Monetary Policy Transmission in Segmented Markets*

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Abstract

Repo markets are an important first stage of monetary policy transmission. In the European repo market, the majority of participants, including non-dealer banks and non-banks, do not have access to centralized trading platforms. Rather, they rely on OTC intermediation by a small number of dealers that exert significant market power. Dealer market power causes the passthrough of the ECB's policy rate to be inefficient and unequal. Allowing market participants access to centralized trading platforms, or a secured deposit facility with the central bank, could improve the transmission efficiency of monetary policy while reducing the dispersion in repo rates across customers.

Keywords: Monetary policy, passthrough 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. Repos appear to be safe and standardized contracts: they have short terms, and are often fully collateralized or over-collateralized by government bonds. Nonetheless, repo rates in the euro area have become increasingly dispersed and disconnected from the European Central Bank's (ECB) main policy rates. An important question is what imperfections are present in repo markets, and whether they have the potential to impede the efficient transmission of monetary policy.

We show that dealer market power creates significant frictions for monetary policy passthrough in the European repo market. We find that even identical repo contracts fully secured by the same collateral trade at substantially different rates for the vast majority of market participants. This rate dispersion arises because dealer banks enjoy near-exclusive access to centralized repo trading platforms while other market participants, like mutual funds, insurance companies, and money market funds, rely on over-the-counter (OTC) trading with dealer banks. Because establishing trading relationships in the OTC market is costly, market participants are only able to form a few links with dealers, implying that dealer banks have market power over their OTC customers.

Understanding how dealer market power impacts the passthrough of monetary policy to bank and non-bank institutions is important because the OTC repo market is the main source of short-term secured deposits and funding for the majority of market participants. In the euro area and the US, the OTC segment is estimated to be 30% of total trading volume (ECB, 2018). Our estimates show that dealers on average passed on only 71.7% to 79.4% of the inter-dealer (ID) repo rate change to OTC customers, following the ECB's September 2019 rate cut. Repo rate passthrough was also highly unequal across customers and sectors.

Our results also show how regulatory interventions can alleviate passthrough frictions induced by dealer market power. We show that allowing OTC customers to access the inter-dealer repo market directly, at a sufficiently low cost, would improve passthrough by partially reducing the dependence on dealer banks. Passthrough would also improve if OTC customers could access a secured deposit facility at the central bank, like the Federal Reserve's Reverse Repo (RRP) Facility, which gives OTC customers an outside option to negotiate better rates with dealer banks.

Our 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 dealers. The MMSR is the first dataset that records both inter-dealer and OTC trades made by dealers with all bank and non-bank customers, including money market funds, mutual funds, pension funds, insurance companies, hedge funds, and other financial institutions. Outside of the euro area, comprehensive transaction-level data on OTC repos is limited. In the US, for example, there are only several snapshots of data available for bilateral repo markets and tri-party repo data is limited to money market funds.

We begin by documenting a number of novel facts. First, the vast majority of non-dealers are barred from accessing the centralized trading platforms that constitute the inter-dealer repo market. Instead, non-dealer market participants trade repos bilaterally with a concentrated set of dealers: the median non-bank customer only ever trades with a single dealer from February 2017 to February 2020. Second, there is substantial dispersion in OTC repo rates for observably identical repos backed by the same ISIN-level collateral, which suggests that dealers have the power to price discriminate across customers. Third, dealers lend at higher rates than they borrow, so dealers attain net interest margins in the OTC market. The magnitudes of dispersion and net interest margins are large. For German collateral-backed repos, for example, the weighted standard deviation in customers' repo deposit rates is 11.1bps and dealers' average net interest margin amounts to 12.6bps. In comparison, the average German repo rate at which customers lend to dealers is -69.9bps. Neither effect is explained by heterogeneity in loan and collateral characteristics. Fourth, customers who form more links receive more favorable repo rates, suggesting that customers with more bargaining power can negotiate better rates. Together, these findings suggest that customers face high costs for connecting to additional repo dealers, giving dealers market power over their OTC customers.

Dealer market power can also impede the passthrough of monetary policy: if dealers set prices different from their marginal costs, they would imperfectly transmit changes in inter-dealer repo rates to OTC market participants. Passthrough should be especially low for market participants who are connected to fewer dealers, and thus have less bargaining power. We shed light on this conjecture by examining repo rate passthrough following the ECB's September 2019 Deposit Facility Rate (DFR) cut from -40bps to -50bps.[1] On average, only 79.4% (71.7%) of inter-dealer repo rate changes passed on to customers that lend to (borrow from) dealers, respectively. This inter-dealer to OTC passthrough is also highly unequal: customers that formed fewer links in the pre-rate-cut period experienced worse passthrough. These differences in passthrough cannot be explained by changes in customers values and dealer balance sheet costs. We also conduct our analysis with residualized repo rates to rule out the effect of collateral and loan differences.

We then develop a simple model to rationalize our empirical findings. In the model, dealer banks can buy or sell secured funds in a competitive inter-dealer market. OTC customers do not have direct access to the inter-dealer market, and rely on dealers to intermediate repo trades. A depositing customer, for example, is willing to trade with a dealer who offers a rate higher than her reservation value; the dealer is willing to trade with the customer at any rate lower than the inter-dealer repo rate minus her balance sheet costs. When bilateral gains from trade are possible, the customer and the dealer negotiate a price that splits the surplus. To determine the division of surplus, customers bilaterally bargain with each of their connected dealers using other connected dealers'

[1] We measure the passthrough of DFR to inter-dealer (ID) and OTC repo rates by dividing the change in observed ID and OTC repo rates by the magnitude of the DFR cut. We then obtain passthrough from the inter-dealer market to the OTC market by dividing the DFR-OTC passthrough by the DFR-ID passthrough.

offers as outside options, as in Stole and Zwiebel (1996). Investing in more links with dealers thus allows customers to capture a larger share of the surplus and receive better repo rates. In equilibrium, customers choose the number of relationships to invest in, trading off the gains from improved bargaining power with the costs of forming new links.[2]

Our model predictions are consistent with the empirical variations in net interest margins and rate dispersion. In particular, our model shows imperfect passthrough as a sharp test of the existence of market power. If repo markets were competitive, dealers would always charge rates equal to their marginal cost. Further, our model provides a framework for incorporating endogenous link formation under different counterfactual scenarios.

We proceed to structurally estimate the model in order to quantitatively evaluate the effect of different policies on repo market outcomes. First, using the empirical relationship between the number of links formed by customers and repo rate passthrough, we estimate a model parameter governing the extent to which bilateral match surplus is divided between dealers and their OTC customers. Our estimation shows that the bargaining power of dealers in each bilateral negotiation ranges between 22.7% and 30.7%. We then jointly estimate parameters determining the costs of link formation, the distributions of customer values, and the balance sheet costs of dealers, by matching data moments on repo rate dispersion, net interest margins, and the empirical relationship between volume and the number of links formed. Intuitively, rate dispersion is informative about the variance in customers' values for a given number of links, while net interest margins depend on balance sheet costs as well as customers' values. The cost of link formation determines the extent to which customers with larger trade volumes form more links. In the data, customers who trade much larger volumes only modestly form more links, so we infer that the costs of link formation are quite high.

[2]The cost of link formation can include the effort of starting a relationship and the expense of setting up the trading infrastructure. Once these costs are paid, they are sunk and irreversible.

Using our estimated model, we evaluate the extent to which monetary policy passthrough will continue to be inhibited if the ECB raises interest rates in the future. As rates rise, the total trade surplus to be divided between lending repo customers and their dealers increases, giving customers increased incentive to form new links with dealers. We find, however, that link formation increases only modestly with higher inter-dealer repo rates. As a result, even if policy rates were raised to a 200bps inter-dealer rate, passthrough would only improve slightly by 3.8%, compared to when the inter-dealer repo rate is -40bps. In this counterfactual, we allow for endogenous link formation from higher rates to improve customers' bargaining power. Nevertheless, we note that our results are model-based extrapolations using parameters estimated during a fairly low interest rate environment. In practice, high interest rate environments may differ from low interest rate environments in other ways that our model does not capture. For example, changes in general economic conditions that accompany higher rates may also affect customer valuation and dealer intermediation costs.

We then analyze how regulatory interventions could improve passthrough efficiency. First, if OTC customers were given free access to inter-dealer trading platforms, they would have perfect passthrough from the inter-dealer rate. However, if access was provided at a cost, only a fraction of customers for whom the benefits exceed the costs would choose to participate. For example, when annual access costs are €5K, 42.6% of customers would pay to access inter-dealer platforms and passthrough would be improved by 7.5%. If access costs were €100K, however, passthrough would only be improved by 1.6%. Thus, allowing direct access to centralized trading platforms can improve passthrough only if the associated fees are sufficiently low.

Passthrough would also improve if OTC customers had access to a secured deposit facility with the ECB, similar to the Federal Reserve's RRP Facility. When the RRP rate is higher than the inter-dealer repo rate less balance sheet costs, it acts like a classical price floor. However, even if the RRP rate is lower than dealers' break-even rate, the RRP can improve passthrough by improving customers' outside option in bargaining with dealers. We quantitatively evaluate the effects of such an RRP. For example, we find that when the RRP rate is set 10bps below dealers' break-even rate, the average passthrough is increased by 13.6%.

Our paper contributes to understanding the passthrough 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, and Bech, Klee and Stebunovs (2012) examine the spread between repo rates and the Fed funds rate. While the literature has mostly relied on aggregate time-series data to infer passthrough frictions, we use transaction-level data to directly analyze these frictions in repo markets and their effect on passthrough efficiency.

We also contribute to the European repo literature, which has mostly focused on the resilience of repo markets (Mancini, Ranaldo and Wrampelmeyer, 2016) and the effect of collateral scarcity on inter-dealer repo rates (Buraschi and Menini, 2002; Ferrari, Guagliano and Mazzacurati, 2017; Brand, Ferrante and Hubert, 2019; Corradin and Maddaloni, 2020). Most closely related to us is Arrata, Nguyen, Rahmouni-Rousseau and Vari (2020), who relate repo specialness to the transmission of asset purchases on repo rates, and who examine the effect of deposit facility access and collateral eligibility for asset purchases. 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), Ballensiefen and Ranaldo (2019), and Ballensiefen, Ranaldo and Winterberg (2020). Our paper complements the existing literature by showing that market power in the OTC segment is a significant determinant of repo rate variation. Importantly, our analysis sheds light on how market power impedes the efficient transmission of monetary policy in the European repo market.

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

(Krishnamurthy, Nagel and Orlov, 2014; Copeland, Martin and Walker, 2014; Infante and Vardoulakis, 2018; Afonso et al., 2020). 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. In particular, Huber (2022) focuses on how money market funds' aversion to portfolio concentration and preference for stable funding awards dealers with market power in the US triparty repo market. We identify a complementary but distinct channel of dealer market power that arises from market participants' costly link formation. We uncover this friction by including non-banks other than money market funds in our analysis, such as mutual funds, insurance companies, and pension funds, whose repo trades are not reported in the US.

For the US bilateral repo market, there are three snapshots of data available from 2015Q1, which Baklanova et al. (2019) examine with a focus on collateral. More recently, Hempel et al. (2023) analyze another three snapshots of data from 2022Q2 and show that bilateral repos have distinctively different haircuts than tri-party repos. Other papers studying US repo markets include Anderson, Du and Schlusche (2019), Correa, Du and Liao (2020), Hu, Pan and Wang (2021), Copeland, Duffie and Yang (2021), d'Avernas and Vandeweyer (2021*a*), d'Avernas and Vandeweyer (2021*b*), and Anbil et al. (2022).

Our model of bargaining and endogeneous network formation builds most directly on Stole and Zwiebel (1996), and is related to other models of endogeneous network formation, such as Farboodi (2014), Wang (2017), Craig and Ma (2018), Chang and Zhang (2018), and Dugast, Üslü and Weill (2019). We are also related to a literature analyzing trading on exogenous networks, see Gofman (2014), Malamud and Rostek (2017), Eisfeldt et al. (2018), Babus and Kondor (2018), Colliard and Demange (2019), and Colliard, Foucault and Hoffmann (2021).

The remaining paper proceeds as follows. Section 2 describes institutional features and our data. Section 3 shows stylized facts about the OTC repo market. Section 4 presents our model. Section 5 describes how we structurally estimate our model. Section 6 discusses our policy counterfactuals, and Section 7 concludes. Proofs and supplementary results are in the 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 deposit facility rate (DFR) is an unsecured policy rate available to European banks, similar to the Federal Reserve's IOER for US banks. How well this policy rate transmits to general funding costs 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). The size of the European repo market at the end of 2019 was around €3.9 trillion (ECB, 2020), which is comparable to the size of the US repo market at $4.6 trillion (SIFMA, 2022).

A repo 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 it back after a set period of time at a set price. The repo lender is promised an interest rate and also has access to the collateral during the repo transaction. Most repos are fully or over-collateralized. The security of collateral typically implies that repo rates are below unsecured market rates. In the euro area, there is some segmentation between repos backed by sovereign bonds from different European countries, whereas in the US repo market, sovereign bonds used as repo collateral are predominantly comprised of US Treasuries.

Repos can be 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. Schaffner, Ranaldo and Tsatsaronis (2019) estimate that turnover in the SC segment is around five times higher than turnover in the GC segment. Thus, our analysis includes both GC and SC repos for completeness and we assign repos in each GC country basket with a uniform collateral-ISIN to reflect the absence of specific collateral identities. In Appendix Tables A.2 and A.3, we further show that GC and SC subsamples display similar levels of rate dispersion and interest margins, which are indicators of dealer market power.[3]

Repo contracts are traded either through centralized 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 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

[3]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 ECB's 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.

segment because of data limitations. The majority of the OTC segment in the euro area is comprised of bilateral trades between dealer banks and market participants. Tri-party repos, where a third party clearing bank acts as an intermediary and alleviates the administrative burden between two parties engaging in a repo, are estimated to account for only 10% of all repo trades. This is distinct from the US context, where there is a larger fraction of tri-party repos. Nevertheless, the bilateral OTC market is also important in the US. As Baklanova et al. (2019) state, "the bilateral repo market is important not only because of its sheer size but also because it is a key source of funding for smaller financial firms without access to tri-party repo." Data on the US bilateral repo market is scarce, with only three snapshots of data available from 2015.

2.2 The MMSR Data

The primary dataset we use is the Money Market Statistical Reporting (MMSR) data from the ECB.[4] This dataset collects all repo transactions made by 38 dealer banks, who are the main intermediaries in the European repo market. Our dataset is at the transaction-level and our sample 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. 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.

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

3 Stylized Facts

This section introduces a number of novel facts about the European repo market that illustrate how dealer market power affects OTC market participants in different sectors.

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 one or two dealer banks in the OTC market.*

Surprisingly, participation in the centralized repo trading platforms described in Section 2 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 like money market funds, mutual funds, insurance companies and pension funds, do not have direct access to inter-dealer trading platforms. While the direct fees charged by these platforms are fairly low, there are a number of requirements that make it infeasible for non-dealer market participants to access these markets directly. We discuss details about these barriers to entry in Appendix E.

Since the majority of customers cannot access inter-dealer markets directly, they rely on OTC intermediation by dealer banks to access repo markets.[5] This OTC segment of the repo market is economically important. In 2018, dealer-customer trades amounted to 30% of inter-dealer volume (ECB, 2018). In addition, the economic significance of the OTC market is understated by its relative volume, 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. We classify repos between dealer banks that occur on centralized trading platforms as inter-dealer trades, and repos between dealer banks and other market participants as OTC trades.

[5] 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. Eurex Repo introduced its ISA Direct program in August 2020, but it has not gained widespread adoption.

We find that most market participants rely on a very small number of dealers to intermediate their trades in the OTC repo market. We calculate the number of dealer banks each OTC customer has traded with over our three-year sample period and show the three quartiles of the distribution by customer sector and collateral segment in Table 1. From Table 1, we observe that the median non-bank customer, in almost every sector, relies on intermediation by one dealer bank, throughout our sample period. The third quartile of customers in most non-bank sectors also only have one or two dealer connections. Insurance companies and pension funds are slightly better connected, with the third quartile institution trading with three dealer banks in the German and French collateral segments. Non-dealer banks are relatively better connected, but even the third-quartile bank connects to only four dealer banks.

The fact that most repo market participants are sparsely connected potentially increases the extent to which dealers can charge markups over marginal costs. If OTC customers did not have access to inter-dealer markets but were connected to a large number of dealers, they could in principle still obtain competitive rates by requesting competing quotes from multiple dealers. In later sections, we will show that customers who are better connected indeed receive better rates and improved passthrough.

3.2 OTC Repo Rate Dispersion

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

We find that there is substantial rate dispersion in the OTC repo market. We measure dispersion as the weighted average standard deviation of repo rates following Duffie and Krishnamurthy (2016). The solid lines in Figure 1 show the notional-volume-weighted standard deviation of repo rates for different collateral segments over time. The average dispersion over our sample period is shown in Table A.1. 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 magnitude is sizable given that the average loan rates for depositing and borrowing cash backed by German collateral are -69.9bps and -57.3bps, respectively, over the same time period. [6]

Differences in repo rates within a collateral segment could also arise from heterogeneity in repo loans' characteristics. For example, certain repos in the German segment may be backed by specific ISINs which trade at lower rates, since they are in higher demand for shorting or delivery into futures contracts. To ensure that observed rate dispersion is not solely driven by these features, we 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 in every month t:

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

where r_{it} is the repo rate and X_{it} includes fixed effects for each collateral ISIN, fixed effects for each loan maturity bracket, and the collateral haircut as a control variable.[7] We then construct the residual $\hat{\varepsilon}_{it}$ from the predicted value for each transaction. The amount of residual dispersion indicates the extent to which non-fundamental factors, including dealer market power, influence repo rates. Using the residualized rates to recompute dispersion in repo rates in each collateral segment, we find that 67% to 94% of the dispersion is preserved (dotted lines in Figure 1). To ensure that our results are not driven by time-series changes within each month, we further repeat our estimation

[6]The decline in rate dispersion occurred at the same time as an increase in the number of links that repo market participants formed with dealer banks. As we will show in the model, as more links are formed, dealers' effective market power is reduced and and thus the dispersion in repo rates should decline accordingly.

[7]Loan maturity brackets specified in the data include ON, SN, TN, 1 week, 1 month, 2 months,..., 12 months, and more than 12 months.

of equation 1 at the daily level and show that the daily dispersion in residualized rates remain similar (Figures A.2).

Overall, the fact that very similar repo loans trade at different prices suggests that dealers have market power, and are able to price discriminate, charging customers rates that depend on their willingness-to-pay.

3.3 OTC Net Interest Margins

Fact 3. *Dealers attain net interest margins in the OTC market, which cannot be explained by observable collateral and loan characteristics.*

Next, we find that dealers earn substantial net interest margins from intermediating repos in the OTC market. In Panel (a) of Figure 2, we plot the volume-weighted average of OTC repo rates for transactions in which dealers lend to and borrow from customers. We observe a substantial gap between the solid and dotted lines of the same color, which indicates that dealers lend to OTC customers at systematically higher rates than they borrow. On average, the volume-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 (Table A.1). These net interest margins are significant compared to the average repo lending rates for each collateral country, which are -57.3, -48.6, -41.5, and -42.4bps, respectively.[8] In contrast, there is almost no difference between the dealer lend and dealer borrow rates in the inter-dealer market (Figure 2 Panel (b)).

As before, we compute dealers' net interest margins using residualized repo rates to ensure that they are not mechanically driven by repos with different collateral ISINs and loan characteristics. From Figure 3, we observe that the OTC net interest margins using residualized rates remain substantial, but are slightly lower in magnitudes at 9.9,

[8] OTC net interest margins are also comparable in magnitude to "specialness"-driven repo spreads across collateral countries. The difference in repo rates across collateral segments likely arises from collateral scarcity (Duffie, 1996; Fisher, 2002; Ferrari, Guagliano and Mazzacurati, 2017; Brand, Ferrante and Hubert, 2019; Corradin and Maddaloni, 2020; Arrata et al., 2020; Ballensiefen, Ranaldo and Winterberg, 2020).

6.2, 7.6, and 3.5bps for German, French, Italian, and Spanish collateral, respectively. We also estimate net interest margins using daily residuals and show that they are of similar magnitudes (Figures A.3). Hence, observable repo characteristics do not explain away dealers' net interest margins in the OTC repo market.

