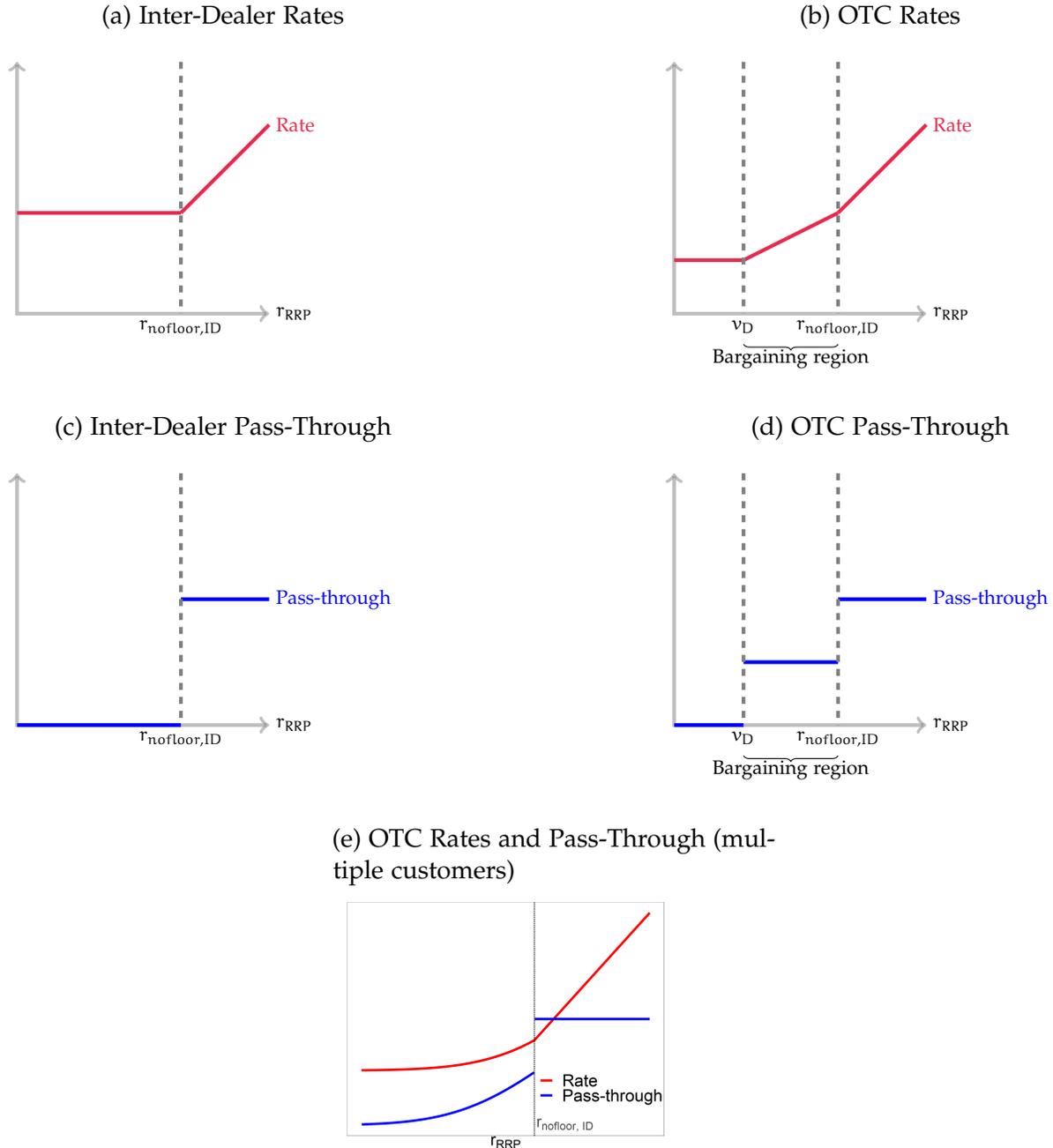
Notes. Panel (a) and (b) show the effect of a RRP facility, with rate r_{RRP}, on rates and pass-through for the inter-dealer market, using (25) and (27) of Claim 7. Panel (b) and (d) show the effect of r_{RRP} on rates and pass-through for the OTC market, for a single customer, using (29) and (30) of Claim 8. Panel (e) shows average OTC rates and pass-through, averaging across many customers. We set $r_{\text{ID}} = 0.8$, v_D normal with mean 1 and SD 0.8, and θ_D uniform on $[0, 1]$.

Table 1: Customer Characteristics and Bargaining Power

	(1) RA Borrow	(2) RA Borrow	(3) RA Lend	(4) RA Lend
Bilateral Vol	0.962***	0.812***	-0.855***	-0.736**
	[0.241]	[0.243]	[0.311]	[0.307]
Total Vol	-0.090**	-0.073**	0.205***	0.203***
	[0.036]	[0.036]	[0.029]	[0.029]
RA Num	0.515**	0.437*	-1.045***	-0.798***
	[0.232]	[0.232]	[0.219]	[0.219]
Insurance or Pension	-0.393	-0.465	-0.953	-0.680
	[0.700]	[0.684]	[0.594]	[0.586]
Bank	-1.809***	-1.542**	-2.584***	-2.264***
	[0.637]	[0.629]	[0.550]	[0.549]
Money Market Fund	-1.355	-2.657***	1.611	1.887*
	[0.969]	[0.967]	[1.052]	[1.046]
Non Money Market Fund	-0.122	-0.090	-0.747	-0.358
	[0.637]	[0.623]	[0.566]	[0.559]
Other Financial Institution	-1.715**	-1.371**	-0.637	-0.158
	[0.666]	[0.654]	[0.595]	[0.589]
Constant	-3.520***	-3.568***	5.793***	5.292***
	[0.604]	[0.592]	[0.528]	[0.524]
Cntp Country FE	Yes	Yes	Yes	Yes
RA FE	No	Yes	No	Yes
Observations	3947	3942	4160	4155
Adj. R-squared	0.101	0.162	0.099	0.147

Notes. This table shows the results from specification (2), in which we regress residualized repo rates against a number of customer and network characteristics. The dependent variable are the average residualize repo rates at the customer-dealer-ISIN level across our sample period from February 2017 to February 2020. For repos backed by a given collateral-ISIN, Bilateral Vol is the bilateral volume traded between a customer and an RA, while Total Vol is the total volume traded by that customer. RA Num is the customer's number of connected RAs during our sample period. We also include categorical variables for the sector and country of the customer. Columns (1) and (2) report the results in which dealers borrow; Columns (3) and (4) report the results in which dealers lend. The specifications in Columns (2) and (4) further include dealer fixed effects.

Table 2: Net Interest Margin and Dispersion of Residualized Rates in the OTC Market

| | Rates (bps) | | Residualized Rates (bps) | |
	Net Interest Margin	Dispersion	Net Interest Margin	Dispersion
DE RA Borrow	12.6	11.1	9.9	7.3
DE RA Lend		9.5		7.5
ES RA Borrow	3.8	6.4	3.5	5.6
ES RA Lend		6.2		5.2
FR RA Borrow	7.5	7.8	6.2	6.4
FR RA Lend		5.8		5.4
IT RA Borrow	10.0	4.7	7.6	3.9
IT RA Lend		6.5		5.3

Notes. This table shows the average net interest margins and dispersion of repo rates and residualized repo rates at which dealers lend and borrow in the OTC market. Residualized repo rates are obtained according to specification (1). The net interest margin and standard deviation for the rrepo rates and residualized repo rates are calculated monthly from February 2017 to February 2020 for each country segment. Their time-series averages are expressed in basis points and displayed in the table.

Table 3: ID-OTC Pass-through

	(1) DE	(2) FR	(3) ES	(4) IT
p75-p25 Loan Rate$_k^{pre}$	-1.432*	-2.382***	-1.110	-1.186**
	[0.795]	[0.661]	[0.855]	[0.582]
RA Lend	-22.896***	-0.135	-9.563**	-5.118
	[6.312]	[6.609]	[4.772]	[3.814]
Constant	97.083***	92.771***	96.180***	90.511***
	[5.118]	[5.206]	[3.917]	[3.073]
Observations	107	117	103	183
Adj. R-squared	0.11	0.09	0.03	0.02

Notes. This table shows the results from specification (19), in which we regress estimated ID-OTC pass-through on the interquartile range in OTC loan rates in the pre-rate-cut period. To calculate the dependent variable, Passthrough$_k^{ID-OTC}$, we first measure DFR-ID and DFR-OTC pass-through as in specification (18), by taking pre- and post-rate-change average repo rates for ISIN k in the inter-dealer and OTC segments, respectively. We then calculate ID-OTC pass-through for ISIN k as the ratio of DFR-OTC and DFR-ID pass-throughs for ISIN k. p75-p25 Loan Rate$_k^{pre}$ is the interquartile range from all OTC trades in which the dealers lend (borrow) in the pre-rate-cut period for collateral k, expressed in bps. RA Lend is a dummy variable equal to one when the dealer is the lender. Each collateral country is shown in a separate column.

