

Monetary Policy Transmission in Segmented Markets*

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Abstract

This paper studies two frictions that impede the effective pass-through of monetary policy in the European repo market. Collateral scarcity creates a wedge between the ECB's Deposit Facility Rate and inter-dealer repo rates. Dealer market power causes inter-dealer repo rates to pass through imperfectly to customer-facing OTC repo rates. Using a dataset covering both inter-dealer and OTC repo trades, we provide empirical evidence consistent with dealer market power in the OTC repo market. We build a model to illustrate how collateral scarcity and market power create interacting frictions in repo markets, and we verify its predictions using the September 2019 monetary policy rate cut. The model implies that policies that alleviate dealer market power, such as customer access to centralized trading and customer-facing secured funding facilities like the Federal Reserve's RRP, can alleviate dealer market power and improve the pass-through of monetary policy.

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

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1 Introduction

Repo markets are a crucial first stage of monetary policy transmission to the real economy. Following the disruptions in unsecured funding markets in the 2008 financial crisis, repos have become the dominant form of funding in money markets. In the European context, repos are short-term, commonly backed by government bonds, and often fully or over-collateralized. Nevertheless, the rates on these safe and short-term repos have become increasingly dispersed and disconnected from the European Central Bank's main policy rates, which questions the efficiency of monetary policy transmission. This paper sheds light on the frictions present in repo markets that lead to rate dispersion and inefficiencies in the pass-through of monetary policy.

A growing literature has pointed to *collateral scarcity* as the main reason for rate dispersion in repo markets. In environments with a scarcity of safe assets as collateral, repo rates can fall below policy rates and diverge across collateral types. These results are obtained from the CCP repo market: repo transactions on e-trading platforms with centralized trading, which are almost exclusively available to dealer banks. However, little is known about the over-the-counter (OTC) repo market, in which dealers trade bilaterally with a large number of non-dealer banks and non-banks.

Our analysis provides the first glimpse of the previously unexplored OTC repo market and its interaction with the CCP repo market. We find that OTC repo rates display significantly different and higher dispersion than CCP repo rates. Importantly, the observed dispersion in repo rates for the majority of market participants in OTC markets cannot be explained by collateral scarcity alone. Rather, there is widespread dispersion in repo rates across OTC market participants because they rely on a concentrated set of dealer banks that have substantial *market power*. Consequently, dealer market power causes the pass-through of the ECB's policy rate to the large OTC segment of the market to be inefficient and unequal. We thereby provide the first systematic analysis of market power and its impact on price formation in the European repo market. We derive the effect of market power on monetary policy transmission jointly with the effects of collateral scarcity, exploiting the simultaneous presence of CCP and OTC repo trades with the same collateral and loan terms in our dataset.

Our results bear important implications for how regulatory interventions may alleviate frictions in the pass-through of monetary policy. First, we show that allowing OTC customers access to the CCP repo market would improve pass-through by alleviating market power frictions. Under our estimates, pass-through efficiency would improve by 20-28%. Second, if the central bank made a secured deposit facility available to OTC customers, like the Fed's Reverse Repo Facility (RRP), both sources of pass-through frictions would be reduced. Collateral scarcity frictions would be alleviated by making secured deposits available to a wide range of market participants. Dealer market power would also be reduced as OTC customers obtain an outside option they can use to negotiate better rates with dealers.

We use the ECB's Money Market Statistical Reporting (MMSR) dataset, which contains transaction-level data on all repo trades conducted by large Euro-area dealers. The MMSR dataset allows us to observe both CCP and OTC trades made by dealers with various customers, such as non-dealer banks, pension funds, insurance companies, hedge funds, and other financial institutions. The European repo literature, thus far, has largely analyzed trades on e-trading platforms with centralized trading. However, apart from dealer banks, the vast majority of market participants cannot directly participate in these e-trading platforms. They can only access repo funding by trading bilaterally with dealers in the OTC repo market, which is economically significant at 30% of total repo trading volume (ECB, 2018).

We document a number of stylized facts about the OTC segment of the repo market. First, OTC customers are very sparsely connected to dealers: the median customer in our data only ever trades with a single dealer. Second, there is substantial dispersion in OTC repo rates for observably similar loans backed by the same ISIN-level collateral. Third, dealers lend at higher rates than they borrow, so dealers attain a net interest margin in the OTC market. The magnitudes of dispersion and net interest margins are large: for German collateral-backed loans, the weighted standard deviation in customers' repo lending rates is 11.6 bps, and dealers' average net interest margin amounts to 14.0 bps. Moreover, neither effect is explained by heterogeneity in loan characteristics, such as terms, haircuts, and collateral ISINs. Together, these stylized facts point to the presence of dealer market power in the OTC repo market: dealers appear to be able to price discriminate across their OTC customers, charging different rates to different customers

for the same repo loan.

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

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

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

To test these predictions, we utilize the ECB's September 2019 Deposit Facility Rate (DFR) cut from -40bps to -50bps. This rate cut allows us to measure the pass-through of DFR rates to CCP and OTC repo rates, for any segment of the repo market, by dividing

the change in observed CCP and OTC repo rates by the magnitude of the DFR rate cut. We can then back out pass-through from the CCP market to the OTC market, by comparing the relative magnitudes of DFR-CCP and DFR-OTC pass-through. We measure OTC pass-through for different collateral types and different market participants, and we verify that both model predictions hold across a number of empirical specifications.

Our results bear important implications for how regulatory interventions can help improve the pass-through efficiency of monetary policy. We find that, if OTC customers had direct access to the CCP repo market, they would no longer be subject to dealer market power in trading repos. Consequently, monetary policy pass-through to OTC customers would improve. Quantitatively, we find that CCP access would improve pass-through by 13%-21% for OTC customers lending to dealers and by 26%-32% for customers borrowing from dealers. Nevertheless, access cannot eliminate pass-through frictions generated by collateral scarcity.

Both market power and collateral scarcity frictions could be alleviated if the central bank provides a secured deposit facility for both dealers and customers, like the Federal Reserve's RRP Facility. First, we show that a secured deposit rate available to dealers behaves like a classical price floor. If it is binding, CCP repo rates would be equal to the RRP rate, and some fraction of market participants would use the facility instead of trading in the CCP market.

If the RRP facility were available also to market participants in the OTC segment, however, the RRP rate would also affect OTC repo rates by changing customers' bargaining position. Even when the RRP rate is lower than the prevailing CCP repo rate, it gives customers an additional outside option for borrowing funds, which they can use to negotiate better repo rates with dealers. Thus, the RRP facility can improve policy rate pass-through, even when the RRP rate is lower than the prevailing CCP repo rate. Moreover, since the RRP facility serves as an outside option, it can influence OTC rates even if there is no take-up of the facility in equilibrium.

Taken together, our results show that dealer market power is an important friction impeding the pass-through of monetary policy. Regulatory interventions that reduce dealer market power can thus improve pass-through efficiency. Besides their implications for the European market, our results apply more generally to settings where market

segmentation and market power frictions are salient features of money markets.

1.1 Literature review

Pass-through Efficiency of Monetary Policy. This paper contributes to the understanding of monetary policy pass-through efficiency in money markets. In the US setting, Bech and Klee (2011) highlight how market segmentation in the access to central bank reserves has driven a wedge between the Interest on Excess Reserves (IOER) and the Fed funds rate after the 2008 financial crisis. Using time-series data, Bech, Klee and Stebunovs (2012) further examine the wedge between repo rates and the Fed funds rate. More recently, Duffie and Krishnamurthy (2016) measure dispersion across aggregate money market rates that cannot be explained by credit risk nor interest rate risk.

Nevertheless, there has been a lack of systematic empirical analysis of how market power frictions affect monetary pass-through across market participants because micro-level data for US money markets is incomplete. In particular, for the bilateral OTC repo market that makes up half of the \$3 trillion US repo market, the only available data are three snapshots taken in 2015Q1 (Baklanova et al., 2019).

Using transaction-level data from the ECB's MMSR dataset, we provide the first analysis of market power frictions stemming from market segmentation and concentration in OTC repo markets. We estimate how much these frictions impeded monetary transmission and how much policy measures resembling the Fed's RRP could restore pass-through efficiency. Our specific estimates are based on the European setting, but our qualitative findings and predictions speak to OTC repo markets more generally, in which a large number of market participants depend on concentrated intermediation by a small set of dealer banks that have access to central bank balance sheets.

Empirical studies of European repo markets. In the European context, empirical papers have focused on understanding the effect of collateral scarcity and specialness in CCP repo rates. An early paper on the topic is Buraschi and Menini (2002). Ferrari, Guagliano and Mazzacurati (2017) introduces a new collateral reuse measure, and uses it to study specialness premia. Corradin and Maddaloni (2020) show that Italian bonds that are purchased more by the Eurosystem have higher specialness spreads, using data

from MTS repo. Arrata et al. (2020) study the effect of Euro asset purchases on repo rates through raising the scarcity of collateral. Brand, Ferrante and Hubert (2019) analyze a range of factors that affect repo specialness premia. Ballensiefen, Ranaldo and Winterberg (2020) examine the distinctions between banks with and without access to the deposit facility and the distinctions between collateral that is and is not eligible for asset purchase programs.

Other papers on European repo markets more broadly include Dunne, Fleming and Zholos (2011), Mancini, Ranaldo and Wrampelmeyer (2016), Boissel et al. (2017), Schaffner, Ranaldo and Tsatsaronis (2019), Ranaldo, Schaffner and Vasios (2019), Bechtel, Ranaldo and Wrampelmeyer (2019), and Ballensiefen and Ranaldo (2019).

We are the first paper to study the OTC segment alongside the CCP segment of the repo market. Using the ECB's MMSR data, we find empirical evidence that *market power* in the OTC segment is a significant source of market friction, and we estimate its impact on the pass-through of monetary policy to OTC market participants.

Theoretical models of repo markets. Our model combines a relatively standard model of collateral scarcity-induced specialness in the CCP market with a network bargaining model of price-setting in OTC markets. The CCP-market model builds on several theory papers analyzing collateral scarcity and specialness, including Duffie (1996), Fisher (2002), Bottazzi, Luque and Páscua (2012), Huh and Infante (2018), and Roh (2019).¹ Our model of the CCP market is technically most similar to that of Fisher (2002), who assumes that special repo rates are generated by partially elastic supply and demand curves for repo funding.

To our knowledge, we are the first to apply a core-periphery network bargaining model to study the transmission of monetary policy in repo markets.

Networks and OTC markets. More broadly, our model also relates to the literature on networks and OTC markets. Weill (2020) surveys the OTC markets literature. Some theory papers in this literature include Duffie, Gârleanu and Pedersen (2005), Duffie, Gârleanu and Pedersen (2007), Hugonnier, Lester and Weill (2014), Farboodi (2014), Afonso and Lagos (2014), Wang (2017), Babus and Hu (2017), Chang and Zhang (2018), Colliard and

¹Some other theory papers on repo markets include Duffie and Krishnamurthy (2016), Infante (2019), and Nyborg (2019).

Demange (2019), and Colliard, Foucault and Hoffmann (2020). Some empirical papers on trade networks and OTC markets are Collin-Dufresne, Junge and Trolle (2016), Craig and Ma (2018), Li and Schürhoff (2019), and Hendershott et al. (2020).

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 2008 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 (DRF) is an unsecured policy rate available to European banks similar to the Interest on Excess Reserves (IOER) set by the Federal Reserve on excess reserves by US depository institutions. How well this unsecured policy rate available to banks transmits to funding costs available to general market participants in money markets depends on the type of transactions between banks and money market participants and the market structure of their trading.

In the Euro-area, repurchase agreements (repo) have become the predominant form of short-term funding after the 2008 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 shrunken from around 170 billion to 20 billion (ECB, 2018). A repurchase agreement (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 them back after a set period of time at a set price. The repo lender is promised an interest rate and also benefits from having access to the collateral during the repo transaction. The security and convenience of collateral drive repo rates to be below unsecured market rates, where the difference depends on the value of the collateral pledged.

Repos are backed by a specific collateral (SC repo) or a pool of collateral (GC repo). In GC repo, any asset from a predefined basket of assets is accepted as collateral. In SC repo, the specific security used as collateral is known to both counterparties when entering the

contract. Although SC repos have been characterized as relatively more collateral-driven than GC repos, they nevertheless serve as a secured source of deposits for lenders and as a source of funding for borrowers as also noted by Ballensiefen and Ranaldo (2019). Moreover, SC repos have become increasingly important relative to GC repos. Using data from Brokertec, Eurex, and MTS Repo, Schaffner, Ranaldo and Tsatsaronis (2019) estimate that turnover in the SC segment is around five times higher than turnover in the GC segment.

Repo contracts are traded either through centralized platforms or over-the-counter. There are three main centralized platforms for trading repos in Europe: BrokerTec, Eurex Repo, and MTS Repo. These platforms are centralized markets, organized as limit-order books, and repo transactions are centrally cleared through various clearinghouses. Henceforth, we will refer to the centralized segment of the market as the “CCP market”. Participation in the CCP market is largely limited to dealer banks (ICMA, 2019). The vast majority of non-dealer repo market participants, such as non-dealer banks and non-bank financial institutions, do not have direct access to CCPs and trade repos in the OTC market.² The number of participants and the volume transacted in the OTC market are economically significant. For example, the 2018 European Money Market Study reports dealer-customer trades to be a third of the dealer-dealer volume (ECB, 2018).

While previous studies have focused on the CCP repo market, little is known about the OTC segment. As the next subsection details, our data uniquely allows us to shed light on the functioning of the OTC repo market and its role in the transmission of monetary policy.

2.2 The MMSR Data

The primary dataset we use is the Money Market Statistical Reporting (MMSR) data from the European Central Bank.³ This dataset collects all repo transactions, both in the CCP and in the OTC segment, made by 38 dealer banks, who are the main intermediaries in the

²Recently, sponsored access programs, such as Eurex’s ISA Direct facility, have begun to allow for on-dealer participation, but the scope remains limited.

³The dataset is described in more detail [here](#).

European repo market.⁴ Our dataset is at the transaction-level and covers the period from March 2017 to March 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, where sectors are defined as in Section 2.S.12 of the 2010 European System of Accounts.

We focus on repos backed by German, French, Italian, and Spanish government collateral. We focus on the three major segments of the repo market: overnight (O/N) repo, which is opened at t and closed at $t + 1$; same-next (S/N), which is opened at $t + 1$ and closed at $t + 2$; and tomorrow-next, which is opened at $t + 2$ and closed at $t + 3$. We limit our analysis to SC repo trades, where the specific collateral identity is known by all agents and can thus be systematically used in our analysis. As discussed above, SC repos have increasingly taken up a dominant share of the repo market in recent years.

In our sample, the OTC market is economically significant, albeit smaller in volume than the CCP market. Figure 1 shows the daily volumes at which dealers lend and borrow OTC from other dealers (i.e., Dealer-CCP) and non-dealer counterparties (i.e., Dealer-OTC). These values are compared against dealers borrowing via centralized e-trading platforms (i.e., Dealer-CCP).⁵

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.