Dealers' net interest margins in OTC markets further vary depending on the sector of the OTC customer. In Figure 4, the top and bottom of each bar represents the average residualized rates at which dealers lend to and borrow from customers in a given sector. For example, money market funds receive worse rates when lending to and borrowing from dealers in the OTC repo market, while banks almost always receive the most favorable rates. This variation in rates is indicative of dealers' varying degrees of bargaining power with respect to different customers. The next subsection examines the drivers of this variation in greater detail.

3.4 Customer Characteristics and Repo Rates

Fact 4. *Customers that form more links with dealers obtain more favorable lending and borrowing rates in the repo market.*

If net interest margins and rate dispersion are indeed driven by dealers' bargaining power over customers, OTC customers with more bargaining power should also obtain more favorable repo rates.

We first average the residualized repo rates to obtain residualized rates, $\text{Rate}^{resid}_{cdm}$, for repos between customer c and dealer d backed by collateral from country m. Then, we examine the relationship between these averaged residuals with our proxy for customer bargaining power with dealers, the number of unique dealers for customer c, Num Dealers_c. Formally, we estimate the following regression specification:

$$\text{Rate}^{resid}_{cdm} = \beta_1 \text{Num Dealers}_c + \gamma_m + \delta_s + \omega_d + Maturity_{cdm} + Haircut_{cdm} + \varepsilon_{cdm}, \quad (2)$$

where we include collateral country fixed effects, γ_m, customer-sector fixed effects, δ_s, and dealer fixed effects, ω_d, and controls for the average repo maturity and collateral haircut. We scale observations by one divided by the number of links, so that the sum of weights for observations for each customer are the same, implying that the coefficients represent the effect on the average customer. We cluster standard errors by dealer.

From the results in Tables 2 and 3, we see that the coefficients on the number of dealers is positive for dealer borrow and negative for dealer lending rates. This means that when lending to (borrowing from) dealers, customers that are connected to more dealers receive higher (lower), i.e., more favorable, rates. Notice that our findings are not just driven by rate differences across dealers because they remain robust to the inclusion of dealer fixed effects in columns (2) and (4). Quantitatively, connecting to an additional dealer bank increases a customer lending rates by 0.25 bps and decreases customer borrowing rates by 0.49 bps in our most restrictive specification in column (4). Our findings thus provide suggestive evidence that dealer market power is driving variation in rates across customers. These patterns are also in line with our sector-level results that banks form the most connections with dealers and receive the most favorable rates, whereas money market funds only link to one dealer and incur worse rates.

3.5 Passthrough of Monetary Policy

Fact 5. *The passthrough of rates from the inter-dealer to the OTC market is imperfect. The passthrough efficiency is relatively better for OTC customers that form more links.*

In a competitive market, we would expect dealers to fully pass through changes in the inter-dealer rate that they receive to their customers independent of the customer's value of the trade. However, if dealers have market power and price discriminate against their customers, they may only partially pass through changes in inter-dealer rates to their customers. This passthrough inefficiency should particularly affect customers with worse bargaining power against their dealers.

Inefficient passthrough from the inter-dealer rate to OTC rates inhibits the efficient and equal transmission of monetary policy. Monetary policy transmits through repo markets in two stages. Dealer banks have access to the ECB's unsecured deposit facility rate (DFR) as well as the inter-dealer repo market; non-dealer customers trade with dealers in the OTC repo market, being unable to access either the deposit facility or the inter-dealer repo market. Thus, when dealer market power inhibits the passthrough of changes in inter-dealer rates to OTC repo rates, OTC repo rates will also move less for any change in the ECB's DFR.[9]

3.5.1 Measuring Passthrough

To measure passthrough, we use the change in the DFR from -40 to -50bps in September of 2019. 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 passthrough 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.

One concern about measuring passthrough could be that expectations of the rate change were already incorporated in repo rates before the implementation date. However, the very short maturity of repo contracts limits the effect of future expectations on repo rates. For overnight and short-term repos, for example, lending dealers can choose between lending overnight using the Deposit Facility and lending in the repo markets.

[9]The inter-dealer repo rate also does not move one-for-one with the ECB's DFR, due to "repo specialness" and the value of collateral; though this is not the focus of our paper, we show how specialness affects DFR-ID passthrough in an extension model in Appendix A.3.

Once the ECB implements a change in the DFR, lending dealers' substitution should cause rates in the inter-dealer repo market to shift in response. Knowledge that an overnight policy rate will change in the future should not affect current rates of short-term repos because they are set to mature. Thus, the DFR should matter for short-term repo rates when they have been implemented.[10]

To measure the inter-dealer (ID) to OTC passthrough following the 2019 DFR change, we first calculate the DFR-OTC passthrough for repos backed by each collateral-ISIN k, as:

$$\mathsf{Passthrough}_k^{\mathrm{DFR\_OTC}} = \frac{\mathrm{Rate}_k^{\mathrm{OTC,post}} - \mathrm{Rate}_k^{\mathrm{OTC,pre}}}{-10}, \tag{3}$$

where $\mathrm{Rate}_k^{\mathrm{OTC,pre}}$ and $\mathrm{Rate}_k^{\mathrm{OTC,post}}$ are the average OTC rates on repos backed by collateral ISIN k in the pre- and post-rate-change periods, respectively. Similarly, we calculate the DFR-ID passthrough for repos backed by collateral k using pre- and post-rate-cut average inter-dealer repo rates in (3). Finally, ID-OTC passthrough is obtained from dividing DFR-OTC passthroughs by DFR-ID passthroughs:

$$\mathsf{Passthrough}_k^{\mathrm{ID\_OTC}} = \frac{\mathsf{Passthrough}_k^{\mathrm{DFR\_OTC}}}{\mathsf{Passthrough}_k^{\mathrm{DFR\_ID}}}. \tag{4}$$

3.5.2 Inter-dealer to OTC Passthrough

Panel (a) of Table 4 shows moments of the volume-weighted cross-sectional distributions of DFR-OTC and ID-OTC passthroughs. Consistent with the presence of dealer market power, ID-OTC passthrough is substantially lower than 100% for the majority of trades. On average, dealers that lend and borrow only pass through 71.7% and 79.4% of rate changes in the inter-dealer market to their OTC customers. Only 11% (24%) of repo trades

[10] The slight pre-trends observed in Figure 5 are not due to anticipation effects but money market timing conventions. Overnight repo trades arranged at date T may settle at date $T, T+1$, or $T+2$: these are referred to as O/N, T/N, and S/N trades respectively. In Appendix Figure A.4, we separately analyze repo rates on O/N, T/N, and S/N trades, and show that the DFR change has a sharp effect exactly at the implementation date. Thus, the gradual trends in Figure 5 simply reflect an average of O/N, T/N, and S/N repo rates, which are affected by the DFR change at different dates. Our baseline analysis uses data before September 12th and after September 18th, which avoids the period with potential pre-trends.

in which dealers lend (borrow) have complete passthroughs. As a robustness check, we repeat the exercise using residualized rates in panel (b) of Table 4.[11] Our results remain very similar.

Importantly, the imperfect passthrough from inter-dealer to OTC markets hinders the efficient transmission of monetary policy to the vast majority of market participants, who rely on OTC repo markets for secured deposits and funding. As Table 4 shows, for a change in the DFR, only 59.7% and 70.3% of the rate change passes through to OTC dealer lend and dealer borrow repo rates, on average. The incomplete inter-dealer to OTC passthrough is an important impediment to overall DFR to OTC passthrough efficiency: even if a DFR change could pass through perfectly to dealers, dealer market power would only allow 71.7% and 79.0% of the DFR change to reach the average OTC repo trade. These magnitudes remain similar using residualized repo rates.

3.5.3 Customer Characteristics and Passthrough

If inefficient passthrough is indeed driven by dealers' bargaining power over customers, OTC customers with more bargaining power should experience relatively better passthrough than OTC customers with less bargaining power. We again use residualized repo rates to calculate ID-OTC passthrough and average them for repos between customer c and dealer d backed by collatateral from country m. We then examine the relationship with the number of active dealers that the customer is connected with in the pre-rate-cut month, Num Dealers$_c$, as a proxy for market power. Formally, we estimate:

$$\text{Passthrough}^{\text{ID\_OTC}}_{cdm} = \beta_1 \text{Num Dealers}_c + \gamma_m + \delta_s + \omega_d + Maturity_{cdm} + Haircut_{cdm} + \varepsilon_{cdm}, \quad (5)$$

[11] Note that the coefficients in (1) vary monthly, and both the pre- and post-periods are in September. Thus, the effect of the rate cut remains in the residuals of (1).

where we include collateral country fixed effects, γ_m, customer-sector fixed effects, δ_s, and dealer fixed effects, ω_d, and controls for the average repo maturity and collateral haircut. As in specification (2), we weight each observation by one divided by the number of links, so that the coefficients represent the effect on the average customer. We cluster standard errors by dealer.

The results are reported in Table 5. Across all specifications, the coefficient on Num Dealers$_c$ is positive and significant. Based on the most conservative specification in Column (4), being connected to one more dealer bank is associated with a 3.96% improvement in passthrough, when customers of the same sector trade repos with a given dealer.

One may ask whether other factors could explain the imperfect and heterogeneous ID-OTC passthrough. For example, there may be potential changes in customers' values for repo borrowing and lending that coincide with the DFR change. As our model will show, prices in competitive markets should be set equal to marginal costs, and are thus unaffected by changes in willingness-to-pay. Absent dealer market power, ID-OTC passthrough should always be 100% and thus unaffected by changes in customer valuation. Concerns about shocks to individual dealer's balance sheet costs to lend or borrow repos following the policy rate cut are also alleviated by the within-dealer results in columns (2) and (4). That is, for the same dealer, customers with better bargaining power receive improved passthrough.

4 Model

In this section, we build a simple model to rationalize the stylized facts we documented in the previous section, i.e., net interest margins, repo rate dispersion, and imperfect passthrough of inter-dealer repo rates to OTC repo rates. Importantly, we let customers choose the number of links they form with dealers, trading off the cost of forming links with the benefits from improved bargaining power with dealers. The formulation of this tradeoff lays the foundation for our estimation of link formation costs in Section 5 and eventually the counterfactual results in Section 6.

Our baseline model focuses on the interaction between dealers and customers to shed light on the passthrough from inter-dealer repo rates to OTC repo rates, which is driven by dealer market power. In Appendix A.3, we analyze a simple extension building on the literature on repo specialness, showing how the inter-dealer repo rate is determined by the central bank's DFR and the value of collateral.[12]

Model Setup. Customers are divided into borrowers and depositors. Borrowers want to borrow a unit of cash from their dealer, using collateral to secure the loan. Each borrower is characterized by the maximum rate ν_B she is willing to pay to borrow, and the volume Ψ_B that she wishes to borrow. ν_B and Ψ_B are arbitrarily jointly distributed across borrowers. Repo depositors wish to lend cash to dealers, secured by collateral; each depositor is characterized by a minimum rate ν_D she will accept, and a volume Ψ_D she wishes to deposit.

When a customer borrows, her dealer borrows in the inter-dealer market at rate r_{ID} to lend to the customer. Similarly, when a customer deposits, the dealer lends in the inter-dealer market at rate r_{ID}, receives collateral, and rehypothecates the collateral to the customer. In both cases, the dealer makes exactly offsetting trades, taking no net position in funds or collateral. Dealers may face balance sheet costs for intermediating repo trades: a dealer pays τ_B (τ_D) for each unit of repo she intermediates for borrowing (depositing) customers. Thus, a dealer's break-even rate is $r_{ID} + \tau_B$ for borrowing customers, and $r_{ID} - \tau_D$ for depositing customers. In the main text, we take r_{ID} as given. In Appendix A.3, we microfound r_{ID} in an equilibrium model of the inter-dealer repo market, in which r_{ID} is determined by the central bank's deposit facility rate and the supply and demand

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

for scarce collateral.[13]

The game proceeds in two stages. At $t = 0$, customers choose the number of dealers, N, that they wish to form trading relationships with. At $t = 1$, customers bargain with their connected dealers to determine the division of surplus. We first solve for the repo rates at $t = 1$ for a given number of links N, and then consider endogenous link choice at $t = 0$.

Bargaining at $t = 1$**.** The marginal benefit from link formation arises at $t = 1$, when customers and connected dealers engage in bilateral Nash bargaining with renegotiable contracts, as in Stole and Zwiebel (1996). Each dealer-customer pair bargains over the repo rate relative to their outside options, where we let the dealer's and customer's bargaining power be ϕ and $1 - \phi$, respectively. For example, when a depositing customer only has one link to the dealer, she has an outside option of ν_D so that

$$\phi(r_D - \nu_D) = (1 - \phi)(r_{ID} - \tau_D - r_D), \tag{6}$$

and thus

$$r_D = \nu_D + (1 - \phi)(r_{ID} - \tau_D - \nu_D). \tag{7}$$

If this customer formed relationships with two dealers, then her outside option in each of the negotiations would be (7), which is larger than ν_D and leads to her receiving a higher repo rate than the one in (7) with just one connected dealer. Following Stole and Zwiebel (1996), we can generalize the division of surplus to N dealers in Proposition 1.

Proposition 1. *Let* $t(N)$ *represent the share of surplus attained by each dealer, if the customer*

[13] In the extension model, dealers with excess funds and dealers who wish to borrow funds trade in the inter-dealer repo market on their own behalf and to intermediate repo trades for their OTC customers. Lending dealers can also choose to lend to the ECB's deposit facility, and receive rate ρ. The deposit facility is an imperfect substitute for repo lending because it is unsecured. As a result, shocks to ρ pass through imperfectly to inter-dealer repo rates, and the magnitude of $\frac{\partial r_{ID}}{\partial \rho}$ depends on the relative elasticities of the supply and demand for collateral.

connects to N *dealers.* $t(N)$ *is characterized by the recursion equation:*

$$t(1) = \phi,\ t(N+1) = \frac{N}{\frac{1-\phi}{\phi} + (N+1)} t(N). \tag{8}$$

Repo rates are:

$$r_D(\nu_D, N) = \nu_D + ((r_{ID} - \tau_D) - \nu_D)(1 - Nt(N)), \tag{9}$$

where customers' share of trade surplus, $1 - Nt(N)$*, is increasing in* N.

Expression (9) shows that the OTC repo rate is a weighted average of the dealer's and customer's reservation values, $r_{ID} - \tau_D$ and ν_D. In other words, dealers are able to pay depositors a markdown relative to their break-even repo rate due to their market power, which arises because customers are linked to and can only negotiate with a limited set of dealers. The markdown is higher when the customer is linked to fewer dealers so that $Nt(N)$ is a proxy for dealer market power. As N decreases, $Nt(N)$ increases, so prices approach the customer's value ν_D. Customers thus have incentives to form more links, receive better rates from their dealers, and capture a larger share of trade surplus. For simplicity and because OTC customers are predominantly net lenders to dealers, we focus on depositing customers in Proposition 1 and our subsequent predictions in the main text. We show analogous results for borrowing customers in Appendix A.1.

We show that our model predictions are consistent with dealer market power driving the variations in net interest margins, rate dispersion, and imperfect passthrough documented in Section 3.

Claim 1. *Dealers' average interest margin, relative to the inter-dealer rate* r_{ID}*, is:*

$$r_{ID} - E[r_D(\nu_D, \Psi_D) \mid \nu_D < r_{ID} - \tau_D] = \\ \tau_D + E[Nt(N)((r_{ID} - \tau_D) - \nu_D) \mid \nu_D < r_{ID} - \tau_D] \tag{10}$$

Dispersion in repo rates among repo depositors is:

$$Var\left[r_D\left(\nu_D,\Psi_D\right) \mid \nu_D < r_{ID}-\tau_D\right] = Var\left[Nt\left(N\right)\left(\left(r_{ID}-\tau_D\right)-\nu_D\right) \mid \nu_D < r_{ID}-\tau_D\right] \quad (11)$$

Expression (10) implies that the average rates at which OTC customers deposit funds will be lower than the inter-dealer rate r_{ID}, where the interest margin arises from dealers market power and balance sheet costs. The market power component of interest margins increases when customers are sparsely connected, , i.e. when N is small and $Nt\left(N\right)$ is large. Expression (11) shows that market power also induces dispersion in interest rates. Rate dispersion tends to be high when customers have few connections so $Nt\left(N\right)$ is large, and when there is substantial dispersion in customers' values ν_D.

Claim 2. *Given that a customer forms* N *dealer links, the passthrough of inter-dealer rates to OTC repo rates is:*

$$\frac{\partial r_D}{\partial r_{ID}} = 1 - Nt\left(N\right) \quad (12)$$

Passthrough $\frac{\partial r_D}{\partial r_{ID}}$ *is higher when* N *is larger.*

Expression (12) states that the passthrough of inter-dealer rates to OTC rates, holding fixed the number of dealer connections N, is less than one-to-one, and is lower when there is a smaller number of dealer links N. A simple intuition comes from setting $Nt\left(N\right)$ to 0, corresponding to competitive markets. Perfect competition implies that prices are equal to marginal costs, so changes to marginal cost must pass through one-to-one to prices. This is true regardless of what intermediation costs are, or what customers' values are. It is only imperfect competition that can result in the imperfect passthrough that we find in Section 3.5.2. Note that this prediction is not specific to our Nash bargaining model, but is a general feature of models of competitive markets. This is why imperfect passthrough of cost shocks to prices is often used as a model-agnostic test of the existence of market power in the empirical industrial organization literature (Fabra and Reguant, 2014; Atkin and Donaldson, 2015). Expression (12) also predicts that passthrough is worse when customers are sparsely connected, i.e., when N is small, consistent with our findings in Section 3.5.3. Again, this would not hold without dealer market power because passthrough would always be perfect without any variation.

Link Formation at $t = 0$: We proceed to analyze customers' optimal choice of links at $t = 0$. To establish the n^{th} link at $t = 0$, the customer incurs cost C_n. These costs include the effort of starting a relationship and the expense of setting up the trading team and infrastructure, for example. We let the per-link cost to vary with the number of links. For example, customers may have already exhausted dealers in their proximity and additional links must be formed with dealers in other jurisdictions at a higher cost. Once these costs are paid, they are sunk and irreversible. In equilibrium, customers choose to form links until the cost of forming the marginal link equals the marginal surplus. Formally, we have that:

Proposition 2. *The customer's total utility from connecting and trading with* N *dealers is:*

$$\Psi_D \left(\left(r_{ID} - \tau_D \right) - \nu_D \right) \left(1 - Nt \left(N \right) \right) - \sum_{i=1}^{N} C_i. \tag{13}$$

When the customer chooses N *to maximize (13), the optimal choice of* N *is weakly increasing in trade volume* Ψ_D*.*

Expression (13) shows that customers choose the number of dealers to connect with to maximize the sum of trade surplus and connections costs. Connecting to more dealers improves prices on each trade, which is worth more for customers who trade larger volumes Ψ_D. Thus, all else equal, customers who trade higher volumes should optimally connect to more dealers in equilibrium.

Endogeneous link formation tends to improve rate passthrough. As inter-dealer rates increase, the total trade surplus between depositing customers and dealers increases, so customers have larger incentives to form dealer links. When a given customer forms an additional link, her bargaining power $(1 - Nt(N))$ increases, as from (9). Hence, when endogeneous link formation is taken into account, the passthrough of repo rate increases to depositing customers will be higher than (12) of Claim 2, which characterizes passthrough holding fixed dealer links.

While it is qualitatively intuitive that customers investing in more links can attain better repo rates, the magnitude of link formation and improved surplus are important to understand because they determine the extent to which endogeneous link formation can mitigate the effects of dealer market power. If customers have no connection costs, many links will be formed and prices will be close to dealers' marginal costs; if customers have high costs, few links will be formed and dealers will endogeneously have high market power in equilibrium.

5 Model Estimation

In this section, we structurally estimate our model. The goal of our estimation is to quantitatively capture the benefits of link formation relative to their costs. These results will allow us to predict whether customers' connection costs are low enough that endogeneous connections effectively limit dealer market power under different counterfactual scenarios.

Our estimation proceeds in two main steps. First, we estimate the bargaining power parameter ϕ from the relationship between passthrough and the number of links as in expression (12). Second, we jointly estimate the cost of link formation, balance sheet costs, and the distribution of customers' values using granular moments on net interest margins, rate dispersion, and the volume-links relationship.

