The Market for Sharing Interest Rate Risk: Quantities and Asset Prices

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Abstract

We study interest rate risk sharing across the financial system by exploiting granular transaction-level data covering the near-universe of UK interest rate swap market. We show that pension funds and insurers (PF&I) are natural counterparties to banks and corporations: overall, and in response to a decline in interest rates, PF&I buy duration, whereas banks and corporations sell duration. This cross-sector netting reduces dealers' aggregate net supply. However, investor demand is highly segmented by maturity - PF&I hold long-tenor swaps while banks hold short-to-intermediate tenor swaps - resulting in significant *maturity-specific* imbalances absorbed by dealers. We calibrate a preferred-habitat investors model with risk-averse dealers to examine how demand imbalances interact with supply side constraints to determine asset prices (swap spreads). Our model embeds empirically estimated demand elasticities that govern the spillover effects of demand shocks: using dealer-level portfolio compression to instrument for exogenous supply shifts, we show that PF&I have less elastic demand for swaps than banks. The model delivers two novel insights. First, demand imbalances are quantitatively more important in explaining the entire *shape* of the swap spread curve than supply-side factors alone. Second, demand shifts in one sector can have economically significant spillover effects on other sectors' hedging costs due to large adjustments in asset prices. Our findings uncover incomplete risk sharing in one of the world's largest financial markets, and our counterfactual analyses inform policymakers on potential externalities of sector-specific regulation of interest rate risk.

Keywords: Interest rate risk, Pension funds, Insurers, Banks, Demand elasticities, Swap spreads

JEL classification: G11, G12, G15, G21, G22, G23, G24, G32

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The recent banking and pension market crises have led to extensive debates about interest rate risk mismatch across the financial system, spurring efforts to develop more comprehensive risk regulation. Much of this policy effort has focused on individual financial sectors. A major shortcoming of this sector-specific approach is that it ignores externalities in markets where multiple sectors participate to share common risks. For example, when we change regulations for one type of institution, e.g., commercial banks, it may affect the hedging decisions of other types, e.g., pension funds or insurance companies. This is because large shifts in hedging demand of a given sector could affect asset prices, materially impacting hedging costs more broadly. Higher costs may then prompt other institutions to lower hedging, if demand is relatively elastic, amplifying interest rate exposures elsewhere in the financial system. Making progress on these issues requires a comprehensive understanding of the joint dynamics of asset prices and quantities using an equilibrium framework that simultaneously accounts for demand and supply forces across the financial system.

We undertake this exercise for interest rate swaps. With an outstanding gross notional of $470 trillion and daily turnover of $4.5 trillion (BIS, 2022), interest rate swaps are economically important instruments through which various financial and non-financial institutions mitigate their interest rate risk exposures. Despite its significance, however, relatively little is known about how demand and supply-side forces across sectors collectively shape asset prices (swap spreads) and the precise channels through which shocks in one part of the market propagate to other parts.

There are two key challenges in studying this question. First, the literature that studies the dynamics of swap spreads (e.g., Klingler and Sundaresan (2019), Hanson et al. (2024)) has typically lacked data on swap positions for a large number of market participants. Even when data are available, they often cover a limited subset of institutions, typically a sector at a time, and frequently lack the granularity and features necessary to accurately quantify the risk exposures traded by various institutions. In the absence of these data, it is unclear if institutions have offsetting positions and share risks with each other or whether the market is mostly segmented, which would instead require intermediaries (e.g., dealers) to bear unmatched demand imbalances in equilibrium. We overcome this challenge by exploiting granular transaction-level data covering the near-universe of UK interest rate swap market, including all institutions – banks, pension funds, insurers, asset managers, and corporations – as well as detailed contract characteristics that enable us to characterize the demand of various end-users and the sources of risk sharing and market segmentation.

Second, assessing the extent of cross-sectoral spillovers requires considering potential policy counterfactuals within an equilibrium model of demand and supply. This approach involves estimating several parameters that encapsulate the dynamics of swap spreads and quantities. For example, end-users' demand elasticities govern the response of quantities to exogenous changes in hedging costs. However, estimating demand elasticities requires isolating supply shocks from concurrent changes in demand as equilibrium quantities and prices are simultaneously determined.

Similarly, the slope of dealers' supply curve governs the degree to which demand imbalances affect asset prices or are absorbed by dealers without causing significant price impact. To capture the underlying demand and supply forces that influence asset prices, we calibrate a structural model featuring heterogeneous end-users and risk-averse dealers, which closely match the key dynamics of the market.

We make three novel contributions to the literature. First, we characterize the demand for swaps for all market participants showing that pension funds and insurers (PF&I) are natural counterparties to banks and corporations with significant offsetting positions. While this cross-sector netting reduces the risks borne by the dealer sector, demand is highly segmented with investors exhibiting preferred habitats in certain maturity segments. This exposes dealers to persistent maturity-specific demand imbalances. Second, we quantify the impact of these imbalances on equilibrium swap spreads by calibrating a preferred-habitat investors model in the spirit of Vayanos and Vila (2021), featuring empirically estimated demand elasticities. We show that demand imbalances are quantitatively more important in explaining the entire shape of the swap spread curve than supply-side factors alone. Importantly, we find that swap spread at the long-end is sensitive to the demand imbalances at the short-end, and vice versa, implying transmission of shocks along the term structure. Third, motivated by this evidence, we conduct a series of counterfactual experiments to study how demand shocks in one sector spill over to other parts through adjustment in asset prices and quantities. Our counterfactual simulations show that regulations requiring PF&I or banks to increase hedging would significantly reduce the hedging costs faced by the other sector.

Our analysis leverages Bank of England's confidential granular transactions and positions data covering the near-universe of the UK interest rate swap market. The following features of the data are important. First, we observe *all* end-users of swaps, which we classify into five types (a) pension, liability-driven investment funds, and insurers (together referred to as PF&I); (b) end-user banks, which are distinct from dealers and considered separately; (c) corporations; (d) funds (including hedge funds and asset managers); and (e) official institutions.[1] Second, for each entity we observe the stock of outstanding positions and the flow of new transactions. Third, we observe detailed characteristics for each position and trade, including notional amounts, contracted fixed rate, trade direction, maturity, floating rate benchmark, and currencies. Thus, we can accurately compute risk exposures using two metrics: (i) the net notional value of receive fixed swaps (receive fixed minus pay fixed) and (ii) dollar duration, measured as the dollar value of a one basis point parallel shift in interest rates. Moreover, using the joint dynamics of prices and positions along the term structure, we can estimate investors' demand elasticities in different maturity segments. Finally, our data spans from December 2019 to June 2024, which allows us to calibrate our model under

[1]The official sector includes sovereign and supra-national institutions. As they are relatively few, we omit discussing them in detail.

different interest rate regimes.

Our paper proceeds in four parts. In the first part of the paper, we present two novel facts on end-users swap positions and trading, which determines the quantity and the nature of demand imbalances being borne by the dealer sector. First, we show that pension funds and insurers (PF&I) are natural counterparties to banks and corporations with large offsetting positions. As a sector, PF&I consistently receive fixed rates, adding duration to their portfolios with swaps throughout the sample. In contrast, banks and corporations consistently pay fixed rates, selling duration. This pattern holds at the entity level, with a vast majority of individual PF&I receiving fixed and banks and corporations paying fixed.

Importantly, their trading behavior in response to interest rate changes further reinforces that PF&I are natural counterparties to banks and corporations. We evaluate how swap exposures of various end users adjust in response to interest rate changes. Specifically, we examine the sensitivity of changes in net notionals and dollar durations to lagged changes in a common interest rate factor, which we construct as the first principal component of yields at the 3 month, 5 year, 10 year, and 30 year maturity points, as well as to changes in individual rates at different maturity points. We find that, as rates fall, PF&I buy duration, whereas banks and corporations sell duration, implying that investors have opposite exposure to aggregate demand shocks. These results also hold when we consider unanticipated UK monetary policy shocks instead of changes in yields overall.

Second, we show that investors' swap holdings are highly segmented by maturity, consistent with investors having strong preferred habitats in different maturities (Vayanos and Vila, 2021). We classify holdings into four maturity groups: below 3 months (very short), 3 months to 5 years (short-to-intermediate), 5 to 10 years, and 10 years & above (long). We find that PF&I largely hold long maturity swaps, and consistently do so throughout the sample. In contrast, banks and corporations mostly hold short-to-intermediate maturity swaps. Interestingly, even at the entity level, most investors trade primarily in one maturity group. For example, 90% of bank trades occur in one maturity group.

The strong segmentation by maturity and preferred habitat behavior limits the extent of cross-sector netting we obtain from PF&I, banks, and corporations having offsetting positions. Dealers still have to absorb significant maturity-specific demand imbalances to clear the market. Specifically, we show that dealers receive fixed (are long duration) in short maturities, opposite of banks and corporations, and pay fixed (are short duration) in long maturities, opposite of PF&I. These imbalances are substantial. For example, a 10 bps parallel downward shift in rates would increase the value of dealers' position by about GBP 500 million in short-tenor swaps but reduce it by about GBP 1.5 billion in long-tenor swaps. Unexpected demand shifts in specific maturities (e.g., due to lower demand from banks) could expose dealers to non-parallel shifts in the swap spread curve,

causing negative mark-to-market in their positions. Dealers are therefore exposed to convergence risk, i.e. the risk that relative swap spreads diverge, negatively impacting the value of their swap positions (Hanson et al., 2024).

We note that dealer imbalances are also affected by the trading of funds for part of our sample, who briefly hold substantial pay fixed positions at the start of the interest rate hiking cycle in late 2021, consistent with market timing. However, their positions carry relatively smaller duration risk for dealers: a vast majority of positions are in very short maturities and there is large netting within the fund sector due to the contrasting strategies followed by different types of funds.[2] While we account for fund positions throughout, our discussion focuses more on banks and PF&I that are the primary sources of persistent imbalances and duration risk for dealers in GBP swaps.

In the second part of the paper, we exploit plausibly exogenous variation in swap spreads to estimate end users' demand elasticities, which are a crucial parameter that determine how asset prices respond to demand shifts. We focus on swap spreads as the relevant measure of price, instead of fixed rates, as they reflect the relative attractiveness of swaps over comparable maturity bonds. We utilize *portfolio compression* as a source of exogenous variation in swap spreads. Compression reduces dealers' outstanding gross notionals by replacing multiple offsetting trades into a single net trade. This relaxes dealers' leverage ratio constraints which, under the current exposure method of Basel III regulations, are based on gross positions (Duffie, 2018, Haynes and McPhail, 2021). Notably, between 2016 and 2019, UK dealers compressed $2,656 trillion of notional (LCH SwapClear, 2023), substantially reducing gross positions without affecting net economic exposure.