3 Stylized Facts

This section introduces a number of stylized facts about the European repo market to motivate our model and policy counterfactuals. First, we introduce the market structure and highlight that the vast majority of repo market participants are only sparsely con-

⁴The list of reporting agents is available [here](#).

⁵The relatively higher volumes of CCP repo trades by dealers is consistent with the observed market structure as dealers may use e-trading platforms not only to meet their own trading needs but also as part of their intermediation of customers’ demand to borrow or lend against a given collateral.

nected to dealer banks. Then, we uncover a series of new findings about dealers' average lending rates, borrowing rates, and rate dispersion in the OTC market, which are unlikely to be explained by differences in collateral scarcity. Finally, we develop a novel approach that purges dealers' net interest margin and rate dispersion from the effect of collateral and loan terms to confirm the presence of substantial dealer market power in OTC repo markets.

3.1 Market Structure

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

The core of the European repo market consists of the inter-dealer market. Dealers trade repos with each other on e-trading platforms with centralized trading. As described in Section 2, access to the e-trading platforms, at present, is largely limited to large dealer banks. Most other repo market participants do not have direct access to centralized clearing and rely on dealer banks to intermediate their repo trades.⁶

The periphery of the European repo market consists of the dealer-customer market. This is an OTC market in which dealers trade bilaterally with customers. We find that most OTC customers are only connected to a small number of dealers. Over our sample period from March 2017 to March 2020, the median repo customer lends to only a single dealer, while the 75th percentile customer lends to only two dealers. Similarly, the median customer borrows from only a single dealer, while the 75th percentile customer borrows from two dealers. Even when we aggregate the number of connected dealers by the country-sector of customers, we find that the median country-sector transacts with only one to two dealers.

Moreover, the sparse connectivity between the core and periphery is fairly stable over time. Even after accounting for all connected dealers during our sample period, most counterparties do not switch beyond a given dealer as their intermediary. The segmented access to e-trading coupled with the concentrated access to OTC intermediaries are

⁶For example, a list of agents eligible to participate in the Eurex GC pooling marketplace, which is one of the largest e-trading platforms, is available [here](#).

suggestive of high market power by dealers over their customers.

3.2 CCP Repo Rates and Collateral Scarcity

Fact 2. *CCP repo rate differences are driven primarily by collateral scarcity.*

The CCP segment of the European repo market appears to be segmented by collateral type (Duffie (1996), Fisher (2002), Ferrari, Guagliano and Mazzacurati (2017), Brand, Ferrante and Hubert (2019), Corradin and Maddaloni (2020), Arrata et al. (2020), and Ballensiefen, Ranaldo and Winterberg (2020)). Our data largely corroborate these findings from the repo literature. We demonstrate a number of these stylized facts in our data to show how outcomes in the OTC segment differ from the CCP segment and to illustrate how collateral scarcity and market power interact.

We begin by examining the time-series variation in repo rates at which dealers lend to and borrow in the CCP market. For different government collateral, we plot the notional-volume-weighted average of repo rates for S/N, T/N, and O/N transactions in Figure 2. We find that dealers' repo borrowing rates in CCP markets are -62.1, -53.8, -46.1, and -48.4 basis points when backed by German, French, Italian, and Spanish government collateral, respectively. Their corresponding repo lending rates in CCP markets are -62.4, -54.5, -44.4, and -46.5 basis points.

Notice that both lending and borrowing rates follow a strict order by the type of collateral pledged. Repos backed by German government bonds command the lowest rates, which suggests that German collateral is in the most scarce supply because borrowers pledging German collateral enjoy the lowest funding rates. Repo rates backed by French, Spanish, and Italian government bonds follow in order, which suggests that in descending order of relative scarcity, we have German, French, Spanish, and Italian collateral.

Also notice that for a given type of collateral, there is almost no difference between the rates at which dealers lend and borrow in the CCP market. This confirms the competitiveness and efficiency of the CCP market that dealer banks can access. It also suggests that the dealer banks in our sample make up a dominant share of the trades in the various e-trading platforms. Otherwise, if trades focused on particular sets of collateral are by non-observed participants, the CCP lend and CCP borrow rates that are

averaged over SC repo trades by dealers in our sample may diverge.

3.3 OTC Repo Rate Dispersion

Fact 3. *There is substantial repo rate dispersion in the OTC segment of the repo market.*

In contrast to the relatively competitive CCP repo market, there is substantial rate dispersion in the OTC market segment. One way to capture rate dispersion is through the weighted average dispersion of repo rates. Duffie and Krishnamurthy (2016) first used the weighted average dispersion across money market rates to measure pass-through efficiency. We extend the measurement to transaction-level data to also capture dispersion in rates across different market participants.

Figure 3 shows the notional-volume-weighted standard deviation of repo rates for S/N, T/N, and O/N transactions for different government collateral. From the figure, we see that dispersion within both borrowing and lending rates is substantial. For example, over our sample period, market participants depositing cash backed by German collateral earn -70.2 basis points; however, the weighted standard deviation across customers is 11.6 basis points. Similarly, market participants borrowing funds backed by German collateral pay an average cost of -56.0 basis points, but the weighted standard deviation across customers amounts to 13.1 basis points.

Dispersion in repo rates backed by other types of collateral is also significant and persistent. The weighted standard deviation in dealers' repo borrow rates for French, Italian, and Spanish collateral are 7.9, 6.5, and 6.1 basis points, respectively, while the standard deviation for dealers' repo lend rates are 9.9, 8.5, and 10.3 basis points.

Rate dispersion suggests that dealers have market power in the OTC segment of the repo market. In particular, it indicates that dealers are able to partially price discriminate, charging customers different rates depending on their willingness-to-pay. We further corroborate that dealer market power drives rate dispersion in the OTC market in Section 3.5 by removing the effect from differences in collateral at the ISIN-level.

3.4 OTC Net Interest Margins

Fact 4. *Dealers attain net interest margins in the OTC market by charging higher rates for lending funds than for borrowing funds.*

In Figure 4, we plot the notional-volume-weighted average of OTC repo rates for S/N, T/N, and O/N transactions for different government collateral. Figure 4 shows that dealers attain a substantial net interest margin in the OTC market: dealers lend to customers at an average rate that is systematically higher than the rate at which they borrow from customers. From March 2017 to March 2020, the average value-weighted net interest margins for repos backed by German, French, Italian, and Spanish sovereign bonds are 14.2, 9.5, 11.1, and 6.1 basis points, which are economically significant given that the average lending rates are -56.0, -47.3, -40.2, and -41.0 basis points, respectively.

Net interest margins fluctuate over time and display spikes at quarter-ends and year-ends, consistent with higher dealer balance sheet costs around reporting windows. In this sense, the positive net interest margins we find are consistent with the presence of dealer bank market power, but balance sheet costs may also drive a wedge between dealers' lend and borrow rates in the OTC market. To this end, our findings in Section 3.5 suggest that balance sheet costs are unlikely to explain away dealer market power because balance sheet space is unlikely to be differentially costly for different repo trades backed by government collateral from the same country.

3.5 Loan characteristics

Fact 5. *Repo rate dispersion and net interest margins in the OTC segment cannot be explained by observable collateral and loan characteristics.*

In principle, Facts 3 and 4 could be driven by heterogeneity in repo loans' characteristics rather than dealer market power. Repo rates may differ simply because repo loans in OTC markets have different collateral ISINs, haircuts, terms, or other characteristics. Dealers could attain net interest margins because they lend and borrow using repo loans with different characteristics. For example, dealers will attain a positive net interest margin if they borrow against expensive collateral and lend against cheaper collateral.

To demonstrate that repo heterogeneity is not driving our results, we attempt to purge repo rates of variation arising from observable loan characteristics. We then show that Facts 3 and 4 still hold after accounting for the effects of observable characteristics.

Formally, let i index a given repo loan, 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 estimate the following pooled regression:

$$r_i \sim X_i\beta + \epsilon. \quad (1)$$

That is, $X_i\beta$ captures all variation in repo rates, which is predictable based on X_i . For each observed transaction, we can thus construct a predicted value and a residual as:

$$\hat{r}_i = X_i\beta,$$

$$\hat{\epsilon}_i = r_i - \hat{r}_i = r_i - X_i\beta. \quad (2)$$

The residual, $\hat{\epsilon}_i$, captures the component of r_i , which is not predictable based on the vector of features X_i . Under the hypothesis that all rate dispersion is explained by fundamentals X_i , and there is no price discrimination stemming from dealers' market power, the residual $\hat{\epsilon}_i$ should be 0. Hence, by studying (2), we can see how much residual dispersion there is in repo rates and understand the extent to which non-fundamental factors, e.g., dealer market power, influence repo rates.

We estimate specification (1) within each country-collateral segment using collateral ISIN, collateral haircut, and loan maturity as explanatory variables X_i . We use daily data and estimate coefficients at the monthly level to allow for time-varying preferences for different securities as collateral (e.g., collateral-specific demand shocks) and terms of trade (e.g., maturity management over the business-cycle). We collect the remaining residuals and analyze their implied dispersion and net interest margins.

Figure 5 shows the value-weighted standard deviation of dealer-lend residuals ($\hat{\epsilon}_{Li}$) and dealer-borrow residuals ($\hat{\epsilon}_{Bi}$) for each collateral segment. These dispersions are induced by market power rather than differences in fundamentals and are indicative of dealers' ability to discriminate between market participants.

Figure 5 shows that most of the dispersion in repo rates is not attributable to differences in collateral and loan characteristics. Over our sample period, the average standard

deviation of dealer-borrow residuals are 6.4, 8.3, 5.0, and 5.4 basis points for German, French, Italian, and Spanish collateral, respectively. In comparison, the standard deviation of dealer-borrow rates are 11.6, 7.9, 6.5, and 6.1 basis points. Similarly, the average standard deviation of dealer-lend residuals are 7.3, 5.4, 3.8, and 5.2 basis points for German, French, Italian, and Spanish collateral, respectively. In contrast, the standard deviation of dealer-lend rates are 13.1, 9.9, 8.5, and 10.3 basis points. Thus, the dispersion in residuals declines by less than half compared to the dispersion in raw rates across all collateral segments, which indicates the importance of dealer market power in affecting OTC repo rates.

We can also examine dealers' residual net interest margins to compare them to the net interest margins based on repo rates in Section 3.4. If net interest margins are driven entirely by differences in the characteristics of repo loans on the borrow and lend sides of dealers' balance sheets, the average values of residuals should be equal to 0 for both lend and borrow transactions. On the other hand, if lend residuals tend to be higher than borrow residuals, this implies that dealers charge different rates for repo loans with identical collateral and loan characteristics.

Figure 6 shows the value-weighted dealer-lend residual ($\hat{\epsilon}_{Li}$) and dealer-borrow residual ($\hat{\epsilon}_{Bi}$) for each collateral segment. Accounting for repo characteristics decreases the size of net interest margins only slightly, implying that observable repo characteristics cannot explain the majority of dealers' net interest margins. Quantitatively, the average residual intermediation spreads we recover are 9.8, 6.7, 7.2, and 4.5 basis points for German, French, Italian, and Spanish collateral, respectively, compared to the raw net interest margins of 14.2, 9.5, 11.1, and 6.1 basis points.

4 Model

We build a simple model to demonstrate how collateral scarcity and market power both limit policy rate pass-through to repo markets.

We model a repo market for a single collateral ISIN. Motivated by our stylized facts, the model has a two-tiered structure, as depicted in Figure 7. Dealers lend and borrow from each other in a competitive inter-dealer market (i.e., the CCP repo market), and

dealers trade with customers in an OTC market. We will show that *collateral scarcity* constrains pass-through from the DFR to the CCP market, whereas *market power* constrains pass-through from the CCP market to the OTC market.

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

4.1 The OTC Repo Market

Our model of the OTC market is a simple OTC network bargaining model.⁷ The goal of the model is to show how dealers' market power in the OTC segment constrains interest rate pass-through, and we derive novel predictions about which submarkets and customers should have higher and lower pass-through.

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

There are two types of customers: borrowers and depositors. Borrowers want to borrow a unit of cash from the dealer and are willing to put up a unit of collateral to secure the loan. Each borrower is characterized by two parameters: v_B , the maximum rate a borrower is willing to pay for borrowing secured, and θ_B , which is the dealer's bargaining power with the borrower. v_B and θ_B can be arbitrarily jointly distributed in the population of borrowers. Repo depositors wish to lend cash to dealers, secured by collateral. Depositors are characterized by the parameters v_D , which is the minimum repo rate that the depositor is willing to accept, and θ_D , which is the dealer's bargaining

⁷See Weill (2020) for a survey of this literature.

power with the depositor. v_D and θ_D can be arbitrarily jointly distributed.

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

The assumption that dealers face no intermediation costs is strong. We relax this assumption in Appendix A.5. We show that heterogeneous intermediation costs can explain net interest margins and OTC rate dispersion, but they cannot explain imperfect pass-through from CCP repo rates into OTC rates, which is the main prediction of the model we bring to the data.

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

$$r_B(v_B, \theta_B, r_{CCP}) = r_{CCP} + \theta_B(v_B - r_{CCP}). \quad (3)$$

That is, the OTC repo rate is set as the weighted average of the dealer's and customer's reservation values, with weight θ_B on the borrower's value. Thus, the transaction leaves the dealer with a share θ_B of the total trade surplus.

Analogously, dealers borrow from all depositors with values lower than the CCP rate, that is, with $v_D < r_{CCP}$. A depositor with value v_D and bargaining power parameter θ_D receives rate:

$$r_D(v_D, \theta_D, r_{CCP}) = r_{CCP} - \theta_D(r_{CCP} - v_D). \quad (4)$$

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

There are several reasons why dealers' bargaining power may differ across customers. Some customers may be more sophisticated and aware of market conditions, allowing them to negotiate better rates. Many dealers also trade a variety of other assets with customers, such as corporate bonds and swaps. Dealers may be willing to charge better repo prices to customers who generate significant profits in other lines of business. Additionally, some customers may be connected to multiple dealers, allowing them to negotiate better prices with each dealer. We formalize this competition effect in Appendix A.6. Building on Stole and Zwiebel (1996), we construct a model in which customers connected to multiple dealers trade at better rates.

Equilibrium outcomes. Our model can simultaneously rationalize the three stylized facts we observe in the data: dealers' net interest margins, dispersion in OTC repo rates, and imperfect pass-through from CCP repo rates to OTC repo rates.