Table 4: Residualized OTC Pass-through and OTC Rates

	(1)	(2)	(3)	(4)	(5)	(6)
	RA Borrow Passthrough			RA Lend Passthrough		
Loan Rate$_{cmns}^{pre,resid}$	1.931***	2.038***	3.108***	-5.052***	-4.491***	-0.773
	[0.388]	[0.393]	[0.375]	[0.741]	[0.647]	[1.532]
ES	-10.835**	-9.085**	24.537***	39.480***	20.063*	27.354***
	[4.239]	[4.478]	[5.372]	[11.422]	[10.299]	[9.027]
FR	-6.551	-3.938	2.164	18.217*	14.922*	27.556**
	[5.127]	[5.338]	[4.806]	[9.353]	[8.402]	[12.069]
IT	2.964	3.990	7.867*	-1.574	-13.954**	4.567
	[4.482]	[4.551]	[4.103]	[7.749]	[6.944]	[12.586]
Constant	84.984***	83.723***	70.930***	85.514***	90.476***	54.436***
	[2.886]	[3.004]	[2.950]	[8.099]	[7.033]	[13.994]
Cntp Country FE	No	No	Yes	No	No	Yes
Cntp Sector FE	No	Yes	Yes	No	Yes	Yes
Observations	433	433	433	192	192	192
Adj. R-squared	0.057	0.057	0.269	0.227	0.422	0.530

Notes. This table shows the results from specification (20), in which we regress estimated customer-level DFR-OTC pass-through against the customer's OTC residualized loan rates in the pre-rate-cut period. The first and last three columns show the results for transactions in which dealers borrow and lend, respectively. To calculate the dependent variable, we first residualize repo rates, and then calculate Passthrough$_{cmns}^{DFR\_OTC,resid}$, by taking the difference between pre- and post-rate-change average OTC repo rate residuals for customer c from country n and sector s, trading collateral of country m, and dividing by the rate cut of -10bps. The dependent variable, Loan Rate$_{cmns}^{pre,resid}$, is the average residual of customer c trading collateral of country m, for transactions in the pre-rate-cut period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. The pre-rate-cut period refers to the week before the announcement.

Table 5: Residualized OTC Pass-through and OTC Rates (Bilateral)

	RA Borrow		RA Lend	
	(1)	(2)	(3)	(4)
Loan Rate$_{cdm}^{pre,resid}$	2.805***	3.186***	-0.121	-0.513
	[0.287]	[0.294]	[0.289]	[0.325]
ES	-2.336	21.968***	22.647***	21.604***
	[4.080]	[4.971]	[7.495]	[7.371]
FR	-13.780***	-10.641***	5.155	4.226
	[4.186]	[4.008]	[6.615]	[6.260]
IT	-0.532	4.362	11.454**	10.385**
	[3.701]	[3.605]	[5.235]	[5.000]
Constant	83.095***	76.779***	59.096***	56.017***
	[2.383]	[2.354]	[4.713]	[4.722]
Cntp FE	No	Yes	No	Yes
Observations	537	533	315	307
Adj. R-squared	0.18	0.29	0.02	0.20

Notes. This table shows the results from specification (21), in which we regress estimated customer-dealer-level DFR-OTC pass-through against the customer-dealer pair's OTC residualized loan rates in the pre-rate-cut period. The first and last two columns show the results for transactions in which dealers borrow and lend, respectively. To calculate the dependent variable, we first residualize repo rates, and then calculate Passthrough$_{cdm}^{DFR\_OTC,resid}$, by taking the difference between pre- and post-rate-change average OTC repo rate residuals for customer c, dealer d, trading collateral of country m, and dividing by the rate cut of -10bps. The dependent variable, Loan Rate$_{cdm}^{pre,resid}$, is the average residual of customer c, dealer d trading collateral of country m, for transactions in the pre-rate-cut period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline.

Table 6: Inter-Dealer Market Access and Pass-through Dispersion

Collateral Segment	Dealer Borrow	
	Without Access	With Access
DE	24.5	13.6
ES	30.6	23.8
FR	41.7	14.9
IT	30.1	9.4

Collateral Segment	Dealer Lend	
	Without Access	With Access
DE	36.5	19.6
ES	30.1	23.4
FR	37.5	23.0
IT	31.2	13.6

Notes. This table shows the pass-through dispersion in the OTC segment depending on market participants' inter-dealer market access. The observed pass-through dispersion for the current OTC market participants without access to the inter-dealer repo market is shown in the first column. The counterfactual pass-through dispersion for the current OTC market participants if they obtain access to the inter-dealer repo market is indicated in the second column. Pass-through dispersion is calculated as the standard deviation in DFR to OTC pass-through across customers in each collateral country segment for repos in which dealers lend (top panel) and dealers borrow (bottom panel). Pass-through dispersion is expressed in percent.

Appendix

A Proofs

A.1 Proof of Claim 1

To find net interest margins, by taking conditional expectations of 3 and 4, expected loan rates conditional on trade are:

$$E\left[r_B\left(v_B, \theta_B, r_{ID}\right) \mid v_B \geqslant r_{ID}\right] = r_{ID} + E\left[\theta_B\left(v_B - r_{ID}\right) \mid v_B \geqslant r_{ID}\right] \tag{34}$$

Similarly, expected deposit rates, conditional on trade, are:

$$E\left[r_D\left(v_D, \theta_D, r_{ID}\right) \mid v_D \leqslant r_{ID}\right] = r_{ID} - E\left[\theta_D\left(r_{ID} - v_D\right) \mid v_D \leqslant r_{ID}\right] \tag{35}$$

Combining these, we get expression (5) for net interest margins.

A.2 Proof of Claim 2

To get lend and borrow rate dispersion, we take the variance of (3) and (4), conditional on trade occurring; this gives (6) and (7).

A.3 Proof of Claim 3

This follows from differentiating (3) and (4) with respect to r_{ID}.

A.4 Proof of Claim 4

This follows from applying the implicit function theorem to (14). In the numerator, $Q'_{L,Dealer}\left(\rho - r\right)$ is always negative. In the denominator, the terms:

$$Q'_{B,OTC}\left(r_{ID}\right), Q'_{B,Dealer}\left(r_{ID}\right), Q'_{L,Dealer}\left(\rho - r_{ID}\right), -Q'_{D,OTC}\left(r_{ID}\right)$$

are always negative. Hence, $\frac{dr_{ID}}{d\rho}$ is always positive, and bounded between 0 and 1.

A.5 Proof of Claim 6

If OTC customers had direct access to the inter-dealer market, all customers would trade at the inter-dealer rate. However, the supply and demand for repo funding from OTC customers would be unchanged from (14) in the baseline model: at any inter-dealer repo rate r, all OTC borrowers with $v_B > r$ would borrow, and all OTC depositors with $v_D < r$ would deposit. Thus, allowing customer access would not change equilibrium inter-dealer repo rates. However, all customers trade at exactly the inter-dealer rate, r_{ID}. Hence, all customers trade at exactly the inter-dealer rate, r_{ID}. This gives (22), (23), and (24).

A.6 Proof of Claim 7

Suppose first that:

$$r_{nofloor,ID} \geqslant r_{RRP}$$

so the reverse repo facility rate does not bind. In this case, lending dealers weakly prefer lending in the inter-dealer market, compared to lending using the RRP. Thus, all lenders lend in the inter-dealer market. Since OTC customers cannot access the RRP, OTC customers' supply and demand are unaffected. Supply and demand for repo funding from all agents is unchanged from the baseline model, so the equilibrium repo rate must be $r_{nofloor,ID}$.

   Suppose now that:

$$r_{nofloor,ID} < r_{RRP} \tag{36}$$

so the repo facility rate does bind. Conjecture that there exists an equilibrium with $r_{ID} = r_{RRP}$. At this rate, lending dealers are indifferent between lending in the inter-dealer market and the central bank. Now, since

$$Q_{B,OTC}(r_{ID}) + Q_{B,Dealer}(r_{ID}) = Q_{L,Dealer}(\rho - r_{ID}) + Q_{D,OTC}(r_{ID})$$

and since we have assumed (36), we have:

$$Q_{L,Dealer}(\rho - r_{RRP}) > Q_{B,OTC}(r_{RRP}) + Q_{B,Dealer}(r_{RRP}) - Q_{D,OTC}(r_{RRP})$$

that is, at rate r_{RRP}, the supply of funds from lending dealers is greater than than the demand for funds from all other agents. Since lenders are indifferent between lending to the RRP and in the

market, lenders can lend a total of:

$$Q_{L,Dealer}\left(\rho - r_{RRP}\right) + Q_{D,OTC}\left(r_{RRP}\right) - Q_{B,OTC}\left(r_{RRP}\right) - Q_{B,Dealer}\left(r_{RRP}\right)$$

to the reverse repo facility, and the remaining mass of funds

$$Q_{B,OTC}\left(r_{RRP}\right) + Q_{B,Dealer}\left(r_{RRP}\right) - Q_{D,OTC}\left(r_{RRP}\right)$$

in the inter-dealer market. In this case, funding supply and funding demand in the inter-dealer market are equal, so this is an equilibrium. To show that this is the unique equilibrium, note that the equilibrium rate r_{ID} can never be below r_{RRP}, otherwise all lending dealers would strictly prefer lending to the central bank, so supply and demand could not be equal. r_{ID} also cannot be below r_{RRP}, otherwise lenders would strictly prefer lending in the inter-dealer market, and funding supply and demand could not be equal.