The key identifying assumption is that compression influences prices solely through a reduction in dealers' balance sheet costs and not via other channels. Threats to our identification strategy could come from omitted factors that influence both compression as well as prices offered. One such concern arises from simultaneous demand shifts: if end-users trade in the opposite direction of maturity-specific demand imbalances, e.g., due to reversal in macro conditions, it could lower prices while also enabling greater compression. Another concern is that dealers may strategically seek to reduce net imbalances by offering better *(non-price)* contract terms. This would increase compression and demand with minimal price changes, biasing the estimates. The relevant exclusion restriction therefore requires that compression be not related to wide-ranging demand reversal or dealers' strategic behavior.

Consistent with this, we show that compression activity does not co-move with broad macro factors and dealers' balance sheet characteristics. We argue that the institutional set-up weakens the link between the extent of compression activity with demand shifts or dealer behavior. (i) Compression takes place according to schedules decided by clearing houses; (ii) is driven by multilateral

[2]For example, we find that macro funds pay fixed rates, while fixed income funds and other asset managers receive fixed rates.

netting across various counterparties — often other dealers or a central clearing house — which makes it unlikely to reflect simultaneous changes in demand or strategic dealer behavior; and (iii) dealers have little control over the exact timing when forward-looking swap cash flows will settle, which follow market conventions and end-users' needs to align with underlying liabilities or loan schedules.

We find that an increase in compression activity significantly affects prices: swap spreads *reduce* for short to intermediate maturities and *increase* for longer maturities, consistent with a reduction in dealers' balance sheet costs of absorbing these demand imbalances and indicating strong relevance of our instrument. We then use the instrumented swap spreads to estimate end-users' demand elasticities. We estimate that investors in the short to intermediate maturity groups (e.g., banks) have significantly more elastic demand than investors in the long maturity group (PF&I), implying that where demand shocks originate may have different implications for swap spreads.

Motivated by the empirical facts, in the third part of the paper, we calibrate a preferred-habitat investors model of the interest rate swap market to investigate two key objectives: how the interaction between end-users' demand imbalances and dealers' constraints shape the term structure of swap spreads and to quantify the spillover effects of demand shifts across sectors. Building on the preferred-habitat framework of Vayanos and Vila (2021), the model incorporates maturity segmentation among end-users such as banks, corporations, and PF&I, who, as shown in our reduced form facts, demand swaps in a specific maturity group. Such demand may arise because investors are exposed to interest rate shocks from other parts of their balance sheets and trading interest rate swap may be a capital-efficient way to hedge that risk (Klingler and Sundaresan, 2019). We specify the demand for swaps as a function of swap spreads, i.e. the relative price of swaps to bonds, as investors can choose to hedge their interest rate risk either in the cash or the swap market, and swap spreads capture the relative attractiveness of swaps over bonds. In addition, swap spreads help net out the direct impact of interest rate changes on investors' demand. We allow investors trading in different maturity segments to have different demand elasticities and to load differentially on a time-varying aggregate demand factor, capturing the fact that macroeconomic conditions affect the hedging demand of investors in heterogeneous ways.

While preferred-habitat investors only trade in specific maturity segments, dealers act as arbitrageurs and trade across maturity groups to take advantage of the relative differences in swap spreads.[3] Arbitrageurs are risk-averse and face time-varying funding costs from holding swaps on their balance sheets (He, Nagel, and Song, 2022). Following the literature, we consider these arbitrageurs as specialized intermediaries, who hedge the interest rate risk arising from their swap positions in other markets, such as in the government bond market (Hanson et al., 2024). As a

[3]For funds that trade across maturity groups, we also treat them as arbitrageurs, similar to dealers.

result, the arbitrageurs are only concerned about convergence risk. The arbitrageur's funding cost captures gap in the swap reference rate and dealers' funding rate, or dealers' leverage constraints due to government bonds held on balance sheet in order to hedge the interest rate risk arising from their swap positions (Bicu-Lieb, Chen, and Elliott, 2020, Du, Hébert, and Li, 2023). We model the total cost incurred as linear in the net swap position held on arbitrageurs' balance sheet.

We calibrate the model to match the price and quantity moments in four maturity segments — below 3 months, 3 months to 5 years, 5 to 10 years, and 10 years & above. We obtain estimates of demand elasticities for end-users in each segment using compression ratio as an instrument to obtain exogenous supply shifts. We estimate the remaining parameters using method of moments, where we match the average level of swap spreads and net imbalances, as well as their dynamics. On the demand side, we calibrate investors' demand intercepts and their demand sensitivity to a single aggregate factor. On the supply side, we estimate dealers' risk aversion and funding costs. Finally, we estimate all the parameters for the full sample period, as well as for two subsamples separately to account for the sharp increase in interest rates after December 2021. Our simulated moments closely align with their empirical counterparts, both in terms of net imbalances and the observed swap spreads for the full sample period as well as each subsample period.

Parameters uncovered from the estimation show that the demand pressure (defined as the intercept of the demand function) is concentrated among investors trading in the short-to-intermediate maturity group (3 months to 5 years) and the long maturity group (10 years & above). The demand pressure in these two groups has an opposite sign — while investors in the short-to-intermediate group have a preference to pay fixed, investors in the long maturity group have a preference to receive fixed. In addition, investors in these two groups have the opposite exposure to the aggregate demand shock. Even though we do not impose any sign restrictions on demand parameters for investors in different maturity groups, the estimated demand pressure and exposure to shocks are consistent with the types of institutions trading in each group and match the reduced form facts. For swap arbitrageurs, we estimate the absolute risk aversion parameter at about 13, and their average funding cost at 1%, which closely aligns with the balance sheet cost of 81 bps in Fleckenstein and Longstaff (2020) and He, Nagel, and Song (2022). We find that both the risk aversion and the funding costs are greater during the higher interest rate environment in the second subsample.

We then use our model to quantify the contribution of different supply and demand factors to the equilibrium swap spreads. To do this, we set each parameter to zero one at a time and assess the impact on the term structure of swap spreads. First, we set the average funding cost to 0. This leads to a 13 bps change in swap spreads across all maturity groups, which is relatively small compared to the range of swap spreads from 10 bps to negative 80 bps across all maturities. Then, we set the average demand pressure for all sectors to zero, which brings the swap spread to almost 0 for all maturities. The magnitude of change from shutting down the demand pressure is larger

than that from removing funding costs, highlighting the importance of local demand imbalances. Therefore, we find that investors' demand pressure, interacted with arbitrageurs' risk aversion, plays a quantitatively important role in determining the term structure of swap spreads. However, we show that the effect of demand imbalances on swap spreads is much smaller when arbitrageurs are less risk averse. Hence, we emphasize that it is the interaction between end-users' demand imbalance and arbitrageurs' risk aversion that generates large effects on swap spreads.

In the final part of the paper, we evaluate the ways in which the distribution of demand imbalances influences the term structure of the swap spreads, and quantify the cross-sector spillovers in hedging costs due to end-users' demand shifts. We start by considering two polar scenarios. The first scenario assumes banks have no demand for swaps (i.e., the demand intercept equals zero). We interpret changes in banks' demand by shutting down the demand of preferred-habitat investors in the short-to-intermediate group, where a vast majority of banks' holdings are. We find that eliminating demand imbalances in the short-intermediate maturity group leads to more negative swap spreads across maturities, particularly in long tenors. This outcome arises because banks typically offset PF&I positions, reducing dealers' aggregate risk exposure. Without bank demand, dealers face larger imbalances and require greater compensation for holding risky positions, resulting in lower swap spreads. The second scenario assumes PF&I have no demand for swaps, which we obtain by shutting down the demand in the longest maturity group. This results in an upward-sloping swap spread curve, with positive spreads across maturities. Dealers demand higher fixed rates to supply swaps at shorter maturities and forego larger amounts to attract opposite receive-fixed positions at longer maturities. These results underscore the significance of the distribution of demand imbalances across maturities in shaping the term structure of swap spreads.

We next quantify the impact of demand shifts for a given sector on changes in hedging costs and quantities for the other sectors. First, when banks hedge more, swap spreads rise in all maturity groups, implying that while the hedging costs increase for banks, they decrease for PF&I. Similarly, when PF&I hedge more, swap spreads fall in all maturity groups. Thus, the hedging costs increase for PF&I but decrease for banks. In other words, given that banks and PF&Is have offsetting positions, an increase in one sector's hedging demand reduces the hedging cost for the other sector. Second, we show the counterfactual swap spreads are much larger in the second subsample, as a result of the substantially higher balance sheet costs and larger risk aversion we estimate for dealers. Third, the magnitudes of the changes in spreads crucially depend on end-users' demand elasticities, with less elastic investors leading to higher price impact. Finally, we find that the effect on swap spreads is much larger when the demand shift happens in the PF&I sector. Intuitively, demand imbalances in longer maturity groups expose the dealer sector to more risks, leading to larger price impact. We conclude that the shape of the swap spreads curve reacts differently to changes in both the magnitude and the specific source of demand imbalances.

A back of the envelope estimation of the effect of the demand shifts on hedging costs suggests that a 20% increase in banks' hedging demand would raise swap spreads by 13 bps in the second subsample. This would lead to about GBP 2 billion lower hedging costs over the typical life of swaps for the PF&I sector. On the other hand, a 20% increase in PF&I's hedging demand would reduce the swap spread faced by banks by about 11 bps, leading to an estimated GBP 0.5 billion reduction in average hedging costs for banks. If investors were half as elastic as our empirical estimates suggest, then the same 20% increase in PF&I demand would would lead to a GBP 0.8 billion reduction in average hedging costs for banks. We also note that part of the savings is offset because end-users demand more swaps as hedging costs decline. However, we note that because demand is relatively inelastic, this effect is muted and the net demand do not change meaningfully.