Claim 1. *The net interest margins are:*

$$\begin{aligned} E[r_B(v_B, \theta_B, r_{CCP}) | v_B \geq r_{CCP}] - E[r_D(v_D, \theta_D, r_{CCP}) | v_D \leq r_{CCP}] \\ E[\theta_B(v_B - r_{CCP}) | v_B \geq r_{CCP}] + E[\theta_D(r_{CCP} - v_D) | v_D \leq r_{CCP}]. \end{aligned} \quad (5)$$

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

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

$$\text{Var}[r_B(v_B, \theta_B, r_{CCP}) | v_B \geq r_{CCP}] = \text{Var}[\theta_B(v_B - r_{CCP}) | v_B \geq r_{CCP}], \quad (6)$$

$$\text{Var}[r_D(v_D, \theta_D, r_{CCP}) | v_D \leq r_{CCP}] = \text{Var}[\theta_D(r_{CCP} - v_D) | v_D \leq r_{CCP}]. \quad (7)$$

Claim 2 shows that dispersion in OTC borrower (depositor) repo rates is also generated

by dispersion in θ_B (or θ_D) and dispersion in $v_B - r_{CCP}$ (or $r_{CCP} - v_D$). Rate dispersion is high when θ_B and θ_D are large, so dealers have high bargaining power when there is significant dispersion in customers' values, v_B and v_D , and when there is large dispersion in θ_B and θ_D among customers.

The next claim characterizes the pass-through of CCP rates to OTC rates for different OTC customers.

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

$$\frac{dr_B(v_B, \theta_B, r_{CCP})}{dr_{CCP}} = 1 - \theta_B. \quad (8)$$

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

$$\frac{dr_D(v_D, \theta_D, r_{CCP})}{dr_{CCP}} = 1 - \theta_D. \quad (9)$$

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

Based on Claims 1, 2, and 3, we can derive two testable predictions.

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

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

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

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

4.2 The CCP Repo Market

Next, we show how the interest rate r_{CCP} is determined in the CCP repo market when some dealers can choose between lending repos and using the ECB's deposit facility. This allows us to describe how r_{CCP} is affected by changes in the ECB's deposit facility rate. We assume that, in addition to dealers' interactions with customers, dealers may have a fundamental demand for repo borrowing and lending and that dealers can trade repo loans with each other in a competitive inter-dealer market. There are two kinds of dealers in the model.

There are N_L identical *lending dealers* who have excess cash they wish to lend out. These dealers can either deposit cash in the central bank's deposit facility at rate ρ (which is set by the central bank) or lend secured in the CCP repo market. There are N_B identical *borrowing dealers*, who hold collateral and wish to borrow against it in the CCP repo market. For simplicity, we will assume that all lending dealers are identical, and all borrowing dealers are identical, in their preferences for cash and collateral, though this can easily be relaxed. We will first examine dealers' own demand for repo borrowing and lending, then analyze the demand and supply from OTC customers that is passed on to the CCP market through OTC trades with dealers.

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

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

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

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

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

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

Lending dealers collectively have quantity L of excess funds to lend. They can use the central bank's deposit facility, but may prefer to lend in the CCP market because they value the collateral they receive.⁸ Lenders' valuation for collateral may arise from a number of sources: lenders may need collateral to cover short bond positions; lenders may want to preserve the option to rehypothecate collateral to other market participants; or lenders may simply have institutional constraints forcing them to lend collateralized.

Formally, lending dealers' utility for receiving q units of collateral is:

$$W_L(q).$$

where $W_L(\cdot)$ is twice differentiable, with $W''_L(q) < 0$. Dealers behave competitively, taking the CCP repo rate as given. Thus, if the repo rate is r , lending dealers choose lending quantity q to maximize:

$$\max_q \rho(L - q) + rq + W_L(q). \quad (11)$$

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

⁸Note that our model corresponds to an "excess funds" environment, where the supply of funds is large enough that the CCP rate r_{CCP} will tend to be below the deposit facility ρ , so that ρ is a binding outside option for at least some lending dealers. This is a reasonable assumption for the Euro-area during the time period in our sample. In an environment where funds were scarce, the CCP rate r_{CCP} may be well above ρ , in which case all dealers would strictly prefer to lend in the CCP market, so the Deposit Facility Rate would not be binding. Our model abstracts away from this case for simplicity.

market. The solution to (11) is:

$$W'_L(q) = \rho - r. \quad (12)$$

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

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

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

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

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

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

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

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

where $Q_{D,OTC}(r)$ is increasing in r . The equilibrium CCP repo rate, r_{CCP} , must equate the supply and demand for repo funding from dealers and OTC customers. That is, r_{CCP} must satisfy:

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

Note that $Q_{B,OTC}(r)$ and $Q_{B,Dealer}(r)$ are both decreasing in r , whereas $Q_{L,Dealer}(\rho - r)$ and $Q_{D,OTC}(r)$ are increasing in r , so the supply and demand curves cross at most once.

By applying the implicit function theorem to (14), we can show how changes in the Deposit Facility Rate, ρ , affect the equilibrium CCP repo rate, r_{CCP} .

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

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

where $\frac{dr_{CCP}}{d\rho}$ is always between 0 and 1.

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

This intuition is graphically illustrated in Figure 8. We can write the equilibrium condition in the CCP market as:

$$Q_{L,Dealer}(\rho - r_{CCP}) = Q_{B,OTC}(r_{CCP}) + Q_{B,Dealer}(r_{CCP}) - Q_{D,OTC}(r_{CCP}). \quad (16)$$

In words, (16) says that the supply of funds from lending dealers must equal the net demand from all other kinds of agents. In both panels of Figure 8, the red curve shows $Q_{L,Dealer}(\rho - r_{CCP})$, and the blue curve shows net demand from all other agents, that is, all terms on the right-hand side of (16).

In the left panel, the red curves are relatively flat, so lending dealers' supply of funding is inelastic, and the blue curve is relatively steep, so the market demand for funding is relatively elastic. If the Deposit Facility Rate ρ rises slightly, r_{CCP} cannot one-for-one, since

the demand for funds would decrease too much, so r_{CCP} will be relatively insensitive to changes in ρ . In the right panel, the red curves are steep, so lending dealers have an elastic funding supply, and the blue curve is relatively flat, so the market demand for funding is inelastic. If ρ rises, r_{CCP} must increase approximately one-for-one to keep loan supply constant, so r_{CCP} will be very sensitive to changes in ρ .⁹

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

4.3 DFR to OTC Pass-through

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

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

$$\frac{dr_B(v_B, \theta_B, r_{CCP})}{d\rho} = \frac{dr_B(v_B, \theta_B, r_{CCP})}{dr_{CCP}} \frac{dr_{CCP}}{d\rho}, \quad (17)$$

$$\frac{dr_D(v_D, \theta_D, r_{CCP})}{d\rho} = \frac{dr_D(v_D, \theta_D, r_{CCP})}{dr_{CCP}} \frac{dr_{CCP}}{d\rho}. \quad (18)$$

In words, Claim 5 says that the pass-through of the Deposit Facility Rate ρ to OTC repo rates is simply the product of DFR-CCP pass-through and CCP-OTC pass-through. This decomposition is useful because it highlights two distinct pass-through frictions, which have different economic sources. *Collateral scarcity* in the CCP market constrains the pass-through of the Deposit Facility Rate to CCP repo rates. *Market power* in the OTC

⁹Claim 4 also shows why it is important to assume that funding supply and demand are both imperfectly elastic for modeling pass-through. If all lending dealers had infinite willingness-to-pay for collateral, then (15) implies that DFR-CCP pass-through would always be 0, regardless of the elasticity of funding demand. This is rejected in the data: in the following section, we show that the 2019 rate change had a statistically significant and fairly large effect on repo rates. This suggests that there are at least some funding suppliers in special repo markets who are willing to stop lending if specialness spreads are too large.

market constrains the pass-through of CCP rates to customer-facing rates in the OTC market.

5 Empirical Tests

In this section, we test Predictions 1 and 2 in the data.

5.1 September 2019 DFR Rate Cut

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

Figure 9 plots the average daily repo rates in the CCP and OTC market for repos backed by German, French, Italian, and Spanish collateral. The first vertical dotted line corresponds to the announcement of the rate change on September 12, whereas the second dotted line corresponds to the implementation of the rate cut on September 18.

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

5.2 Measuring Pass-through

Our model characterizes three different kinds of pass-through: DFR-CCP pass-through, DFR-OTC pass-through, and CCP-OTC pass-through. Moreover, (17) and (18) of Claim 3 imply that DFR-OTC pass-through is the product of DFR-CCP pass-through and CCP-OTC pass-through, implying that any two of these quantities can be used to back out the

third.

The 2019 policy rate cut allows us to measure DFR-CCP and DFR-OTC pass-throughs for any segment of the repo market. For example, to calculate DFR-OTC pass-through for repos backed by collateral i , let $\text{rate}_{i,\text{OTC},\text{pre}}$ represent the average OTC rates on repos backed by (ISIN-level) collateral i in the pre-rate-change period, in basis points, and let $\text{rate}_{i,\text{OTC},\text{post}}$ represent the corresponding rates in the post-rate-change period. We define DFR-OTC pass-through for collateral i , $\text{Passthrough}_i^{\text{DFR-OTC}}$, as:

$$\text{Passthrough}_i^{\text{DFR-OTC}} = \frac{\text{rate}_{i,\text{OTC},\text{post}} - \text{rate}_{i,\text{OTC},\text{pre}}}{-10}. \quad (19)$$

In words, $\text{Passthrough}_i^{\text{DFR-OTC}}$ is simply the pre-post change in OTC rates, divided by the size of the DFR rate change. It is thus the empirical counterpart of $\frac{dr_{\text{CCP}}}{dp}$ in the model.

Similarly, we could calculate DFR-CCP pass-through for repos backed by collateral i using pre- and post-rate-cut average CCP repo rates in (19). Based on expressions (17) and (18) of Claim 5, we can then calculate CCP-OTC pass-throughs as the ratio of DFR-CCP and DFR-OTC pass-throughs.

Before testing Predictions 1 and 2 of the model, we first examine our estimates for DFR-CCP pass-through. While Subfigures (c) and (d) in Figure 9 show the average CCP repo rates by collateral segment, significant variation in CCP pass-throughs exists for repos backed by different ISINs. Figure 10 shows binned scatter plots of CCPs pass-throughs against pre-rate-cut loan rates within each collateral segment. From the Figure, we see that CCP pass-throughs are not perfect, and they mostly range between 60% to 100%.¹⁰ Moreover, Figure 10 shows that pass-throughs are lower for ISINs with lower pre-cut loan rates, that is, repos backed by scarcer collateral. Claim 4 suggests that for these ISINs, lending dealers' funding supply is relatively inelastic, and the net demand for funding is relatively elastic.

¹⁰This range is obtained from the binned scatter plots and is an underestimate of the actual range of pass-throughs.

5.3 OTC Rate Dispersion and Pass-through by Collateral

We use our pass-through estimates to test our model predictions. Prediction 1 states that CCP-OTC pass-through should be negatively correlated with OTC rate dispersion across collateral types. Intuitively, if dealers have more market power in the OTC market for a given kind of collateral, repo rates should be more dispersed since they are closer to customers' values, and dealers should be able to pass through less of any changes in CCP rates to customers.

Table 1 confirms Prediction 1 in the data. We estimate the following specification:

$$\text{Passthrough}_i^{\text{DFR_OTC}} = \alpha + \beta \text{p75-p25 Loan Rate}_i + \gamma \text{RA Lend}_i + \epsilon_i. \quad (20)$$

Each observation involves repo backed by the same ISIN-level collateral. The dependent variable, $\text{Passthrough}_i^{\text{DFR_OTC}}$, is the DFR-CCP pass-through for ISIN i , and the main explanatory variable, $\text{p75-p25 Loan Rate}_i$, is the interquartile range in pre-rate-change OTC repo rates for ISIN i . A dummy variable distinguishing between dealer-lend and dealer-borrow transactions is also included. Except for the Spanish collateral segment, the coefficient on the OTC interquartile ranges are all negative and significant, confirming that higher OTC rate dispersion is associated with lower pass-through efficiency.¹¹

Notice that this finding does not stem from collateral scarcity because CCP repo rates for the same ISIN-level collateral is conditioned on in the CCP-OTC pass-through variable. Dealer balance sheet costs are also unlikely to determine the result unless balance sheet costs for intermediating repos backed by different ISIN-level collateral are differentially impacted by changes in monetary policy.

5.4 OTC Loan Rates and Pass-through by Customer

Another way to shed light on the presence of dealer market power is from OTC customers' perspective. According to Prediction 2, CCP-OTC pass-through should be positively (negatively) correlated with the level of OTC rates for customers who lend to (borrow from) dealers. Intuitively, if a dealer has higher bargaining power with a customer that

¹¹The lack of significance in the Spanish segment may in part be driven by the smaller sample size.

they borrow from, the dealer will be able to borrow at lower rates and pass-through changes in CCP rates less. Similarly, if a dealer has higher bargaining power with a customer that they lend to, the dealer will be able to lend at higher rates and pass-through changes in CCP rates less.

To test this prediction, we first estimate the following specification:

$$\text{Passthrough}_{jc}^{\text{DFR_OTC}} = \alpha + \beta \text{Loan Rate}_{jc} + \gamma \text{FR}_j + \theta \text{IT}_j + \delta \text{ES}_j + \epsilon_{jc}, \quad (21)$$

where c indexes individual customers, and j indexes collateral countries. We do our analysis at the collateral-country level rather than at the ISIN level to increase statistical power since we do not observe many repo transactions for most individual customers. Loan Rate_{jc} is the rate at which customer c borrows from dealers in the pre-rate-cut period. To absorb systematic differences in pass-throughs by collateral country, we include dummy variables for French, Italian, and Spanish collateral segments, and the German collateral segment forms the baseline.

Table 2 shows results from estimating specification (21) on customers who lend to dealers (dealers borrowing from customers). We find that OTC pass-through and OTC loan rates are positively correlated: within each country segment, market participants who enjoy a higher rate when lending to dealers in the pre-rate-cut period also have more efficient pass-through to their repo rates following the rate cut. Table 3 shows results from estimating specification (21) using transactions in which customers borrow from dealers. We find that pass-through is negatively correlated with pre-cut loan rates: market participants who borrow from dealers at a higher rate in the pre-rate-cut period also have less efficient pass-through to their repo rates, following the rate cut. Both sets of results are in line with Prediction 2.

One concern for specification (21) is that Loan Rate_{jc} is a relatively coarse measure. Since it is at the level of customer-countries, it cannot account for differences in collateral between more and less scarce bonds of a given country. To ensure that this is not driving our results, we repeat our analysis using a residualized measure for customers' pre-rate-change loan rates. As in Section 3.5, we first regress transaction-level repo rates against categorical variables for each collateral-ISIN and control variables for loan-level characteristics. These regressions are performed monthly within each country-segment to allow for

time-varying collateral scarcity effects. We then use the regression residuals to calculate residualized versions of OTC pass-through, which we call $\text{Passthrough}_{jc}^{\text{DFR_OTC, resid}}$, and OTC loan rates, which we call $\text{Loan Rate (Residual)}_{jc}$. We then estimate the following specification for OTC borrowers and lenders:

$$\text{Passthrough}_{jc}^{\text{DFR_OTC, resid}} = \alpha + \beta \text{Loan Rate (Residual)}_{jc} + \gamma \text{FR}_j + \theta \text{IT}_j + \delta \text{ES}_j + \epsilon_{jc}. \quad (22)$$

We report the results from specification (22) for lending and borrowing customers in Tables 4 and 5, respectively. The coefficient's sign and significance are unchanged, which corroborates that the positive relationship between sticky OTC pass-through, lower dealer borrowing rates, and higher dealer lending rates stem from variations in dealer market power against different OTC market participants.