Thus, we have shown that:

$$r_{ID} = \begin{cases} r_{nofloor,ID} & r_{nofloor,ID} \geqslant r_{RRP} \\ r_{RRP} & r_{nofloor,ID} < r_{RRP} \end{cases}$$

This is exactly (25). (27) follows from differentiating (25).

A.7   Proof of Claim 8

First, suppose that:

$$r_{nofloor,ID} \geqslant r_{RRP}$$

so the RRP rate does not bind. In this case, lending dealers weakly prefer lending in the inter-dealer market, compared to lending to the central bank using the RRP. Thus, all lending dealers lend in the inter-dealer market. However, since OTC depositors now have the option to lend at rate r_{RRP} to the central bank, depositors will never be willing to receive less than r_{RRP} for repo deposits from dealers. Hence, when negotiating rates with dealers, a depositor's outside option is the maximum of her value v_D and the policy rate r_{RRP}. That is, a depositor negotiates prices with dealers as if she had value:

$$\tilde{v}_D \equiv \max\left(v_D, r_{RRP}\right) \tag{37}$$

As in the baseline model, all depositors with value v_D greater than r_{ID} trade, but depositors now trade at rates:

$$r_D (v_D, \theta_D) = r_{ID} - \theta_D (r_{ID} - \tilde{v}_D) \tag{38}$$

Since all depositors with value v_D greater than r_{ID} trade, the set of OTC depositors who trade is unchanged from the baseline model. Lending dealers also do not use the RRP, so aggregate supply and demand of funds are unchanged from the baseline model. Hence, the equilibrium rate in the inter-dealer market must be:

$$r_{ID} = r_{nofloor,ID} \tag{39}$$

Plugging (39) into (38), and using the definition of $\tilde{v}_D$ from (37), we get:

$$r_D (v_D, \theta_D) = \begin{cases} r_{nofloor,ID} - \theta_D (r_{nofloor,ID} - v_D) & r_{nofloor,ID} < v_D \\ r_{ID} - \theta_D (r_{ID} - r_{RRP}) & v_D \leqslant r_{RRP} \leqslant r_{nofloor,ID} \end{cases}$$

This proves the first two cases of (29). Now, suppose that:

$$r_{nofloor,ID} < r_{RRP}$$

so the RRP rate does bind. Conjecture that there exists an equilibrium with

$$r_D (v_D, \theta_D) = r_{ID} = r_{RRP} \, \forall v_D, \theta_D$$

That is, the inter-dealer repo rate, as well as all OTC depositors' repo rates, are equal to r_{RRP}. In such an equilibrium, lending dealers and OTC depositors are indifferent between lending in the inter-dealer market and using the RRP. By an argument identical to Appendix A.6, lending dealers and OTC depositors lend a total net amount:

$$Q_{L,Dealer} (\rho - r_{RRP}) + Q_{D,OTC} (r_{RRP}) - Q_{B,OTC} (r_{RRP}) - Q_{B,Dealer} (r_{RRP})$$

of funds using the RRP facility, and the remainder is lent in the inter-dealer market. Supply and demand for funds are thus equal, so this is an equilibrium. In such an equilibrium, since OTC depositors have the outside option of using the RRP and receiving r_{RRP}, dealers cannot pay

depositors any rate lower than r_{RRP}. Hence, we must have

$$r_D(v_D, \theta_D) = r_{ID} = r_{RRP}$$

This equilibrium is unique, because the equilibrium rate r_{ID} can never be below r_{RRP}, otherwise all lending dealers and OTC depositors would strictly prefer lending to the central bank, so supply and demand could not be equal. r_{ID} also cannot be below r_{RRP}, otherwise lenders would strictly prefer lending in the inter-dealer market, and funding supply and demand could not be equal. This proves the third case of (29). Differentiating (29), we get (30). This proves all cases of Claim 8.

A.8 Identifying and estimating balance sheet costs

In the model, if we assume balance sheet costs are constant across dealers, balance sheet costs are identified as long as we observe customers trading the same collateral with two or more dealers. We illustrate this result using a simple example. Suppose we observe a borrowing customer, with value v_B, making identical trades with two different dealers, 1 and 2, who have identical balance sheet costs c_B. Suppose the customer has bargaining power θ_1 with the first dealer, and θ_2 with the second dealer, and $\theta_1 \neq \theta_2$. From (3), the prices the customer trades at are respectively:

$$r_{B1} = (1 - \theta_1)(r_{ID} + c_B) + \theta_1 v_B \tag{40}$$

$$r_{B2} = (1 - \theta_2)(r_{ID} + c_B) + \theta_2 v_B \tag{41}$$

From arguments in section 5, θ_1 and θ_2 are identified, utilizing the 2019 DFR rate cut to measure the pass-throughs $\frac{\partial r_{B1}}{\partial r_{ID}}, \frac{\partial r_{B2}}{\partial r_{ID}}$. Moreover, we observe the rates r_{B1} and r_{B2}. Thus, the only unknowns in equations (40) and (41) are c_B and v_B. We have two equations with two unknowns, hence c_B (and v_B) are identified.

An intuition behind this identification result is that, when one customer trades with two dealers, the repo rates are weighted averages of the dealers' common marginal cost, $r_{ID} + c_B$, and the customer's value v_B, with weight θ on the customer's value. If we observe two weighted averages of $r_{ID} + c_B$ and v_B, with different (known) weights, we can recover $r_{ID} + c_B$ and v_B. The identification of c_D for depositing customers is analogous.

Estimation. We will empirically estimate c_B and c_D as follows. Suppose we observe customers indexed by c, each of whom trades repo loans with multiple different dealers d, possibly with different collateral ISINs k from country m. Let θ_{cd} denote customer c's bargaining power with

dealer d. Each borrowing (depositing) customer c has some value v_{cm}^B (v_{cm}^D) for trading collateral from country m. We allow the inter-dealer repo rate, r_m^{ID}, to vary across collateral countries m. We assume dealers have balance sheet costs, c_B for borrowing customers and c_D for depositing customers.

From (3), customer c borrows cash from dealer d, secured by collateral k from country m, at rate:[16]

$$r_{cdmk}^B = (1 - \theta_{cd}) \left(r_m^{ID} + c_B \right) + \theta_{cd} v_{cm}^B + \varepsilon_{cdmk}^B, \tag{42}$$

where ε_{cdmk}^B is a conditionally mean-0 error term. Analogously, from (4), customer c deposits funds with dealer d, secured by collateral k of country m, at price:

$$r_{cdmk}^D = (1 - \theta_{cd}) \left(r_m^{ID} - c_D \right) + \theta_{cd} v_{cm}^D + \varepsilon_{cdmk}^D. \tag{43}$$

We can write (42) and (43) jointly as:

$$r_{cdmk} = (1 - \theta_{cd}) \gamma_m + (1 - \theta_{cd}) 1_{cdm}^B \tau + \theta_{cd} \mu_{cm} + \varepsilon_{cdmk}, \tag{44}$$

where 1_{cdmk}^B is a dummy variable equal to 1 for transactions where customer c borrows from dealer d, and 0 otherwise. From (42) and (43), we have:

$$\tau = c_B + c_D, \ \gamma_m = r_m^{ID} - c_D, \ \mu_{cm} = v_{cm}.$$

We first obtain θ_{cd} from the ID-OTC passthrough following the 2019 rate-cut for each dealer-customer pair. We then estimate specification (44) on the cross-section of repo trades in the pre-rate-cut week using residualized rates, r_{cdmk}, to ensure that variation is not driven by characteristics of repo loans, such as differences in collateral-ISINs. The terms γ_m and μ_{cm} are collateral country and customer-collateral-country fixed effects, respectively. Effectively, the estimated coefficient τ in specification (44) finds the value of balance sheet costs $c_B + c_D$ that best rationalize the relationship between repo rates in the pre-rate-cut period and pass-throughs observed in the data. Our estimate of τ is 3.774bps so that $\phi = 0.419$ from specification (33).[17]

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[16]Note that, compared to (3) and (4) we have moved some borrow and deposit indicators B, D for notational convenience.