Our results can be useful in several settings. One direct application is to understand how changes in interest rate risk regulation in one part of the financial sector may affect other sectors through changes in hedging costs and subsequently hedging demand. Other applications may involve cross-country comparisons in which different sectors exhibit different type of demand for swaps. For example, economies with a smaller PF&I sector—e.g., those with pay-as-you-go pension systems or younger demographics—may have a different distribution of demand imbalances with short-tenor imbalances likely dominating long-tenor imbalances. Conversely, different mortgage contracts and regulatory frameworks could generate different hedging demand for banks (Hoffmann et al., 2019). For example, McPhail et al. (2023) show that US banks have limited hedging demand for swaps. This may lead to the opposite distribution of demand imbalances with significantly higher long-tenor imbalances. Our counterfactual analyses provide insights about the asset pricing consequences of different configurations of demand imbalances. Indeed, when we shut down the hedging demand of UK banks, the counterfactual term structure of swap spreads start to appear closer to the observed spreads in the US. Our findings underscore the broader implications of demand imbalances, offering a framework to analyze how sector-specific regulatory changes, demographic shifts, or market structures influence the pricing and distribution of hedging costs across financial markets.

Related literature. Our paper contributes to the literature that analyzes the interest rate swap market - one of the largest and most actively traded financial instruments globally (BIS, 2022). We build on studies that leverage newly available regulatory micro-data to study investor behavior in this market: using the European Markets Infrastructure Regulation data, Abad, Aldasoro, Aymanns, D'Errico, Rousová, Hoffmann, Langfield, Neychev, and Roukny (2016) document the market structure and its main participants, while Fontana, Holz auf der Heide, Pelizzon, and Scheicher (2019) focus on trading networks and the effect of central clearing. In the US market, Baker, Haynes, Roberts, Sharma, and Tuckman (2021) use a one-day snapshot of entity-level exposures to document that net exposures are smaller than gross notionals, and Bolandnazar (2020) studies

the imperfect competition among capital-constrained dealers and the effect of dealer regulation.

We take a macrostructure approach to show that end-users' hedging behavior interacts with intermediary constraints to shape asset prices (Haddad and Muir, 2025). Our paper emphasizes maturity segmentation and supply-side frictions that limit interest rate risk sharing among different investors. Our model captures investors' behavior in different maturity segments and allows us to study how hedging demand affects the term structure of asset prices. Further, we leverage the rich cross-sectional and time-series heterogeneity of our data to estimate investors' demand elasticities and quantify how demand shifts percolate across the financial system.

Our work also relates to the growing literature that analyzes interest rate risk management by end-users. Several papers have looked at risk management by *individual* sectors: Begenau, Piazzesi, and Schneider (2015), Hoffmann, Langfield, Pierobon, and Vuillemey (2019), McPhail, Schnabl, and Tuckman (2023) and Jiang, Matvos, Piskorski, and Seru (2023) study banks, Bretscher, Schmid, and Vedolin (2018) study corporations, Sen (2019) studies insurers, Jansen (2021) and Jansen, Klingler, Ranaldo, and Duijm (2023) study pension funds, Kaniel and Wang (2020) study mutual funds, and Pinter and Walker (2023) study non-bank financial institutions. In contrast, our paper studies the demand of *all* end-users jointly and analyzes their interactions across market segments. This cross-sector perspective helps us draw asset pricing implications and estimate the spillover effects of localized demand shocks.

Our paper contributes to the asset pricing literature by analyzing the determination of swap spreads. Negative swap spreads, i.e. the difference between fixed rates on long-dated interest rate swaps and the corresponding government bond yield, have long been a puzzle in asset pricing. Recent work shows the importance of both demand and supply factors. Klingler and Sundaresan (2019) argue that the demand to receive fixed rates from underfunded pension funds explains why swap spreads turned negative after the financial crisis. Jermann (2020) emphasizes that supply frictions alone can generate negative swap spreads in equilibrium. Hanson, Malkhozov, and Venter (2024) use dealers' bond positions to impute swap quantities, and combine supply frictions and demand factors to estimate the relative importance of the two for explaining long-term swap spreads. We add to this literature in two important ways.

First, on the demand side, we find that there is a large heterogeneity across maturity segments, which is masked in the aggregate dealer positions. In our model, we account for the end-user demand in each maturity segment separately and allow for heterogeneous demand elasticities and exposure to the aggregate shock. Such a detailed account of the quantity-side has been lacking in the literature so far due to the unavailability of granular cross-sector holdings data directly from the swap market. Second, on the supply side, dealers optimize their swap positions across all maturity segments jointly, subject to balance sheet constraints. Accounting for the segmentation of end-user

demand and dealers' arbitrage activities across maturity segments is crucial for matching the shape of the entire swap spread curve and for considering spillover effects among different sectors.

Finally, we build on the literature on preferred habitat investors and how their demand impacts asset prices (Vayanos and Vila, 2021). This framework has been used extensively to study the impact of monetary policy and investor demand on the yield curve of bonds (e.g., Greenwood, Hanson, and Vayanos 2016, Greenwood and Vissing-Jorgensen 2018, Li 2024). Recent work has combined arbitrageurs' wealth effect and balance sheet constraints in the preferred-habitat model (He, Nagel, and Song, 2022, Kekre, Lenel, and Mainardi, 2023). The framework has been applied to other asset classes, for example, the currency markets (Gourinchas, Ray, and Vayanos, 2023, Greenwood, Hanson, Stein, and Sunderam, 2023) and the US Treasury markets (Jansen, Li, and Schmid, 2024). Bahaj, Czech, Ding, and Reis (2023) analyze the UK inflation swap market and dealers' supply in the short-maturity and long-maturity segment. Focusing on the interest rate swap market, we leverage detailed quantity and price data in each maturity segment to estimate the demand elasticities and aggregate exposures in a non-parametric way, uncovering substantial heterogeneity across sectors. Our framework allows us to quantify how investors' hedging costs vary with shocks to the system, that informs policy discussions on optimal hedging requirements.

1. Data

We use detailed position and transaction-level data in over-the-counter (OTC) interest rate swaps that cover all sectors of the economy, and where at least one of the counterparties to a trade is legally based in the United Kingdom (UK).[4] Our sample includes both UK headquartered entities, and UK branches and subsidiaries of any counterparty which may be headquartered in another jurisdiction. Our access to these data is enabled via the Bank of England by a key post-financial crisis reform, known as European Markets Infrastructure Regulation (EMIR), which seeks to improve derivative markets transparency by mandating the reporting of derivatives to trade repositories (TR). Reporting obligation under EMIR started in February 2014, where all OTC and exchange-traded derivatives contracted by EU and UK counterparties from August 2012 (or open at that point) had to be reported.[5] We source our data from two of the largest trade repositories, DTCC and

[4]OTC interest rate swap is the main instrument used for hedging interest rate risks. The Bank for International Settlements reports that OTC markets constitute over 85% of outstanding interest rate derivatives, and over 80% of those contracts are swaps (BIS, 2023).

[5]Note that trades starting January 2021 are reported under UK EMIR, while trades prior to 2021 are reported under EU EMIR. For the period under EU EMIR, we additionally observe trades between EU-domiciled banks and non-UK counterparties. However, as part of the post-EU-exit arrangements of the UK, trades between those entities are not covered starting 2021. For consistency, therefore, we exclude such trades from the earlier part of our sample. More details on the UK EMIR reporting obligation are available at: www.bankofengland.co.uk/financial-stability/trade-repository-data

UnaVista, that together constitute a 90% market share in interest rate derivatives (Abad et al., 2016). Our sample spans from December 2019 through June 2024. We restrict attention to this period because the reporting quality meaningfully improves starting late 2019.

1.1. Coverage

Our data consist of single currency fixed-to-floating interest rate swaps (IRS) and overnight indexed swaps (OIS) referencing all floating rate benchmarks, currencies, and tenors, and contracted by all types of counterparties. We estimate that our data cover at least 60% of the global swaps turnover denominated in any currency and 84% of the swaps denominated in GBP.[6] We arrive at these estimates based on the April 2022 triennial OTC derivatives turnover data from the Bank for International Settlements (BIS, 2022). Table A1 reports an average daily turnover of $3.4 trillion in April 2022 in our data, which compares with about $5 trillion of turnover reported by the BIS for all interest rate derivatives excluding options and complex swaps.[7] Within GBP swaps, we observe a daily average turnover of $287 billion, which is about 84% of the BIS estimate of $341 billion.

Our analysis focuses on GBP swaps due to our largest coverage in this currency and our ability to observe the entire interest rate swap portfolio of UK entities. Our vast coverage of this market is enabled by the fact that London serves as the center of global derivatives trading; BIS (2022) reports that 46% of all interest rate derivatives (amounting to $2.1 trillion) were traded in the UK in April 2022. Our data cover nearly all of these trades, plus swaps executed outside the UK involving a UK entity. To the best of our knowledge, this is the most comprehensive cross-sector interest rate swaps data deployed in academic research to date.

1.2. Outstanding Positions and Transactions

We source two types of complementary reports available from trade repositories: outstanding positions ("state files") and new transactions ("activity files") at an investor level. The stock of outstanding positions includes all trades contracted at any time in the past and open as on a given date, which helps us track the evolution of outstanding swap positions for each entity. The daily flow of new transactions includes trades contracted on a particular date and permits a more granular analysis of investors' trading activity along dimensions of maturities, prices, and volumes, in conjunction with current market conditions. These two reports jointly provide us with a complete picture of investor behavior in this market.

We extract 55 snapshots of outstanding position reports as of the beginning of each month from

[6] Our overall coverage closely matches with Abad et al. (2016), who report that EU EMIR covered 70% of outstanding notional in global interest rate derivatives in 2015.

[7] This is after adjusting for double counting of reported trades (see subsection 1.2).

December 2019 through June 2024 for every investor in our sample. The trade-level variables we use from these reports include the outstanding notional, maturity date, identities of the counterparties, direction (receive or pay fixed), whether a trade is centrally cleared, and the underlying floating benchmark and currency. We use these variables to construct investor-level outstanding net position (expressed as net receive fixed rate notional), and the remaining maturity as of the date of report. Over the same period, we collect daily records of new transactions initiated in single currency fixed-to-floating swaps. The variables that characterize new transactions are similar to those in outstanding position files, with the addition of price (expressed as the fixed rate of the trade), which we use to calculate swap spreads. We use the maturities of new transactions to validate the preferred-habitat assumption of investors because outstanding maturities in state files undergo natural decay with the passage of time.

Main data processing steps. Trade repositories' data suffer from some well-known reporting issues.[8] We therefore dedicate a significant amount of time to address these issues, which entails three major steps. First, we exclude likely erroneously reported trades. Specifically, closely following Abad et al. (2016), we drop trades below notional values of $1,000 and above $10 billion, filter out trades whose maturity date lies before the effective date or whose reporting date precedes the execution date,[9] and drop intra-group trades which, while not erroneous, may indicate risk transfers within a group and not necessarily trading in response to changes in market conditions.