5.1 Estimation Strategy

Bargaining Power. We first estimate the bargaining power parameter ϕ_p, where $p \in \{D, B\}$ denotes trade parity, i.e., whether the OTC customer is a repo depositor or borrower. As Proposition (1) and Claim 2 show, ϕ_p determines the division of surplus between customers and dealers, and thus the passthrough of inter-dealer rates to OTC repo rates for a given number of dealer links N. Intuitively, when ϕ_p is higher and dealers have more bargaining power, customers capture less surplus for any number of connections, so that the passthrough of changes in r_{ID} to repo rates will also be lower. Empirically, passthrough is a useful quantity to target in estimation, because it only depends on $t(N)$, and is not confounded by other factors like balance sheet costs, customers' values, trade volumes. We measure passthrough in the data as described in Section 3.5.[14] We capture the empirical relationship between passthrough and the number of dealer links a customer has formed by regressing passthrough for customer c against indicator variables for the number of links in the pre-rate-cut month being equal to 1 to 5:

$$\mathit{Passthrough}_c^{IDtoOTC} = \beta_N \mathbb{1}(\mathit{NumDealers}_c \equiv N) + \gamma_m + \epsilon_c, \tag{14}$$

where γ_m is a collateral country fixed effect. The coefficients on the indicator variables, β_N, thus capture the average passthrough for a given number of links in the data. We visualize this relationship in the blue line in Figure 6. Then, in the model, for any given value of ϕ_p, we solve for passthrough as a function of N using (12). Finally, we find the value of ϕ_p which minimizes the sum of squared distances between model- and data-implied passthrough, for each value of dealer connections N.

Link Formation Costs, Customer Values, and Balance Sheet Costs. We then estimate the remaining parameters to jointly match the volume-links relationship, net interest margins, and rate dispersion in the data. To fully capture the granular variation in the

[14]We assume that customers do not substantially change the number of dealers they interact with within this short time window so that the measured passthrough corresponds to $\frac{\partial r_D}{\partial r_{ID}}$ in (12) of Claim 2.

data, we use empirical moments and estimate model parameters at the level of collateral country m, customer sector s, and parity p.[15] We refer to each combination msp as a market segment.

Specifically, we estimate three sets of parameters for each market segment msp: the joint distribution of customers' volumes and values, customers' costs of connecting to more dealers, and dealers' balance sheet costs.

Customer heterogeneity is described by the joint distribution of trade volumes Ψ and values ν_D, ν_B. In each segment msp, we calibrate the distribution of trade volumes Ψ by modelling it as a discrete distribution, with masses at uniformly spaced quantiles of the empirical distribution of observed volumes in segment msp. For each value of trading volume, we assume that customer values are normally distributed with the same mean μ_{msp} and variance σ_{msp}.

Let C^N_{msp} denote the cost of connecting to the Nth dealer for a market participant in segment msp. We parametrize C^N_{msp} as:

$$\log\left(C^N_{msp}\right) = \zeta^1_{msp} + \zeta^2_{msp}\log\left(N-1\right) \tag{15}$$

That is, in each segment, the cost of connecting to the Nth dealer is log-linear in $N-1$, where the constant and slope terms, ζ^1_{msp}, and ζ^2_{msp}, may differ by market segment. This implies that the cost of connecting to the second dealer, C^2_{msp}, in segment msp, is simply $\exp\left(\zeta^1_{msp}\right)$; the slope parameter ζ^2_{msp} captures how much more expensive it is to connect to additional dealers.[16] We constrain ζ^2_{msp} to be positive, so that it is increasingly more costly to connect to more dealers. We also constrain the maximum number of dealer

[15]We do not further break down the the passthrough-link relationship used to estimate ϕ_p by market segment because of the more limited sample for which passthrough is available. This is because the estimation of passthrough relies on a given customer trading repos with the same ISIN collateral in both pre and post periods, which is not available for all customers in our sample. Nevertheless, the passthrough-link relationship by market segment remains economically significant but statistically less robust.

[16]Note that we cannot identify the cost of connecting to the first dealer since market participants only enter our data by connecting with at least one dealer.

connections for an agent in each market segment to be equal to the maximum connections any market participant in that segment has in the data.

We estimate these model parameters by matching three sets of moments in the data for each market segment. First, we calculate the residualized rate dispersion for transactions within each market segment in the pre-rate-cut month (see Table 6). This is consistent with the model, where the residualized rate dispersion corresponds to the standard deviation of rates conditional on trade.[17] Similarly, we obtain the residualized net interest margin for transactions within each market segment in the pre-rate-cut month (see Table 6). Third, we use the relationship between customers' trading volume and the number of dealer links they form. For each customer, we count the number of dealers they connect with and measure their total volume in the pre-rate-cut month.[18] Within each market segment, we run a binscatter plot of the number of links against the associated trading volume. To illustrate, we show a pooled version of the binscatter plot at the sector level in Figure 7, where the blue dots correspond to the observed relationship in the data.

Intuitively, fixing the number of connections made by traders, rate dispersion is driven by the variance in traders' values. Net interest margins depend on balance sheet costs, and the mean and variance of traders' values. In particular, the balance sheet cost increases the net interest margin without changing rate dispersion. The connection cost parameters ζ^1_{msp}, and ζ^2_{msp} affect the relationship between volume and links, through (9) of Proposition 1: when costs are lower, lower volumes are required for forming more connections to be worth the cost.[19]

[17]We add an additional small ad-hoc penalty term in the optimization when inferred value dispersion is very small, to prevent the parameter search from inferring that there is no dispersion in values; this penalty term is only binding for 4 out of 48 of our market sectors.

[18]We convert our flow data to average outstanding volumes by multiplying trade size by the maturity in days, and then dividing by the number of days in the month. For example, if a customer did thirty 1-day repos of €2 million, or two 15-day repos of €2 million in a month, we would count both as having the same average outstanding volume. If the customer repeatedly did either trade over the course of a year, she would be borrowing €2 million for a year. Thus, our connection cost estimates can be interpreted in units of annual €.

[19]The smoothness of the volume-links relationship is also affected by variation in customer values, since for any given trade volume, consumers with values of v_{msp} further from r_{ID} will have greater bilateral match surplus, and thus a larger incentives to form more links.

To simulate these moments in the model, for any set of parameters, we can calculate model outcomes as follows. Each market segment is characterized by a two-dimensional grid of customer volumes Ψ_{msp} and values ν_{msp}. All customers in that market segment face the same balance sheet cost τ_{msp} and connection cost parameters $\zeta^1_{msp}, \zeta^2_{msp}$. All depositors (borrowers) with $\nu_{msp} < r_{ID} - \tau_{msp}$ ($\nu_{msp} > r_{ID} + \tau_{msp}$) will trade in equilibrium. For each customer that trades, we can solve for $N(\Psi_{msp}, \nu_{msp})$, the number of dealers the customer optimally connects to, and $r(\Psi_{msp}, \nu_{msp})$, the repo trade price, using the expressions in Proposition 1. Then, aggregating over customers, we can calculate the average number of connections formed as a function of trade volume, net interest margins, and rate dispersion. We show analytical expressions for all moments in the model in Appendix B.1. We estimate parameters by minimizing the distance between model outcomes and moments in the data.

We calculate confidence intervals on all estimated parameters and counterfactual outcomes using a standard nonparametric bootstrap: we construct 100 random samples with replacement of all OTC customers in our sample, balancing on collateral country and customer sector. For each sample, we re-estimate all input moments, and then the values of the parameter ϕ_p, link formation costs, balance sheet costs, and customer value distribution parameters using the bootstrap input moments. We then run all the counterfactuals in Section 6 for each bootstrap sample. We construct 95% confidence intervals using outcomes from the bootstrap samples.

5.2 Estimation Results

Bargaining Power. We estimate ϕ_B and ϕ_D to be 0.307 and 0.227, respectively. This means that the bargaining power of dealers in each bilateral negotiation is 30.7% for borrowing customers, and 22.7% for depositing customers. Overall, our estimates of bargaining power generate a relationship between passthrough and the number of links that closely align with the observed relationship in the data, as shown in Figure 6 for repo depositors, and Figure A.5 for repo borrowers. One exception is the relatively poor fit when N = 5, which is likely driven by a lack of statistical power as only a small fraction of customers in our data have 5 or more links.[20]

Link Formation Costs, Customer Values, and Balance Sheet Costs. Since our main counterfactuals focus on repo depositors, we present the estimation results for depositors in the main text, and show results for repo borrowers in Appendix F.1. Table 6 shows our estimates for the cost of link formation. For the ease of presentation, we show sector-level averages of our results by weighing each collateral country by the number of customers in that collateral segment for each sector. The costs of link formation we find are fairly high and vary across industries. For the second link formed, for example, costs range from around €17.7K annually for non-MMF funds, to €42.0K for banks, to €228.8K for MMFs. Third connection costs are higher than second connection costs, and are ordered roughly similarly.

Recall that we infer the costs of link formation from the relationship between trading volume and the number of links in the data. Figure 7 shows this relationship for each sector in the model and in the data. The model is able to match the volume-links relationship fairly well for all industries. Moreover, we are able to match the stylized fact that the volume-links relationship is stronger in some industries, such as insurance and pension funds, compared to other industries, such as MMFs and OFIs. The model rationalizes this fact by inferring that the link formation cost is higher for the latter class of industries.[21]

[20] Note also that there is only a single parameter used to fit both the level and slope of the passthrough-link relationship. Relatively, the slope is slightly larger in the model than in the data. Our model would thus tend to slightly overestimate the responsiveness of link formation. In Appendix F.2, we show that this feature of the model does not materially drive our results. We fit a two-parameter model which can fit the slope of passthrough with respect to the number of connections separately from the level, by allowing ϕ to depend on the number of links formed. All results remain similar.

[21] Note that our connection costs are not precisely estimated for all industries: for industries with very high link formation costs, we can infer that costs are large, but have low power in identifying exactly how large they are. However, as we show in Section 6, we can still estimate counterfactual outcomes fairly precisely. Intuitively, any sufficiently large link formation cost implies that customers will not form many dealer links as rates increase, meaning that the endogeneous link formation cost has little effect on passthrough in these cases.

Table 6 also shows the remaining parameter estimates from our model, including the mean and standard deviation of customer values and the balance sheet costs. These parameters are mainly inferred from the variation in net interest margins and dispersion. Table 7 shows that our model matches both quantities in the data fairly well. The main source of error is that the fitted model produces dispersions slightly lower than those in the data, and net interest margins slightly larger than those in the data. However, the model captures the trend across industries fairly well. Our estimates of balance sheet costs are also relatively low at around 1bps.

6 Counterfactuals

In this section, we use our model to predict passthrough in several counterfactual scenarios. In Section 6.1, we estimate passthrough when there are further monetary policy rate hikes that increase the inter-dealer rates. Then, we analyze how much customer access to inter-dealer platforms can improve passthrough in Section 6.2. Finally, in Section 6.3, we show the effect of the central bank offering a secured deposit facility to customers, like the Fed's RRP Facility, on passthrough.

6.1 Passthrough with Higher Rates

One may ask to what extent the passthroughs we estimate in 2019 still apply when the central bank raises the policy rate and thereby the inter-dealer repo rate. In particular, when the inter-dealer rate increases relative to customers' reservation values, customers have the incentive to form more links to improve the share of surplus when bargaining with dealers, which may eventually translate into improved passthrough.

To quantitatively evaluate the effect of endogenous link formation within our model, we vary the inter-dealer repo rate r_{ID} to proxy for a change in the policy rate, while holding all estimated parameters, including connection costs, customer characteristics, and balance sheet costs, constant. We then apply Proposition 1 to solve for customers' optimal connection count at the new inter-dealer rates, and the average passthrough from inter-dealer rates. The counterfactual passthrough we estimate thus combines two forces: passthrough frictions due to market power holding fixed the number of dealers links, as described in Claim 2, and the alleviating effects of customers endogeneously forming more links. This passthrough should be higher than the passthrough holding the number of dealer links fixed, which we used to estimate the bargaining power parameter ϕ in the model.

Our results are shown in Figure 8. The first panel shows the average number of links formed by customers in each sector. We observe that the average number of links formed indeed increases with higher inter-dealer rates, consistent with the higher surplus incentivizing link formation. However, the number of links formed is generally quite small. For example, the average number of links increases only marginally for MMFs, and even for MFIs, the number of links only increases from an average of 1.4 to around 2.0. Consistent with the results on link formation, passthrough improves slightly with higher interest rates but remains largely imperfect. As the inter-dealer rate increases from -40bps to 200bps, the estimated average passthrough increases slightly from 82.9% to 86.7%.

Intuitively, the reason why rate increases lead to a quantitatively small amount of new link formation is the weak relationship between trade volumes and new link formation. As shown in Figure 7, customers with multiple orders of magnitude higher total trade volume only form a few more links in the data. We thus infer that the cost of connecting to new dealers must be fairly large. Moreover, from Figure 6, connecting to more dealers improves passthrough, but around 4-5 dealers are required for passthrough to be close to 100%. Taken together, these two facts imply that, in our fitted model, new link formation only partially ameliorates the passthrough frictions from market power as inter-dealer rates rise.

Nevertheless, we acknowledge that our counterfactual results are based on parameters estimated during a fairly low interest rate environment. While our projection captures the effect of endogenous link formation due to higher rates, there may be other changes in high interest rate environments compared to low interest rate environments. In particular, policy rates are determined based on macroeconomic conditions. These economic conditions could at the same time affect customers' valuation for secured lending and borrowing as well as dealers' intermediation costs, which in turn influence link formation and passthrough. Our current findings can thus be best interpreted as the effect of a shock from policy rate hikes, all else equal.

6.2 Access to Inter-Dealer Trading Platforms

One way to mitigate the effect of dealer market power in limiting passthrough is to give customers direct access to inter-dealer trading platforms. Customers who can connect to the inter-dealer platform trade at the inter-dealer rate and thus have a perfect passthrough from the inter-dealer rate. However, if access to the platform incurs a cost, then only the fraction of customers for whom the surplus from connecting to the inter-dealer market exceeds surplus from connecting to dealers would choose to access the inter-dealer market. Formally, suppose that OTC customers can pay C_{ID} to access the inter-dealer market; from (13), customers connect to the inter-dealer platform if:

$$\Psi_D\left(r_{ID} - \nu_D\right) - C_{ID} \geqslant \Psi_D\left(\left(r_{ID} - \tau_D\right) - \nu_D\right)\left(1 - Nt\left(N\right)\right) - \sum_{i=1}^{N} C_i, \tag{16}$$

where N is chosen optimally on the RHS. The LHS is the surplus from connecting to the inter-dealer platform and paying the connection cost, and the RHS is the surplus from optimally forming links with dealers. Any customers who connect to the inter-dealer market trade at rate r_{ID}, hence passthrough for these customers is 100%.

The costs of accessing the inter-dealer market could include fees charged by the platform to support its operation as well as the customer's logistical costs of trading on the platform. Because the magnitude of these costs are difficult to measure, we repeat our estimation for a range of costs informed by the range of link formation costs with dealers from Section 5.2. Specifically, for costs of accessing the inter-dealer market of €5K, €25K, and €100K annually, we solve for customers' optimal link formation and passthrough.

The results are shown in Table 8. If access to the inter-dealer platform was free, all customers participate and passthough would be 100% from the inter-dealer rate. However, even moderate costs of access can limit the effectiveness of inter-dealer platform access. When annual access costs are €5K, 42.6% of customers participate, and average passthrough is improved from 82.9% to 90.4%. The dispersion in rates would also drop slightly, from 3.0 to 2.6bps. When the cost for accessing the inter-dealer platform is higher, at €100K annually, inter-dealer access is restricted to 12.8% of customers and becomes much less effective at reducing dispersion and improving passthrough. Overall, our results show that allowing direct access to inter-dealer platform to customers can alleviate the effects of market power, but only if the cost of connecting to these platforms can be kept relatively low.

6.3 Reverse Repurchase Facility

We proceed to examine what would occur if the central bank offered a secured deposit rate to OTC market participants. In the U.S., for example, a secured deposit facility was made available to some non-bank market participants under the Federal Reserve's RRP Facility.

Several papers have examined the effect of the RRP Facility. Anderson and Kandrac (2018) and Anbil and Senyuz (2018) show that the RRP Facility partially crowded out MMFs's repo lending to banks. Macchiavelli (2019) and Infante (2020) analyze the implications of the RRP Facility as a new source of safe asset. Klee, Senyuz and Yoldas (2016) document that the RRP Facility contributed to stronger co-movement among money market rates and Duffie and Krishnamurthy (2016) analyze the effect of the RRP Facility on different deposit and money market rates. Afonso, Cipriani and La Spada (2022) examine the drivers of RRP uptake.

Claim 3. *Suppose OTC depositors and dealers were given access to the RRP facility, paying rate* r_{RRP}*. If* $r_{RRP} \geqslant r_{ID} - \tau_D$*, then OTC depositors connect with no dealers and use the RRP for all trades. If* $r_{RRP} < \nu_D$*, then the RRP facility is not used, and all OTC depositors' repo trades are made with dealers. When* $r_{RRP} < r_{ID} - \tau_D$*, an OTC depositor with value* ν_D *and bargaining power* θ_D *trades at rate:*

$$r_D(\nu_D, \theta_D) = \tilde{\nu}_D + ((r_{ID} - \tau_D) - \tilde{\nu}_D)(1 - Nt(N)) \tag{17}$$

The customer chooses the number of dealers N *to maximize:*

$$\Psi_D(1 - Nt(N))(r_{ID} - \tau_D - \tilde{\nu}_D) - \sum_{i=1}^{N} C_i \tag{18}$$

where, in (17) and (18):

$$\tilde{\nu}_D \equiv \max(\nu_D, r_{RRP})$$

Claim 3 states that, when r_{RRP} is below customers' reservation value ν_D, the RRP facility has no effect on outcomes. When r_{RRP} is above the inter-dealer rate minus balance sheet costs, $r_{ID} - \tau_D$, the RRP facility serves as a binding price floor on OTC repo rates, and changes in r_{RRP} pass through one-to-one to customer-facing rates. The interesting case is when r_{RRP} is below $r_{ID} - \tau_D$, but above ν_D. In this case, the customer does not deposit in the RRP facility, but uses it as an outside option to negotiate better rates with her dealer. The customer's outside option if she does not trade with the dealer is to get r_{RRP}, so dealers must offer the customer a rate better than r_{RRP}. Under Nash bargaining, the customer ultimately receives rate:

$$r_{RRP} + ((r_{ID} - \tau_D) - r_{RRP})(1 - Nt(N)),$$

which is higher than the rate the customer would receive if the RRP were not available. Thus, by setting RRP rates below inter-dealer repo rates, the central bank can influence OTC repo rates even without any actual uptake from the RRP Facility. Moreover, for these customers, if the central bank increases r_{RRP} one-for-one with increases in r_{ID}, passthrough is equal to 1.

We proceed to quantify the effects of having an RRP on passthrough in our structural model. We let the RRP rate be Δ_{RRP} below the dealers' break-even rate, that is, the inter-dealer rate less balance sheet costs. We then consider what happens to customers' repo rates, number of dealer connections formed, and passthrough, as the central bank raises r_{ID} given various Δ_{RRP}.

Table 9 shows the results. In general, providing an RRP Facility improves passthrough in repo rates. When the RRP is offered with a spread of $\Delta_{RRP} = 10bps$, the average passthrough is increased to 96.5% from a baseline of 82.9% without the RRP. Dispersion decreases to 0.9 bps, from 3.0 bps without the RRP. However, the RRP is less effective when it is set with a higher Δ_{RRP}. When $\Delta_{RRP} = 25bps$, passthrough only improves to 88.2% and dispersion only declines to 2.0 bps. When $\Delta_{RRP} = 50bps$, passthrough and dispersion remain almost unchanged at 83.7% and 2.8 bps.

So far, we assume that access to the RRP is free for customers. In Appendix F.3, we further consider the case where customers must pay a fixed cost to connect to the RRP, which limits the fraction of customers that use the RRP similar to the case in Section 6.2.

7 Conclusion

In this paper, we have shown that dealer market power impedes the passthrough of monetary policy in the European repo market. The majority of market participants in the OTC repo market are sparsely connected to dealers. Repo rates for very similar repo loans are disperse. Customers who are connected to fewer dealers receive worse rates and worse passthrough.

We then estimated a structural model, in which customers endogeneously choose how many dealers to connect to, trading off the costs of link formation with the benefits of being able to negotiate better repo rates when connected to more dealers. Using the structural model, we estimated how much increases in inter-dealer repo rates would pass through to OTC market participants under different counterfactual scenarios.