[17]This estimate is comparable to, though slightly smaller than, estimates from other papers focusing on US banks, which measure dealers' balance sheet costs using spreads between different money market rates (Anderson, Du and Schlusche, 2019; Correa, Du and Liao, 2020; Copeland, Duffie and Yang, 2021) Our estimates may be lower because European banks are subject to less stringent leverage regulation than their US counterparts, where the leverage ratio is a particularly important constraint for extending repos.

Internet Appendix

IA   Additional Results and Robustness

IA.1   Net Interest Margins and Dispersion in GC versus SC Repos

This appendix shows the net interest margin and dispersion in repo rates and residualized repo rates separately for GC and SC repos.

Table IA.1: Net Interest Margin and Dispersion of Repo Rates (GC versus SC)

	SC Repo		GC Repo	
	Net Interest Margin	Dispersion	Net Interest Margin	Dispersion
DE RA Borrow	14.2	11.5	11.3	11.5
DE RA Lend		13.1		7.5
ES RA Borrow	6.1	5.9	4.7	4.0
ES RA Lend		10.2		4.1
FR RA Borrow	8.9	9.4	6.5	9.6
FR RA Lend		9.8		3.4
IT RA Borrow	11.1	6.6	12.5	5.7
IT RA Lend		8.5		3.1

Notes. This table shows the average net interest margins and dispersion of repo rates at which dealers lend and borrow in the OTC market for SC and GC repos. The net interest margin and standard deviation for the residualized repo rates are calculated monthly from February 2017 to February 2020 for each country segment. Their time-series averages are displayed in the table. Data are from the MMSR.

Table IA.2: Net Interest Margin and Dispersion of Residualized Rates (GC versus SC)

| | SC Repo | | GC Repo | |
	Net Interest Margin	Dispersion	Net Interest Margin	Dispersion
DE RA Borrow	9.9	6.4	11.4	10.9
DE RA Lend		7.3		7.7
ES RA Borrow	4.5	5.5	3.1	4.4
ES RA Lend		4.4		4.5
FR RA Borrow	6.8	6.0	2.1	7.7
FR RA Lend		5.5		3.9
IT RA Borrow	7.1	5.0	11.9	5.9
IT RA Lend		3.8		3.1

Notes. This table shows the average net interest margins and dispersion of residualized repo rates at which dealers lend and borrow in the OTC market for SC and GC repos. Residualized repo rates are obtained according to specification (1). The net interest margin and standard deviation for the residualized repo rates are calculated monthly from February 2017 to February 2020 for each country segment. Their time-series averages are displayed in the table. Data are from the MMSR.

IA.2 Monetary Policy Pass-through in Short-Maturity Repos

Appendix Figure IA.1 shows how the 2019 rate cut affected rates, separately for O/N, T/N, and S/N trades. All three groups are trades with one-day maturity. However, in an overnight (O/N) trade at date T, money is lent at business day T and returned at business day $T+1$. In a tomorrow-next (T/N) trade, traders agree to money is lend from $T+1$ and return it at $T+2$, and a spot-next trade corresponds to lending from $T+2$ to $T+3$. We would thus expect the deposit facility rate cut to change O/N rates immediately after it is implemented, to change T/N rates one business day earlier than the implementation date, and S/N trades two business days earlier. Appendix Figure IA.1 shows that these patterns hold for all kinds of collateral.

Appendix Tables IA.3, IA.4, and IA.5 then show results from estimating the specifications in Tables 3, 4, and 5 in the main text, restricting the sample to repo trades with maturities at most one week. The results remain qualitatively the same and quantitatively similar as in the baseline results.

Figure IA.1: September 2019 Rate Cut by Repo Maturity
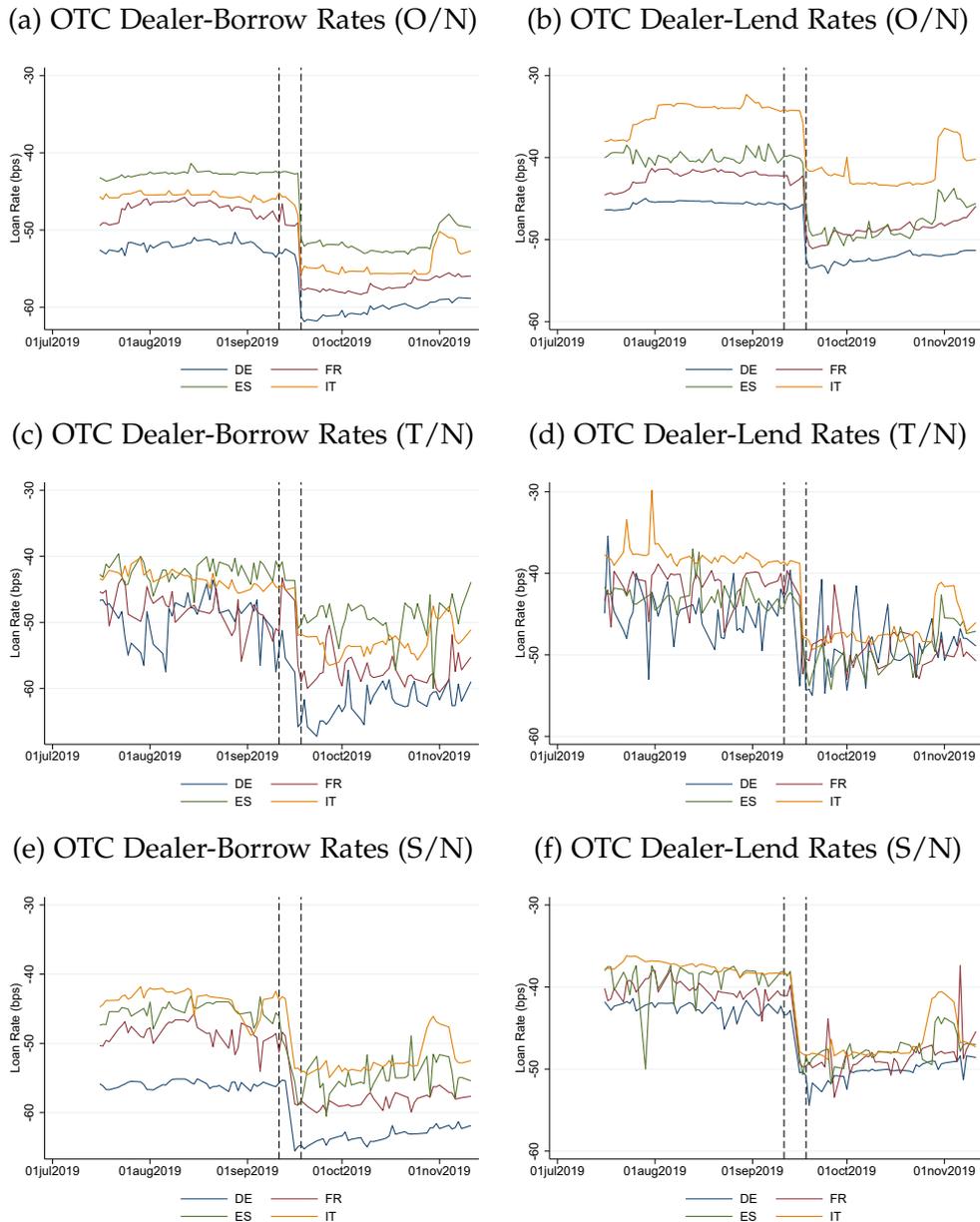
(a) OTC Dealer-Borrow Rates (O/N)

(b) OTC Dealer-Lend Rates (O/N)

(c) OTC Dealer-Borrow Rates (T/N)

(d) OTC Dealer-Lend Rates (T/N)

(e) OTC Dealer-Borrow Rates (S/N)

(f) OTC Dealer-Lend Rates (S/N)

Notes. This figure shows the value-weighted average daily repo rates for German, French, Italian, and Spanish government collateral around the monetary policy rate cut in September 2019. Subfigures (a) and (b), (c) and (d), and (e) and (f) correspond to O/N, T/N, and S/N repo rates at which dealers borrow and lend in the OTC market, respectively The dotted vertical lines represent September 12, 2019, and September 18, 2019, which correspond to the announcement and implementation of a 10 basis point rate cut on the ECB's Deposit Facility Rate. Some data points have been omitted due to confidentiality reasons.