Second, we remove duplicate trades. The most common cause of duplicates is the "dual reporting" requirement under EMIR, where each of the two counterparties needs to report a trade if they both fall under the reporting obligation. Following Cenedese et al. (2020), we retain one copy of these trades using the unique trade identifier field. The second reason for duplicates is that, for centrally cleared trades, we observe the original trade contracted between the dealer and its client, and a "novation" trade that is a leg facing the centralized clearing house and a clearing member (usually the same or another dealer), both with different trade identifiers. Since we focus on end-user trades, this duplication does not affect our assessment of *client* level positions but it does lead to double counting of centrally cleared trades in the estimation of total turnover. Therefore, when estimating our data coverage, we halve the notional of centrally cleared trades. A third reason for duplicates is trade compression. Compression entails netting trades with similar economic characteristics at a counterparty level and re-booking a single entry of the net exposure to reduce the size of trading books. The raw positions data include both the original trades and the net trade arising out of compression exercise, which can lead to a miscalculation of outstanding positions. Therefore, we drop all trades tagged as compression when calculating exposures, but

[8] European Securities and Markets Authority (2021) provides a recent report on EU EMIR data quality.

[9] Execution date refers to the trade date, reporting date refers to when the counterparty reports to TR (usually within 2 business days of execution date), and effective date refers to when the swap gets active.

separately use these trades to construct a supply shifter when estimating demand elasticities.

In the final step, we construct our main variables. As floating rate benchmarks are typically not directly available under a single field, we construct them by concatenating information from multiple fields referencing the floating rate index (e.g., SONIA, LIBOR, SOFR), the currency, and the reset frequency.[10] Finally, we calculate swap spreads, defined as the difference between the swap fixed rate and the maturity-matched bond yield, by sourcing daily bond yields at six-monthly maturity intervals from the Bureau van Dijk Bank of England database.

1.3. Sector Classification

We classify each entity in our dataset into either a Dealer, a Central Counterparty Clearing House (CCP), or one of the five end-user sectors: (a) Banks; (b) Funds (including hedge funds and asset managers); (c) Pension, Liability-driven investment (LDI) funds, and Insurers (together referred to as PF&I); (d) Corporate entities; and (e) Official institutions (sovereign funds or supra-national institutions). Even though trade repositories have a reporting field for the counterparty sector, it is sparsely (and often erroneously) filled and not fully reliable. We leverage the non-anonymized unique identifier of each counterparty called the Legal Entity Identifier (LEI) to populate its sector using external databases.[11] In all, we allocate nearly 6,000 LEIs that trade across all currencies to one of these seven sectors.[12]

We start by filling in the missing names and jurisdictions of the LEIs using the Global Legal Entity Identifier Foundation (GLEIF) public database. Then, we use CapitalIQ and Thomson Reuters to populate the sectors associated with the individual LEIs. This method works well for larger entities. However, a substantial number of LEIs also need to be manually classified using their names and details of incorporation. Manual classification is particularly helpful for funds, where a main fund family often has several separate legal entities that trade derivatives but are too small to be reported in standardized data sources.

An important part of our sector classification is to make an economically meaningful distinction between end-user "banks" and market-making "dealers". This distinction helps us capture hedging of interest rate risk arising out of banking activities separately from intermediation services. From

[10] After 2021, multiple indexes referencing the London Interbank Offered Rate (LIBOR) were discontinued from guaranteed publication, and GBP-denominated fixed income instruments transitioned to the Sterling Overnight Index Average (SONIA) benchmark (Klingler and Syrstad, 2021). During our sample period prior to this transition, the share of SONIA-denominated new GBP swap transactions steadily increased from about 75% in December 2019 to 90% in late 2021.

[11] LEI is a unique identifier for each legally distinct entity that engages in a financial transaction. Multiple LEIs may roll up into the same firm or fund family. Financial Stability Board (2019) provides institutional details on LEI implementation.

[12] In the UK, some pension funds use liability-driven investment (LDI) funds to manage their funding risk, predominately via increased exposure to gilts. Hence, we consider LDIs as part of the PF&I segment.

the list of all the entities classified as banks, we carve out dealers, defined as entities that meet any of the following four criteria: members of a clearing house such as the LCH Ltd. (formerly London Clearing House) or the Chicago Mercantile Exchange (CME), globally systemically important banks (GSIBs), participating dealers defined by the Federal Reserve Bank of New York, or broker-dealers and non-bank liquidity providers that facilitate order-matching.[13] Membership of clearing houses provides the sharpest identification of dealers because end-users are not allowed to directly clear trades with CCPs but large financial institutions and broker-dealers that meet certain minimum capital thresholds are.[14] Moreover, the list of CCP members is available both by product (e.g., interest rate derivatives) and LEI, which enables a direct matching with our database. We also verify that the entities we classify as end-user banks do not trade with other end-user sectors and do not directly face clearing houses, which lends credibility to our classification process.

2. Risk Exposures Across the Financial System

We present the key facts on interest rate swap exposures across all participating investors, along with their estimated demand elasticities. While we focus on GBP swaps, the main empirical patterns we find are also present in other currencies.

We start by constructing measures of risk exposure for outstanding positions and transactions. We compute the net signed dollar exposures (Q_t), defined as the notional in receive fixed swaps minus pay fixed swaps at an end-user investor level,

$$Q_t = \sum_p \text{Signed Notional}_{pt}, \tag{1}$$

where $\text{Signed Notional}_{pt}$ is the gross notional of position (or trade) p at time t, signed *positive* for receive fixed and *negative* for pay fixed swaps. Thus, positive values of Q_t denote net receive fixed positions. For sector-level analyses, we aggregate this measure across all the investors within the sector. We complement this measure with swaps' dollar duration, i.e. the dollar value of one basis point parallel shift in interest rates, which we label as DV01.[15]

The interest rate swap market is dominated by funds, banks, and pension funds and insurers

[13] We retrieve the list of clearing members directly from LCH Ltd. website. The corresponding list for CME is available here. We source the list of GSIBs from the Financial Stability Board website, and the list of participating dealers from the Federal Reserve Bank of New York website.

[14] For example, the membership criteria of LCH Ltd. states "major financial groups (including the majority of the major investment banks), broker-dealers and specialist commodity houses" (www.lch.com/membership). As of August 2023, there were 124 unique LEIs that qualified as LCH Ltd. clearing members for interest rate derivatives.

[15] Note that $DV01_t = \sum_p Notional_{pt} \times Duration_p/10,000$, where $Duration_p$ refers to the signed Macaulay duration of the fixed rate leg of the swap. We use currency and maturity-matched bond yields as at the beginning of our sample period to calculate the swap durations.

(PF&I), both in terms of outstanding positions and transaction volume. Columns (1) and (2) of Table 1 show the gross outstanding positions and net exposures (Q_t) held by each end-user sector in our sample as of February 1, 2022. In aggregate, funds held the largest stock of gross outstanding positions at GBP 1.2 trillion, followed by PF&I at GBP 1 trillion, banks at GBP 364 billion, official sector at GBP 73 billion, and corporations at GBP 68 billion. Net exposures in column (2) follow a similar pattern, while the net DV01 in column (3) is the largest for PF&I. Columns (4) and (5) report the average monthly gross and net transaction volumes for these sectors during our sample period. Similar to outstanding positions, funds have the largest trading volume, followed by PF&I and banks. However, the net notional relative to gross volume of new transactions is smallest for funds, indicating frequent two-way trading.

At an investor level, Table A2 shows that 365 funds, 576 PF&I, 105 banks, 258 corporations, and 16 official institutions held outstanding GBP swap positions in our sample as of February 1, 2022. The average fund and bank is large, each holding about GBP 1.4 billion of net exposure, while the average PF&I and corporate entity holds GBP 435 million and GBP 165 million of net exposure, respectively. We observe only a few very large official institutions that trade infrequently. Hence, we omit discussing them in detail henceforth.

2.1. Trading Direction Across Sectors

We examine the direction of net exposures both at a sector and an individual investor level. First, we find a significant heterogeneity in the direction of net exposures *across* sectors. Figure 1 shows the net outstanding positions aggregated for all entities for a given sector at a monthly frequency. Throughout the sample period, PF&I receive fixed rates, i.e. they add duration to their portfolios using swaps. In contrast, banks and corporations pay fixed rates, i.e. they sell duration using swaps.[16] This suggests that PF&I are natural counterparties to banks and corporations in the swaps market.[17] On the other hand, funds flip trading directions, receiving fixed rates at the start and end of the sample while paying fixed rates in the middle. The shift in funds' net position is most pronounced at the onset of the 2022 rate hike cycle.

Second, we examine intra-sector heterogeneity in the direction of net exposures at the entity (LEI) level. Figure 2 plots the fraction of entities within each sector that receive fixed rates during our sample period, depicted on the right-hand side axis. The left-hand side axis of Figure 2 maps this fraction to an "agreement score", where a value closer to +/-1 indicates homogeneity in the

[16] Figure A1 confirms that these directions are consistent for swaps denominated across all currencies.

[17] Since we observe only partial holdings of non-UK entities in our data (i.e., their trades booked with a UK counterparty), one may be concerned that the direction of exposures we document may not reflect the full portfolio of investors' swap holdings. However, we find consistent results when considering the net exposures of UK entities only (for whom we observe all trades). Figure A2 shows that the exposures held by UK PF&I and UK banks are also in opposite direction and are of comparable magnitude.

direction of exposures, and a value closer to 0 indicates heterogeneity. We find that corporations, PF&I, and banks are largely homogeneous: 80% of corporate entities pay fixed, 80% of PF&I receive fixed, and 70% of banks pay fixed rates. However, funds exhibit significant heterogeneity, with roughly half the entities receiving fixed and the other half paying fixed in any given month.[18]

Third, we find that the heterogeneity in funds' direction of exposure is largely explained by the different trading strategies they adopt. We scan the names of fund entities to classify them into granular categories that reflect well-known trading strategies: (i) fixed income or bond, (ii) macro, (iii) quant or relative value, and (iv) other asset managers, and report their gross and net exposures in Table A3. Macro funds are the largest and, similar to banks and corporations, primarily pay fixed. They hold 45% of the fund sector's gross notional, but with a net-to-gross position ratio of 0.6, they account for 85% of *net* (absolute) exposures, as also visible in the time series in Figure A4. In contrast, other asset managers primarily receive fixed rates. Strikingly, the net-to-gross position ratio of quant or relative value funds is only 0.03, implying that they hold two-way positions that mostly net out, consistent with their perceived role of exploiting relative value. Overall, some funds behave like end-user hedgers (e.g., macro), while others behave like tactical traders (e.g., quant).