6 Policy Counterfactuals

Our framework also addresses how different policy changes affect monetary pass-through and guides the empirical estimation of policy counterfactuals. We consider two classes of policy changes: allowing customer access to CCP markets and providing Reverse Repo (RRP) Facilities in the CCP and OTC market segments.

6.1 Access to CCPs

If OTC customers could have direct access to centralized trading on e-trading platforms, through "sponsored access" for example, they could trade at the competitive CCP repo rate r_{CCP} . This would eliminate the market power component of pass-through frictions as the following claim characterizes.

Claim 6. *Suppose OTC customers had direct access to the competitive CCP repo market. Then*

OTC market interest rates would be equal to the CCP rate:

$$r_B(v_B, \theta_B, r_{CCP}) = r_D(v_D, \theta_D, r_{CCP}) = r_{CCP}. \quad (23)$$

The DFR-CCP pass-through is unchanged from (15):

$$\frac{dr_{CCP}}{d\rho} = \frac{Q'_{L,Dealer}(\rho - r)}{Q'_{B,OTC}(r) + Q'_{B,Dealer}(r) + Q'_{Lj}(\rho - r) - Q'_{D,OTC}(r)}. \quad (24)$$

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

$$\frac{dr_L(v_B, \theta_B, r_{CCP})}{d\rho} = \frac{Q'_{L,Dealer}(\rho - r)}{Q'_{B,OTC}(r) + Q'_{B,Dealer}(r) + Q'_{Lj}(\rho - r) - Q'_{D,OTC}(r)}. \quad (25)$$

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

We then take our policy counterfactual to the data to quantify the improvement in pass-through from CCP access. For a given repo in the OTC segment, we calculate its counterfactual pass-through as the pass-through to repos backed by the same collateral in the CCP segment following the September 2019 rate cut.

Figure 11 shows our results. Compared to the original OTC pass-throughs to dealer-borrow trades in the German, French, Italian, and Spanish segment of 62%, 49%, 60%, and 65%, we find that CCP access improves pass-through by 13%, 27%, 20%, and 21%, respectively. For dealer-lend trades in the German, French, Italian, and Spanish segment, the original pass-throughs of 43%, 48%, 55%, and 59% are improved by 26%, 32%, 28%, and 29%, respectively. The improvements in pass-through efficiencies are significant, indicating the importance of market power frictions. Nevertheless, the final pass-through efficiencies are well below 100% because collateral scarcity frictions remain.

Another benefit of extending access to CCP markets is to lower pass-through dispersion so that a given change in the policy rate can transmit to various market participants more equally independently of their bargaining power with respect to dealers. We again

estimate this improvement empirically by letting OTC market participants take on their corresponding CCP pass-throughs. That is, pass-throughs to a given customer's repo loan backed by a given collateral becomes the CCP pass-through to repo rates backed by the same collateral. As Table 6 shows, pass-through dispersion for OTC market participants decreases across the board. For dealer-borrow repos, pass-through dispersion decreases from 22.4% to 13.6%, 41.9% to 13.8%, 31.7% to 23.8%, and 30.2% to 9.1% for the German, French, Italian, and Spanish segments, respectively. Pass-through dispersion of dealer-lend transactions is also improved from 36.4% to 18.5%, 36.3% to 20.0%, 29.3% to 20.9%, and 30.9% to 8.3% respectively. The reduction in dispersion arises from the elimination of market power frictions, whereas the remaining dispersion stems from the use of different collateral in backing repo trades.

6.2 Reverse Repo Facility (RRP)

The Deposit Facility Rate is an unsecured rate, at which banks can deposit with the central bank. If central banks also offered a secured deposit rate, market participants would be able to lend cash to the central bank and receive securities in return. In the U.S., a secured deposit facility was made available to a wide range of market participants under the Federal Reserve's Reverse Repo (RRP) Facility.

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

6.2.1 The CCP market

First, suppose that the central bank conducts RRP's with dealers but not directly with OTC customers. By providing a policy rate, r_{RRP} , at which repo depositors can deposit funds with the central bank backed by collateral, the central bank essentially introduces a floor to CCP repo rates.

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

$$r_{CCP} = \begin{cases} r_{RRP} & r_{\text{nofloor},CCP} \leq r_{RRP} \\ r_{\text{nofloor},CCP} & r_{\text{nofloor},CCP} \geq r_{RRP}, \end{cases} \quad (26)$$

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

$$r_{\text{nofloor},CCP} = \{r : Q_{B,OTC}(r_{CCP}) + Q_{B,Dealer}(r_{CCP}) = Q_{L,Dealer}(\rho - r_{CCP}) + Q_{D,OTC}(r_{CCP})\}. \quad (27)$$

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

$$\frac{\partial r_{CCP}}{\partial r_{RRP}} = \begin{cases} 1 & r_{\text{nofloor},CCP} \leq r_{RRP} \\ 0 & r_{\text{nofloor},CCP} \geq r_{RRP}. \end{cases} \quad (28)$$

Expression (28) characterizes the effect of changes in RRP rates on equilibrium rates. The top left panels of Figure 12 illustrate the results graphically. The RRP rate is binding if $r_{RRP} \geq r_{\text{nofloor},CCP}$. In this case, the market rate is the RRP rate, so changes in r_{RRP} pass on one-to-one to the market rate. If $r_{RRP} < r_{\text{nofloor},CCP}$, then the rate is non-binding, and changes do not affect the market rate.

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

6.2.2 The OTC market

Instead, what would happen if central banks conducted RRP's with non-dealer customers directly? In this section, we provide a novel finding that the central bank can influence market rates and improve pass-through even if RRP rates are not binding. The improvement in pass-through is also highly effective because it can resolve both collateral scarcity and market power frictions.

Recall from the baseline model that OTC customers do not have access to CCP platforms and rely on intermediation by dealer banks, which subjects them to dealer market power. The following claim characterizes market outcomes, if OTC repo depositors as well as dealers were given access to the RRP facility, which allows all agents to deposit secured at rate r_{RRP} .

Claim 8. *Suppose OTC depositors and dealers had access to the RRP Facility, paying rate r_{RRP} . The CCP repo rate is identical to (26) of Claim 7:*

$$r_{CCP} = \begin{cases} r_{RRP} & r_{\text{nofloor},CCP} \leq r_{RRP} \\ r_{\text{nofloor},CCP} & r_{\text{nofloor},CCP} \geq r_{RRP}, \end{cases} \quad (29)$$

where $r_{\text{nofloor},CCP}$ is the equilibrium rate which would prevail in the absence of the RRP facility, as defined in (27). If $r_{RRP} \geq r_{\text{nofloor},CCP}$, then OTC depositors are indifferent between trading with dealers and using the RRP. If $r_{RRP} < r_{\text{nofloor},CCP}$, then the RRP Facility is not used, and all OTC depositors' repo trades are made with dealers. An OTC depositor with value v_D and bargaining power θ_D trades at rate:

$$r_D(v_D, \theta_D) = \begin{cases} r_{\text{nofloor},CCP} - \theta_D (r_{\text{nofloor},CCP} - v_D) & r_{\text{nofloor},CCP} < v_D \\ r_{CCP} - \theta_D (r_{CCP} - r_{RRP}) & v_D \leq r_{RRP} \leq r_{\text{nofloor},CCP} \\ r_{RRP} & r_{RRP} > r_{\text{nofloor},CCP}. \end{cases} \quad (30)$$

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

$$\frac{dr_D(v_D, \theta_D, r_{CCP})}{dr_{RRP}} = \begin{cases} 0 & r_{RRP} < v_D \\ \theta_D & v_D \leq r_{RRP} \leq r_{\text{nofloor},CCP} \\ 1 & r_{RRP} > r_{\text{nofloor},CCP}. \end{cases} \quad (31)$$

The top-right and middle-right panels of Figure 12 illustrate Claim 8. Unlike in the CCP market, the rate curve has three regions. When r_{RRP} is below v_D , it has no effect. When r_{RRP} is above $r_{\text{nofloor},CCP}$, OTC depositors are indifferent between using the r_{RRP} or trading with dealers, so r_{RRP} changes pass through one-to-one to customer-facing rates. However, in the intermediate region, changes in r_{RRP} partially pass through to customers'

repo rates.

Intuitively, when r_{RRP} exceeds $r_{nofloor,CCP}$, pass-through becomes perfectly efficient because both market power frictions and collateral scarcity frictions are eliminated. When r_{RRP} is between v_D and $r_{nofloor,CCP}$, customers have an outside option of lending secured to the RRP Facility. In this range, the customer continues trading with dealers, but at a rate that is affected by their outside option rate, r_{RRP} . Thus, offering the RRP rate, r_{RRP} , to market participants exerts competitive pressure on dealer rates and policy pass-through even without the central bank actually having to make any repo trades. Claim 8 implies that the range in which this bargaining power channel improves pass-through is heterogeneous, depending on the distribution of market participants' bargaining power and values. The aggregate effect is an average across customers, as shown in the bottom panel of Figure 12.

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

7 Conclusion

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

We build a simple model to show how repo rates are affected by collateral scarcity and dealer market power. The model shows that market power reduces the pass-through

of central bank policy rates to customer-facing repo rates and generates a number of predictions, which are aligned with the observations following the September 2019 rate cut.

Our findings have important policy implications. Granting OTC customers access to CCP repo markets would decrease dealer market power and improve the pass-through of the Deposit Facility Rate. Moreover, if the central bank gave OTC customers access to a secured deposit facility, like the Federal Reserve's RRP, policy rate pass-through could be further enhanced. Notably, this bargaining channel is present even if there is no actual take-up of the facility in equilibrium.

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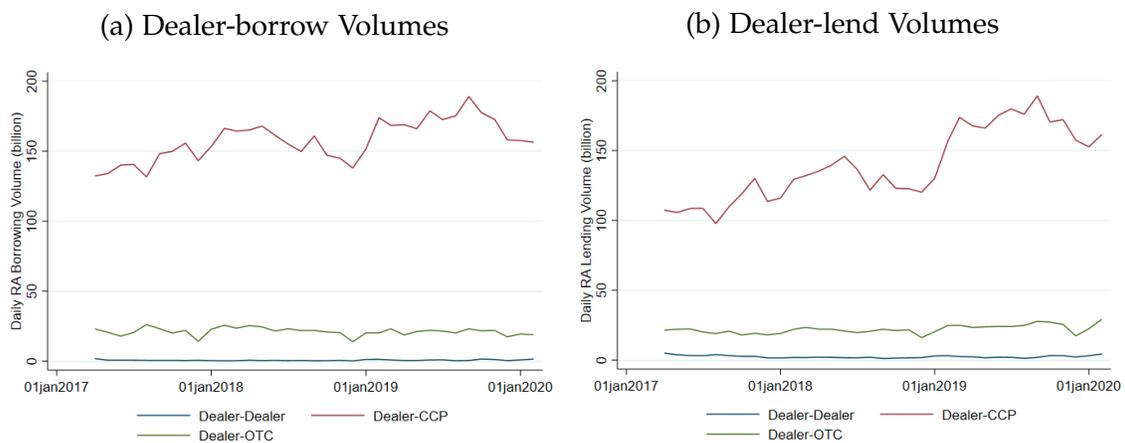
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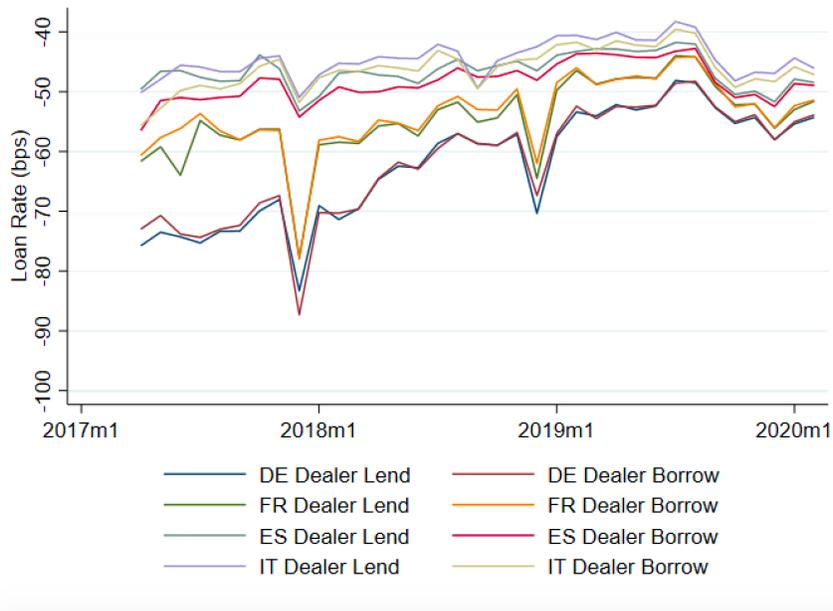
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Figure 1: Repo Loan Volumes



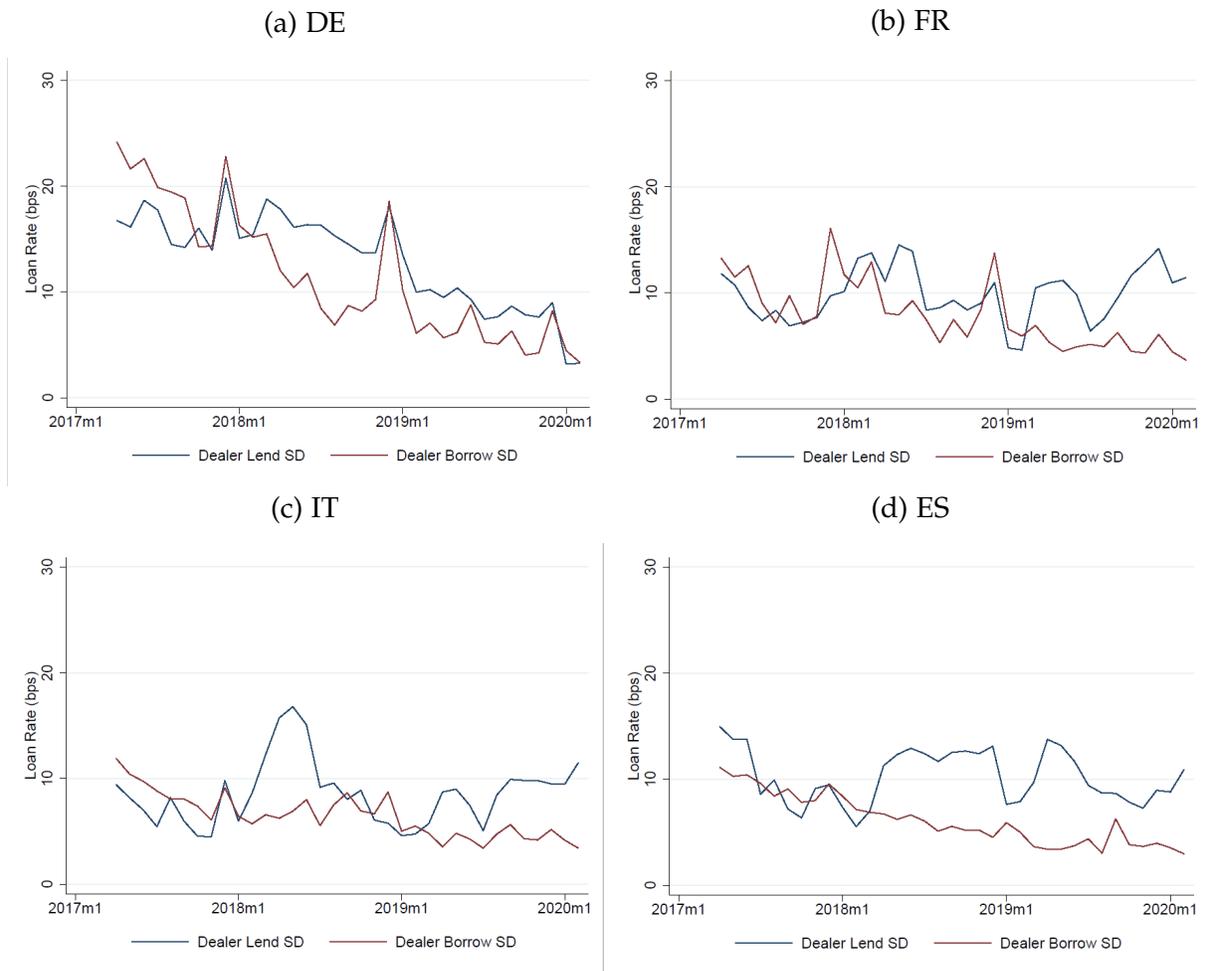
Notes. This figure plots averages, within each month in our data, of daily volumes of repo transactions in which dealers borrow and lend secured funds backed by German, French, Italian, and Spanish government collateral. “Dealer-CCP” indicates trades in which dealers borrow via e-trading platforms with centralized trading. “Dealer-OTC” indicates trades in which dealers borrow from non-dealer counterparties in the over-the-counter market. “Dealer-Dealer” represents trades in which dealers borrow from other dealers, without using e-trading platforms and central clearing. The sample period is from March 2017 to March 2020.