Table IA.3: ID-OTC Pass-through (< 1 week maturity)

	(1) DE	(2) FR	(3) ES	(4) IT
p75-p25 Loan Rate$_k$	-1.523*	-2.380**	-1.473	-1.139**
	[0.862]	[0.993]	[0.943]	[0.483]
RA Lend	-15.191***	-10.062*	-9.346**	-2.144
	[5.065]	[5.077]	[4.502]	[3.247]
Constant	90.041***	108.595***	97.821***	93.160***
	[3.315]	[4.200]	[3.779]	[2.550]
Observations	104	108	100	172
Adj. R-squared	0.08	0.06	0.04	0.02

Notes. This table shows the results from specification (19), in which we regress estimated ID-OTC pass-through on the interquartile range in OTC loan rates in the pre-rate-cut period. To calculate the dependent variable, Passthrough$_k^{\text{ID\_OTC}}$, we first measure DFR-ID and DFR-OTC pass-through as in specification (18), by taking pre- and post-rate-change average repo rates for ISIN k in the inter-dealer and OTC segments, respectively. We then calculate ID-OTC pass-through for ISIN k as the ratio of DFR-OTC and DFR-ID pass-throughs for ISIN k. p75-p25 Loan Rate$_k^{\text{pre}}$ is the interquartile range from all OTC trades in which the dealers lend (borrow) in the pre-rate-cut period for collateral k, expressed in bps. RA Lend is a dummy variable equal to one when the dealer is the lender. Each collateral country is shown in a separate column. We restrict the sample to repo trades with maturity at most 1 week.

Table IA.4: Residualized OTC Pass-through and OTC Rates (< 1 week maturity)

	(1)	(2)	(3)	(4)	(5)	(6)
	RA Borrow Passthrough			RA Lend Passthrough		
Loan Rate$_{cmns}^{pre,resid}$	2.455***	2.724***	4.436***	-2.451***	-2.361***	-0.424
	[0.569]	[0.581]	[0.586]	[0.659]	[0.540]	[0.649]
ES	-23.154***	-18.506**	16.484**	24.877**	9.497	18.051**
	[6.067]	[6.403]	[8.263]	[10.935]	[9.140]	[8.734]
FR	-8.315	-1.933	-1.390	15.690	18.549**	31.797**
	[7.603]	[7.911]	[7.359]	[10.070]	[8.332]	[9.951]
IT	4.580	7.948	8.797	-1.945	-10.246	3.448
	[6.180]	[4.374]	[5.990]	[7.675]	[6.748]	[10.264]
Constant	94.166***	90.773***	77.857***	76.338***	80.781***	59.760***
	[4.062]	[4.253]	[4.373]	[8.099]	[6.177]	[7.703]
Cntp Country	No	No	Yes	No	No	Yes
Cntp Sector	No	Yes	Yes	No	Yes	Yes
Observations	396	396	395	181	181	181
Adj. R-squared	0.064	0.071	0.216	0.092	0.397	0.570

Notes. This table shows the results from specification (20), in which we regress estimated customer-level DFR-OTC pass-through against the customer's OTC residualized loan rates in the pre-rate-cut period. The first and last three columns show the results for transactions in which dealers borrow and lend, respectively. To calculate the dependent variable, we first residualize repo rates, and then calculate Passthrough$_{cmns}^{DFR\_OTC,resid}$, by taking the difference between pre- and post-rate-change average OTC repo rate residuals for customer c from country n and sector s, trading collateral of country m, and dividing by the rate cut of -10bps. The dependent variable, Loan Rate$_{cmns}^{pre,resid}$, is the average residual of customer c trading collateral of country m, for transactions in the pre-rate-cut period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. The pre-rate-cut period refers to the week before the announcement. We restrict the sample to repo trades with maturity at most 1 week.

Table IA.5: Residualized OTC Pass-through and OTC Rates (Bilateral) (< 1 week maturity)

	(1)	(2)	(3)	(4)
	RA Borrow		RA Lend	
Loan Rate$_{cdm}^{pre,resid}$	2.568***	2.985***	-0.894***	-0.223
	[0.305]	[0.318]	[0.325]	[0.403]
ES	-9.651**	17.863***	16.897**	15.046*
	[3.932]	[4.779]	[7.830]	[7.977]
FR	-0.929	3.295	12.829	11.311
	[4.409]	[4.075]	[7.772]	[7.358]
IT	-4.561	0.452	8.949	4.220
	[3.599]	[3.382]	[5.448]	[5.390]
Constant	87.871***	80.690***	69.570***	68.265***
	[2.243]	[2.186]	[4.796]	[5.220]
Cntp	No	Yes	No	Yes
Observations	456	451	245	239
Adj. R-squared	0.15	0.30	0.04	0.19

Notes. This table shows the results from specification (21), in which we regress estimated customer-dealer-level DFR-OTC pass-through against the customer-dealer pair's OTC residualized loan rates in the pre-rate-cut period. The first and last two columns show the results for transactions in which dealers borrow and lend, respectively. To calculate the dependent variable, we first residualize repo rates, and then calculate Passthrough$_{cdm}^{DFR\_OTC,resid}$, by taking the difference between pre- and post-rate-change average OTC repo rate residuals for customer c, dealer d, trading collateral of country m, and dividing by the rate cut of -10bps. The dependent variable, Loan Rate$_{cdm}^{pre,resid}$, is the average residual of customer c, dealer d trading collateral of country m, for transactions in the pre-rate-cut period. *FR, IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. We restrict the sample to repo trades with maturity at most 1 week.

IB   Additional Theoretical Results

IB.1   Heterogeneous Intermediation Costs

In the baseline model, we assumed dealers face no costs for intermediating repo trades with customers: this may not hold in practice. For example, dealers' balance sheet space may be costly, so dealers may charge margins on repo trades to reflect this. Dealers may also charge customers margins valuation adjustments (XVAs) based on the dealer's perception of credit risk from dealing with the customer, and these costs may differ across different customers (Cenedese, Ranaldo and Vasios (2020)). When dealers are lending cash, as long as haircuts are sufficiently large, dealers should face essentially no risk. However, dealers who borrow cash against collateral face some risk of "repo runs", where customers fail to return collateral (Infante and Vardoulakis (2018)).

In this appendix, we show how intermediation costs would affect outcomes in the OTC market. To begin with, Internet Appendix IB.1.1 solves for net interest margins, rate dispersion, and rate pass-through assuming that dealers have no market power, but may have intermediation costs which differ across customers. We show that heterogeneous costs can rationalize net interest margins and rate dispersion, but not heterogeneous ID-OTC pass-through. Thus, heterogeneous costs alone cannot produce Predictions 1 and 2 about pass-through. For simplicity, throughout the appendix, we take the equilibrium repo rate in the inter-dealer market, r_{ID}, as given.

In Internet Appendix IB.1.2, we solve for outcomes when dealer have market power, and also face heterogeneous intermediation costs. The outcomes essentially combine the effects of market power and intermediation costs.

IB.1.1   Competitive Markets with Intermediation Costs

Suppose that dealers, when they lend to customers, face some cost c_B per unit repo that they intermediate. On the borrowing side, suppose dealers' costs are c_D. c_B and c_D could represent a number of factors, such as balance sheet costs, or on the deposits side, the possibility that the depositor fails to return the dealer's collateral, as in the "repo runs" literature (Infante and Vardoulakis (2018)). We allow c_B and c_D to differ across customers, but we assume c_B and c_D are fixed as other quantities, such as the inter-dealer rate r_{ID}, vary.

Intermediation costs imply that the break-even rate for dealers to lend in the repo market, for a customer of type c_B, is $r_{ID} + c_B$, and the break-even rate for taking deposits is $r_{ID} - c_D$. To begin with, we assume that markets are perfectly competitive, so dealers lend at exactly their

intermediation costs. This is equivalent to assuming that dealers set prices with zero bargaining power over customers. The following claim characterizes market outcomes.

Claim 9. *Suppose* $\theta_B = 0, \theta_D = 0$. *Rates are:*

$$r_B(v_B, c_B, r_{ID}) = r_{ID} + c_B$$

$$r_B(v_B, c_B, r_{ID}) = r_{ID} + c_B$$

Net interest margins are:

$$E[r_B(v_B, c_B, r_{ID}) \mid v_B > r_{ID} + c_B] - E[r_D(v_D, c_D, r_{ID}) \mid v_D < r_{ID} - c_D] =$$
$$E[c_B \mid v_B > r_{ID} + c_B] + E[c_D \mid v_D < r_{ID} - c_D] \quad (45)$$

Rate dispersion is:
$$\text{Var}[r_B(v_B, c_B, r_{ID})] = \text{Var}[c_B \mid v_B > r_{ID} + c_B]$$

$$\text{Var}[r_D(v_D, c_D, r_{ID})] = \text{Var}[c_D \mid v_D < r_{ID} - c_D]$$

Rate pass-through is:
$$\frac{dr_B(v_B, c_B, r_{ID})}{dr_{ID}} = 1 \quad (46)$$

$$\frac{dr_D(v_D, c_D, r_{ID})}{dr_{ID}} = 1 \quad (47)$$

Proof. This is a special case of Claim 10 below, setting dealers' bargaining power to $\theta_B = \theta_D = 0$.
$\square$

Claim 9 shows that heterogeneous costs can explain both net interest margins and rate dispersion. Expression (45) shows that even if markets are competitive, positive costs for intermediation will cause dealers to attain a net interest margin. This is intuitive: for example, if $c_D = c_B = c$, so dealers have some cost of intermediation, dealers will charge a net interest margin to cover that marginal cost, even in competitive markets. Expressions (9) and (9) show that, if costs are heterogeneous across consumers, this also can create dispersion in competitive markets. Intuitively, dispersion in repo rates simply reflects dispersion in costs across customers.