2.1.1. Sensitivity to Interest Rates

Next, we examine the impact of changes in macroeconomic conditions on investors' swap exposures. Specifically, we consider movements in the level of interest rates, which could either affect hedging needs (via shifts in the duration mismatch of the underlying balance sheet) or alter expectations of future swap returns. We estimate a model of the form

$$\Delta q_{i,t} = \alpha_i + \beta \Delta Rate_{t-1} + \epsilon_{i,t}, \tag{2}$$

where $\Delta q_{i,t}$ is the change in the net outstanding position for investor i from month $t-1$ to t, scaled by the average absolute position held by the investor in the two months. This scaled variable approximates percentage changes and is bounded between +/-2, similar to the Davis and Haltiwanger (1992) growth rate measure that mitigates the effect of outliers. We also consider the change in DV01 as an alternate dependent variable to account for swap durations.[19]

The independent variable, $\Delta Rate_{t-1}$, denotes the change in the monthly average of the first principal component (PC) extracted from daily UK government bond (gilt) yields for maturities of 3 months, 5 years, 10 years, and 30 years. We use lagged changes to mitigate the simultaneity problem to some extent. We also use the yields for 3 months, 5 years, 10 years, and 30 years as

[18] Fund exposures are also highly concentrated within a few large entities. Figure A3 shows that the 10 largest entities held over 80% of net outstanding exposure in the fund sector as of February 2022.

[19] DV01s can mechanically change with interest rates even without active trading by investors. Hence, we fix swap durations as at the beginning of our sample period such that ΔDV01 reflects only active trading.

separate regressors for robustness. Finally, we include investor fixed effects and cluster standard errors by investor. Table 2 reports the estimation results.

Swap positions across sectors are sensitive to changes in interest rates, but there is striking cross-sector heterogeneity in the direction and the magnitude of the sensitivities. All the results in Table 2 show that β (i.e., the loading on rate changes) is negative for PF&I and positive for banks and corporations. As rates fall, PF&I buy duration and increase their net receive fixed exposures, whereas banks and corporations sell duration and increase their net pay fixed exposures. Specifically, for a one percentage point decline in the first principal component of yields, the average entity in the PF&I sector increases its net receive fixed exposure by 5%, and the average bank and corporation increases their net pay fixed exposure by 6% and 11%, respectively. The impact on DV01s is also of a comparable magnitude. The opposite adjustment in demand from PF&I and banks further suggests that they are natural counterparties in the swap market.

In order to better account for endogeneity in the co-movement between yields and swap positions, we consider an alternate regressor that reflects unexpected movement in yields arising out of central bank policy announcements: monetary policy shocks (MPS). We obtain the MPS measure from Braun, Miranda-Agrippino, and Saha (2024), calculated as the difference in the intra-day gilt yields before and after the monetary policy decision announcement of the Bank of England. We use monetary policy shocks reflected in gilt yields of three different available maturities — 2 years, 5 years, and 10 years — as separate regressors to estimate a model of the form

$$\Delta q_{i,t} = \alpha_i + \beta MPS_{t-1} + \epsilon_{i,t}, \tag{3}$$

with the rest of the specification analogous to Equation 2. Table 3 reports the estimation results, with changes in the net outstanding position as the dependent variable in panel A and DV01 in panel B. Note that the number of observations is fewer than in Table 2 because the MPS variable exists only when the Bank of England meets (37 out of the 55 months in our sample period).

We continue to find robust evidence that banks and PF&I react in opposite direction to changes in interest rates arising out of monetary policy announcements. For a one-standard-deviation positive monetary policy shock in 10Y gilt yield (3.8 bps), banks reduce their net pay fixed position by 2.6% and PF&I reduce their net receive fixed position by 1.4%. Finally, funds also exhibit strong sensitivity to monetary policy surprises, in a pro-cyclical manner similar to PF&I.

Discussion on end-user demand. The net positions of PF&I, banks, and corporations appear consistent with the hedging needs arising out of their respective underlying balance sheet maturity mismatch. Moreover, the sensitivity of investors' swap positions to shifts in interest rates is also consistent with the sectors' underlying interest rate mismatch.

PF&I face liabilities that are both long-dated and embed fixed rate guarantees. However, the asset side of PF&I balance sheet contains government and corporate bonds, which typically have shorter maturities than liabilities (EIOPA, 2014, Domanski, Shin, and Sushko, 2017, Jansen, Klingler, Ranaldo, and Duijm, 2023). As a result, the duration of their assets is shorter than that of their liabilities, i.e. the sector has a negative duration gap and is therefore exposed to a decline in interest rates. A pension fund or an insurer wanting to close the duration gap with swaps would need to receive the fixed rate. Moreover, as interest rates increase, the discounted liabilities of the PF&Is fall faster than that of its assets, reducing the need to receive fixed rate swaps as a hedge.

In contrast to PF&I, we observe that banks in our sample (most of which are located in the UK) pay fixed rates and reduce swap duration as rates decline. Moreover, the total exposure from their swap position constitutes an economically meaningful portion of their underlying exposures.[20] Ordinarily, we expect banks to have a positive duration gap because their assets, which include fixed rate mortgages, have longer duration than their liabilities, which are mainly short-term deposits. If so, a bank wanting to close the mismatch between assets and liabilities with swaps would need to pay the fixed rate. While our finding is consistent with the basic business model of banks, it is in contrast to US banks, who do not seem to meaningfully hedge their interest rate risks with swaps (McPhail et al., 2023). There are several institutional differences between the US and the UK banking sector that may help reconcile the findings. First, UK (and European) banks face higher regulatory pressure to hedge their interest rate risk (Wilkes, 2023a,b), compared to US banks. Second, UK banks have higher deposit betas (Walker, 2023), which implies larger duration mismatch on the banks' balance sheets. Third, US banks face high prepayment risk from mortgages and to hedge that risk, they need to *receive* the fixed rate (Hanson, 2014). This is less applicable to UK banks as mortgage prepayment is often associated with a penalty (Benetton, 2021).

Similar to banks, corporations in our sample primarily hedge the interest rate risk arising out of floating rate debt issuance. Therefore, they demand to pay fixed rate swaps to hedge the risk from the fluctuations in short-term floating rates, consistent with the predictions in Titman (1992).

2.2. Maturity Segmentation

In contrast to the offsetting direction of exposures that facilitates risk sharing, we find that the swap holdings of various end-users are highly segmented across maturities. To account for the heterogeneity in exposures, we split positions into four maturity groups: below 3 months, 3 months to 5 years, 5 years to 10 years, and 10 years & above. For each group, we compute the net position as described in Equation 1 and label these variables $Q^{<3M}$, Q^{3M-5Y}, Q^{5Y-10Y}, and $Q^{\geq 10Y}$. Figure 3

[20] For the UK banks in our sample, we find that a 100 bps upward shift in the yield curve would lead to a 4.9% increase in their equity due to an increase in the market value of their swap positions as on April 1, 2022. Velez et al. (2024) find corroborating evidence that Italian banks hedge interest rate risk using swaps.

panels (a) through (d) show the breakdown of net position in these four maturity groups.

PF&I swap holdings are consistently concentrated in the long-maturity group (10 years & above) throughout the sample period. In contrast, a bulk of bank and corporate positions are in the short to intermediate maturity groups (3 months to 5 years and 5 years to 10 years). Funds hold very short maturity swaps (below 3 months) and short to intermediate maturity swaps (3 months to 5 years). While their trading in the below 3 months segment is quite volatile, funds pay fixed rates in the 3 months to 5 years segment, particularly during the middle part of the sample period. Figure A5 confirms that all fund types predominantly hold short to intermediate maturity swaps.

Due to the longer maturity holdings of PF&I, Figure 4 shows that their net outstanding DV01 is the highest among all end-users. For a one basis point upward parallel shift in the interest rate curve, PF&Is lose about GBP 150 million on swap positions during our sample period. Correspondingly, banks in our sample gain about GBP 40 million. While funds trade very large notional of swaps, their positions carry relatively smaller duration risk due to a preference for short-term maturities.

The extent of segmentation is even starker when we look at the maturity distribution of new transactions. Panel A of Table 4 shows the fraction of investors within each sector that trades at least 50% of their swap volume in a single maturity bucket. About 90% of LEIs for any given end-user sector have a majority of their trading in a single maturity bucket, which we define to be the investor's *dominant* maturity bucket. Panel B of Table 4 shows that an average bank or fund executes over 80% of trades in its own dominant maturity bucket, with the corresponding fraction for PF&I at 66% and corporate at 91%. Panel C of Table 4 confirms that banks and corporations mainly trade in the 3 month to 5 year maturity group, funds in the below 3 month group, and PF&I in above 10 year group, consistent with their outstanding positions in Figure 3. Overall, the holdings and trading behavior of end-users show strong segmentation along the dimension of maturity, suggesting that swap investors have preferred habitats.

2.2.1. Aggregate Net Demand and Dealer (Im-)balances

We turn to understanding the dynamics of aggregate net end-user demand and dealer balances. Since swaps are in zero net supply, dealers take the other side of end-user demand, and their net position is the opposite of the aggregate net end-user demand. Dealer balance is defined as

$$Dealer\ Balance_t = -\sum_s Q_t^s, \tag{4}$$

where s denotes all the five end-user sectors, including banks, funds, PF&I, corporations, and official institutions. We construct dealer balance in terms of DV01 analogously.

Figure 1 and Figure 3, which we discussed above, also overlay the dealer sector balances (in brown). We observe that a large portion of PF&Is' net receive fixed positions is offset by banks'

and corporations' net pay fixed positions. This cross-sector netting reduces the total aggregate net demand that is supplied by the dealer sector.

However, two factors impede cross-sector netting and add to dealer imbalances across maturities. First, even though PF&I trade in the opposite direction relative to banks and corporations, their respective demands are highly segmented (Figure 3). As a result, dealers consistently receive the fixed rate in the 3 months to 5 years tenor and pay the fixed rate in longer tenors, exposing them to maturity-specific price fluctuations. Another way to see this is through dealers' net DV01 position, depicted in Figure 4. Dealers consistently bear the risk of a downward parallel shift in the yield curve because long-tenor PF&I trades receive a higher weight in this risk measure.