Our results have implications for how regulators could intervene in repo markets to improve monetary policy passthrough. Granting OTC customers direct and low-cost access to inter-dealer repo markets would decrease dealer market power and improve passthrough. Moreover, if the central bank gave OTC customers access to a secured deposit facility, like the Federal Reserve's RRP facility, passthrough could be further enhanced. Notably, the RRP facility can improve passthrough even without actual take-up of the facility in equilibrium.

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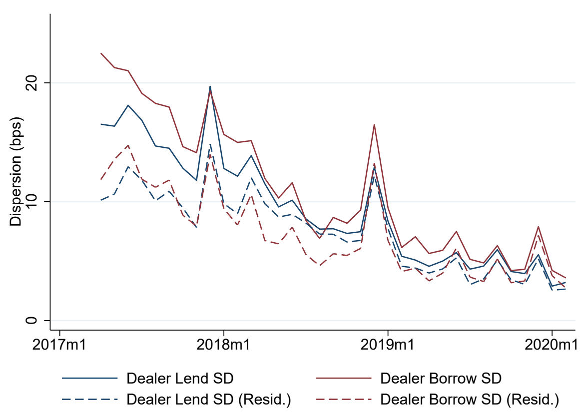
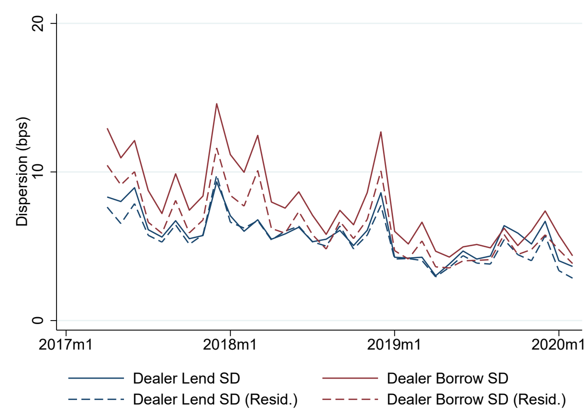
Figure 1: Dispersion in OTC Rates

This figure shows the dispersion in repo rates and residualized repo rates at which dealers lend to and borrow from their customers in the OTC market at a monthly frequency. Dispersion is measured as the monthly volume-weighted standard deviation of repo rates and residualized repo rates. The four panels show results for repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

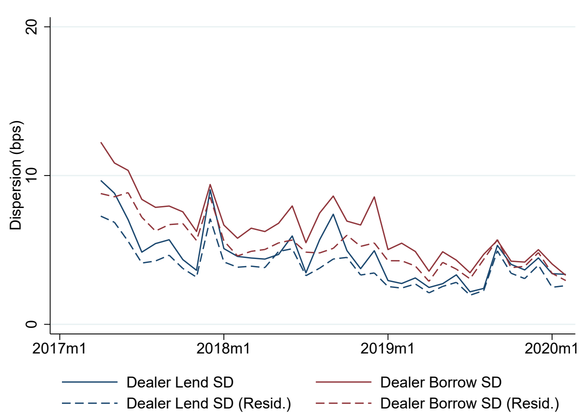
(a) DE



(b) FR



(c) IT



(d) ES

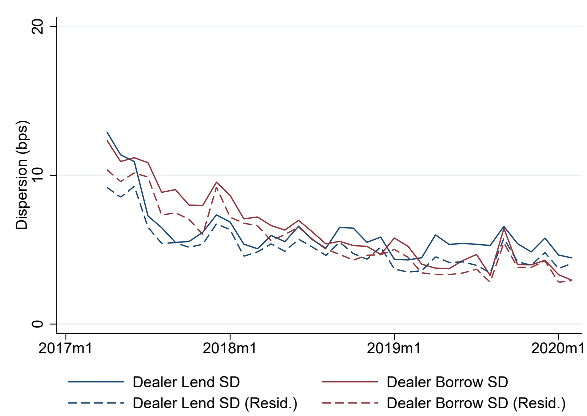
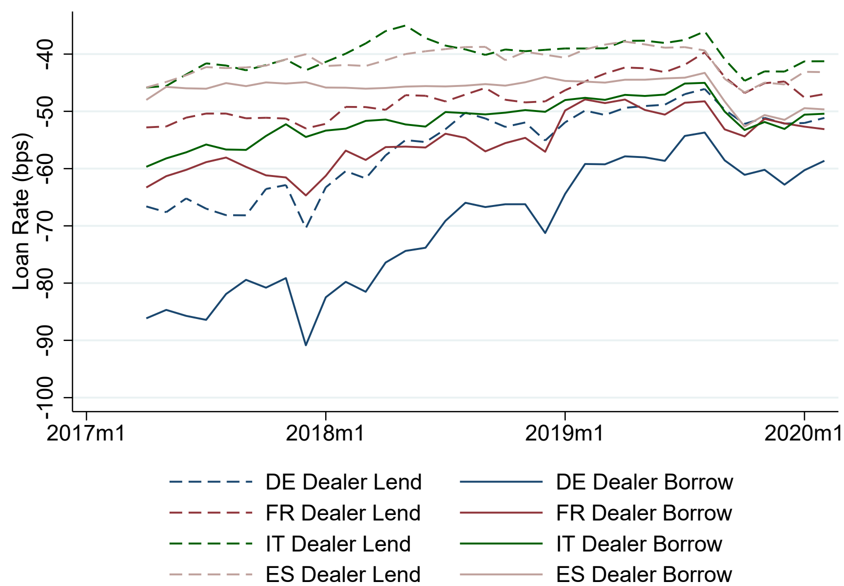


Figure 2: Dealer Lend and Borrow Rates in Inter-Dealer and OTC Markets

This figure shows the volume-weighted average repo rates at which dealers borrow and lend using German, French, Italian, and Spanish government collateral at a monthly frequency. Panel (a) shows the results for OTC repos and panel (b) shows the results for inter-dealer repos. The sample period is from February 2017 to February 2020.

(a) Over-the-Counter Market



(b) Inter-dealer Market

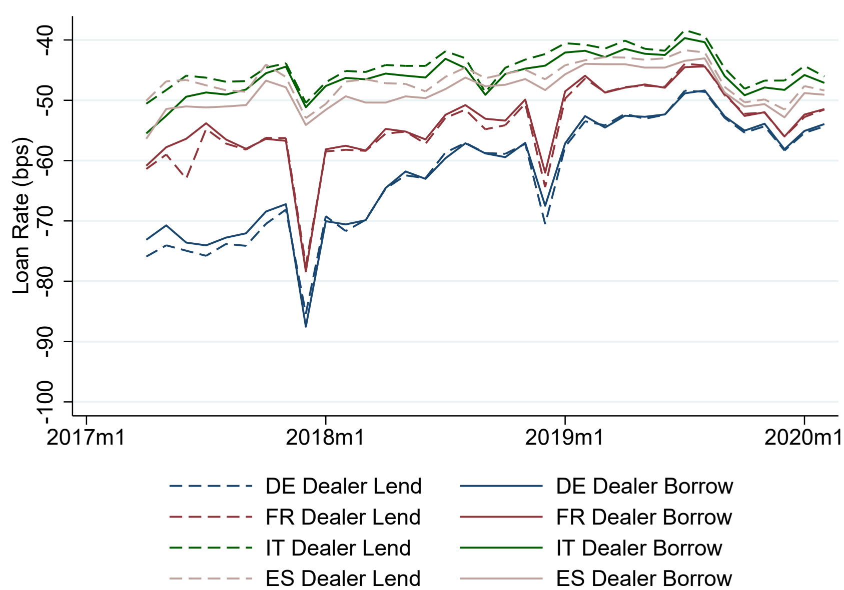


Figure 3: Net Interest Margins

This figure shows the volume-weighted average residualized repo rates at which dealers lend and borrow in the inter-dealer and OTC markets, at a monthly frequency. The four panels show the results for repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

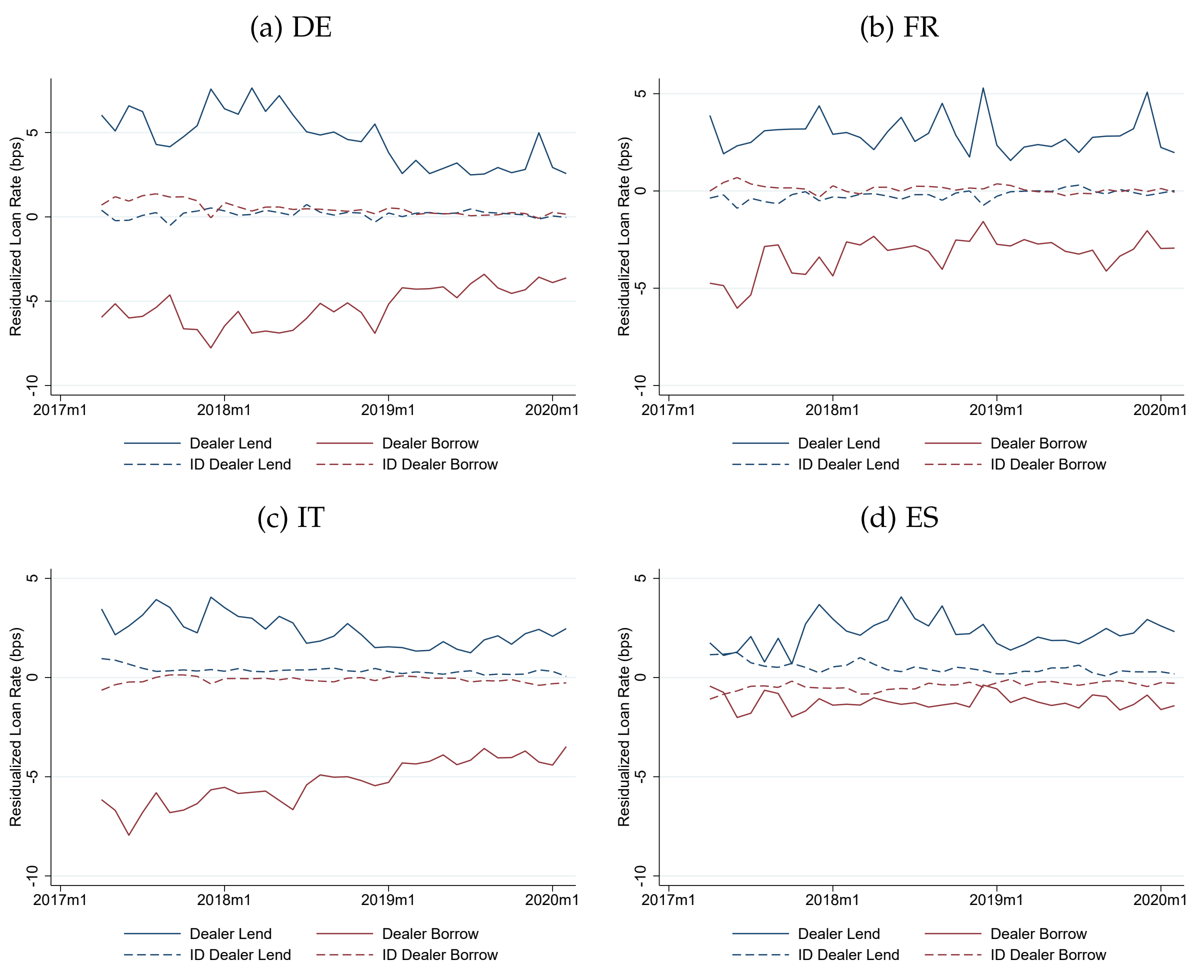


Figure 4: Net Interest Margins by Sector

This figure shows dealers' residualized net interest margins with respect to OTC customers in different sectors. The top and bottom of each bar refer to the average residualized repo rate at which dealers lend to and borrow from customers in that sector. The length of each bar corresponds to the size of dealers' net interest margins. The four panels show the results for repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

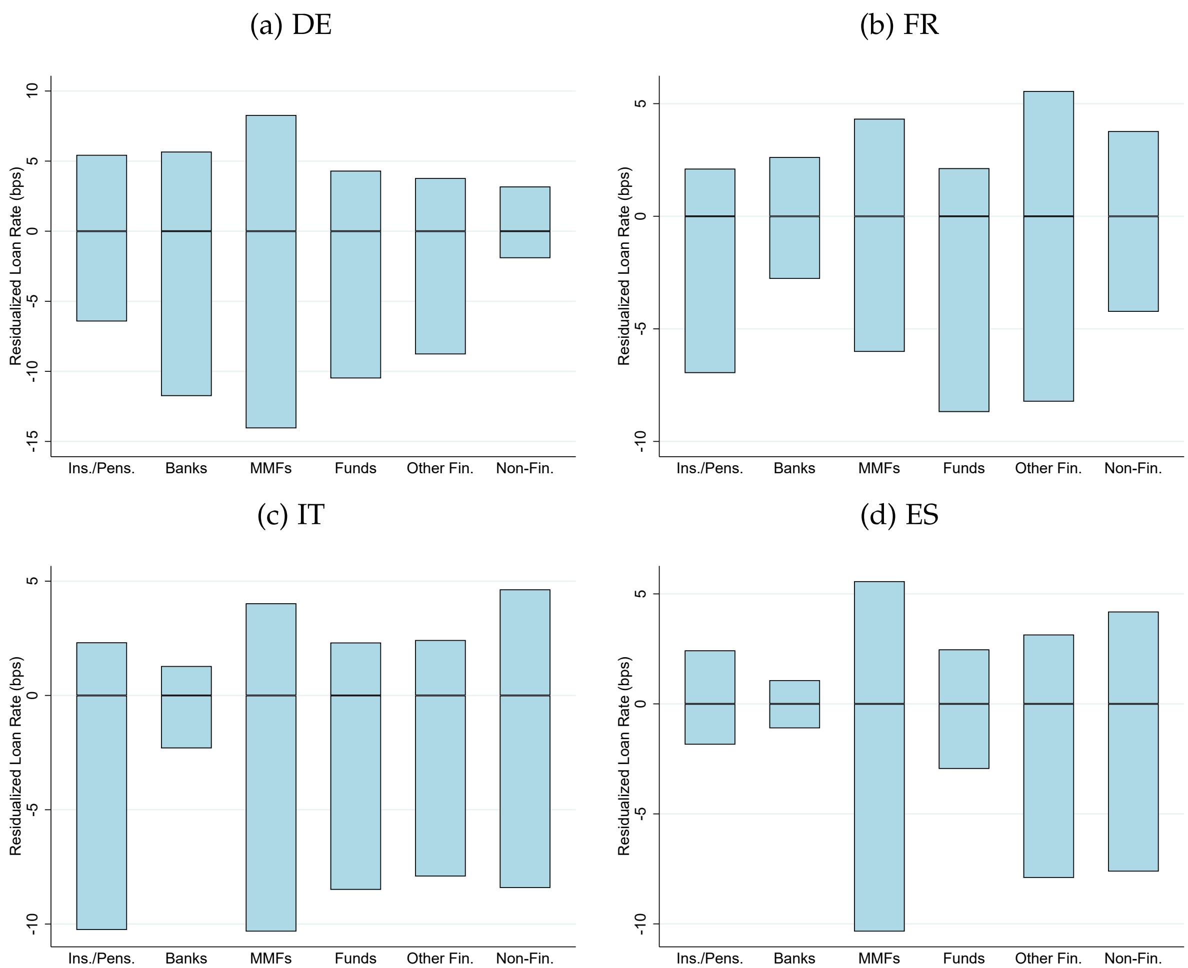
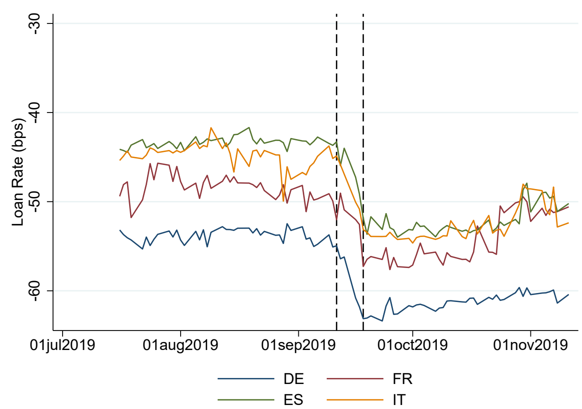


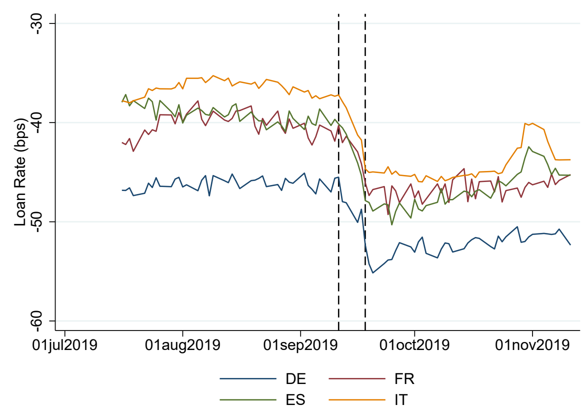
Figure 5: September 2019 Rate Cut

This figure shows the volume-weighted average daily repo rates for German, French, Italian, and Spanish government collateral around the monetary policy rate cut in September 2019. Panels (a) and (b) correspond to the rates at which dealers borrow and lend in the OTC market, and panels (c) and (d) correspond to the rates at which dealers borrow and lend in 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 the ECB's Deposit Facility Rate cut. Some data points have been omitted for confidentiality reasons.

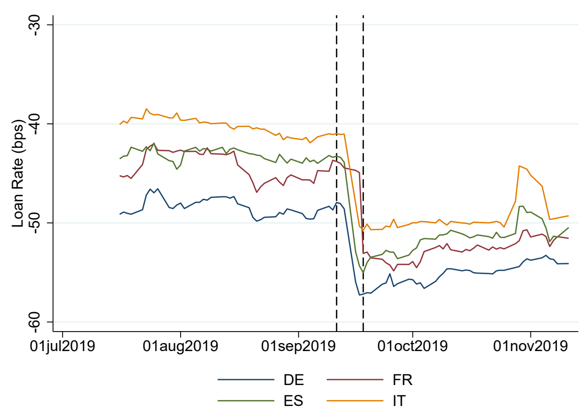
(a) OTC Dealer-Borrow Rates



(b) OTC Dealer-Lend Rates



(c) Inter-dealer Borrow Rates



(d) Inter-dealer Lend Rates

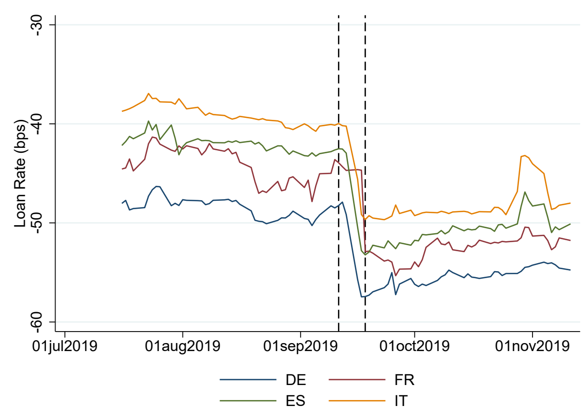


Figure 6: Model Fit: Relationship between Passthrough and the Number of Links

This figure shows the passthrough from the inter-dealer repo rate to the OTC repo rate for depositing customers with different number of links. The blue line corresponds to estimates of β_N from Specification (14). The red line corresponds to passthrough from the fitted model. Error bars show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

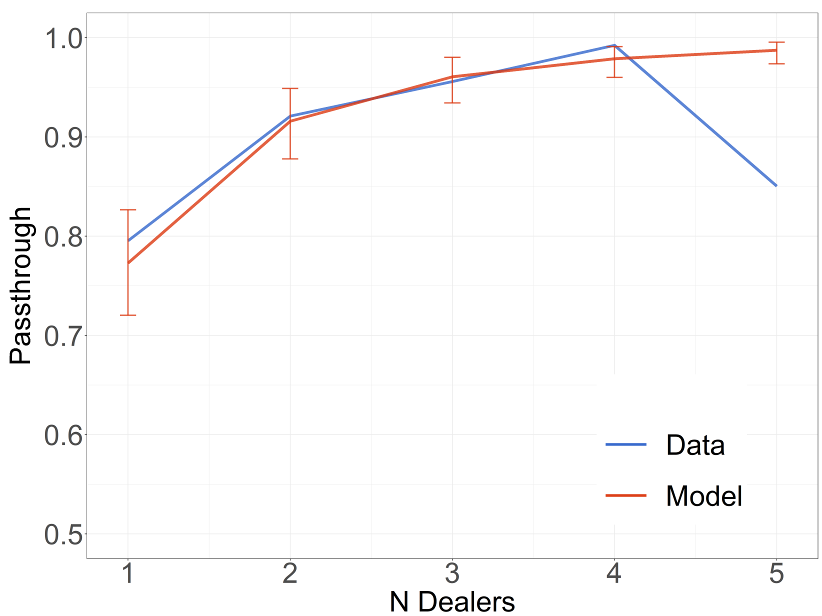


Figure 7: Model Fit: Relationship between the Number of Links and Trading Volume

This figure shows binscatter plots of trading volume versus the number of dealer links formed for repo depositors in different sectors in the pre-rate-cut month. The blue and red dots correspond to the data and model predictions, respectively. In the data, flow repo volumes are converted to average outstanding volumes by multiplying trade size by the maturity in days, and then dividing by the number of days in the month, as described in footnote 18. Volumes are in € thousands. In the model, we aggregate across collateral countries within a sector weighting the binscatters by the number of customers trading within the collateral country.