Figure 2: CCP Repo Rates



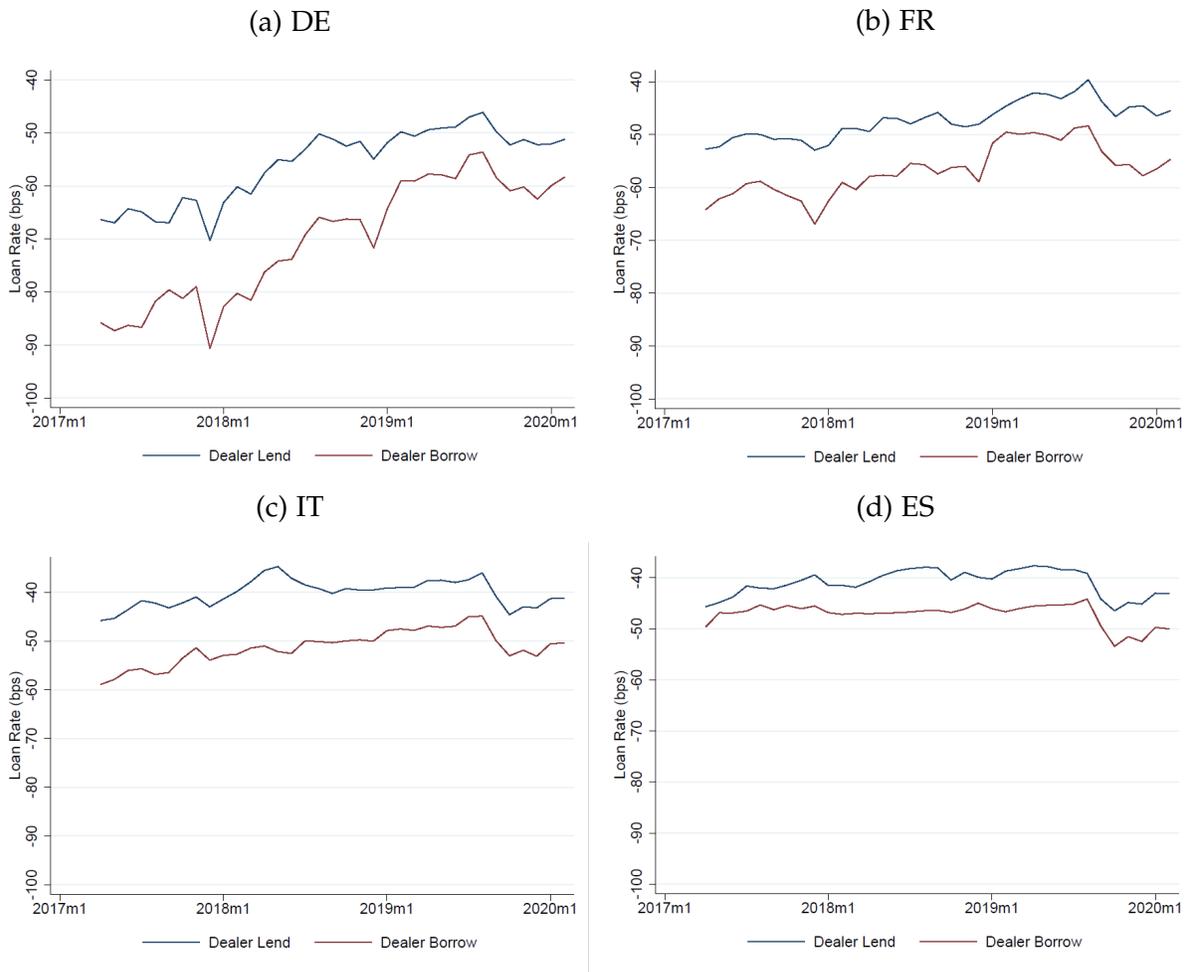
Notes. This figure shows the value-weighted average repo rates at which dealers borrow and lend in the CCP market using German, French, Spanish, and Italian government collateral at a monthly frequency. The sample period is from March 2017 to March 2020.

Figure 3: Dispersion in OTC Rates



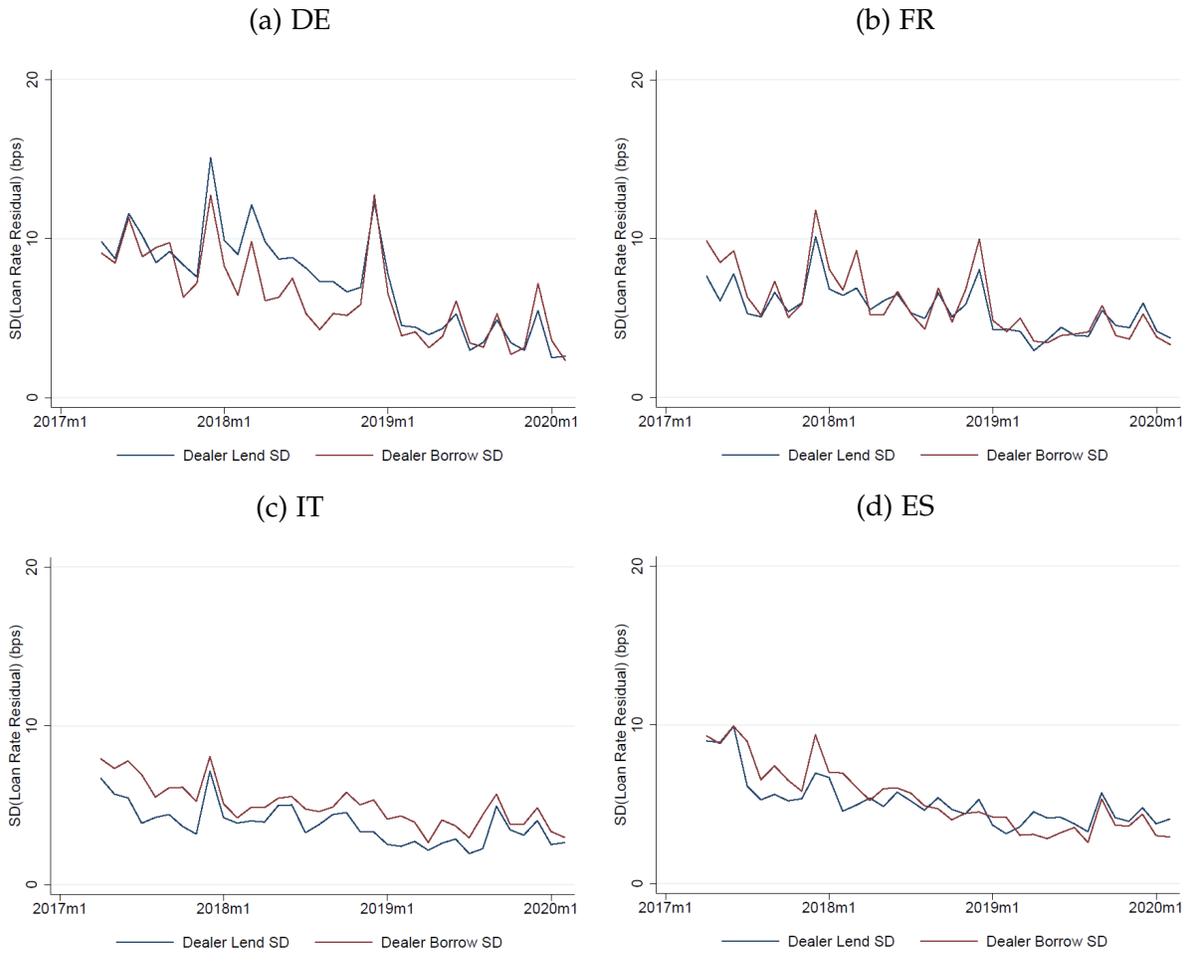
Notes. This figure shows the value-weighted standard deviation of repo rates at which dealers lend to and borrow from their counterparties in the OTC market at a monthly frequency. The four panels show rates on repos backed by German, French, Italian, and Spanish government collateral, respectively.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

Figure 4: OTC Dealer Lend and Borrow Rates



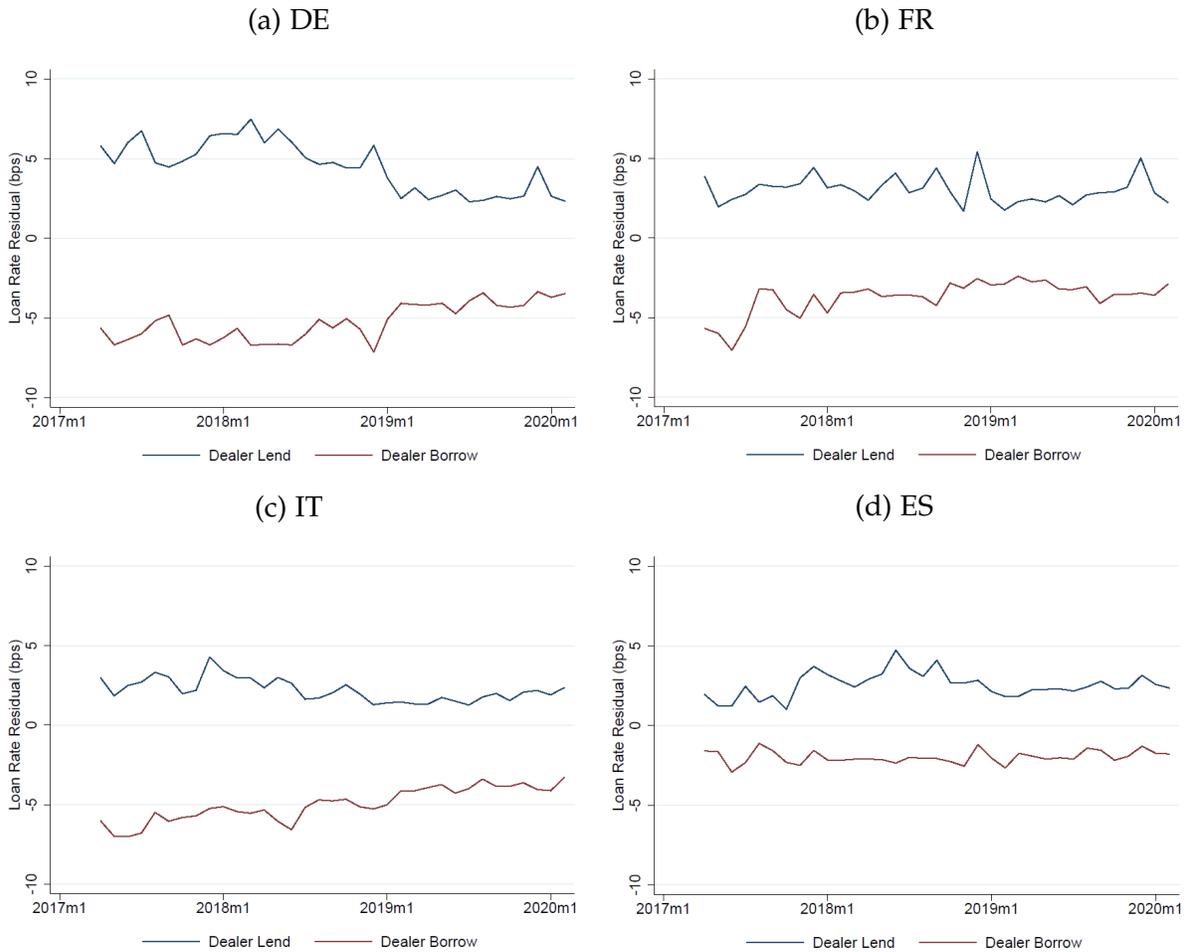
Notes. This figure shows the value-weighted average repo rates at which dealers lend to and borrow from their counterparties in the OTC market, at a monthly frequency. The four panels show rates on repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period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

Figure 5: Dispersion in OTC Rates (Residualized)



Notes. This figure shows the value-weighted standard deviation of residualized repo rates at which dealers lend and borrow in the OTC market at a monthly frequency. Residualized rates are obtained according to specification (2), where explanatory variables include collateral ISIN, month, haircut and maturity. The four panels show residualized rates on repos backed by German, French, Italian, and Spanish government collateral, respectively. The sample period is from March 2017 to March 2020.

Figure 6: OTC Dealer-Lend and Dealer-Borrow Rates (Residualized)



Notes. This figure shows the value-weighted average residualized repo rates at which dealers lend to and borrow from their counterparties in the OTC market at a monthly frequency. The four panels show residualized rates on repos backed by German, French, Italian, and Spanish government collateral, respectively. Residualized rates are obtained according to specification (2), where explanatory variables include collateral ISIN, month, haircut, and maturity. The sample period is from March 2017 to March 2020.