Second, funds tend to amplify the magnitude and volatility of net imbalances absorbed by dealers. For example, at the start of the interest rate hiking cycle in 2022, macro funds substantially increased their pay fixed position in the same maturity group as banks, which amplified dealer sector's net receive fixed position. Furthermore, in the shortest maturity group (below 3 months), funds frequently change the direction of their net exposure, inducing volatility in the net demand that dealers need to absorb. These two factors worsen dealer imbalances in different parts of the term structure, exposing them to non-parallel movements in rates in addition to the duration risk.

We note that the direction of maturity-specific imbalance absorbed by dealers is consistent with the shape of the swap spreads curve shown in Figure A6. Swap spreads reflect the relative price of trading swaps over bonds, and are positive in the short-tenor of the curve, where dealers receive fixed rates, and negative in the long-tenor, where dealers pay fixed rates.[21] Existing studies suggest that dealers hedge the interest rate risk on these positions using instruments such as bonds. For example, Hanson et al. (2024) proxy for dealers' net swap position using the negative of their aggregate Treasury holdings, and Wallen and Lu (2024) find that the profits of dealers' trading desks are not sensitive to rate changes, implying that the interest rate risk arising from their positions is largely hedged away.[22] As a result, the primary risk that dealers face on swap positions is the convergence (or curve risk) of swap spreads, rather than that of swap fixed rates.

2.3. Estimating Demand Elasticities

In this section, we exploit plausibly exogenous variation in swap spreads to estimate end-users' demand elasticities. These estimates form an important input to our model calibration later, as

[21] In contrast, Figure A7 shows that USD swap spreads are negative throughout the term structure. A potential explanation for this cross-currency variation is that US banks do not hedge using swaps (McPhail et al., 2023), while we find that banks in the UK pay fixed rates in short-maturity swaps. On the other hand, both USD and GBP swap spreads are quantitatively similar in the long-tenor, consistent with Klingler and Sundaresan (2019) who argue that US pension funds receive fixed rates in long-tenor swaps.

[22] Related studies on other derivatives find that dealers hedge the underlying delta risk on S&P 500 index options (Baltussen, Terstegge, and Whelan, 2023) and "0DTE" options (Dim, Eraker, and Vilkov, 2023).

they determine the extent to which demand shocks affect price (e.g., by changing hedging costs if investors are inelastic) or are absorbed through quantity adjustments (if investors are elastic). We focus on swap spreads as the relevant measure of price, as opposed to fixed rates, as it reflects the relative attractiveness of swaps over comparable maturity bonds and allows us to net out the component associated with bond yields.

2.3.1. Empirical Design

Estimating demand elasticities is inherently challenging due to the simultaneity bias that arises because prices and quantities are jointly determined in equilibrium. We propose "portfolio compression" as an instrument that shifts the supply curve independently of demand conditions by changing dealers' balance sheet constraints.

Portfolio compression is a widespread market practice that involves canceling the existing stock of offsetting derivative trades and replacing them with a single trade that retains the net exposures but reduces the gross notional outstanding. Regulatory requirements under the Basel III framework, which became mandatory in 2018, prescribe a minimum leverage ratio based on the *gross* notional of outstanding derivatives, with exposure calculations relying on replacement costs and potential future exposure—both of which increase with gross notional (Haynes and McPhail, 2021).[23] By condensing multiple trades into a single net trade, compression allows dealers to reduce regulatory capital requirements (International Swaps and Derivatives Association, 2012, Duffie, 2018), thereby lowering their marginal cost of supplying swaps and influencing swap spreads.[24] The economic impact of compression can be substantial: between January 2016 and December 2019, LCH SwapClear, the primary platform through which dealers in the UK clear trades, compressed $2,656 trillion of gross notional, leading to a substantial reduction in the counterfactual outstanding notional (LCH SwapClear, 2023). Moreover, compression activity is primarily driven by multilateral netting across various counterparties — often other dealers or a central clearing house — which makes it unlikely to reflect simultaneous changes in demand or strategic dealer behavior.

Measurement of compression. To proxy for compression activity, we leverage our transaction-level data, which allows us to identify trades that have been compressed on a given date. Using these data, we construct a dealer-level weekly time series of the ratio of compressed trades relative to the total number of outstanding trades, which we refer to as Compression Ratio.[25] Table 5 provides

[23] Gross notional of derivatives is considered under the Current Exposure Method, whereas duration-adjusted effective notional is considered under the Standardized Approach for Counterparty Credit Risk calculations (Basel Committee on Banking Supervision, 2023).

[24] In fact, (Duffie, 2018) argues that improvements in regulatory capital and margin requirements may at least partially explain the increased prevalence of compression.

[25] We observe that a trade is tagged as compressed, rather than the actual gross dollar volume that was compressed. However, a large number of net compressed trades should correlate with a substantial dollar volume being compressed, as the number of trades compressed typically indicates the scale of compression activity.

summary statistics, as well as the characteristics of compressed trades. The average compression ratio is about 19%, with a standard deviation of 15%. Validating the key idea of our instrument, we find that compressed trades are almost always facing the central clearing house (LCH Ltd.) and are centrally cleared, suggesting that compression follows largely automated processes, which we validate in more detail below.

We construct our panel aggregating the net positions of a dealer across all its clients, separately for each maturity group, at a weekly frequency. We aggregate positions at a dealer-maturity group level for two reasons. (i) From a dealer's perspective, asset prices are driven by the aggregate imbalances across maturity groups, i.e. the collective imbalances of its clients in each group rather than that of an individual client. In line with that, our equilibrium framework considers policy counterfactuals of demand shocks arising in specific maturity groups. Notably, each end-user sector has preferred habitat in specific maturity groups, as we show before. This requires estimating elasticities of a end-user sector as a whole, which is isomorphic to a maturity group in our setting. (ii) There is limited heterogeneity in positions and trading behavior *within* end-user sectors (Figure 2), suggesting that treating each sector as a whole does not overlook significant sources of variation that could be material to asset prices. In terms of frequency, we construct a weekly time series that allows us to exploit high-frequency variation in compression and prices (LCH executes multiple weekly compression runs). This strengthens our instrument's power in explaining prices and reduces the likelihood of end-users switching dealers within a short interval. We consider dealers for whom we observe prices in at least 90% of the weeks in our sample to ensure we utilize prices provided by active dealers only.

Two-stage least squares regression. Using this measure, we consider the following two-stage least squares regression.

$$\text{First stage:} \quad \Delta\text{Swap Spread}^m_{i,t} = \gamma^m \Delta\text{Compression ratio}_{i,t} + \text{Controls} + \alpha_i + \alpha_t + v_{i,t}. \tag{5}$$

$$\text{Second stage:} \quad \Delta q^m_{i,t} = \beta^m \Delta\widehat{\text{Swap Spread}}^m_{i,t} + \text{Controls} + \alpha_i + \alpha_t + \varepsilon_{i,t}. \tag{6}$$

The first stage regresses the change in notional-weighted swap spreads offered by dealer i in week t on the change in dealer i's compression ratio. We estimate this model separately for each maturity group, m, because the impact of compression on swap spreads, γ, differs depending on the net position held by the dealer in that particular maturity group, as discussed below. We control for changes in the net position facing the dealer in the previous week, as well as dealer and time fixed effects. In robustness, we also control for dealers' balance sheet characteristics such as assets and capital ratios. In the second stage, we examine the extent to which the instrumented swap spreads affect the changes in the net client position facing the dealer in a given maturity group.

Since dealers *pay* fixed rates in long-dated swaps, opposite of PF&I, we expect more compression

activity (decrease in balance sheet costs) to *increase* swap spreads in the longest maturity group ($\gamma > 0$). This is because dealers would be willing to accept these positions at worse terms. Similarly, dealers *receive* fixed rates in shorter maturities, opposite of banks and corporations. As increase in compression activity should lead to *lower* swap spreads, as dealers would be willing to accept these positions at lower fixed rates ($\gamma < 0$). In other words, an increase in compression ratio "lowers" the price faced by end-users.

The coefficient β can be interpreted as the elasticity of demand for swaps with respect to prices. We expect $\beta > 0$, which would indicate that as swap spreads rise, end users would like to increase their received fixed positions.

2.3.2. Identifying Assumptions

We next discuss the two key assumptions for compression activity to be a valid instrument to estimate the demand elasticities.

Relevance. First, we argue that compression activity affects swap spreads by easing dealers' balance sheet constraints, with the direction of the price impact (captured by γ) determined by dealers' net swap positions in a maturity group. Table 6 (Panel A) reports the results of estimating Equation 5 for the two key maturity groups (short-intermediate and long) which reflect the demand of the main end-user sectors (PF&I, banks, and corporations). The first stage coefficient γ is statistically significant (at the 99% level) with high F-statistic showing that the relevance condition holds. Importantly, consistent with the balance sheet cost channel, a 10 pp increase in compression ratio is associated with about 3.7 bps *decrease* in swap spreads for the short-intermediate maturity group, and about 4 bps *increase* in swap spreads for the long maturity group.[26]

Exogeneity. The second assumption we require is that changes in compression ratio are unrelated to changes in the *net* demand imbalances within maturity buckets. We discuss potential threats to our identification below.

Concern 1: Demand shifts. A key concern is that shifts in end-user demand influence both prices and facilitate more compression. To understand the specific type of demand shock that would be a threat to identification, consider the following illustrative example. Imagine a dealer has some positive or negative imbalances. First, notice that one-sided demand shifts matter for compression only when they are offsetting the dealer's existing positions in the same maturity bucket. For example, if the dealer is net pay fixed in the long maturity group, more PF&I trading that is pay fixed (received fixed for the dealer) will increase compression whereas more receive fixed

[26] We focus attention on maturity groups 2 and 4 because it reflects the demand for the main end-users we are interested in. In addition, dealers' net positions are not consistently in one direction in the first maturity group (Figure 3), implying that it is not entirely obvious how to sign the first-stage coefficient. Finally, end-user positions in the third maturity group mainly reflect long-tenor swaps whose maturity has decayed over time and Table 4 confirms that the third maturity group is not a preferred habitat for any sector.

trading will not. However, if PF&I indeed do more pay fixed trading, we would observe compression increase and swap spreads also increase (i.e. become less negative), yielding a positive sign for γ in the long maturity group exactly as we estimate. Crucially, though this sign can be explained by both a balance sheet cost reduction effect (supply) and a demand pressure effect, violating the identifying assumption. Second, note that we also simultaneously estimate a negative γ for the short-intermediate maturity group. For a demand-based explanation, we now also require that banks buy more offsetting swaps relative to dealers' current position in this group, at the same time as PF&I buy more offsetting swaps. In other words, the type of demand shock that would be threat to identification is the one where offsetting demand shifts occur simultaneously in both maturity groups, which could occur e.g., due to high market volatility.