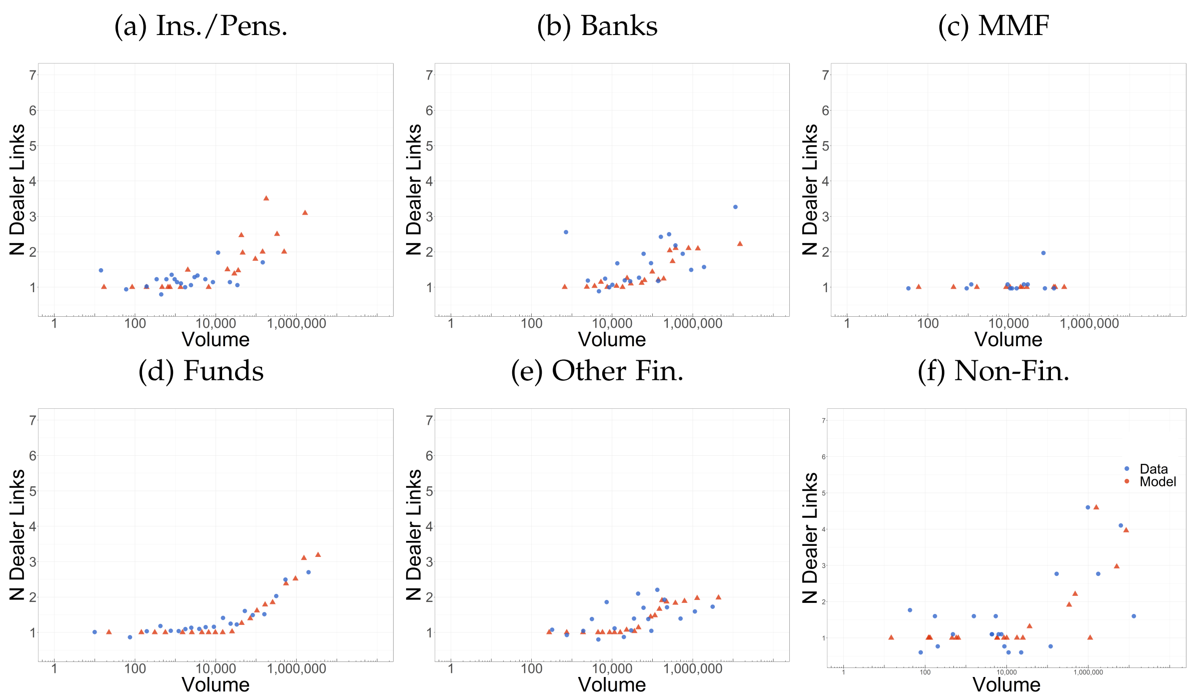


Figure 8: Number of Links and Passthrough with Rate Increases

This figure shows the number of dealer links formed, the inter-dealer to OTC passthrough, and rate dispersion, that our model predicts as monetary policy increases the inter-dealer rate. Each line corresponds to the results for a different sector. We present results for different sectors averaged across collateral country, where the weights are the number of customers in that segment in the data.

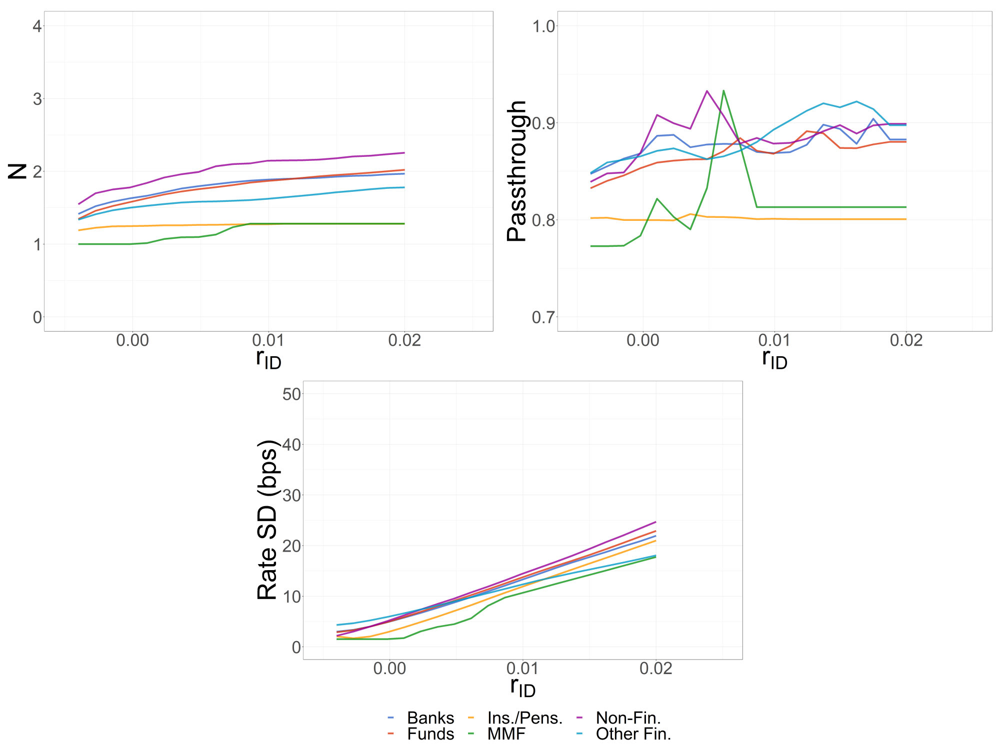


Table 1: OTC Repo Market Structure

This table shows the distribution of trading relationships and repo volumes for OTC repo customers in different sectors, for German (DE), French (FR), Italian (IT) and Spanish (ES) collateral-backed repos. The sectors include insurance and pensions, banks, money market funds, investment funds, other financial institutions, and non-financial institutions. The first three rows of each panel show the first, second, and third quartile of the number of unique dealers for customers in each sector, where the number of unique dealers for each customer is counted from February 2017 to February 2020. The last two rows of each panel show the average monthly volumes that dealers lend and borrow from customers in each sector in €1 billion from February 2017 to February 2020.

(a) DE

	Ins./Pens.	Banks	MMF	Funds	Other Fin.	Non-Fin.
No of Links (Q1)	1	1	1	1	1	1
No of Links (Q2)	1	2	1	1	1	1
No of Links (Q3)	3	4	1	2	2	2
Dealer Borrow Volume	22	19	26	202	153	8
Dealer Lend Volume	22	59	16	74	59	53

(b) FR

	Ins./Pens.	Banks	MMF	Funds	Other Fin.	Non-Fin.
No of Links (Q1)	1	1	1	1	1	1
No of Links (Q2)	2	2	1	1	1	1
No of Links (Q3)	3	4	1	2	2	2
Dealer Borrow Volume	18	40	28	80	63	27
Dealer Lend Volume	94	58	10	45	31	98

(c) IT

	Ins./Pens.	Banks	MMF	Funds	Other Fin.	Non-Fin.
No of Links (Q1)	1	1	1	1	1	1
No of Links (Q2)	1	2	1	1	1	1
No of Links (Q3)	2	3	1	2	2	2
Dealer Borrow Volume	15	36	12	125	36	10
Dealer Lend Volume	18	50	6	166	47	36

(d) ES

	Ins./Pens.	Banks	MMF	Funds	Other Fin.	Non-Fin.
No of Links (Q1)	1	1	1	1	1	1
No of Links (Q2)	1	2	1	1	1	1
No of Links (Q3)	1	4	1	1	2	1
Dealer Borrow Volume	36	26	15	186	18	19
Dealer Lend Volume	7	36	9	57	29	16

Table 2: Customer Characteristics and Residualized Repo Rates (Dealer Borrow)

This table shows how the residualized repo rates at which dealer borrow from customers vary with the number of links that customers form. For the dependent variable, we first calculate the residualized repo rates for each collateral ISIN. Then, we average the residualized repo rates by collateral country between each dealer-customer pair. Number of Dealers is the number of unique dealers that the customer trades with during our sample period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. We control for the average maturity and haircut of repos between each dealer-customer pair. We also include customer-sector and dealer fixed effects and cluster standard errors by dealer. Observations are weighted by one over the number of links that the customer forms.

	(1)	(2)	(3)	(4)
	Residual Borrow Rates			
Number of Dealers	0.227**	0.203**	0.272***	0.249**
	[0.089]	[0.093]	[0.100]	[0.106]
ES	-3.448**	-4.253***	-3.463**	-4.124**
	[1.401]	[1.227]	[1.581]	[1.526]
FR	-0.134	-0.875	0.499	-0.419
	[0.725]	[0.625]	[1.037]	[0.932]
IT	-1.560	-1.662	-1.244	-1.514
	[1.072]	[1.068]	[1.359]	[1.312]
Maturity			-0.011	0.017
			[0.086]	[0.087]
Haircut			-0.360	1.161
			[3.848]	[4.360]
Cntp Sector FE	Yes	Yes	Yes	Yes
Dealer FE	No	Yes	No	Yes
Observations	3536.000	3531.000	3105.000	3098.000
Adj. R-squared	0.237	0.283	0.250	0.300

Table 3: Customer Characteristics and Residualized Repo Rates (Dealer Lend)

This table shows how the residualized repo rates at which dealers lend to customers vary with the number of links that customers form. For the dependent variable, we first calculate the residualized repo rates for each collateral ISIN. Then, we average the residualized repo rates by collateral country between each dealer-customer pair. Number of Dealers is the number of unique dealers that the customer trades with during our sample period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. We control for the average maturity and haircut of repos between each dealer-customer pair. We also include customer-sector and dealer fixed effects and cluster standard errors by dealer. Observations are weighted by one over the number of links that the customer forms.

	(1)	(2)	(3)	(4)
		Residual Lend Rates		
Number of Dealers	-0.454***	-0.434***	-0.507***	-0.485***
	[0.122]	[0.119]	[0.134]	[0.121]
ES	-2.576	-2.237	-2.145	-1.793
	[1.759]	[1.625]	[1.810]	[1.711]
FR	-2.060**	-1.649**	-2.471***	-2.085***
	[0.826]	[0.668]	[0.851]	[0.651]
IT	-2.724***	-2.953***	-2.620**	-2.637***
	[0.933]	[0.799]	[1.033]	[0.921]
Maturity			0.056**	0.069**
			[0.027]	[0.026]
Haircut			-0.187	-2.390
			[3.024]	[1.918]
Cntp Sector FE	Yes	Yes	Yes	Yes
Dealer FE	No	Yes	No	Yes
Observations	3626.000	3622.000	3108.000	3103.000
Adj. R-squared	0.056	0.179	0.070	0.232

Table 4: Distribution of Passthrough

This table shows the distribution of passthroughs from the September 2019 rate cut, expressed in percent. Panel (a) calculates passthrough using repo rates and panel (b) calculates passthrough using residualized repo rates. For each ISIN, the DFR-OTC passthrough is the average change in repo rates in the OTC market from the pre- to post-rate cut period, divided by the deposit facility rate change of -10bps. The first two rows of each panel show their volume-weighted distribution. For each collateral ISIN, the ID-OTC passthrough is the average change in repo rates in the OTC market from the pre- to post-rate cut period, divided by that in the inter-dealer market from the pre- to post-rate cut period. The last two rows of each panel show the volume-weighted distribution of ID-OTC passthroughs.

(a) Repo Rates

	Average	p10	p25	p50	p75	p90
DFR to OTC, Dealer Lend	59.7	24.4	38.1	69.1	78.2	84.7
DFR to OTC, Dealer Borrow	70.3	18.6	61.5	79.8	85.8	94.9
ID to OTC, Dealer Lend	71.7	29.4	49.9	73.4	89	101.1
ID to OTC, Dealer Borrow	79.4	21.8	67.1	83.9	100.3	115.5

(b) Residualized Repo Rates

	Average	p10	p25	p50	p75	p90
DFR to OTC, Dealer Lend	58.4	20.9	36.2	67.1	76.3	85.9
DFR to OTC, Dealer Borrow	69.6	17.4	62.3	77.6	89.6	98.4
ID to OTC, Dealer Lend	72.1	27.5	41.1	77.6	94.4	101.7
ID to OTC, Dealer Borrow	79	19.7	63.4	83.8	99.2	108.5

Table 5: Customer Characteristics and Passthrough

This table shows how ID-OTC passthrough to customers varies with he number of links that customers form. For the dependent variable, we first calculate ID-OTC passthrough for each collateral ISIN as the average change in residualized repo rates in the OTC market from the pre- to post-rate cut period, divided by that in the inter-dealer market from the pre- to post-rate cut period. Then, we average ID-OTC passthrough by collateral country between each dealer-customer pair. Number of Dealers is the number of unique dealers that the customer trades with during the pre rate-cut month. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. We control for the average maturity and haircut of repos between each dealer-customer pair. We also include customer-sector and dealer fixed effects and cluster standard errors by dealer. Observations are weighted by one over the number of links that the customers forms.

	(1)	(2)	(3)	(4)
	Passthrough			
Number of Dealers	2.788*	3.893***	2.673*	3.958***
	[1.510]	[1.230]	[1.493]	[1.212]
ES	-41.920**	-43.757**	-38.137*	-39.553*
	[18.194]	[18.969]	[18.741]	[19.172]
FR	6.612	5.700	8.962	8.220
	[12.458]	[13.333]	[12.187]	[12.738]
IT	2.358	-3.779	4.937	-2.303
	[7.090]	[5.479]	[6.882]	[4.924]
Dealer Lend	-5.310	-1.785	-3.936	-0.812
	[3.398]	[3.468]	[3.340]	[3.333]
Haircut			-33.977	4.801
			[31.779]	[17.987]
Maturity			-0.685	-0.533
			[0.465]	[0.392]
Cntp Sector	Yes	Yes	Yes	Yes
Dealer FE	No	Yes	No	Yes
Observations	808	804	805	801
Adj. R-squared	0.231	0.354	0.233	0.356

Table 6: Parameter Estimates

This table shows the parameter estimates of our model for repo depositors. ϕ is the bargaining power of dealers over customers in each bilateral negotiation. μ and σ are the mean and standard deviation of customers' values, respectively, in basis points. τ is the weighted average balance sheet cost. $exp(\zeta^1)$ and ζ^2 are the connection cost parameters in (15). We report $exp(\zeta^1)$, the cost of connecting to the second dealer, in units of €1K per year. We report values as NA when $exp(\zeta^1)$ is above €1 billion annually, or when ζ^2 is above 1000. We estimate $\mu, \sigma, \tau, \zeta^1, \zeta^2$ separately by customer sector and collateral country, but we report averages of parameters across collateral countries, weighting collateral countries within a customer sector by the number of customers in the segment. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Sector	ϕ	μ	σ	τ	$exp(\zeta^1)$	ζ^2
Banks	0.23	-48.1	19.6	0.31	42.0	3.8
	(0.17, 0.28)	(-61.5, -41.9)	(10.0, 36.8)	(0.02, 0.64)	(5.3, 69.4)	(0.1, 64.0)
Funds		-46.2	20.0	0.37	17.7	1.9
		(-53.2, -41.8)	(14.1, 30.0)	(0.08, 0.55)	(9.8, 42.7)	(0.2, 25.4)
Ins./Pens.		-46.3	4.9	0.07	NA	NA
		(-49.3, -40.4)	(5.1, 15.8)	(0.00, 0.69)	(NA, NA)	(NA, NA)
MMF		-42.6	10.6	0.04	228.8	NA
		(-44.3, -40.0)	(3.6, 21.6)	(0.00, 3.02)	(7.1, NA)	(NA, NA)
Non-Fin.		-46.6	11.9	0.23	9.0	0.1
		(-52.2, -41.0)	(9.9, 37.5)	(0.01, 1.86)	(2.3, 43.4)	(0.0, 36.2)
Other Fin.		-47.3	34.9	0.16	36.8	4.4
		(-54.8, -41.1)	(23.9, 56.7)	(0.05, 1.57)	(4.6, 118.6)	(1.7, 61.4)

Table 7: Model Fit: Net Interest Margin and Dispersion

This table shows the net interest margin and dispersion of repo rates for each sector for repo depositors. Sector is the sector of the customer. Target SD is the observed dispersion in residual repo rates in the data. Model SD is the dispersion in residual repo rates predicted by the model. Target NIM is the average net interest margin of residualized repo rates in the data. Model NIM is the average net interest margin in the model. All quantities are in bps. We present results for different sectors averaged across collateral country, where the weights are the number of customers in that segment in the data. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Sector	Target SD	Model SD	Target NIM	Model NIM
Banks	4.48	2.49	2.49	3.74
		(1.97, 3.40)		(2.98, 4.36)
Funds	3.64	2.71	2.69	3.53
		(2.36, 3.15)		(3.23, 3.91)
Ins./Pens.	2.28	0.87	0.29	1.47
		(0.82, 1.99)		(1.16, 3.63)
MMF	2.28	1.54	1.62	2.17
		(0.55, 2.74)		(0.75, 5.41)
Non-Fin.	2.86	1.92	1.52	2.59
		(1.62, 3.00)		(2.23, 4.74)
Other Fin.	5.58	4.14	3.97	5.24
		(3.17, 5.17)		(4.32, 6.73)

Table 8: Effect of Inter-Dealer Platform Access

This table shows results from the inter-dealer platform access counterfactual. Baseline refers to the benchmark case without any inter-dealer platform access. Access cost 100K, 25K, 5K, and 0K refer to the counterfactual cases where inter-dealer platform access is available at an annual cost of €100K, €25K, €5K, and €0K, respectively. Rate disp is the standard deviation of rates, in bps. Passthrough is the derivative of average repo rates with respect to inter-dealer repo rates. Frac. Connected is the fraction of agents who optimally connect to the inter-dealer platform. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Type	Rate Disp	Passthrough	Frac. Connected
Baseline	3.01	82.9%	
	(2.88, 3.52)	(78.6%, 87.4%)	
100k	3.13	84.5%	12.8%
	(2.99, 3.56)	(81.1%, 88.3%)	(10.8%, 15.3%)
25k	3.10	86.3%	27.0%
	(2.94, 3.51)	(83.7%, 89.7%)	(24.1%, 28.6%)
5k	2.62	90.4%	42.6%
	(2.52, 3.14)	(88.6%, 92.8%)	(39.9%, 44.9%)
0	0.00	100.0%	100.0%
	(0.00, 0.00)	(100.0%, 100.0%)	(100.0%, 100.0%)

Table 9: Effect of the Reverse Repurchase Facility

This table shows results from the RRP counterfactual on the inter-dealer to OTC passthrough and rate dispersion. Baseline refers to the benchmark case without the RRP. 50bps, 25bps, and 10bps refer to the counterfactual cases where Δ_{RRP}, the gap between the RRP rate and the inter-dealer rate minus balance sheet costs, is 50bps, 25bps, and 10bps, respectively. Rate disp is the standard deviation of rates, in bps. Passthrough is the derivative of average repo rates with respect to inter-dealer repo rates. Frac. Binding is the fraction of agents for whom the RRP is a binding outside option. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Type	Rate Disp.	Passthrough	Frac. Binding
Baseline	3.01	82.9%	
	(2.88, 3.52)	(78.6%, 87.4%)	
50bps	2.75	83.7%	5.2%
	(2.57, 3.04)	(79.2%, 88.7%)	(2.0%, 12.2%)
25bps	2.01	88.2%	25.1%
	(1.65, 2.33)	(84.1%, 92.6%)	(17.6%, 40.1%)
10bps	0.92	96.5%	59.6%
	(0.73, 1.46)	(94.9%, 98.0%)	(52.4%, 70.6%)

Appendix

A Proofs and Supplementary Material for Section 4

A.1 Proof of Propositions 1 and 2

We solve the model backwards. First, we calculate outcomes assuming the customer connects with N dealers; then, we solve for the optimal number of dealers to connect with.