Expressions (46) and (47) shows that, in competitive markets, the pass-through of r_{ID} to borrow and deposit rates should be perfect. Intuitively, this is because, if r_{ID} moves, but costs c_B and c_D do not change, individual customers' rates should move one-to-one with r_{ID}. Thus,

heterogeneous costs alone cannot generate imperfect pass-through. As a result, heterogeneous intermediation costs alone cannot generate Predictions 1 and 2, which explain why pass-through is correlated with rate dispersion in the OTC market, and why pass-through differs across OTC customers who receive different rates.

IB.1.2 Bargaining Power and Intermediation Costs

In the general case, we assume that OTC repo rates are still set through Nash bargaining, but dealers use their break-even rates as outside options. On the loan side, dealers will lend to all borrowers with values higher than the inter-dealer interest rate r_{ID} plus the dealer's intermediation cost c_B, that is, $v_B > r_{ID} + c_B$. The rate for a customer with value v_B, bargaining power θ_B is:

$$r_B\left(v_B, \theta_B, c_B, r_{ID}\right) = r_{ID} + c_B + \theta_B\left(v_B - [r_{ID} + c_B]\right) \qquad (48)$$

Similarly, on the deposits side, all depositors with values $v_D < r_{ID} - c_D$ deposit, and attain rates:

$$r_D\left(v_D, \theta_D, c_D, r_{ID}\right) = r_{ID} - c_D - \theta_D\left([r_{ID} - c_D] - v_D\right) \qquad (49)$$

These pricing equations are analogous to (3) and (4) in the main text, except that they have additional terms for dealers' intermediation costs. The following claim characterizes net interest margins, rate dispersion, and rate pass-through in the presence of intermediation costs.

Claim 10. *Net interest margins are:*

$$
\begin{aligned}
\mathsf{E}\left[r_B\left(v_B, \theta_B, c_B, r_{ID}\right) \mid v_B > r_{ID} + c_B\right] &- \mathsf{E}\left[r_D\left(v_D, \theta_D, c_D, r_{ID}\right) \mid v_D < r_{ID} - c_D\right] = \\
&\underbrace{\mathsf{E}\left[c_B \mid v_B > r_{ID} + c_B\right] + \mathsf{E}\left[c_D \mid v_D < r_{ID} - c_D\right]}_{Balance\ Sheet\ Costs} + \\
&\underbrace{\mathsf{E}\left[\theta_B\left(v_B - r_{ID}\right) \mid v_B > r_{ID} + c_B\right] + \mathsf{E}\left[\theta_D\left(r_{ID} - v_D\right) \mid v_D < r_{ID} - c_D\right]}_{Market\ Power} \quad (50)
\end{aligned}
$$

Rate dispersion is:

$$\text{Var}\left[r_B\left(v_B,\theta_B,c_B,r_{ID}\right)\right] =$$
$$\underbrace{\text{Var}\left[\text{E}\left[\left(r_{ID}+c_B\right)+\theta_B\left(v_B-\left[r_{ID}+c_B\right]\right)\mid c_B, v_B > r_{ID}+c_B\right]\mid v_B > r_{ID}+c_B\right]}_{\text{Balance Sheet Costs}} +$$
$$\underbrace{\text{E}\left[\text{Var}\left[\theta_B\left(v_B-\left[r_{ID}+c_B\right]\right)\mid c_B, v_B > r_{ID}+c_B\right]\mid v_B > r_{ID}+c_B\right]}_{\text{Market Power}} \quad (51)$$

$$\text{Var}\left[r_D\left(v_D,\theta_D,c_D,r_{ID}\right)\right] =$$
$$\underbrace{\text{Var}\left[\text{E}\left[\left(r_{ID}-c_D\right)-\theta_D\left(\left[r_{ID}-c_D\right]-v_D\right)\mid c_B, v_D < r_{ID}-c_D\right]\mid v_D < r_{ID}-c_D\right]}_{\text{Balance Sheet Costs}} +$$
$$\underbrace{\text{E}\left[\text{Var}\left[\theta_D\left(\left[r_{ID}-c_D\right]-v_D\right)\mid c_B, v_D < r_{ID}-c_D\right]\mid v_D < r_{ID}-c_D\right]}_{\text{Market Power}} \quad (52)$$

Rate pass-through is:

$$\frac{dr_B\left(v_B,\theta_B,c_B,r_{ID}\right)}{dr_{ID}} = 1-\theta_B \quad (53)$$

$$\frac{dr_D\left(v_D,\theta_D,c_D,r_{ID}\right)}{dr_{ID}} = 1-\theta_D \quad (54)$$

Proof. To prove (50), apply (48), and use linearity of expectations, to get:

$$\text{E}\left[r_B\left(v_B,\theta_B,c_B,r_{ID}\right)\mid v_B \geqslant r_{ID}+c_B\right] =$$
$$r_{ID}+\text{E}\left[c_B\mid v_B \geqslant r_{ID}+c_B\right] +$$
$$\text{E}\left[\theta_B\left(v_B-\left[r_{ID}+c_B\right]\right)\mid v_B \geqslant r_{ID}+c_B\right]$$

This applies to (49) as well. Taking the difference, we get (50).

For rate dispersion, we can take the variance of borrow rates (48). Applying the rule of iterated expectations with respect to intermediation costs c_B, we have:

$$\text{Var}\left[r_{ID}+c_B+\theta_B\left(v_B-\left[r_{ID}+c_B\right]\right)\mid c_B, v_B > r_{ID}+c_B\right] =$$
$$\text{Var}\left[\text{E}\left[r_{ID}+c_B+\theta_B\left(v_B-\left[r_{ID}+c_B\right]\right)\mid c_B, v_B > r_{ID}+c_B\right]\right] +$$
$$\text{E}\left[\text{Var}\left[r_{ID}+c_B+\theta_B\left(v_B-\left[r_{ID}+c_B\right]\right)\mid c_B, v_B > r_{ID}+c_B\right]\right] \quad (55)$$

Now,

$$Var\left[r_{ID} + c_B + \theta_B\left(v_B - [r_{ID} + c_B]\right) \mid c_B, v_B > r_{ID} + c_B\right] =$$
$$Var\left[\theta_B\left(v_B - [r_{ID} + c_B]\right) \mid c_B, v_B > r_{ID} + c_B\right]$$

hence, (55) simplifies somewhat, to (51). (52) follows analogously.

For pass-through, (53) and (54) follow by differentiating (48) and (49) with respect to r_{ID}.

□

Expression (50) for net interest margins, and expressions (51) and (52) for borrow and lend rate dispersion, are complex, but intuitively they contain terms attributable to market power and to intermediation costs. For example, net interest margins contain a term which reflects the expectation of dealers' intermediation costs, conditional on trade:

$$E\left[c_B \mid v_B > r_{ID} + c_B\right] + E\left[c_D \mid v_D < r_{ID} - c_D\right]$$

and a term, analogous to (5) in the main text, which reflects dealers' market power over customers:

$$E\left[\theta_B\left(v_B - r_{ID}\right) \mid v_B > r_{ID} + c_B\right] + E\left[\theta_D\left(r_{ID} - v_D\right) \mid v_D < r_{ID} - c_D\right]$$

Similarly, (51) decomposes the variance of borrow rates into a term attributable to variation in the conditional expectation of rates given intermediation costs, and the expectation of the variance of rates conditional on intermediation costs. Both terms are affected by all parameters, but the first term can be thought of as somewhat more linked to intermediation costs, whereas the second is linked more to variance in customers' values and bargaining power.

As in Claim 9, (53) and (54) show that pass-through only depends on bargaining power, and is unaffected by intermediation costs.

IB.2 Competition and Bargaining Power

In this appendix, we build a simple extension to the baseline model, which rationalizes the stylized facts documented in Subsection 3.5: counterparties who trade higher volumes, and who have more links, trade at better prices. For simplicity, throughout this appendix, we take the equilibrium repo rate in the inter-dealer market, r_{ID}, as given.