A number of factors help argue against this type of demand shock driving our estimates. Table A4 shows the drivers of the underlying variation in compression ratio. We note that compression ratio does not co-move with broad macro factors, including changes in the level or volatility of interest rates, and dealers' balance sheet characteristics. Moreover, changes in end-users trading also does not explain the variation in compression. If end user's trading offsets existing dealer imbalances and drives compression, then compression should correlate with dealers' existing positions. We do not find this to be the case. This is not surprising. First, dealers often engage in multilateral compression (across all their counterparties put together), which weakens the link between client-specific demand and compression at the dealer level. Second, about 93% of compression trades face another dealer or the CCP (Table 5), which suggests that end-user demand shocks may not drive a significant share of the variation in compression ratio.[27] Nevertheless, our empirical specifications account for dealers' net position in the previous week, changes in interest rates and volatility, as well as time fixed effects to account for market-wide factors that could simultaneously affect end-users demand across maturities.

Concern 2: Dealer strategic behavior. Another threat to identification could be that dealers strategically use *non-price* incentives (e.g., lower collateral requirements on bilaterally cleared trades) to attract offsetting trades that increase compression with relatively smaller price changes, overstating demand elasticities.[28] We argue that the institutional arrangement underlying the compression process weakens dealers' ability to influence whether and which trades get compressed. For example, a key requirement for compression is that forward-looking cash flows need to offset, which includes the specific dates on which cash flows settle. In the interest rate swaps market, cash flow

[27] Consider, for instance, a dealer i who enters into a receive-fixed trade with dealer j. If the trade offsets the cash flow of an existing pay-fixed trade held by dealer i, then the dealer can increase compression and offer a better price to its clients. In this example, inter-dealer trades, rather than end-user demand shocks to dealer i, drive variation in the compression ratio.

[28] It is important to note that if the dealer improves prices to attract offsetting trades, which might enable more compression, then our elasticity estimates remain unbiased.

settlement follows standard market conventions - typically annual frequency for fixed leg payment and quarterly frequency for floating leg payment - or is dictated by the end-user's underlying cash flow or loan schedule. Therefore, even if dealers elicit trades that offset their existing positions directionally, they have little control over the cash flow settlement dates which ultimately influences the eligibility of trades to compress.[29] Furthermore, the rules followed by the LCH SwapClear platform automatically identify trades eligible for compression and run multiple weekly runs to cancel gross positions of each member institution across a range of counterparties.[30]

Concern 3: End-user switching. Third, our estimates may be affected if end-users switch across dealers in response to price changes. For example, if a dealer improves prices due to compression and end-users are able to quickly switch dealers, then we will over-estimate the elasticities because the new quantities facing the dealer can be attributed to existing as well as new clients. Panel B of Table 5 confirms that, even at a monthly frequency, investors across all end-user sectors do not switch dealers and that a vast majority of monthly trading activity by investors is with a single dealer only. Given that we construct the panel at a weekly frequency, this makes it less likely that end-users switch dealers at a short time horizon.

2.3.3. Demand Elasticity Estimates

Panel B of Table 6 reports the estimated elasticities of investors' demand to instrumented price changes. We find that as swap spreads rise, investors increase their net receive fixed position i.e. $\beta > 0$. Importantly, there is significant heterogeneity in the estimated elasticities across maturity groups. For example, investors in the short-intermediate maturity group (e.g., banks and corporations) increase net receive fixed position (reduce net pay fixed position) by about 8% in response to a 10 bps increase in swap spreads. investors in the long maturity group (mainly PF&I) have significantly less elastic demand: PF&I increase their net receive fixed position by roughly 3.5 times less for a similar 10 bps increase in swap spreads, with wider confidence intervals. The lower elasticity of PF&I could potentially be explained by their stronger preference for swaps over bonds due to funding ratio constraints (Klingler and Sundaresan, 2019) as well as a shortage of long-dated government bonds in European countries (Du et al., 2023). Table A5 provides a similar conclusion when we add controls for yield changes, rate volatility, and dealers' balance sheet characteristics.

While the second stage estimates for investors in the second maturity group are highly statistically significant, we note that our elasticity estimates for PF&I are somewhat imprecisely estimated. Notwithstanding the imprecision in the estimates, the demand estimation allows us to anchor the

[29] Ehlers and Hardy (2019) note that certain US and European regulations require large dealers to undertake compression activity multiple times a year, introducing an exogenous requirement regardless of dealer preferences.

[30] Signing up for compression with LCH SwapClear is a one-time exercise for dealers, after which eligible trades are automatically compressed. LCH SwapClear Guide provides a step-by-step overview.

elasticities to empirical estimates obtained from the data. In the calibration exercise, which we detail below, we account for the wider confidence intervals of the demand elasticities (rather than simply using the point estimates) by drawing elasticities from the full *distribution* of our estimates in Table 6.

3. Model and Calibration

In this section, we calibrate a structural model of the interest rate swap market. There are two objectives of the model. First, the model helps quantify how demand imbalances, arising from different end-user sectors, interact with dealers' constraints to determine the term structure of swap spreads. Second, the model allows us to conduct a series of counterfactual policy experiments to study the impact of demand shifts and market integration on investors' hedging costs. Given the strong maturity segmentation exhibited by swap investors, our model builds on the preferred-habit investors model of Vayanos and Vila (2021). We begin with a discussion of the model setup and calibration of parameters, followed by the decomposition of equilibrium prices, the role of the distribution of demand imbalances, and counterfactual experiments.

3.1. A Preferred Habitat Model for Interest Rate Swaps

Time is continuous $t \in [0, \infty)$. The maturities of swaps lie in $(0, \infty)$. We specify the demand for swaps as a function of swap spreads, i.e. the relative price of swaps to bonds, for two reasons. First, investors can choose to hedge their interest rate risk either in the cash or the swap market, and swap spreads capture the relative attractiveness of swaps over bonds. For example, demand for swaps would be weaker if they are more expensive relative to bonds of similar maturity. Second, swap spreads help net out the direct impact of interest rate changes on investors' demand.

We denote by $s_t(\tau)$ the swap spread of swaps with maturity τ at time t. The corresponding price $P_t(\tau) \equiv \exp(-\tau s_t(\tau))$ captures the value of a fixed stream of payments in the swap contract *relative to* the value of a government bond with the same maturity.[31] We assume in the very short-term market, the swap spread is always 0. That is,

$$\lim_{\tau \to 0} s_t(\tau) = 0 \quad \text{for} \quad t \geq 0. \tag{7}$$

Preferred-habitat investors. Preferred-habitat investors demand swaps of a specific maturity. We verify empirically that this is true for most clients such as PF&Is, corporations and banks.

[31] To see this, denote the fixed rate in the swap contract by $y_F(\tau)$; the present value of this fixed stream of payments is $P_F = \exp(-\tau y_F(\tau))$. Similarly, denote the yield of a zero-coupon government bond by $y_T(\tau)$; its price is then $P_T = \exp(-\tau y_T(\tau))$. Under $P \equiv P_F/P_T$, $P = \exp(-\tau(y_F(\tau) - y_T(\tau))) = \exp(-\tau s(\tau)))$.

In addition, some funds that specialize in a specific maturity bucket are also preferred-habitat investors in our model, as discussed in Section 2. Following Vayanos and Vila (2021), investors with habitat τ have demand for swaps in maturity bucket τ

$$Q_t(\tau) = -\alpha(\tau)log(P_t(\tau)) - \theta_0(\tau) - \sum_{k=1}^{K} \theta_k(\tau)\beta_{k,t}, \tag{8}$$

where $\alpha(\tau)$ is the demand elasticity; θ_0 is the average demand (intercept) and $\theta_k(\tau)$ is the sensitivity of demand to the aggregate demand factor β_k. Investors in different maturity buckets may be exposed to similar demand shocks, such as the level of interest rates, but the extent to which they are affected could be different, as captured by $\theta_k(\tau)$. For example, Table 2 suggests that banks and PF&Is react to interest rate changes in opposite directions. Finally, if $Q_t(\tau) > 0$, investors are receiving fixed; otherwise, investors are paying fixed.

Arbitrageurs. Arbitrageurs are risk-averse agents who can trade *across* maturity buckets and do not have any preference for specific maturities. Arbitrageurs include dealers as well as certain funds who get funding from dealers in order to conduct arbitrage activities across maturity buckets. Following the literature, we assume that arbitrageurs are specialized intermediaries who hedge the interest rate risk exposure of their swap positions using other instruments, e.g., government bonds (Du et al., 2023, Hanson et al., 2024). This is also consistent with recent empirical findings that dealer desks bear little market risk (Wallen and Lu, 2024). As a result, the primary risk that arbitrageurs face is the convergence risk of swap spreads. Specifically, when receiving fixed in the short tenor and paying fixed in the long tenor, arbitrageurs face the risk that relative swap spreads may diverge, negatively impacting the value of their swap positions.