Figure 7: Stylized Depiction of Model

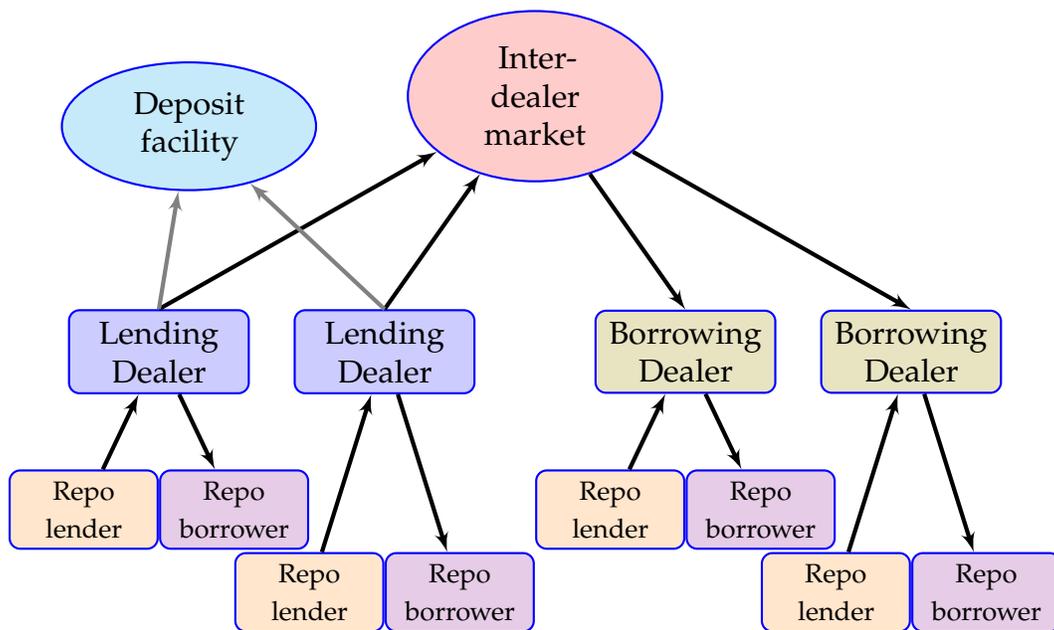
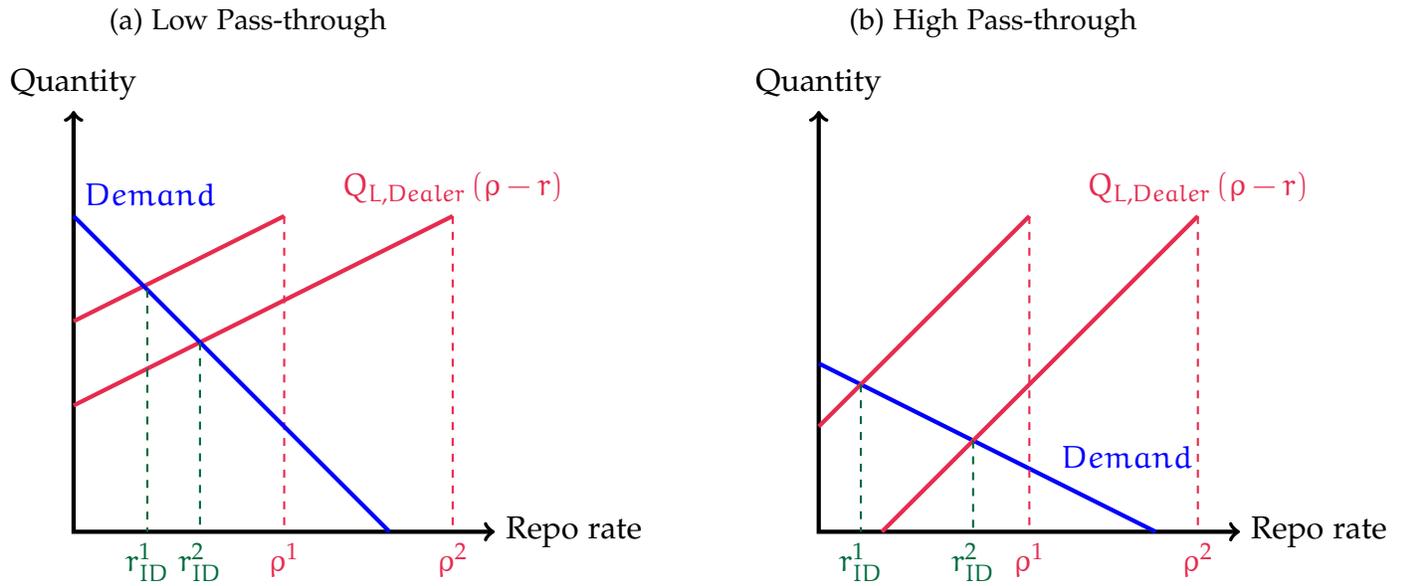
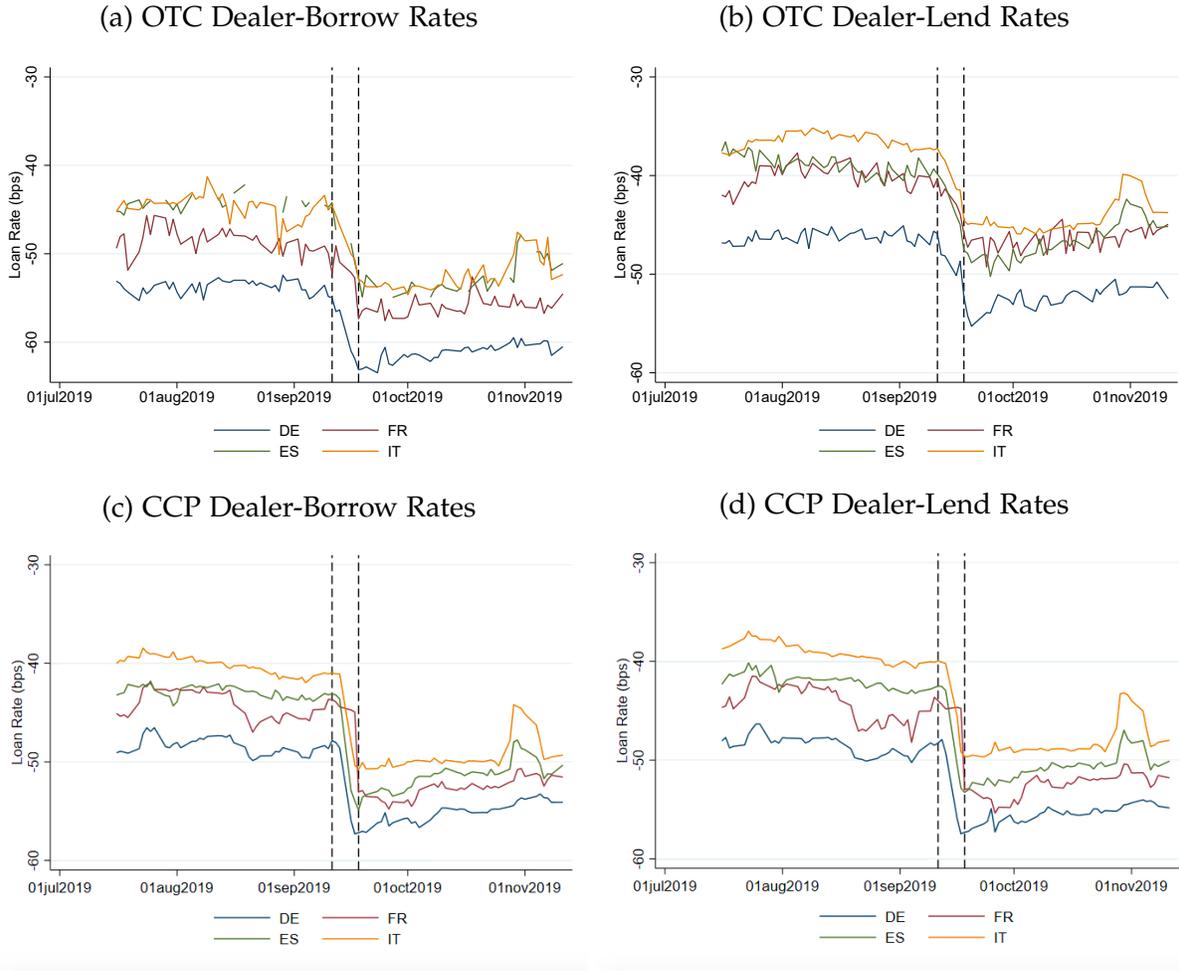


Figure 8: DFR - CCP Pass-through Intuition



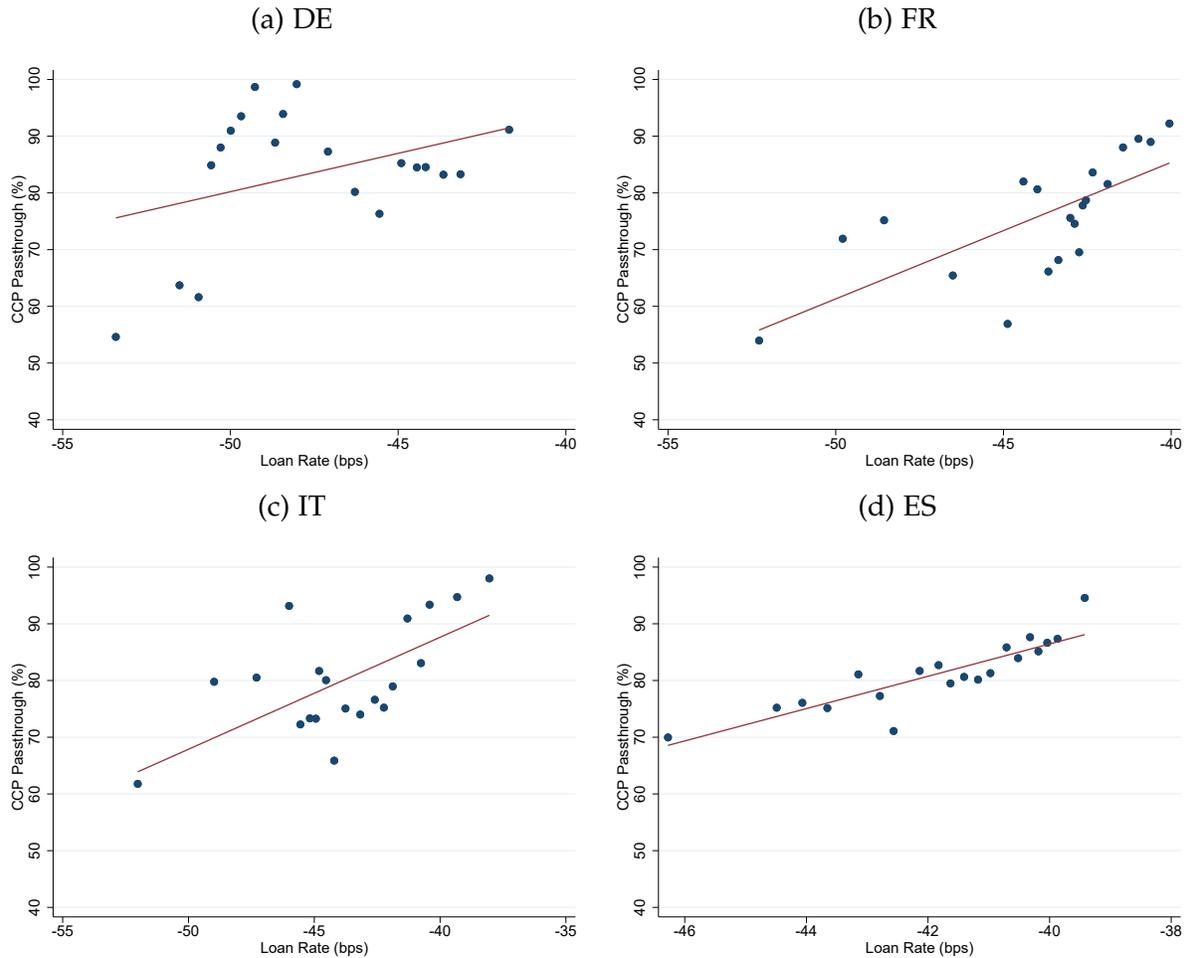
Notes. Intuition for pass-through. In each panel, the red lines represent the supply of repo funding from lending dealers, $Q_{L,Dealer}(\rho - r)$, for two different values of ρ , and the blue lines represent net funding demand from other market participants, $Q_{B,OTC}(r) + Q_{B,Dealer}(r) - Q_{D,OTC}(r)$.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

Figure 9: September 2019 Rate Cut



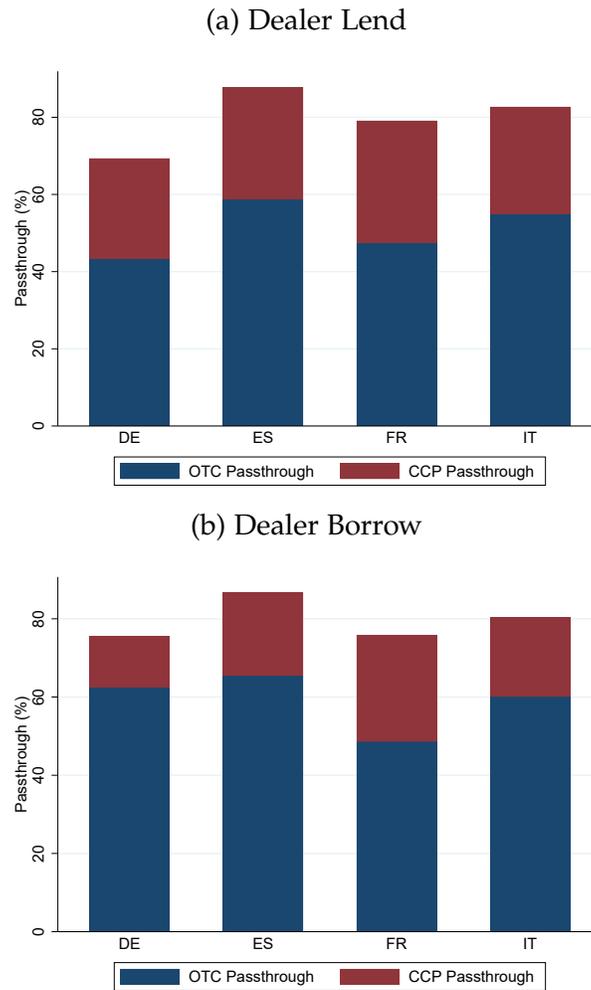
Notes. This figure shows the value-weighted average daily repo rates for German, French, Italian, and Spanish government collateral around the monetary policy rate cut in September 2019. Subfigures (a) and (b) correspond to the rates at which dealers borrow and lend in the OTC market, and subfigures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