Outcomes conditional on connection count. The derivations here closely follow Stole and Zwiebel (1996), with notation adapted to our setting. 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:

$$S = \Psi_D \left(\left(r_{ID} - \tau_D \right) - \nu_D \right) \tag{19}$$

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

$$S \left(1 - Nt(N) \right) \tag{20}$$

We assumed in the main text that, when the customer considers an additional dealer, the dealer keeps a share ϕ of the associated surplus. Thus, when a customer trades with a single dealer, the dealer keeps a share:

$$t(1) = \phi$$

of the surplus, and the customer keeps share:

$$(1 - \phi)$$

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 $N+1$ instead of N dealers, is thus:

$$[S-(N+1)\,t(N+1)]-[S-Nt(N)]$$

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

The utility accruing to the Nth entering dealer is simply $t(N)$. Now, let BMS_N be the bilateral surplus accruing to the Nth dealer and the customer from the Nth dealer joining. If the Nth dealer keeps a share ϕ of the bilateral match surplus, and the customer keeps a share $1-\phi$, we have:

$$\text{Nth Dealer Surplus}=\phi BMS_N,\ \text{Customer Surplus}_N=(1-\phi)\,BMS_N$$

This then implies that:

$$(1-\phi)\,(\text{Nth Dealer Surplus})=\phi\,(\text{Customer Surplus}_N)=\phi\,(1-\phi)\,BMS_N$$

Thus, plugging in for the dealer and customer surplus, we must then have:

$$\underbrace{(1-\phi)\,t(N+1)}_{\text{New Dealer Surplus}}=\underbrace{\phi\,[Nt(N)-(N+1)\,t(N+1)]}_{\text{Customer Marginal Surplus}} \tag{21}$$

Solving for $t(N+1)$, we have:

$$t(N+1)=\frac{N}{\frac{1-\phi}{\phi}+(N+1)}t(N)$$

This proves (8). From (8), $t(N)$ is always positive. Now, since the LHS of (21) is always positive, the RHS is always positive, implying that $Nt(N)$ is always decreasing in N, implying that $1-Nt(N)$ is always increasing in N.

To calculate the customer's trade surplus, note that customers must attain (20). Surplus is:

$$S = \Psi_D \left((r_{ID} - \tau_D) - \nu_D \right)$$

The repo rate (9) is the unique rate which gives customers (20) in surplus.

Optimal link formation. We can thus write the customer's value function for connecting to N dealers as:

$$V(N) = S(1 - Nt(N)) - \sum_{i=1}^{N} C_i$$

where c is the cost of forming a link. Substituting for S using (19), we have:

$$V(N) = \Psi_D \left((r_{ID} - \tau_D) - \nu_D \right) (1 - Nt(N)) - \sum_{i=1}^{N} C_i \tag{22}$$

Customers choose how many dealers to connect to by choosing N to maximize (22). Since, from Proposition 1, $1 - Nt(N)$ is increasing in N, (22) has increasing differences in N and Ψ_D; thus, by Topkis' theorem, the optimal choice of N is weakly increasing in trade volume Ψ_D (Topkis, 1998).

Corresponding expressions for borrowers. For borrowers, prices are:

$$p = \nu_B - (\nu_B - (r_{ID} + \tau_B))(1 - Nt(N)) \tag{23}$$

The customer's total utility from connecting and trading with N dealers is:

$$\Psi_B \left(\nu_B - (r_{ID} + \tau_B) \right) (1 - Nt(N)) - \sum_{i=1}^{N} C_i$$

The expression for $t(N)$ is unchanged from (8).

A.2 Proof of Claims 1 and 2

To get (24), we take the conditional expectation of the gap between r_{ID} and repo rates from (9):

$$E\left[r_{ID} - r_D\left(\nu_D, \Psi_D\right) \mid \nu_D < r_{ID} - \tau_D\right] =$$

$$E\left[r_{ID} - \left[\nu_D + \left(\left(r_{ID} - \tau_D\right) - \nu_D\right)\left(1 - Nt\left(N\right)\right)\right] \mid \nu_D < r_{ID} - \tau_D\right]$$

$$= E\left[\tau_D + \left(\left(r_{ID} - \tau_D\right) - \nu_D\right) Nt\left(N\right) \mid \nu_D < r_{ID} - \tau_D\right]$$

This rearranges to (24).

Price dispersion is:

$$Var\left[r_D\left(\nu_D, \Psi_D\right) \mid \nu_D < r_{ID} - \tau_D\right] =$$

$$Var\left[\left[r_{ID} - \left[\nu_D + \left(\left(r_{ID} - \tau_D\right) - \nu_D\right)\left(1 - Nt\left(N\right)\right)\right] \mid \nu_D < r_{ID} - \tau_D\right]\right]$$

$$= Var\left[\left(\left(r_{ID} - \tau_D\right) - \nu_D\right) Nt\left(N\right) \mid \nu_D < r_{ID} - \tau_D\right]$$

Differentiating (9) with respect to r_{ID}, passthrough is:

$$\frac{\partial r_D\left(\nu_D, \Psi_D\right)}{\partial r_{ID}} = 1 - Nt\left(N\right)$$

giving (12).

Analogously, from (23), expressions for interest margins and dispersion for borrowers are:

$$E\left[r_B\left(\nu_B, \Psi_B\right) \mid \nu_B > r_{ID} + \tau_B\right] - r_{ID} = \tau_B + E\left[Nt\left(N\right)\left(\nu_B - \left[r_{ID} + \tau_B\right]\right) \mid \nu_B > r_{ID} + \tau_B\right] \quad (24)$$

$$Var\left[r_B\left(\nu_B, \Psi_B\right) \mid \nu_B > r_{ID} + \tau_B\right] = Var\left[Nt\left(N\right)\left(\nu_B - \left[r_{ID} + \tau_B\right]\right) \mid \nu_B > r_{ID} + \tau_B\right] \quad (25)$$

Passthrough is exactly (12).

A.3 Extension Model: The Inter-Dealer Repo Market

In the main text, we analyzed the passthrough of changes in the inter-dealer repo rate r_{ID} to OTC repo rates. The ECB's actual policy rate is the deposit facility rate (DFR), which we will call ρ. In this appendix, we construct an extension model to show how r_{ID} is determined in equilibrium, to analyze how changes in ρ may imperfectly pass through to changes in r_{ID}, based on the supply and demand for collateralized lending from dealers and OTC customers. We assume lending dealers have the option of lending in the inter-dealer repo market, as well as using the ECB's Deposit Facility. The model allows us to describe how r_{ID} is affected by changes in the ECB's DFR. The model is a simple variant of models used in the literature on repo specialness (Duffie, 1996; Fisher, 2002; Bottazzi, Luque and Páscoa, 2012; Huh and Infante, 2018; Infante, 2019; Nyborg, 2019).

We assume that, in addition to dealers' interactions with their OTC customers, dealers may have some 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 N_B borrowing dealers, indexed by $b \in \{1 \ldots N_B\}$, who hold collateral and wish to borrow against it. There are N_L lending dealers, indexed by $l \in \{1 \ldots N_L\}$, who have excess cash they wish to lend out. Lending dealers can either deposit cash in the central bank's unsecured deposit facility at rate ρ (which is set by the central bank) or lend secured in the inter-dealer repo market.

Borrowing dealer b has utility $W_b(q)$ for borrowing q units of cash, where each $W_b(\cdot)$ is twice differentiable and strictly concave, and pays interest r per unit of cash borrowed. Dealers behave competitively, taking the inter-dealer repo rate as given. Thus, if the equilibrium repo rate is r, borrowing dealer b chooses her borrowing quantity q to satisfy the first-order condition:

$$W_b'(q) = r. \tag{26}$$

Expression (26), summed across all N_B borrowing dealers, defines an aggregate dealer demand function for repo funding, $Q_{B,\mathrm{Dealer}}(r)$, satisfying:

$$Q_{B,\mathrm{Dealer}}(r) = \sum_{b=1}^{N_B} q_{b,\mathrm{Dealer}}(r), \; q_{b,\mathrm{Dealer}}(r) = \left\{ q : \; W_b'(q) = r \right\}. \tag{27}$$

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

Lending dealer l has some quantity M_l of excess funds to lend. Lending dealers 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.[22] Lenders' valuation for collateral may arise from a number of sources: lenders may need collateral to cover short bond positions, they may want to preserve the option to rehypothecate collateral, or they may simply have institutional constraints requiring them to lend collateralized. Formally, suppose lending dealer l has utility $W_l(q)$ for receiving q units of collateral, where each $W_l(q)$ is twice differentiable and strictly concave. Lending dealers also behave competitively. Thus, if the repo rate is r, lending dealer l chooses q to solve:

$$\max_q \rho (M_l - q) + rq + W_l(q). \tag{28}$$

That is, lender l receives the DFR ρ for the measure $M_l - q$ of funds she deposits in the facility, the repo rate r for the quantity q of funds she lends in the repo market, and utility $W_l(q)$ from the q units of collateral that she receives in the repo market. Analogously to (27), taking the first-order condition of (28) for each dealer, we derive an aggregate dealer supply function for repo funding:

$$Q_{L,\mathrm{Dealer}}(\rho - r) = \sum_{l=1}^{N_L} q_{l,\mathrm{Dealer}}(\rho - r), \; q_{l,\mathrm{Dealer}}(\rho - r) = \left\{ q : \; W_l'(q) = \rho - r \right\}. \tag{29}$$

Note that the supply of repo funds is a function of $\rho - r$, the difference between the DFR, ρ, and the repo rate r. Since each $W_l(q)$ is concave, lending dealers' repo funding supply is decreasing

[22]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 DFR 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 DFR would not be binding. Our model abstracts away from this case for simplicity.

in ρ and increasing in r.

Next, we characterize the total supply and demand of repo funding from OTC borrowers and lenders. Let $M_{B,OTC}$ represent the total mass of OTC borrowers; let $F_{\nu,B}(\nu_B)$ represent the CDF of ν_B among these borrowers, and let τ_B be the balance sheet cost for these OTC customers. Suppose the inter-dealer repo rate is r; OTC borrowers will borrow if their value ν_B is higher than $r+\tau_B$, the sum of the inter-dealer repo rate r and the intermediation cost τ_B for borrowing customers. Thus, the total quantity of repo funding demanded by OTC borrowers is:

$$M_{B,OTC}\int_{\nu_B>r+\tau_B} dF_{\nu,B}(\nu_B) = M_{B,OTC}\left(1-F_{\nu,B}(r+\tau_B)\right). \tag{30}$$

For every unit of funds a dealer lends to OTC customers, she borrows the same amount in inter-dealer markets; hence, (30) exactly describes the contribution of borrowing customers to total funding demand in the inter-dealer market. Thus, define total demand for repo funding from OTC borrowers at rate r as:

$$Q_{B,OTC}(r) \equiv M_{B,OTC}\left(1-F_{\nu,B}(r+\tau_B)\right).$$

Analogously, let $M_{D,OTC}$ represent the mass of OTC depositors, let $F_{\nu,D}(\nu_D)$ represent the CDF of ν_D among these depositors, and let τ_D denote the cost dealers face for intermediating these customers' trades. OTC depositors linked to dealer j will deposit if their value ν_D is lower than $r-\tau_D$. The total quantity of repo funding supplied by all dealers' OTC depositors, if the inter-dealer repo rate is r, is thus:

$$Q_{D,OTC}(r) = M_{D,OTC}\left(F_{\nu,D}(r-\tau_D)\right).$$

The equilibrium inter-dealer repo rate, r_{ID}, must equate the supply and demand for repo funding from lending dealers, borrowing dealers, OTC depositors, and OTC borrowers. That is, r_{ID} must satisfy:

$$Q_{B,OTC}(r_{ID}) + Q_{B,Dealer}(r_{ID}) = Q_{L,Dealer}(\rho - r_{ID}) + Q_{D,OTC}(r_{ID}). \tag{31}$$

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. Thus, the RHS and LHS of (31) 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 (31), we can show how changes in the DFR, ρ, affect the equilibrium inter-dealer repo rate r_{ID}.

Claim 4. *The passthrough of the DFR ρ to inter-dealer repo rates r_{ID} (DFR-ID passthrough) is:*

$$\frac{dr_{ID}}{d\rho} = \frac{Q'_{L,Dealer}(\rho - r_{ID})}{Q'_{B,OTC}(r_{ID}) + Q'_{B,Dealer}(r_{ID}) + Q'_{L,Dealer}(\rho - r_{ID}) - Q'_{D,OTC}(r_{ID})}. \tag{32}$$

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

Claim 4 shows that the passthrough of ρ to r_{ID} is always imperfect. In contrast to the situation in the OTC market, where imperfect ID-OTC passthrough is caused by dealer market power, DFR-ID passthrough is imperfect because the deposit facility and repo trades are imperfect substitutes to lending dealers, since lending in repo markets provides collateral, and the deposit facility does not. When the DFR ρ increases, the deposit facility becomes more attractive relative to repo trading, so some lending dealers substitute towards the deposit facility. If r_{ID} increased one-for-one with changes in ρ, the demand for repo funds would decrease, whereas the supply of repo funds from lending dealers would not change, so markets would not clear. Thus, $\rho - r_{ID}$, the equilibrium price of inter-dealer repo relative to the Deposit Facility, must increase to clear the market. This implies that r_{ID} will increase less than one-for-one with changes in ρ. In the repo literature, this is often called the "collateral scarcity" effect.

Appendix Figure A.1 graphically shows the intuition behind DFR-ID passthrough, expression (32) of Claim 4. We can write (31), the equilibrium condition in the inter-dealer market, as:

$$Q_{L,Dealer}(\rho - r_{ID}) = Q_{B,OTC}(r_{ID}) + Q_{B,Dealer}(r_{ID}) - Q_{D,OTC}(r_{ID}). \tag{33}$$

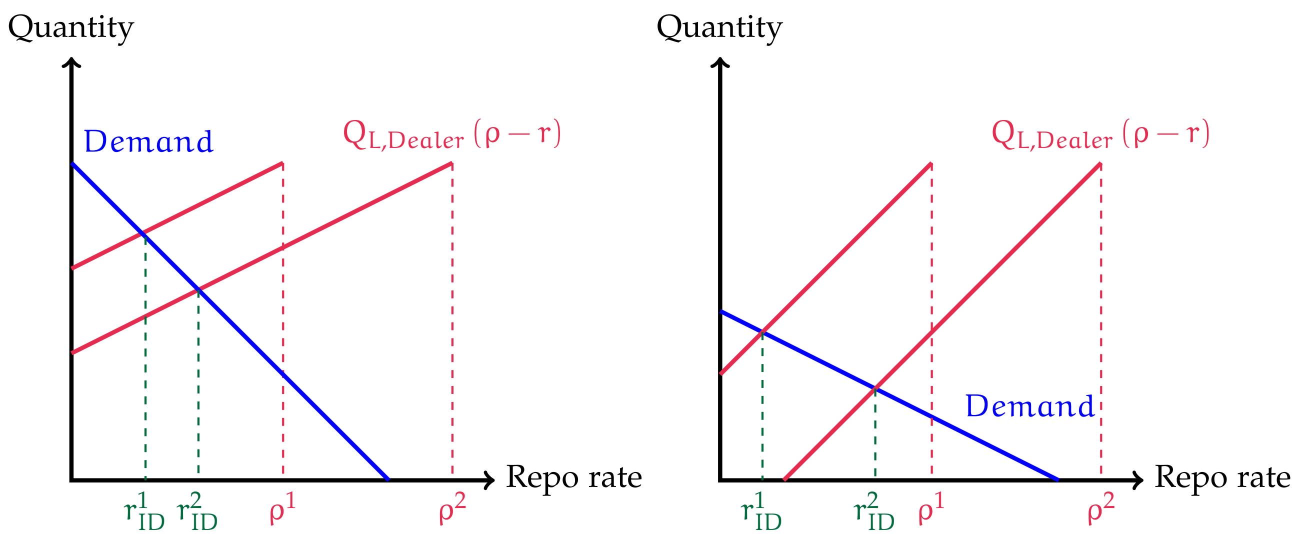
In words, (33) says that the supply of funds from lending dealers must equal the net demand from all other kinds of agents: borrowing dealers, and the demand from OTC borrowers minus the supply from OTC depositors. In both panels of Figure A.1, the red curve shows $Q_{L,Dealer}(\rho - r_{ID})$, and the blue curve shows net demand from all other agents, that is, all terms on the right-hand

Figure A.1: DFR - ID Passthrough Intuition

Intuition for DFR-ID passthrough. 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 passthrough is low. The right plot illustrates a case where funding supply is elastic and funding demand is inelastic, so passthrough is high.

(a) Low Passthrough

(b) High Passthrough



side of (33). 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 DFR ρ rises slightly, r_{ID} cannot rise 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.[23]

[23]Claim 4 also shows why it is important to assume that funding supply and demand are both imperfectly elastic for modeling passthrough. If all lending dealers had infinite willingness-to-pay for collateral, then (32) implies that DFR-ID passthrough 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.

B Proofs and Supplementary Material for Section 5

B.1 Moment Expressions

To calculate the average number of connections formed by consumers with volume Ψ, we take:

$$N(\Psi_{Di}) = \int N(\Psi_{Di}, \nu_{Di})\, dF_{\nu}(\nu_{Di})$$

The average interest rate conditional on trade is:

$$\bar{r} = \frac{\int\int_{\nu_{Di} > r_{ID} - c_D} r(\Psi_{Di}, \nu_{Di})\, dF_{\nu}(\nu_{Di})\, dF_{\Psi}(\Psi_{Di})}{\int\int_{\nu_{Di} > r_{ID} - c_D} dF_{\nu}(\nu_{Di})\, dF_{\Psi}(\Psi_{Di})}$$

Interest margins are:

$$Margin = r_{ID} - \bar{r}$$

Rate dispersion is the standard deviation of rates, conditional on trade:

$$Dispersion = \sqrt{\frac{\int\int_{\nu_{Di} > r_{ID} - c_D} (r(\Psi_{Di}, \nu_{Di}) - \bar{r})^2\, dF_{\nu}(\nu_{Di})\, dF_{\Psi}(\Psi_{Di})}{\int\int_{\nu_{Di} > r_{ID} - c_D} dF_{\nu}(\nu_{Di})\, dF_{\Psi}(\Psi_{Di})}}$$

C Proofs and Supplementary Material for Section 6

C.1 Proof of Claim 3

If $r_{RRP} \geqslant r_{ID} - \tau_D$, then dealers cannot offer the OTC depositor a better price than the RRP, so the depositor uses the RRP for all trades, receiving rate r_{RRP}. Now, suppose that:

$$r_{RRP} < r_{ID} - \tau_D$$

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 ν_D and the policy rate r_{RRP}. That is, a depositor negotiates prices with dealers as if she had value:

$$\tilde{\nu}_D \equiv \max\left(\nu_D, r_{RRP}\right) \tag{34}$$

All depositors with value ν_D less than $r_{ID} - \tau_D$ trade. If a depositor connects with N dealers, from (9) of Proposition 1, she trades at rates:

$$r_D\left(\nu_D, \theta_D\right) = \tilde{\nu}_D + \left(\left(r_{ID} - \tau_D\right) - \tilde{\nu}_D\right)\left(1 - Nt\left(N\right)\right) \tag{35}$$

This is (17). A depositor's value from trade is thus:

$$\Psi\left(r_D\left(\nu_D, \theta_D\right) - \nu_D\right) - \sum_{i=1}^{N} C_i = \Psi\left(r_D\left(\nu_D, \theta_D\right) - \tilde{\nu}_D\right) + \Psi\left(\tilde{\nu}_D - \nu_D\right) - \sum_{i=1}^{N} C_i$$

$$= \underbrace{\Psi\left(\left(r_{ID} - \tau_D\right) - \tilde{\nu}_D\right)\left(1 - Nt\left(N\right)\right) - \sum_{i=1}^{N} C_i}_{A} + \underbrace{\Psi\left(\tilde{\nu}_D - \nu_D\right)}_{B} \tag{36}$$

In expression (36), only term A depends on N; term B is constant in N. Hence, the depositor chooses N to maximize term A. Term A is exactly (13) of Proposition 1, with $\tilde{\nu}_D$ instead of ν_D; hence, the consumer optimally picks N to maximize term A, analogous to Proposition 1. This proves (18).