We construct a simple endogenous network formation game, with prices determined by

bilateral Nash bargaining. A customer wishes to borrow a volume M in the repo market, and she has value v_B per unit that she borrows. Unlike in the main text, we allow M as well as v_B to differ across customers. Customers may also form relationships with more than one dealer. We assume prices are determined by bilateral Nash bargaining with renegotiable contracts, as in Stole and Zwiebel (1996), which yields bargaining outcomes that depend on the number of dealers N that a customer has formed relationships with. The game proceeds in two stages.

1. Customers choose the number of dealers, N, that they wish to form a trading relationship with. In order to form a relationship, customers and dealers must each pay cost C_C. These costs can be thought of as logistical costs, borne by both the customer and the dealer, of setting up infrastructure to begin trading. Once these costs are paid, they are sunk and irreversible for both dealers and the customer. Links will form until the point where the marginal customer and dealers' expected surplus from forming a link does not exceed their costs.

2. In the second stage, the customer and the N dealers she has trading relationships with engage in bilateral Nash bargaining to determine the division of surplus. In addition to the trading gains mentioned in the main model, $v_B - r_{ID}$, we assume there are costs $C_T + Mc$ for the dealer executing a given trade of size M. C_T is a fixed cost per trade: we can think of this cost as, for example, a platform trading fee, or labor and operational costs of arranging a particular trade with the client. Mc is a variable cost component, which may arise from balance sheet costs or XVAs, as we discussed in Internet Appendix IB.1.

We will solve the game backwards. In the second stage, suppose a customer has formed relationships with N dealers. For a given trade of size M that the customer makes, the joint trade surplus is:

$$\underbrace{M\left(v_B - r_{ID} - c\right)}_{\text{Trading Gains}} - \underbrace{C_T}_{\text{Dealer Fixed Costs}} \tag{56}$$

We assume that surplus is split between the customer and the N dealers as in Stole and Zwiebel (1996). Suppose the customer approaches N dealers to trade, and considers approaching $N+1$ dealers: we assume that the marginal surplus accruing to the customer is equal to the marginal surplus which accrues to the $(N+1)$st dealer. Stole and Zwiebel (1996) show that this is equivalent to assuming that surplus is split according to agents' *Shapley values* (Shapley (1953)).

In the first stage, given expected outcomes from forming relationships with N dealers in the second stage, customers decide how many dealers N to optimally form relationships with. Since

both customers and dealers pay the fixed relationship cost C_C, each of the N dealers that the customer forms relationships with must have expected surplus greater than C_C, for this value of N to constitute an equilibrium. The following claim characterizes the unique equilibrium values of N, repo prices, and the customer's expected surplus.

Claim 11. *Suppose a customer has trading volume M, and value v_B. The customer trades with each of N dealers she has a trading relationship with with equal probability $\frac{1}{N}$. the price she gets per unit repo that she trades is:*

$$p = \left(\frac{1}{N+1} v_B + \frac{N}{N+1} (r_{ID} + c) \right) + \frac{C_T}{M} \tag{57}$$

The customer has expected utility:

$$\frac{N}{N+1} [M (v_B - r_{ID} - c) - C_T] \tag{58}$$

Where N is the number of dealers that the customer chooses to form trading relationships with, which is:

$$N = \max \left[\text{floor} \left[\frac{-3 + \sqrt{1 + 4\kappa}}{2} \right], 0 \right] \tag{59}$$

where:

$$\kappa \equiv \frac{M (v_B - r_{ID} - c) - C_T}{C_C} \tag{60}$$

The number of dealers a customer forms trading relationships with is weakly increasing in M and v_B, and weakly decreasing in C_T and C_C.

In Appendix Figure IA.2, we use the expressions of Claim 11 to simulate the equilibrium values of N and p, as a function of trade volume N. Qualitatively, the model works as follows. By forming relationships with more dealers, the customer pays more sunk costs C_C upfront, but gets a larger share of the trade surplus. N is chosen to optimally trade off these forces. Thus, customers who have higher values v_B, and who trade larger volumes M, relative to the relationship cost C_C and the per-trade cost C_T, will form relationships with more dealers. Repo prices are then determined by expression (57). Prices are set to give the customer a share $\frac{N}{N+1}$ of the bilateral trade surplus. There is a $\frac{C_T}{M}$ term in prices, which reflects the payment needed to cover dealers' fixed trading costs. The trading cost term affects prices less for larger trades.

Claim 11 and Figure IA.2 show that the model gives two predictions, which match the observations in our data.

Prediction 3. *Customers who form more links trade at better prices.*

Prediction 4. *Controlling for the number of links, customers who trade larger volumes trade at better prices.*

Predictions 3 and 4 follow from the pricing equation (57), and the right panel of Appendix Figure IA.2. Forming relationships with more dealers allows the customer to trade at better prices, since the customer's outside option in bargaining with each dealer is improves with the number of dealers the customer has trading relationships with. Moreover, fixing the number of dealers a customer has relationships with, customers who trade larger volumes get better prices, since they can amortize dealers' fixed costs C_C over a larger volume of repo trades. Together, Predictions 3 and 4 show how this model extension rationalizes the patterns observed in the data.

Note that, while fixed costs are not present in the model of the main text, this model has the same pass-through predictions as our baseline model. To see this, note that, differentiating the pricing equation (57) with respect to r_{ID}, we have:

$$\frac{\partial p}{\partial r_{ID}} = \frac{N}{N+1}$$

Hence, pass-through is the same as if dealers had bargaining power

$$\theta_B = \frac{1}{N+1}$$

with customers. This model can thus be thought of as one possible microfoundation for the model of the main text: bargaining power could be determined partially by how many dealers a customer forms relationships with, which itself is determined by how much volume the customer expects to trade.

IB.2.1   Proof of Claim 11

The derivations here closely follow Stole and Zwiebel (1996), with notation adapted to our setting. First, suppose the customer has formed relationships with N dealers, and is considering the set of dealers to trade with. If the customer trades with no dealers, the joint surplus is 0. If the customer trades with at least one dealer, the joint surplus available to the customer and the dealers is (56), that is:

$$S = M \left(v_B - (r_{ID} + c) \right) - C_T \tag{61}$$

Now, to calculate prices and outcomes, we proceed inductively. Let $t(N)$ denote a dealer's expected surplus, when there are N dealers considered to trade with. The customer's surplus is

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Figure IA.2: Dealer relationship number and prices with endogeneous link formation
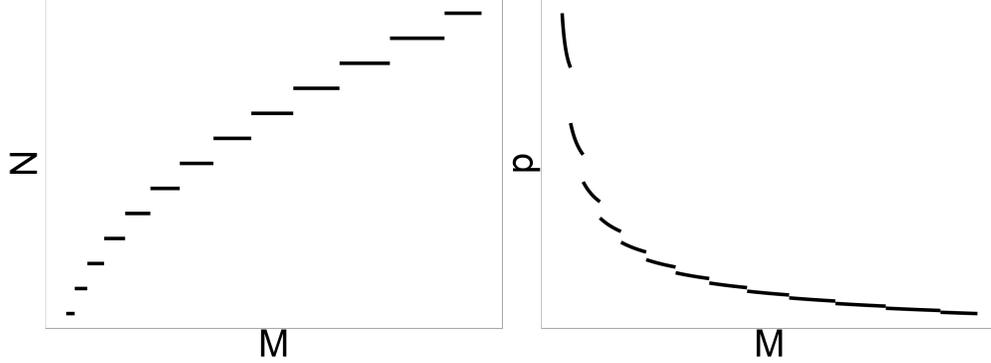
Notes. The left panel shows the total number of dealer N that a customer forms relationships with, as a function of trade volume M. The right panel shows the customer's trade price p, as M (and thus N) vary. Throughout, we set $v_B = 1, r_{ID} = 0, c = 0, C_T = 0.02, C_C = 0.05$.

then the total surplus less what is paid to dealers, that is:

$$S - Nt(N) \tag{62}$$

As in Stole and Zwiebel (1996), we assume that, when the customer considers an additional dealer, the net surplus is split equally between the customer and the marginal dealer. When the customer considers trading with a single dealer, the dealer must get half of the surplus, so:

$$t(1) = \frac{S}{2}$$

and the customer's surplus is:

$$S - t(1)$$

For the induction step, suppose the customer considers trading with N dealers. Letting $t(N)$ denote dealers' expected trade surplus when there are N dealers, The marginal surplus which accrues to the customer, if she expands the set of dealers considered to N instead of $N-1$ dealers, is thus:

$$[S - Nt(N)] - [S - (N-1)t(N-1)]$$

$$= (N-1)\,t\,(N-1) - Nt\,(N)$$

The utility accruing to the Nth entering dealer is simply $t\,(N)$. Split-the-difference bargaining means that the customer and the Nth dealer must have equal surplus, hence:

$$t\,(N) = (N-1)\,t\,(N-1) - Nt\,(N)$$

$$\implies t\,(N) = \frac{N-1}{N+1}t\,(N-1) \tag{63}$$

The unique solution to (63) is:

$$t\,(N) = \frac{S}{N\,(N+1)} \tag{64}$$

To calculate the customer's trade surplus, we plug (64) into (62), to get:

$$S - Nt\,(N) = S\left(\frac{N}{N+1}\right) \tag{65}$$

Plugging (61) into (65), we get (58). Now, to interpret these surplus splits as prices, note that the price p must be set so that the customer gets surplus (58), so we must have:

$$M\,(v_B - p) = \frac{N}{N+1}\,[M\,(v_B - (r_{ID} + c)) - C_T]$$

Solving for p, we have:

$$p = \left(\frac{1}{N+1}v_B + \frac{N}{N+1}\,(r_{ID} + c)\right) + \frac{C_T}{M}$$