Figure 10: CCP Passthroughs



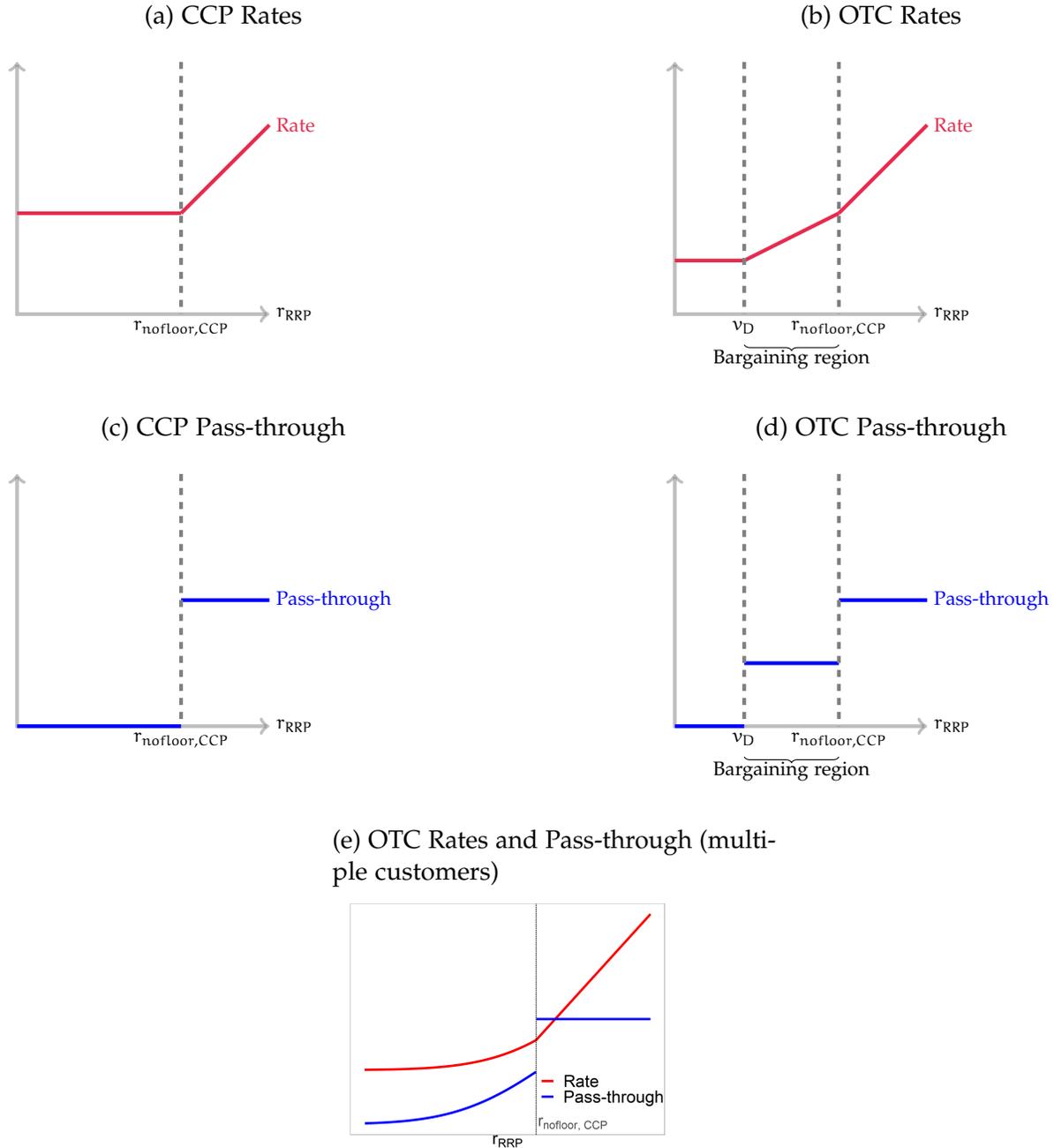
Notes. This figure shows binned scatterplots, where the y-axis is DFR-CCP pass-through, $\text{Passthrough}_i^{\text{DFR_CCP}}$, where i indexes collateral ISINs. As in specification (19), DFR-CCP pass-through is calculated as the change in repo rates from the pre- to post-rate cut period, divided by the rate cut of -10 basis points. The x-axis is the pre-rate-change CCP repo rate for ISIN i . The pre-rate-cut period refers the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019. Each collateral country is shown in a separate panel.

Figure 11: CCP Access and Pass-through



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

Figure 12: The Effect of RRP on CCP and OTC Pass-through



Notes. The top left panel shows the effect of a reverse repo facility, with rate r_{RRP} , on rates and pass-through for the CCP market, using (26) and (28) of Claim 7. The top right panel shows the effect of r_{RRP} on rates and pass-through for the OTC market, for a single customer, using (30) and (31) of Claim 8. The bottom figure shows average rates and pass-through, averaging across many customers. We set $r_{CCP} = 0.8$, v_D normal with mean 1 and SD 0.8, and θ_D uniform on $[0, 1]$. Rates and pass-through for each customer are computed using (30) and (31) of Claim 8.

Table 1: OTC - CCP Pass-through

	(1) DE	(2) FR	(3) ES	(4) IT
Dispersion	-1.513* [0.876]	-2.490*** [0.916]	0.543 [0.491]	-1.598*** [0.414]
RA Lend	-15.231 [9.224]	-8.229 [8.390]	-0.174 [7.356]	-9.608* [5.355]
Constant	97.025*** [7.354]	89.655*** [7.107]	79.429*** [5.508]	86.881*** [4.167]
Observations	108	120	94	194
Adj. R-squared	0.03	0.05	-0.01	0.08

Notes. This table shows the results from specification (20), in which we regress estimated CCP-OTC pass-through on the interquartile range in OTC loan rates in the pre-rate-cut period. To calculate the dependent variable, $\text{Passthrough}_i^{\text{CCP-OTC}}$, we first measure DFR-CCP and DFR-OTC pass-through as in specification (19), by taking pre- and post-rate-change average repo rates for ISIN i in the CCP and OTC segments, respectively, and divide the difference by the rate cut of -10 basis points. We then calculate CCP-OTC pass-through for ISIN i as the ratio of DFR-OTC and DFR-CCP pass-throughs for ISIN i . Dispersion is the interquartile range from all OTC trades in which the dealers lend (borrow) in the pre-rate-cut period and expressed in basis points. DealerLend is a dummy variable equal to one when the dealer is the lender. The pre-rate-cut period refers to the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019. Each collateral country is shown in a separate column.

Table 2: OTC Pass-through and OTC Rates (Dealer Borrow)

	(1)	(2)	(3)	(4)
	Passthrough	Passthrough	Passthrough	Passthrough
Loan Rate	4.332*** [0.869]	2.871*** [0.744]	2.396*** [0.515]	1.585*** [0.495]
ES	10.074 [12.896]	-15.571 [10.070]	-4.776 [7.939]	-4.430 [7.541]
FR	12.694** [5.559]	45.527*** [4.665]	4.639 [3.193]	8.463*** [3.071]
IT	17.006 [12.086]	-12.293 [9.344]	-28.926*** [6.382]	-29.121*** [5.982]
Constant	252.724*** [47.309]	162.430*** [40.408]	161.874*** [27.503]	117.651*** [26.512]
Cntp Country	No	No	Yes	Yes
Cntp Sector	No	Yes	No	Yes
Observations	325	324	324	323
Adj. R-squared	0.195	0.556	0.840	0.862

Notes. This table shows the results from specification (21), in which we regress estimated customer-level DFR-OTC pass-through against the customer's OTC loan rates in the pre-rate-cut period, for transactions in which dealers borrow. To calculate the dependent variable, $\text{Passthrough}_{jc}^{\text{DFR_OTC}}$, we measure DFR-OTC pass-through by taking the difference between pre- and post-rate-change average OTC repo rates for customer c and collateral country j , and dividing by the rate cut of -10 basis points, as in specification (19). Loan Rate is the average pre-rate-cut repo rate of customer c on its OTC trades, in which dealers borrow, in basis points. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. The pre-rate-cut period refers to the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019.

Table 3: OTC Pass-through and OTC Rates (Dealer Lend)

	(1)	(2)	(3)	(4)
	Passthrough	Passthrough	Passthrough	Passthrough
Loan Rate	-0.700*** [0.260]	-0.521** [0.245]	-0.903*** [0.239]	-0.640** [0.292]
ES	3.397 [7.708]	1.149 [7.255]	-0.083 [6.936]	1.508 [7.046]
FR	4.710 [5.943]	9.209 [5.941]	5.642 [5.626]	5.723 [5.681]
IT	14.410*** [5.479]	11.696** [5.516]	2.735 [5.064]	4.281 [5.374]
Constant	36.345*** [12.257]	43.921*** [11.680]	33.477*** [10.853]	43.250*** [12.604]
Cntp Country	No	No	Yes	Yes
Cntp Sector	No	Yes	No	Yes
Observations	175	175	173	173
Adj. R-squared	0.036	0.172	0.306	0.307

Notes. This table shows the results from specification (21), in which we regress estimated customer-level DFR-OTC pass-through against the customer's OTC loan rates in the pre-rate-cut period, for transactions in which dealers lend. To calculate the dependent variable, $\text{Passthrough}_{jc}^{\text{DFR_OTC}}$, we measure DFR-OTC pass-through for as in specification (19), by taking the difference between pre- and post-rate-change average OTC repo rates for customer c and collateral country j , and dividing by the rate cut of -10 basis points. Loan Rate is the average pre-rate-cut repo rate of customer c for collateral country j on its OTC trades, in which dealers lend, in basis points. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. The pre-rate-cut period refers to the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019.

Table 4: Residualized OTC Pass-through and OTC Rates (Dealer Borrow)

	(1)	(2)	(3)	(4)
	Passthrough	Passthrough	Passthrough	Passthrough
Loan Rate	-15.041*** [3.682]	-12.825*** [3.770]	-23.887*** [3.831]	-22.092*** [3.856]
ES	177.412*** [39.909]	226.410*** [44.649]	-103.830* [60.348]	-53.984 [60.526]
FR	17.392 [53.323]	67.226 [55.922]	46.041 [50.191]	86.597* [50.497]
IT	90.840** [45.340]	140.036*** [50.129]	61.609 [45.592]	103.355** [46.399]
Constant	-906.644*** [27.086]	-940.059*** [30.069]	-811.635*** [30.512]	-842.067*** [31.077]
Cntp Country	No	No	Yes	Yes
Cntp Sector	No	Yes	No	Yes
Observations	265	264	265	264
Adj. R-squared	0.113	0.131	0.293	0.324

Notes. This table shows the results from specification (22), for transactions in which dealers borrow. To calculate the dependent variable, we first residualize repo rates, and then calculate $\text{Passthrough}_{jc}^{\text{DFR_OTC}}$, by taking the difference between pre- and post-rate-change average OTC repo rate residuals for customer c and collateral country j , and dividing by the rate cut of -10 basis points. The dependent variable, Loan rate, is the average residual of customer c and collateral country j , for transactions in which dealers borrow in the pre-rate-cut period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. The pre-rate-cut period refers to the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019.

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

	(1)	(2)	(3)	(4)
	Passthrough	Passthrough	Passthrough	Passthrough
Loan Rate	9.742** [4.004]	9.062** [3.750]	6.827** [2.749]	1.232 * [0.702]
ES	-358.587*** [121.318]	-265.168** [115.744]	-143.488 [115.095]	-195.500* [108.781]
FR	-211.289** [92.730]	-218.293** [86.382]	-196.452** [90.218]	-209.672** [88.940]
IT	-185.705** [70.760]	-111.407 [68.512]	-9.192 [73.847]	-81.806 [120.079]
Constant	-544.192*** [64.267]	-586.288*** [61.118]	-646.756*** [69.307]	-569.397*** [99.622]
Cntp Country	No	No	Yes	Yes
Cntp Sector	No	Yes	No	Yes
Observations	96	96	93	93
Adj. R-squared	0.130	0.256	0.306	0.313

Notes. This table shows the results from specification (22), for transactions in which dealers lend. To calculate the dependent variable, we first residualize repo rates, and then calculate $\text{Passthrough}_{jc}^{\text{DFR-OTC}}$, by taking the difference between pre- and post-rate-change average OTC repo rate residuals for customer c and collateral country j , and dividing by the rate cut of -10 basis points. The dependent variable, Loan rate, is the average residual of customer c and collateral country j , for transactions in which dealers lend in the pre-rate-cut period. *FR*, *IT*, and *ES* are dummy variables equal to one if the repo involves French, Italian, and Spanish government collateral, respectively. Repos backed by German government collateral are the baseline. The pre-rate-cut period refers to the week before the announcement of the rate cut on September 12, 2019, and the post-rate-cut period refers to the week after the rate cut on September 18, 2019.

Table 6: CCP Access and Pass-through Dispersion

Dealer Borrow		
Collateral Segment	Without Access	With Access
DE	22.4	13.6
ES	31.7	23.8
FR	41.9	13.8
IT	30.2	9.1

Dealer Lend		
Collateral Segment	Without Access	With Access
DE	36.4	18.5
ES	29.3	20.9
FR	36.3	19.9
IT	30.9	8.3

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

Appendix

A Supplementary material for section 4

A.1 Proof of Claim 1

To find net interest margins, note that expected loan rates, conditional on trade, are:

$$E [r_B (v_B, \theta_B, r_{CCP}) | v_B \geq r_{CCP}] = r_{CCP} + E [\theta_B (v_B - r_{CCP}) | v_B \geq r_{CCP}] \quad (32)$$

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

$$E [r_D (v_D, \theta_D, r_{CCP}) | v_D \leq r_{CCP}] = r_{CCP} - E [\theta_D (r_{CCP} - v_D) | v_D \leq r_{CCP}] \quad (33)$$

Combining these, we get (5).

A.2 Proof of Claim 2

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

A.3 Proof of Claim 3

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

A.4 Proof of Claim 4

This follows from applying the implicit function theorem to (14). $Q'_{L, Dealer} (\rho - r)$ is always positive, and every term in the numerator is positive, hence $\frac{dr_{CCP}}{d\rho}$ is bounded between 0 and 1.

A.5 Heterogeneous Intermediation Costs

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

In this appendix, we show how intermediation costs would affect outcomes in the OTC market. To begin with, Appendix A.5.1 solves for net interest margins, rate dispersion, and rate pass-through assuming that dealers have no market power, but may have intermediation costs which differ across customers. We show that heterogeneous costs can rationalize net interest margins and rate dispersion, but not heterogeneous CCP-OTC pass-through. Thus, heterogeneous costs alone cannot produce Predictions 1 and 2 about pass-through. For simplicity, throughout the appendix, we take the equilibrium repo rate in the CCP market, r_{CCP} , as given.

In Appendix A.5.2, we solve for outcomes when dealer have market power, and also face heterogeneous intermediation costs. The outcomes essentially combine the effects of market power and intermediation costs.

A.5.1 Competitive markets with intermediation costs

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

Intermediation costs imply that the break-even rate for dealers to lend in the repo

market, for a customer of type c_B , is $r_{CCP} + c_B$, and the break-even rate for taking deposits is $r_{CCP} - c_D$. To begin with, we assume that markets are perfectly competitive, so dealers lend at exactly their intermediation costs. This is equivalent to assuming that dealers set prices with zero bargaining power over customers. The following claim characterizes market outcomes.