D Additional Results and Robustness

Table A.1: Net Interest Margin and Dispersion of Residualized Rates in the OTC Market

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 repo 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.

	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

Table A.2: Net Interest Margins and Dispersion of Repo Rates (GC versus SC)

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.

	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

Table A.3: Net Interest Margins and Dispersion of Residualized Rates (GC versus SC)

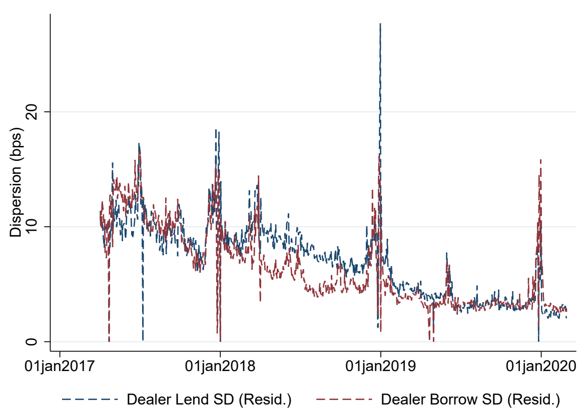
This table shows the average net interest margins and dispersion of residualized repo rates at which dealers lend and borrow in the OTC market for SC and GC repos. Residualized repo rates are obtained according to specification (1). The net interest margin and standard deviation for the residualized 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.

	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

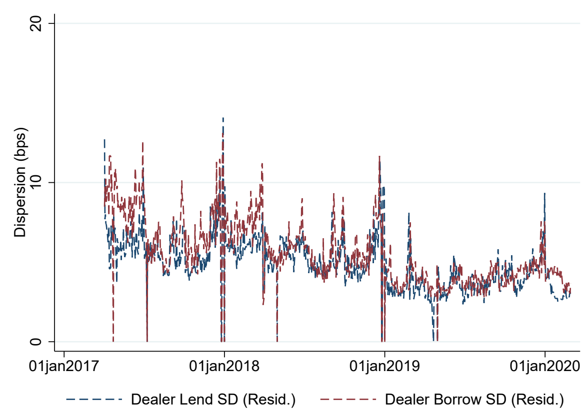
Figure A.2: Dispersion in OTC Rates (Daily)

This figure shows the dispersion in daily residualized repo rates at which dealers lend to and borrow from their customers in the OTC market at a daily frequency. Dispersion is measured as the monthly volume-weighted standard deviation of repo rates and residualized repo rates. The four panels show results for repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

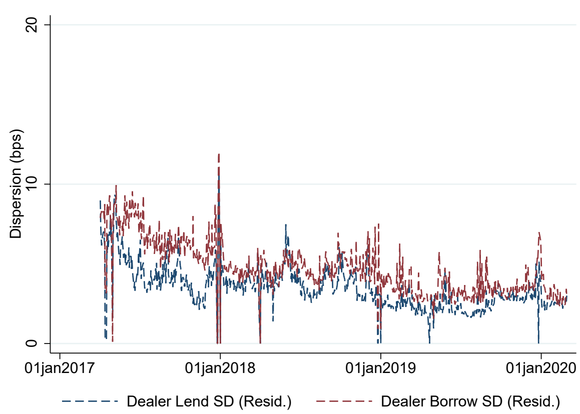
(a) DE



(b) FR



(c) IT



(d) ES

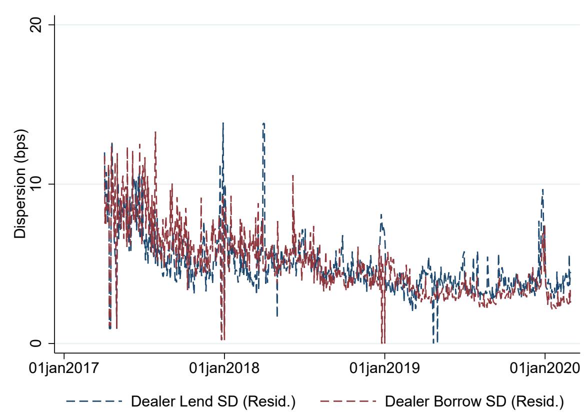
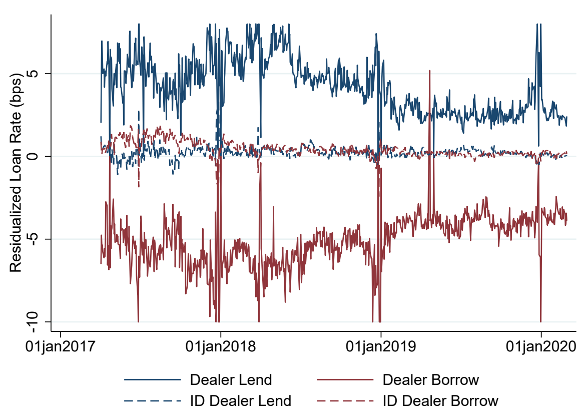


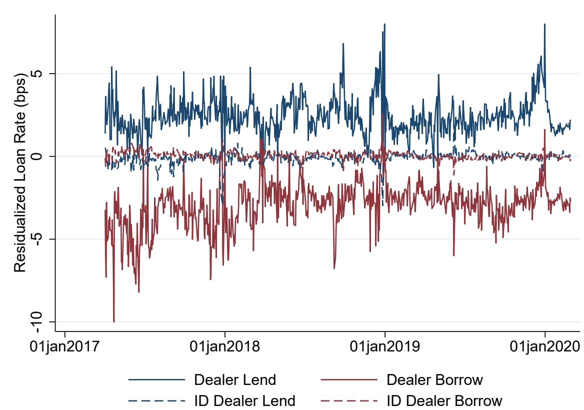
Figure A.3: Net Interest Margins (Daily)

This figure shows the volume-weighted average daily residualized repo rates at which dealers lend and borrow in the inter-dealer and OTC markets, at a daily frequency. The four panels show the results for repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from February 2017 to February 2020.

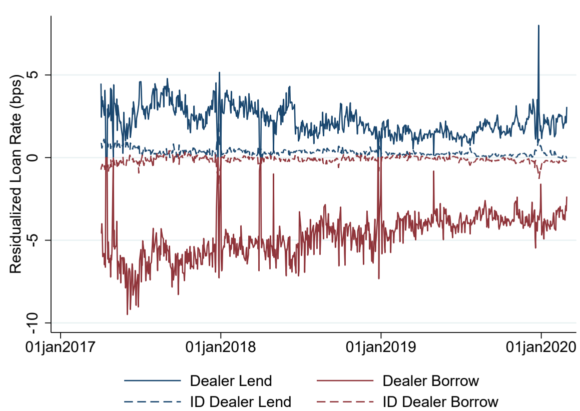
(a) DE



(b) FR



(c) IT



(d) ES

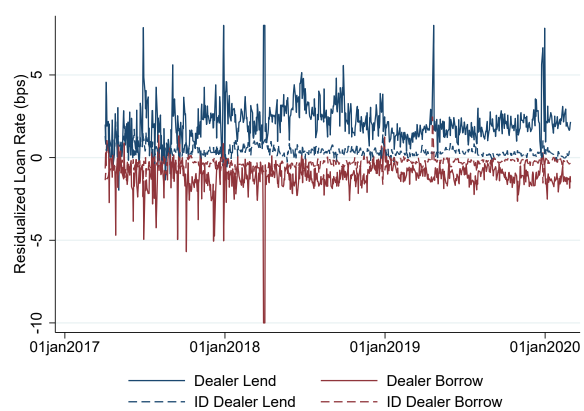
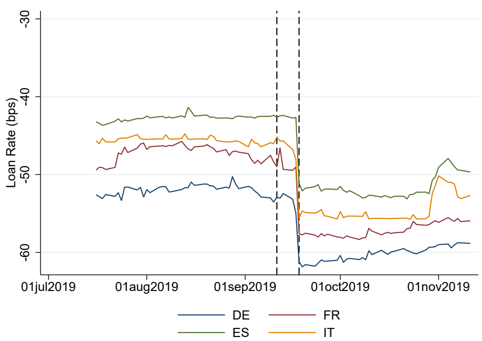


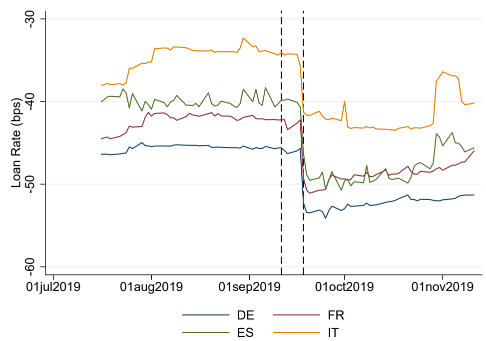
Figure A.4: September 2019 Rate Cut by Repo Maturity

This figure shows the volume-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 for confidentiality reasons.

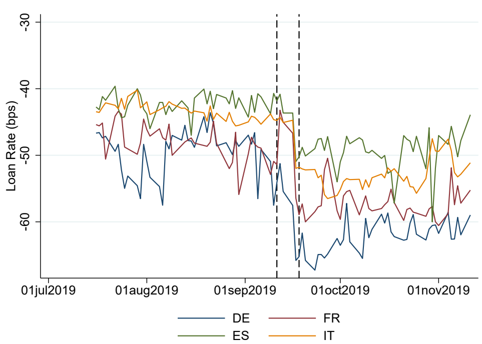
(a) OTC Dealer-Borrow Rates (O/N)



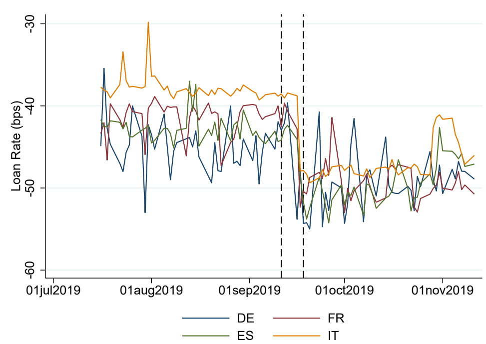
(b) OTC Dealer-Lend Rates (O/N)



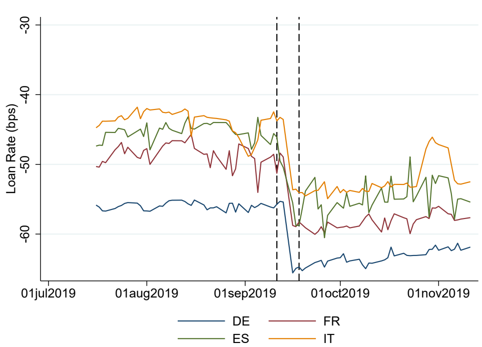
(c) OTC Dealer-Borrow Rates (T/N)



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



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



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

E Barriers to Access For Inter-Dealer Centralized Trading Platforms

This appendix describes the requirements for a market participant to trade on centralized trading platforms, and illustrates the barriers to access for non-dealers. Brokertec and Eurex also publish some data on participants on their market platforms. Brokertec's list of market participants for government bond markets consists of 20-30 banks in each market, all of which are large dealer banks.[24] Brokertec unfortunately does not provide a public list of participants on their repo platform. Eurex provides a list of repo market participants which contains 149 parties, the vast majority of which are international dealer banks, along with a few national central banks.[25]

There are a number of barriers to non-dealer access to centralized trading platforms. E-trading platforms exercise some discretion in admitting market participants; for example, Brokertec imposes vague and discretionary requirements that market participants must be "(a) of sufficiently good repute; (b) have a sufficient level of trading ability, competence and experience; and (c) have sufficient resources for their role as a Participant."[26]

Another major barrier to access is that repo trading platforms require participants to have outstanding derivative agreements with most other participants on the platform, in order to trade. This requirement is essentially infeasible to satisfy for the vast majority of non-dealer participants in our sample, who have contractual arrangements with only one or two dealer banks. For example, Brokertec, one of the three major European repo centralized trading platforms, functions as a platform for arranging trades. Brokertec rules for repo markets require market participants to have credit lines, Global Master Repurchase Agreements, and European Master Agreements with a "sufficient number of Participants in the relevant Bilateral Market."[27] MTS repo has a similar rule requirement, that "the Participant shall also be responsible for ensuring that the relevant ISDA documentation is in place with any counterparty to a Contract."[28]

[24]See, for example, the BrokerTec French European Government Bond Market Client List.
[25]See the Eurex Repo participant list.
[26]Section 4.1.2 of the BrokerTec EU RM Rulebook.
[27]See rule 3.1.2. in the BrokerTec EU RM Rulebook, PRODUCT APPENDIX: REPO.
[28]See MTS S.P.A. MARKETS Terms and Conditions.

F Additional Results from the Structural Model

F.1 Parameter Estimates and Model Fit for Repo Borrowers

Figures A.5 and A.6, and Tables A.4 and A.5, show our parameter estimates and model fit for repo borrowers.

Figure A.5: Model Fit: Relationship between Passthrough and the Number of Links, Repo Borrowers

This figure shows the passthrough from the inter-dealer repo rate to the OTC repo rate for borrowing customers with different number of links. The blue line corresponds to estimates of β_N from Specification (14). The red line corresponds to passthrough from the fitted model. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

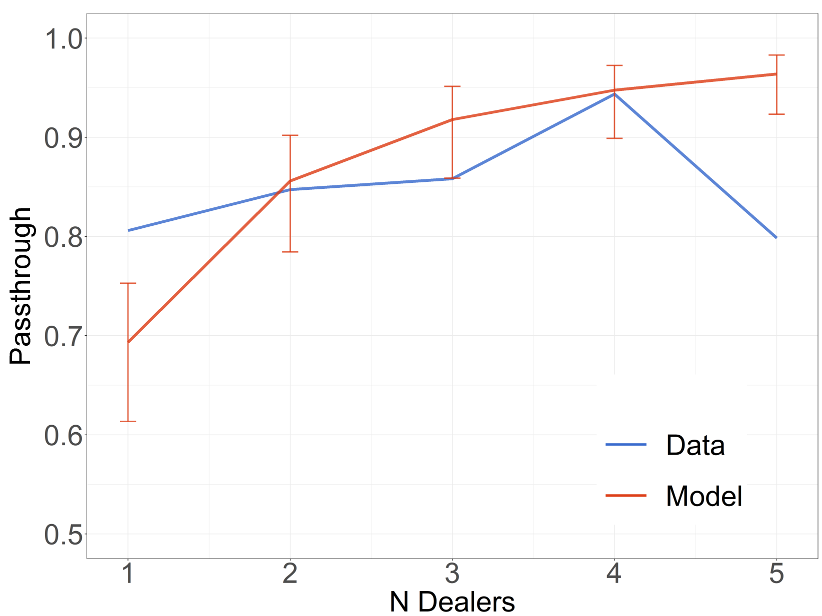
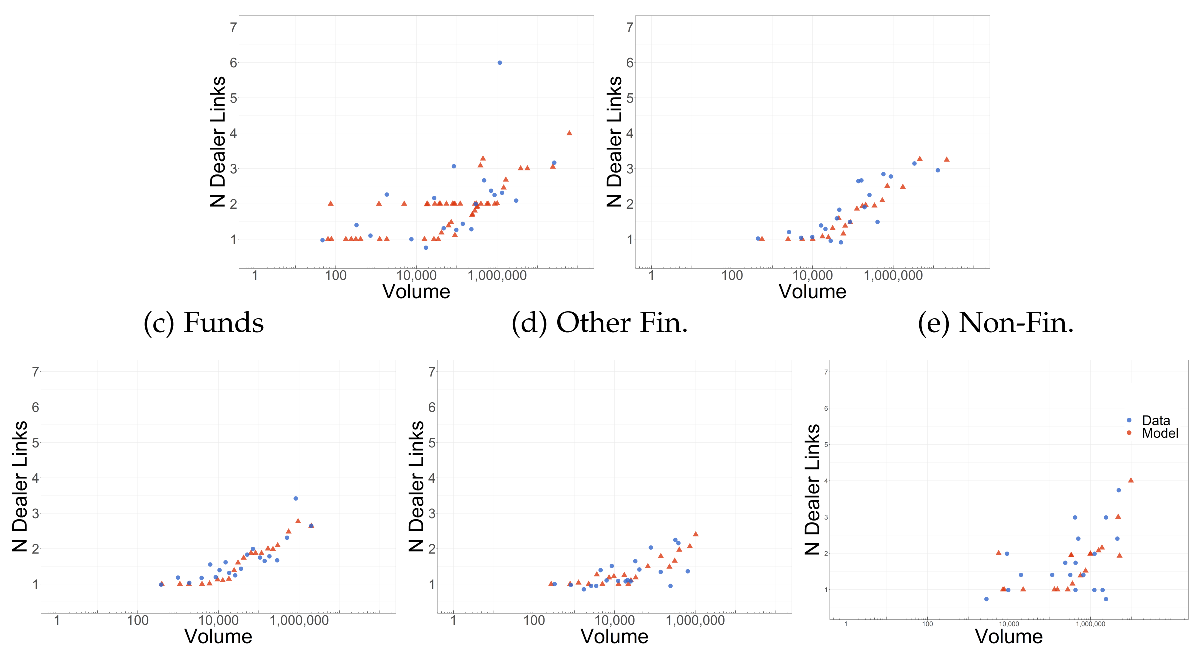


Figure A.6: Model Fit: Relationship between the Number of Links and Trading Volume, Repo Borrowers

This figure shows binscatter plots of trading volume versus the number of dealer links formed for repo depositors in different sectors in the pre-rate-cut month for borrowing customers. The blue and red dots correspond to the data and model predictions, respectively. In the data, flow repo volumes are converted to average outstanding volumes by multiplying trade size by the maturity in days, and then dividing by the number of days in the month, as described in footnote 18. Volumes are in € thousands. In the model, we aggregate across collateral countries within a sector weighting the binscatters by the number of customers trading within the collateral country.



(a) Ins./Pens. (b) Banks

(c) Funds (d) Other Fin. (e) Non-Fin.

Table A.4: Parameter Estimates, Repo Borrowers

This table shows the parameter estimates of our model for repo borrowers. ϕ is the bargaining power of dealers over customers in each bilateral negotiation. μ and σ are the mean and standard deviation of customers' values, respectively, in basis points. τ is the weighted average balance sheet cost. $exp(\zeta^1)$ and ζ^2 are the connection cost parameters in (15). We report $exp(\zeta^1)$, the cost of connecting to the second dealer, in units of €1K per year. We report values as NA when $exp(\zeta^1)$ is above €1 billion annually, and when ζ^2 is above 1000. We estimate $\mu, \sigma, \tau, \zeta^1, \zeta^2$ separately by customer sector and collateral country, but we report averages of parameters across collateral countries, weighting collateral countries within a customer sector by the number of customers in the segment. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Sector	ϕ	μ	σ	τ	$exp(\zeta^1)$	ζ^2
Banks	0.31	-51.4	10.7	0.34	7.2	70.4
	(0.25, 0.39)	(-56.2, -42.8)	(4.6, 25.1)	(0.05, 0.85)	(2.4, 18.7)	(0.9, 136.5)
Funds		-50.7	13.6	0.68	7.5	2.2
		(-53.9, -43.2)	(9.2, 23.5)	(0.14, 0.83)	(2.3, 15.8)	(0.5, 6.6)
Ins./Pens.		-55.9	11.5	0.76	2.6	2.9
		(-57.4, -40.6)	(4.6, 29.8)	(0.02, 0.74)	(0.4, 48.5)	(0.6, 984.7)
Non-Fin.		-44.1	16.0	0.12	4.8	6.0
		(-53.1, -40.9)	(8.9, 30.4)	(0.01, 1.45)	(0.0, 20,287.8)	(1.3, NA)
Other Fin.		-44.7	22.3	0.11	49.0	47.4
		(-49.7, -40.5)	(16.3, 30.9)	(0.01, 0.89)	(8.0, 2,174.0)	(0.1, 871.9)

Table A.5: Model Fit: Net Interest Margin and Dispersion, Repo Borrowers

This table shows the net interest margin and dispersion of repo rates for each sector for repo borrowers. Target SD is the observed dispersion in residual repo rates in the data. Model SD is the dispersion in residual repo rates predicted by the model. Target NIM is the average net interest margin of residualized repo rates in the data. Model NIM is the average net interest margin in the model. All quantities are in bps. We present results for different sectors averaged across collateral country, where the weights are the number of customers in that segment in the data. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Sector	Target SD	Model SD	Target NIM	Model NIM
Banks	4.02	2.20	2.22	3.55
		(1.62, 3.08)		(3.00, 4.32)
Funds	3.21	2.45	3.18	4.07
		(2.08, 2.86)		(3.43, 4.20)
Ins./Pens.	3.86	2.24	1.80	4.17
		(1.53, 3.17)		(2.71, 4.36)
Non-Fin.	4.16	2.30	1.49	3.04
		(1.62, 3.17)		(2.66, 4.82)
Other Fin.	5.13	3.84	4.01	5.10
		(3.03, 4.44)		(4.22, 6.20)

F.2 Multiple-ϕ Model

In the baseline model of the paper, the bargaining process between a customer and dealers is governed by the single parameter ϕ, which determines the split of surplus between the customer and each marginal dealer. As a result, the model cannot simultaneously match the level and slope of the dealer count-passthrough relationship perfectly: in Figure 6, the slope of passthrough with respect to dealer count is slightly steeper in the model than in the data. In this appendix, we construct an extension of the model which relaxes this constraint.