This is (58). The surplus dealers get from trade is thus:

$$M\,(p - (r_{ID} + c)) - C_T = \frac{1}{N+1}\,(v_B - (r_{ID} + c))$$

In order for surplus to be split equally among the N dealers, the customer must trade with each dealer with equal probability, so each dealer's expected utility is:

$$\frac{1}{N\,(N+1)}\,(v_B - (r_{ID} + c)) \tag{66}$$

To determine how many dealers the customer will form relationships with in the first stage, note that if the customer forms trading relationships with to N dealers, her expected utility, net of

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her fixed relationship costs NC_C, is (58), that is:

$$\frac{N}{N+1} [M(v_B - (r_{ID} + c)) - C_T] - NC_C \qquad (67)$$

The customer will choose N to maximize (67). Taking the first difference of (67), the difference between the customer's expected utility with $N+1$ dealers and N dealers is:

$$\underbrace{\frac{1}{(N+1)(N+2)} [M(v_B - (r_{ID} + c)) - C_T]}_{Marginal\ customer\ surplus} - \underbrace{C_C}_{Relationship\ cost} \qquad (68)$$

Expression (68) is strictly decreasing in N, so there is a unique value of N where (68) becomes negative. The optimal choice of N, with integer contraints, is the smallest integer larger than the value of N which sets (68) to 0. First, setting (68) to 0 and rearranging, we have:

$$(N+1)(N+2) = \frac{M(v_B - (r_{ID} + c)) - C_T}{C_C}$$

Defining κ as in (60), we then have (59). Now, to verify that dealers are also willing to pay the fixed relationship cost, note from (66), with $(N+1)$ dealers, dealers' expected surplus is:

$$\frac{1}{(N+1)(N+2)} [M(v_B - r_{ID} - c) - C_T]$$

This is exactly the customer surplus term in (68). Hence, if the customer has marginal surplus greater than C_C for forming a relationship with the Nth dealer, the Nth dealer will also have expected surplus greater than C_C. Thus, the value of N characterized in (59) is the unique equilibrium of this game.

IB.3   Intuition for DFR-ID passthrough

Appendix Figure IA.3 graphically shows the intuition behind DFR-ID passthrough, expression (15) of Claim 4. We can write (14), the equilibrium condition in the inter-dealer market, as:

$$Q_{L,Dealer}(\rho - r_{ID}) = Q_{B,OTC}(r_{ID}) + Q_{B,Dealer}(r_{ID}) - Q_{D,OTC}(r_{ID}). \qquad (69)$$

In words, (69) says that the supply of funds from lending dealers must equal the net demand from all other kinds of agents: borrowing dealers, and the demand from OTC borrowers minus the sup-

ply from OTC depositors. In both panels of Figure IA.3, the red curve shows $Q_{L,Dealer}(\rho - r_{ID})$, and the blue curve shows net demand from all other agents, that is, all terms on the right-hand side of (69).

In the left panel, the red curves are relatively flat, so lending dealers' funding supply is relatively inelastic, and the blue curve is relatively steep, so the market demand for funding is relatively elastic. If the Deposit Facility Rate ρ rises slightly, r_{ID} cannot one-for-one, since the demand for funds would decrease too much, so r_{ID} will be relatively insensitive to changes in ρ. In the right panel, the red curves are steep, so lending dealers have elastic funding supply, and the blue curve is relatively flat, so the market demand for funding is inelastic. If ρ rises, r_{ID} must increase approximately one-for-one to keep loan supply constant, so r_{ID} will be very sensitive to changes in ρ.[18]

Claim 4 allows us to interpret the stylized fact, which we document in subsection 5.2 in the main text, that pass-through is negatively correlated with specialness spreads. If pass-through is lower for collateral with higher specialness spreads, the funding supply (collateral demand) from dealers is relatively inelastic, and the net funding demand (collateral supply) from other market participants is relatively elastic.

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[18]Claim 4 also shows why it is important to assume that funding supply and demand are both imperfectly elastic for modeling pass-through. If all lending dealers had infinite willingness-to-pay for collateral, then (15) implies that DFR-ID pass-through would always be 0, regardless of the elasticity of funding demand. This is rejected in the data: in the following section, we show that the 2019 rate change had a statistically significant and fairly large effect on repo rates. This suggests that there are at least some funding suppliers in special repo markets who are willing to stop lending if specialness spreads are too large.

Figure IA.3: DFR - ID Pass-through Intuition

(a) Low Pass-through

Quantity

$Q_{L,Dealer} (\rho - r)$

Demand

Repo rate

r_{ID}^1 r_{ID}^2 ρ^1 ρ^2

(b) High Pass-through

Quantity

$Q_{L,Dealer} (\rho - r)$

Demand

Repo rate

r_{ID}^1 r_{ID}^2 ρ^1 ρ^2
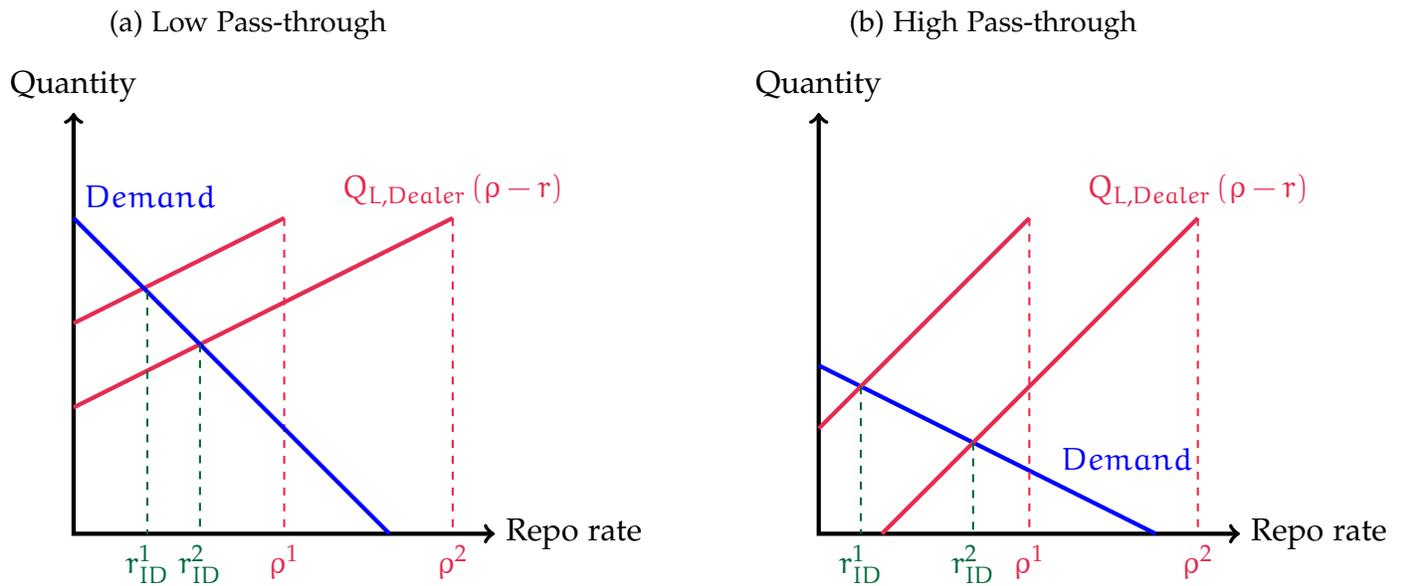
Notes. Intuition for pass-through. In each panel, the red lines represent the supply of repo funding from lending dealers, $Q_{L,Dealer} (\rho - r)$, for two different values of ρ, and the blue lines represent net funding demand from other market participants, $Q_{B,OTC} (r) + Q_{B,Dealer} (r) - Q_{D,OTC} (r)$. The left plot illustrates a case where lending dealers' funding supply is inelastic and net funding demand is elastic, so pass-through is low. The right plot illustrates a case where funding supply is elastic and funding demand is inelastic, so pass-through is high.