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

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

$$r_D(v_D, c_D, r_{CCP}) = r_{CCP} - c_D$$

Net interest margins are:

$$\begin{aligned} E[r_B(v_B, c_B, r_{CCP}) | v_B > r_{CCP} + c_B] - E[r_D(v_D, c_D, r_{CCP}) | v_D < r_{CCP} - c_D] = \\ E[c_B | v_B > r_{CCP} + c_B] + E[c_D | v_D < r_{CCP} - c_D] \end{aligned} \quad (34)$$

Rate dispersion is:

$$\text{Var}[r_B(v_B, c_B, r_{CCP})] = \text{Var}[c_B | v_B > r_{CCP} + c_B]$$

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

Rate pass-through is:

$$\frac{dr_B(v_B, c_B, r_{CCP})}{dr_{CCP}} = 1 \quad (35)$$

$$\frac{dr_D(v_D, c_D, r_{CCP})}{dr_{CCP}} = 1 \quad (36)$$

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

Claim 9 shows that heterogeneous costs can explain both net interest margins and rate dispersion. Expression (34) shows that even if markets are competitive, positive costs for intermediation will cause dealers to attain a net interest margin. This is intuitive:

for example, if $c_D = c_B = c$, so dealers have some cost of intermediation, dealers will charge a net interest margin to cover that marginal cost, even in competitive markets. Expressions (9) and (9) show that, if costs are heterogeneous across consumers, this also can create dispersion in competitive markets. Intuitively, dispersion in repo rates simply reflects dispersion in costs across customers.

Expressions (35) and (36) shows that, in competitive markets, the pass-through of r_{CCP} to borrow and deposit rates should be perfect. Intuitively, this is because, if r_{CCP} moves, but costs c_B and c_D do not change, individual customers' rates should move one-to-one with r_{CCP} . Thus, heterogeneous costs alone cannot generate imperfect pass-through. As a result, heterogeneous intermediation costs alone cannot generate Predictions 1 and 2, which explain why pass-through is correlated with rate dispersion in the OTC market, and why pass-through differs across OTC customers who receive different rates.

A.5.2 Bargaining power and intermediation costs

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

$$r_B(v_B, \theta_B, c_B, r_{CCP}) = r_{CCP} + c_B + \theta_B (v_B - [r_{CCP} + c_B]) \quad (37)$$

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

$$r_D(v_D, \theta_D, c_D, r_{CCP}) = r_{CCP} - c_D - \theta_D ([r_{CCP} - c_D] - v_D) \quad (38)$$

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

Claim 10. *Net interest margins are:*

$$\begin{aligned}
& E [r_B (v_B, \theta_B, c_B, r_{CCP}) \mid v_B > r_{CCP} + c_B] - E [r_D (v_D, \theta_D, c_D, r_{CCP}) \mid v_D < r_{CCP} - c_D] = \\
& \quad \underbrace{E [c_B \mid v_B > r_{CCP} + c_B] + E [c_D \mid v_D < r_{CCP} - c_D]}_{\text{Balance Sheet Costs}} + \\
& \quad \underbrace{E [\theta_B (v_B - r_{CCP}) \mid v_B > r_{CCP} + c_B] + E [\theta_D (r_{CCP} - v_D) \mid v_D < r_{CCP} - c_D]}_{\text{Market Power}} \quad (39)
\end{aligned}$$

Rate dispersion is:

$$\begin{aligned}
& \text{Var} [r_B (v_B, \theta_B, c_B, r_{CCP})] = \\
& \quad \underbrace{\text{Var} [E [(r_{CCP} + c_B) + \theta_B (v_B - [r_{CCP} + c_B]) \mid c_B, v_B > r_{CCP} + c_B] \mid v_B > r_{CCP} + c_B]}_{\text{Balance Sheet Costs}} + \\
& \quad \underbrace{E [\text{Var} [\theta_B (v_B - [r_{CCP} + c_B]) \mid c_B, v_B > r_{CCP} + c_B] \mid v_B > r_{CCP} + c_B]}_{\text{Market Power}} \quad (40)
\end{aligned}$$

$$\begin{aligned}
& \text{Var} [r_D (v_D, \theta_D, c_D, r_{CCP})] = \\
& \quad \underbrace{\text{Var} [E [(r_{CCP} - c_D) - \theta_D ((r_{CCP} - c_D) - v_D) \mid c_B, v_D < r_{CCP} - c_D] \mid v_D < r_{CCP} - c_D]}_{\text{Balance Sheet Costs}} + \\
& \quad \underbrace{E [\text{Var} [\theta_D ((r_{CCP} - c_D) - v_D) \mid c_B, v_D < r_{CCP} - c_D] \mid v_D < r_{CCP} - c_D]}_{\text{Market Power}} \quad (41)
\end{aligned}$$

Rate pass-through is:

$$\frac{dr_B (v_B, \theta_B, c_B, r_{CCP})}{dr_{CCP}} = 1 - \theta_B \quad (42)$$

$$\frac{dr_D (v_D, \theta_D, c_D, r_{CCP})}{dr_{CCP}} = 1 - \theta_D \quad (43)$$

Proof. To prove (39), apply (37), and use linearity of expectations, to get:

$$\begin{aligned} E [r_B (v_B, \theta_B, c_B, r_{CCP}) | v_B \geq r_{CCP} + c_B] = \\ r_{CCP} + E [c_B | v_B \geq r_{CCP} + c_B] + \\ E [\theta_B (v_B - [r_{CCP} + c_B]) | v_B \geq r_{CCP} + c_B] \end{aligned}$$

This applies to (38) as well. Taking the difference, we get (39).

For rate dispersion, we can take the variance of borrow rates (37). Applying the rule of iterated expectations with respect to intermediation costs c_B , we have:

$$\begin{aligned} \text{Var} [r_{CCP} + c_B + \theta_B (v_B - [r_{CCP} + c_B]) | c_B, v_B > r_{CCP} + c_B] = \\ \text{Var} [E [r_{CCP} + c_B + \theta_B (v_B - [r_{CCP} + c_B]) | c_B, v_B > r_{CCP} + c_B]] + \\ E [\text{Var} [r_{CCP} + c_B + \theta_B (v_B - [r_{CCP} + c_B]) | c_B, v_B > r_{CCP} + c_B]] \quad (44) \end{aligned}$$

Now,

$$\begin{aligned} \text{Var} [r_{CCP} + c_B + \theta_B (v_B - [r_{CCP} + c_B]) | c_B, v_B > r_{CCP} + c_B] = \\ \text{Var} [\theta_B (v_B - [r_{CCP} + c_B]) | c_B, v_B > r_{CCP} + c_B] \end{aligned}$$

hence, (44) simplifies somewhat, to (40). (41) follows analogously.

For pass-through, (42) and (43) follow by differentiating (37) and (38) with respect to r_{CCP} .

□

Expression (39) for net interest margins, and expressions (40) and (41) for borrow and lend rate dispersion, are complex, but intuitively they contain terms attributable to market power and to intermediation costs. For example, net interest margins contain a term which reflects the expectation of dealers' intermediation costs, conditional on trade:

$$E [c_B | v_B > r_{CCP} + c_B] + E [c_D | v_D < r_{CCP} - c_D]$$

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

customers:

$$E[\theta_B (v_B - r_{CCP}) | v_B > r_{CCP} + c_B] + E[\theta_D (r_{CCP} - v_D) | v_D < r_{CCP} - c_D]$$

Similarly, (40) decomposes the variance of borrow rates into a term attributable to variation in the conditional expectation of rates given intermediation costs, and the expectation of the variance of rates conditional on intermediation costs. Both terms are affected by all parameters, but the first term can be thought of as somewhat more linked to intermediation costs, whereas the second is linked more to variance in customers' values and bargaining power.

As in Claim 9, (42) and (43) show that pass-through only depends on bargaining power, and is unaffected by intermediation costs.

A.6 Competition and Bargaining Power

In this appendix, we show that one possible microfoundation of dealers' bargaining power over customers, θ_B and θ_D , is competition: repo customers who are connected to more dealers can get rates that are closer to the dealers' marginal costs. The derivations here closely follow Stole and Zwiebel (1996), with notation adapted to our setting. Another related paper using Shapley values is Bolton and Scharfstein (1996). For simplicity, throughout this appendix, we take the equilibrium repo rate in the CCP market, r_{CCP} , as given.

Suppose there is a single repo customer, with value v_B , who wishes to borrow from dealers. In contrast to the main text, we assume that the customer can associate with up to n dealers. Since dealers' marginal costs for lending to the customer are identically equal to the CCP repo rate r_{CCP} , the joint surplus available to the coalition of n dealers and the customer is:

$$S = v_B - r_{CCP}$$

regardless of n . However, n will affect the repo rate, and thus the division of surplus between the customer and the dealers.

Nash bargaining does not immediately apply to settings with more than two agents.

Instead, we assume surplus is split within the coalition according to agents' *Shapley values* (Shapley (1953)). Brügemann, Gautier and Menzio (2019) show that, in this setting, Shapley values are also the unique equilibrium payoffs in a noncooperative game, the Rolodex game, in which the customer bargains sequentially with dealers, splitting the difference at each bargaining stage.

We can calculate Shapley values inductively, closely following the derivations in Subsection 2.1 of Stole and Zwiebel (1996). Suppose the customer is connected to a single dealer. The price is set to split the difference, so the dealer's surplus is:

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

and the customer's surplus is:

$$S - t(1)$$

For the induction step, suppose the customer is connected to n dealers. Letting $t(n)$ denote dealers' expected trade surplus when there are n dealers, the customer's surplus is:

$$S - nt(n) \tag{45}$$

The marginal surplus which accrues to the customer, if she connects to n instead of $n - 1$ dealers, is thus:

$$\begin{aligned} & [S - nt(n)] - [S - (n - 1)t(n - 1)] \\ &= (n - 1)t(n - 1) - nt(n) \end{aligned}$$

The marginal surplus of the n th entering dealer is simply $t(n)$. Split-the-difference bargaining means that the customer and the n th dealer must have equal surplus, on the margin, implying that:

$$\begin{aligned} t(n) &= (n - 1)t(n - 1) - nt(n) \\ \implies t(n) &= \frac{n - 1}{n + 1}t(n - 1) \end{aligned} \tag{46}$$

The unique solution to (46) is:

$$t(n) = \frac{v_B - r_{CCP}}{n(n + 1)} \tag{47}$$

To calculate the customer's surplus, we plug (47) into (45), to get:

$$S - nt(n) = (v_B - r_{CCP}) \left(\frac{n}{n+1} \right) \quad (48)$$

Expressions (47) and (48) thus characterize dealers' and customers' expected surplus, if surplus is split according to agents' Shapley values. These can be interpreted as follows: the customer trades with each of the n dealers with probability $\frac{1}{n}$ (or, equivalently, does a fraction $\frac{1}{n}$ of her business with each dealer), and borrows at rate:

$$r_{CCP} + \frac{v_B - r_{CCP}}{(n+1)} \quad (49)$$

Comparing (49) to (37) in the main text, repo prices in the multi-dealer setting are identical to a setting in which each dealer was a monopolist, but had bargaining power:

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

All the conclusions from the baseline model thus follow through: increasing competition increases the pass-through of policy rates to customer-facing rates. Thus, we can think of θ_B as representing, among other things, the number of dealers that a customer has access to.

B Supplementary material for section 6

B.1 Proof of Claim 6

If OTC customers had direct access to the CCP market, all customers would trade at the CCP rate. However, the supply and demand for repo funding from OTC customers would be unchanged from (14) in the baseline model: at any CCP repo rate r , all OTC borrowers with $v_B > r$ would borrow, and all OTC depositors with $v_D < r$ would deposit. Thus, allowing customer access would not change equilibrium CCP repo rates. However, all customers trade at exactly the CCP rate, r_{CCP} . Hence, all customers trade at exactly the CCP rate, r_{CCP} . This gives (23), (24), and (25).

B.2 Proof of Claim 7

Suppose first that:

$$r_{\text{nofloor,CCP}} \geq r_{\text{RRP}}$$

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

Suppose now that:

$$r_{\text{nofloor,CCP}} < r_{\text{RRP}} \tag{50}$$

so the repo facility rate does bind. Conjecture that there exists an equilibrium with $r_{\text{CCP}} = r_{\text{rf}}$. At this rate, lending dealers are indifferent between lending to the CCP and the central bank. Now, since

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

and since we have assumed (50), we have:

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

that is, at rate r_{RRP} , the supply of funds from lending dealers is greater than the demand for funds from all other agents. Since lenders are indifferent, lenders lend a total of:

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

to the reverse repo facility, and the remaining mass of funds $Q_{\text{L,Dealer}}(\rho - r_{\text{RRP}})$ in the inter-dealer market. Thus, funding supply and funding demand on the CCP are equal, so this is an equilibrium. To show that this is the unique equilibrium, note that the equilibrium rate r_{CCP} can never be below r_{RRP} , otherwise all lending dealers would strictly prefer lending to the central bank, so supply and demand could not be equal.

r_{CCP} also cannot be below r_{RRP} , otherwise lenders would strictly prefer lending to the CCP, and funding supply and demand could not be equal.

Thus, we have shown that:

$$r_{CCP} = \begin{cases} r_{\text{nofloor},CCP} & r_{\text{nofloor},CCP} \geq r_{RRP} \\ r_{RRP} & r_{\text{nofloor},CCP} < r_{RRP} \end{cases}$$

This is exactly (26). (28) follows from differentiating (26).

B.3 Proof of Claim 8

First, suppose that:

$$r_{\text{nofloor},CCP} \geq r_{RRP}$$

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

$$\tilde{v}_D \equiv \max(v_D, r_{RRP}) \tag{51}$$

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

$$r_D(v_D, \theta_D) = r_{CCP} - \theta_D(r_{CCP} - \tilde{v}_D) \tag{52}$$

Since all depositors with value v_D greater than r_{CCP} trade, the set of OTC depositors who trade is unchanged from the baseline model. Lending dealers also do not use the RRP, so aggregate supply and demand of funds are unchanged from the baseline model. Hence,

the equilibrium rate in the inter-dealer market must be:

$$r_{CCP} = r_{\text{nofloor},CCP} \quad (53)$$

Plugging (53) into (52), and using the definition of \tilde{v}_D from (51), we get:

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

This proves the first two cases of (30). Now, suppose that:

$$r_{\text{nofloor},CCP} < r_{RRP}$$

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

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

That is, the inter-dealer repo rate, as well as all OTC depositors' repo rates, are equal to r_{RRP} . In such an equilibrium, lending dealers and OTC depositors are indifferent between lending in the inter-dealer market and using the RRP. By an argument identical to Appendix B.2, lending dealers and OTC depositors lend a total amount:

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

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

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

This equilibrium is unique, because the equilibrium rate r_{CCP} can never be below r_{RRP} , otherwise all lending dealers and OTC depositors would strictly prefer lending to the central bank, so supply and demand could not be equal. r_{CCP} also cannot be below r_{RRP} ,

otherwise lenders would strictly prefer lending to the CCP, and funding supply and demand could not be equal. This proves the third case of (30). Differentiating (30), we get (31). This proves all cases of Claim 8.