We assume that when a customer trades with a single dealer, the dealer keeps a share:

$$t(1) = \phi_0$$

and the customer thus keeps share $(1-\phi_0)$. However, when the customer connects to any additional dealers, we assume dealers keep a share ϕ_1 of marginal surplus. This could be motivated, for example, by additional dealers beyond the first being more effective at bargaining, or more patient, than the initial dealer. Expression (21) in Appendix A.1 then becomes:

$$\underbrace{(1-\phi_1)\, t(N+1)}_{\text{New Dealer Surplus}} = \underbrace{\phi_1 \left[N t(N) - (N+1)\, t(N+1)\right]}_{\text{Customer Marginal Surplus}}$$

Expression (8) in Proposition 1 then becomes:

$$t(1) = \phi_0, \; t(N+1) = \frac{N}{\frac{1-\phi_1}{\phi_1} + (N+1)} t(N)$$

All other expressions in Proposition 1 are unchanged. Practically, this change to the model has the effect of increasing the model to have two parameters, allowing the slope and intercept of the customer share of surplus and passthrough as a function of connection count to vary separately.

We estimate ϕ_0 and ϕ_1 analogously to the main text, by choosing ϕ_0 and ϕ_1 to minimize the distance between data and model-predicted passthrough, for different numbers of dealer connections. During estimation, we constraint both ϕ_0 and ϕ_1 to lie between 0.01 and 0.99; this constraint is not binding for the baseline estimates, but is binding in a small fraction of the bootstrap replications. The results are shown in Figure A.7. Under the multiple-ϕ model, the curve relating the number of dealers to passthrough is slightly flatter, matching the data slightly better than the baseline model.

We then fit the remaining parameters – the mean and standard deviation of values, balance sheet costs, and the connection cost parameters – using the multiple-ϕ version of the model, and re-estimate all our counterfactuals. The results are shown in Figures A.8 and A.9, and Tables A.6, A.7, A.8, and A.9. All results are qualitatively similar to those in our baseline model. Quantitatively, Figure A.9 shows that, in the multiple-phi model, passthrough is lower than in the baseline model, essentially because connecting to dealers is less effective at increasing passthrough in the baseline model.

Figure A.7: Model Fit: Relationship between Passthrough and the Number of Links, Multiple Phi Model

This figure shows the passthrough from the inter-dealer repo rate to the OTC repo rate for depositing customers with different number of links, in the data (blue), the baseline model (red), and the multiple-phi version of our model described in Appendix F.2 (orange). Error bars show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

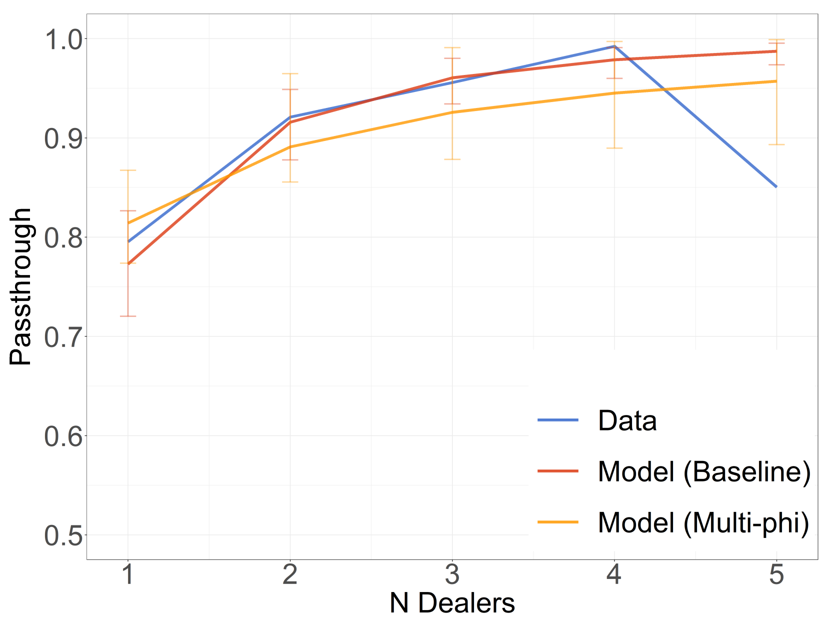


Figure A.8: Model Fit: Relationship between the Number of Links and Trading Volume, Multiple Phi Model

This figure shows binscatter plots of trading volume versus the number of dealer links formed for repo depositors in different sectors in the pre-rate-cut month, in the multiple-phi version of our model described in Appendix F.2. The blue and red dots correspond to the data and model prediction, respectively. The flow data is converted to average outstanding volumes by multiplying trade size by the maturity in days, and then dividing by the number of days in the month. Volumes are in € thousands. In the model, we aggregate across collateral countries within a customer sector weighting the binscatters by the number of customers trading within the collateral country.

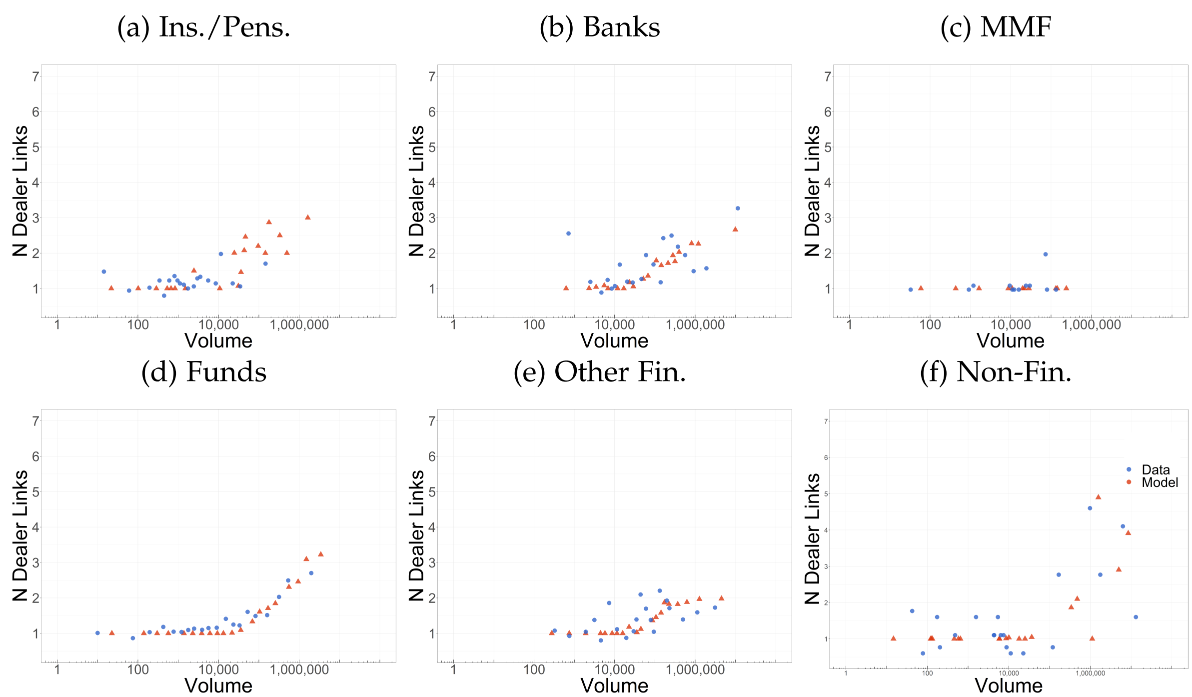


Figure A.9: Number of Links and Passthrough with Rate Increases, Multiple Phi Model

This figure shows the number of dealer links formed, the inter-dealer to OTC passthrough, and rate dispersion, that our model predicts as monetary policy increases the inter-dealer rate, in the multiple-phi version of our model described in Appendix F.2. Each line corresponds to the results for a different sector. We present results for different customer sectors averaged across collateral country, where the weights are the number of customers in that segment in the data.

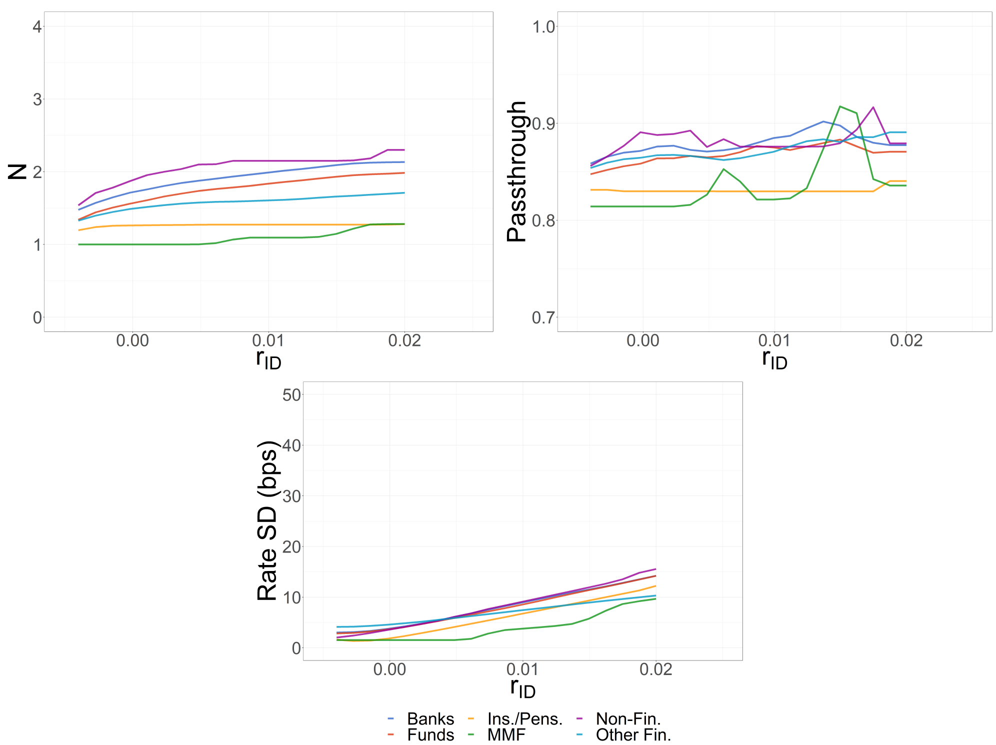


Table A.6: Parameter Estimates, Multiple Phi Model

This table shows the parameter estimates of our model, in the multiple-phi version of our model described in Appendix F.2, for repo depositors. μ and σ are the mean and standard deviation of customers' values, respectively, in basis points. τ is the weighted average balance sheet cost. $exp(\zeta^1)$ and ζ^2 are the connection cost parameters in (15). We report $exp(\zeta^1)$, the cost of connecting to the second dealer, in units of €1K per year. We report values as NA when $exp(\zeta^1)$ is above €1 billion annually, and when ζ^2 is above 1000. We estimate $\mu, \sigma, \tau, \zeta^1, \zeta^2$ separately by customer sector and collateral country, but we report averages of parameters across collateral countries, weighting collateral countries within a sector by the number of customers in the segment. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Sector	μ	σ	τ	$exp(\zeta^1)$	ζ^2
Banks	-53.8	21.4	0.25	22.9	0.0
	(-62.5, -41.4)	(13.5, 37.0)	(0.02, 0.82)	(1.0, 64.9)	(0.0, 23.6)
Funds	-45.3	24.8	0.21	11.1	2.4
	(-53.7, -42.3)	(17.7, 31.9)	(0.07, 0.50)	(1.7, 30.7)	(0.3, 14.5)
Ins./Pens.	-43.3	7.0	0.05	NA	NA
	(-53.4, -40.4)	(6.1, 19.4)	(0.00, 0.72)	(NA, NA)	(NA, NA)
MMF	-40.2	13.9	0.12	217.2	NA
	(-44.3, -40.0)	(4.3, 31.5)	(0.00, 3.04)	(3.2, NA)	(NA, NA)
Non-Fin.	-46.1	13.1	0.41	3.6	0.9
	(-50.0, -41.1)	(11.7, 42.5)	(0.02, 1.84)	(0.2, 457.9)	(0.0, NA)
Other Fin.	-45.3	40.7	0.25	22.7	18.0
	(-58.1, -40.8)	(24.1, 55.3)	(0.03, 1.65)	(1.1, 99.9)	(2.0, 132.2)

Table A.7: Model Fit: Net Interest Margin and Dispersion, Multiple Phi Model

This table shows the net interest margin and dispersion of repo rates for each sector, in the multiple-phi version of our model described in Appendix F.2, for repo depositors. Target SD is the observed dispersion in residual repo rates in the data. Model SD is the dispersion in residual repo rates predicted by the model. Target NIM is the average net interest margin of residualized repo rates in the data. Model NIM is the average net interest margin in the model. All quantities are in bps. We present results for different sectors averaged across collateral country, where the weights are the number of customers in that segment in the data. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Sector	Target SD	Model SD	Target NIM	Model NIM
Banks	4.48	2.42	2.49	4.00
		(1.66, 3.38)		(3.01, 4.40)
Funds	3.64	2.62	2.69	3.59
		(2.28, 3.08)		(3.26, 3.98)
Ins./Pens.	2.28	0.81	0.29	1.34
		(0.72, 1.92)		(1.17, 3.62)
MMF	2.28	1.54	1.62	2.17
		(0.55, 2.74)		(0.75, 5.41)
Non-Fin.	2.86	1.58	1.52	2.58
		(1.45, 2.95)		(2.26, 4.70)
Other Fin.	5.58	3.91	3.97	5.51
		(2.74, 5.01)		(4.35, 6.72)

Table A.8: Effect of Inter-Dealer Platform Access, Multiple Phi Model

This table shows results from the inter-dealer platform access counterfactual, in the multiple-phi version of our model described in Appendix F.2. Baseline refers to the benchmark case without any inter-dealer platform access. Access with cost 100K, 25K, 5K, and 0K refer to the counterfactual cases where inter-dealer platform access is available at an annual cost of €100K, €25K, €5K, and €0K, respectively. Rate disp is the standard deviation of rates, in bps. Passthrough is the derivative of average repo rates with respect to inter-dealer repo rates. Frac. Connected is the fraction of agents who optimally connect to the inter-dealer platform. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Type	Rate Disp	Passthrough	Frac. Connected
Baseline	2.97	84.6%	
	(2.66, 3.45)	(82.1%, 87.8%)	
100k	3.04	86.8%	13.7%
	(2.66, 3.51)	(84.3%, 90.1%)	(10.0%, 15.4%)
25k	2.95	88.6%	26.3%
	(2.58, 3.47)	(86.4%, 91.6%)	(23.7%, 28.2%)
5k	2.53	92.0%	41.6%
	(2.28, 3.09)	(90.5%, 94.0%)	(38.8%, 44.6%)
0	0.00	100.0%	100.0%
	(0.00, 0.00)	(100.0%, 100.0%)	(100.0%, 100.0%)

Table A.9: Effect of the Reverse Repurchase Facility, Multiple Phi Model

This table shows results from the RRP counterfactual on the inter-dealer to OTC passthrough and rate dispersion, in the multiple-phi version of our model described in Appendix F.2. Baseline refers to the benchmark case without the RRP. 50bps, 25bps, and 10bps refer to the counterfactual cases where Δ_{RRP}, the gap between the RRP rate and the inter-dealer rate minus balance sheet costs, is 50bps, 25bps, and 10bps, respectively. Rate disp is the standard deviation of rates, in bps. Passthrough is the derivative of average repo rates with respect to inter-dealer repo rates. Frac. Binding is the fraction of agents for whom the RRP is a binding outside option. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Type	Rate Disp.	Passthrough	Frac. Binding
Baseline	2.97	84.6%	
	(2.66, 3.45)	(82.1%, 87.8%)	
50bps	2.55	86.0%	7.4%
	(2.18, 3.00)	(82.9%, 89.9%)	(4.2%, 15.3%)
25bps	1.64	90.5%	31.5%
	(1.23, 2.22)	(88.0%, 93.9%)	(24.4%, 42.6%)
10bps	0.68	97.4%	62.9%
	(0.51, 1.37)	(96.4%, 98.5%)	(57.8%, 73.6%)

F.3 Costly RRP

In the main text, we assumed that it was costless to connect to the RRP. In this appendix, we assume customers must pay some cost to connect to the RRP. The surplus from connecting to the RRP can be written as, from (36) of Appendix C.1:

$$\underbrace{\Psi\left(\left(r_{ID}-\tau_{D}\right)-\tilde{\nu}_{D}\right)\left(1-Nt\left(N\right)\right)-\sum_{i=1}^{N}C_{i}}_{A}+\underbrace{\Psi\left(\max\left(\nu_{D},r_{RRP}\right)-\nu_{D}\right)}_{B}-C_{RRP} \tag{37}$$

where N is chosen to maximize term A in (37). The surplus from not connecting to the RRP is:

$$\Psi\left(\left(r_{ID}-\tau_{D}\right)-\nu_{D}\right)\left(1-Nt\left(N\right)\right)-\sum_{i=1}^{N}C_{i}$$

where once again N is chosen to maximize surplus. Each customer decides whether to connect to the RRP by comparing the optimal value with and without the RRP. In the data, we repeat the exercise of Subsection 6.3, assuming that the RRP has a spread of 25bps below $r_{ID}-\tau_{D}$, and that cost of connecting to the RRP for each customer group is €5k, €25k and €100k annually. The results are shown in Table A.10. When the RRP is costly, it is less effective; fewer customers connect, so the RRP is less effective at increasing passthrough and reducing rate dispersion.

Table A.10: Costly Reverse Repurchase Facility

This table shows results from the RRP counterfactual on the inter-dealer to OTC passthrough and rate dispersion, when it may be costly to connect to the RRP. Baseline refers to the benchmark case without the RRP. Throughout, we set $\Delta_{\mathsf{RRP}} = 25\mathsf{bps}$, so the RRP rate is the 25bps less than the inter-dealer rate minus the balance sheet cost. 100k, 25k, 5k, and 0 refer to the cost of connecting to the RRP, in annual €. Rate disp is the standard deviation of rates, in bps. Passthrough is the derivative of average repo rates with respect to inter-dealer repo rates. Frac. Binding is the fraction of agents who pay the cost to connect to the RRP, and for whom the RRP is thus binding. Parentheses show 95% confidence intervals from a nonparametric bootstrap with 100 replications.

Type	Rate Disp.	Passthrough	Frac. Binding
Baseline	3.01	82.9%	
	(2.88, 3.52)	(78.6%, 87.4%)	
100k	3.00	83.1%	1.7%
	(2.85, 3.45)	(79.1%, 87.6%)	(1.2%, 3.0%)
25k	2.95	83.6%	5.5%
	(2.80, 3.37)	(79.7%, 88.0%)	(4.3%, 8.5%)
5k	2.67	84.8%	11.5%
	(2.56, 3.02)	(80.8%, 89.2%)	(8.0%, 17.7%)
0	2.01	88.2%	25.1%
	(1.65, 2.33)	(84.1%, 92.6%)	(17.6%, 40.1%)