We assume that for each unit of swap held, the arbitrageur faces a cost c_t at time t, which reflects funding market frictions and balance sheet costs of holding swap positions. This cost could come from multiple sources. First, c_t captures the difference between the short-term floating rate referenced by the swap and the short-term financing rate available to the dealers to fund the bond position for hedging interest rate risk. Second, c_t also partially captures the balance sheet cost of holding government bonds (Bicu-Lieb et al., 2020, He et al., 2022, Du et al., 2023). Third, a sizable fraction of client-facing swaps are not centrally cleared (Cenedese et al., 2020). In this case, the dealer is required to hold additional capital against counterparty risk, which is costly as well.[32] Finally, these costs would also apply to situations where hedge funds, and not dealers themselves, act as arbitrageurs. Since hedge funds often obtain funding from dealers, dealers' balance sheet

[32]The Basel committee on Banking Supervision stipulates capital requirements for costs associated with the default of a counterparty, via Counterparty Credit Risk capitalization, or with changes in the credit quality of a counterparty, via the Credit Valuation Adjustment.

costs would get passed on to hedge funds in the form of higher funding costs.[33]

Arbitrageurs maximize a mean-variance objective over instantaneous changes in wealth dW_t. We denote the arbitrageurs' swap positions in maturity bucket τ as $X_t(\tau)$. Thus, dW_t can be expressed as

$$dW_t = \int_0^\infty X_t(\tau) \left(\frac{dP_t(\tau)}{P_t(\tau)} - c_t \right) d\tau + W_t r_t dt \tag{9}$$

where $\frac{dP_t(\tau)}{P_t(\tau)}$ is the return from holding swaps of maturity τ and r_t is the return from the arbitrageurs' outside option. Arbitrageurs face two sources of risk. On the demand side, shifts in swap demand from end-users can turn the mark-to-market value of existing positions negative. For example, if PF&Is increase demand to receive fixed rates, long-tenor swap spreads may decline and, without a corresponding change in short tenor swap spreads, arbitrageurs would face a loss. This relative change in the term structure of swap spreads can impact arbitrageurs' wealth even when the underlying interest rate risk in each maturity τ is hedged. On the supply side, arbitrageurs are exposed to time-varying funding cost c_t that can add unforeseen costs to their swap holdings. The arbitrageur's problem is

$$\max_{\{X_t(\tau)\}_{\tau=0}^\infty} \left[\mathbb{E}_t(dW_t) - \frac{a}{2} Var\left(dW_t\right) \right] \tag{10}$$

where $a \geq 0$ is the arbitrageur's risk aversion coefficient, partially reflecting regulatory constraints that limit their risk-taking. Arbitrageurs benefit from differences in swap spreads in different maturity buckets, but face both demand and supply-side risks that get reflected in equilibrium prices.

Dynamics and market clearing. The state variables can be represented by a $(K+1)\times 1$ vector $g_t \equiv (c_t, \beta_{1,t}, ..., \beta_{K,t})^\top$. We assume that g_t is stationary and follows the process

$$dg_t = -\Gamma(g_t - \bar{g})dt + \Sigma dB_t \tag{11}$$

$$\bar{g} \equiv \left(\bar{c}, 0, ..., 0 \right)^\top \tag{12}$$

where Γ and Σ are constant $(K+1)\times(K+1)$ matrices; dB_t is a $(K+1)\times 1$ independent Brownian motion.[34] Γ governs the speed of mean-reversion and Σ governs the variance and covariance of

[33] Although our model applies the cost to the net swap notional, empirically, certain regulatory costs are based on the absolute notional. A portion of the regulatory impact on the absolute volume can be thought of as reflected in the risk-aversion term described below. We acknowledge that this framework does not fully capture all the regulatory nuances.

[34] It is without loss of generality to assume that the demand factors, $\beta_{k,t}$, have mean 0.

shocks. Furthermore, $\bar{c}$ is the average funding cost for the arbitrageurs. Note that the arbitrageurs can hold either positive or negative amount of swaps; we verify in our estimation that the net funding cost for the arbitrageurs are indeed positive.

Finally, swaps of any given maturity are in zero-net supply. The market clearing condition is given by

$$X_t(\tau) + Q_t(\tau) = 0, \qquad \forall \tau > 0. \tag{13}$$

Equilibrium characterization. We first guess that the relative price for swaps with maturity τ takes the form

$$P_t(\tau) = \exp[-(A(\tau)^\top g_t + C(\tau))] \tag{14}$$

where $A(\tau)$ is a $(K+1) \times 1$ matrix, and $C(\tau)$ is simply a constant. The first element of $A(\tau)$ captures the price's sensitivity to the supply factor c_t, and the other elements of $A(\tau)$ capture the price's sensitivity to the K demand factors.

Using the arbitrageur's first order conditions and setting $K = 1$, we can characterize $A(\tau)$ and $C(\tau)$ in a set of differential equations, as presented below.

$$\Gamma^\top A(\tau) + A'(\tau) - \begin{pmatrix} 1 \\ 0 \end{pmatrix} - a \left[\int_0^\infty \left(\theta(\tilde{\tau}) \begin{pmatrix} 0 \\ 1 \end{pmatrix} A(\tilde{\tau})^\top - \alpha(\tilde{\tau}) A(\tilde{\tau}) A(\tilde{\tau})^\top \right) d\tilde{\tau} \right] \Sigma\Sigma^\top A(\tau) = 0 \tag{15}$$

$$A(\tau)^\top \Gamma \begin{pmatrix} -\bar{c} \\ 0 \end{pmatrix} + \frac{1}{2} A(\tau)^\top \Sigma\Sigma^\top A(\tau) + C'(\tau) - a A(\tau)^\top \Sigma\Sigma' \int_0^\infty \left(-\alpha C(\tilde{\tau}) + \theta_0(\tilde{\tau}) \right) A(\tilde{\tau}) d\tilde{\tau} = 0 \tag{16}$$

The boundary conditions are

$$A(0) = 0 \qquad C(0) = 0. \tag{17}$$

We leave the details of derivations to Appendix B.

3.2. Calibration Methodology

Discretization. To bring the model to data, we discretize the maturity space into M maturity buckets, separated by a sequence of break-points $m(0) \equiv 0 < m(1) < m(2) < ... < m(M-1) < m(M) \equiv \infty$. With a slight abuse of notation, we use τ to denote the maturity bucket,

$\tau \in \{0, 1, ..., M-1\}$. A swap belongs to maturity bucket τ if its maturity is in $[m(\tau), m(\tau+1))$. We denote the average maturity of swaps in bucket τ by $\bar{m}(\tau)$.

We consider a discretized term structure for two reasons. First, it allows us to estimate investors' demand in each maturity bucket non-parametrically. We do not impose any parametric assumptions on demand side parameters $\theta_0(\tau)$ and $\theta_k(\tau)$: we allow the calibration exercise to uncover the underlying demand parameters of the preferred habitat investors, and we find that the signs are consistent with the direction of hedging demand given the types of institutions trading in each maturity bucket and the empirical counterparts reported in Section 2. Second, the preferred-habitat investor assumption is more likely to hold for a given maturity bucket than for a given maturity point.

Denote $s_t(\tau)$ as the average swap spread in maturity bucket τ, and $X_t(\tau)$ as the total swap holdings by the arbitrageurs in maturity bucket τ. Furthermore, the relative price of the swap can be written as $P_t(\tau) = \exp(-\bar{m}(\tau)s_t(\tau))$. Finally, we define $\delta(\tau) \equiv \frac{1}{\bar{m}(\tau)-\bar{m}(\tau-1)}$, which is the probability that a swap in maturity bucket τ transitions to maturity bucket $\tau-1$ in the next period. The discrete versions of Equation 15 and Equation 16 become

$$\Gamma^\top A(\tau) + [A(\tau) - A(\tau-1)]\delta(\tau) - \begin{pmatrix} 1 \\ 0 \end{pmatrix} = a \left[\sum_{\tilde{\tau}} \left(\theta(\tilde{\tau}) \begin{pmatrix} 0 \\ 1 \end{pmatrix} A(\tilde{\tau})^\top - \alpha(\tilde{\tau}) A(\tilde{\tau}) A(\tilde{\tau})^\top \right) \right] \Sigma\Sigma^\top A(\tau) \tag{18}$$

$$A(\tau)^\top \Gamma \begin{pmatrix} -\bar{c} \\ 0 \end{pmatrix} + \frac{1}{2} A(\tau)^\top \Sigma\Sigma^\top A(\tau) + [C(\tau) - C(\tau-1)]\delta(\tau) = a A(\tau)^\top \Sigma\Sigma' \sum_{\tilde{\tau}} \left(-\alpha C(\tilde{\tau}) + \theta_0(\tilde{\tau}) \right) A(\tilde{\tau}) \tag{19}$$

for all $\tau \geq 1$. Furthermore, the boundary conditions translate to $A(0) = C(0) = 0$.

Maturity groups. We set the number of maturity groups $M = 5$, with $m(1) = 0.05$, $m(2) = 0.25$, $m(3) = 5$ and $m(4) = 10$.[35] Under this definition of maturity groups, we find that the preferred-habitat assumption is satisfied for the majority of the end-user investors. As Table 4 shows, end-users typically concentrate their activities in a single maturity bucket. We find that the main preferred-habitat investors in maturity group one (below 3 months) are funds, while preferred-habitat investors in group two (maturity between 3 months and 5 years) include mainly banks, corporations, and funds. Moreover, in the longest maturity group (maturity 10 years & above), the dominant investors are PF&I.

[35] We need an ultra-short-term maturity group for boundary condition where the swap spread goes to 0. We take $m(1) = 0.05$ as an approximation for ultra short-term swap spreads.

For the first four maturity groups, we set $\bar{m}(\tau)$ to be the mid-maturity in the interval. For the last maturity group, we set $\bar{m}(\tau)$ to be 25, which is the empirically observed notional-weighted average maturity of swaps in that group. The parameters for the maturity buckets are summarized in Table 7.

Demand factor. We consider one aggregate demand factor, i.e., $K = 1$. This implies that we have two aggregate shocks in total, one for the supply side and one for the demand side. We refer to the shocks to arbitrageurs' funding cost c_t as supply shocks, and shocks to the demand factor $\beta_{1,t}$ as demand shocks. We do not take a stance on exactly what the demand factor is. The reduced form evidence in Table 2 suggests the demand factor is related to the level of the interest rate. Importantly, we do not impose any assumptions on Σ, which means that we allow contemporaneous supply and demand shocks to be potentially correlated.

Demand elasticities. We leverage the estimated distribution of the coefficients from Table 6 to pin down the demand elasticities for investors in different maturity buckets. Specifically, for each maturity bucket τ ($\tau = \{1, 2, 3, 4\}$), we draw an estimate from the empirical distribution in Table 6 and compute the demand elasticity $\alpha(\tau)$ accordingly.[36] For each set of demand elasticity coefficients drawn from Table 6, we calibrate the other parameters to target the moments described above, and then compute the counterfactual effects described in the next section. Since we will have a distribution of counterfactual effects, we report both the mean and the 90th confidence interval whenever applicable. Although we primarily focus on maturity groups two and four, where most of the preferred habitat investors reside, for completeness, we also estimate and input the elasticities of maturity groups one and three using the same instrument as before.

Parameter estimation using method of moments. We calibrate a total of 16 parameters in the model by matching a set of model-generated moments with the corresponding empirical moments. We estimate $2 \times (M - 1) = 8$ demand side parameters (θ_0 and θ_1 for maturity groups 1-4). We set the demand side parameters for group 0 to 0. We do not impose any assumptions on the demand parameters of the other groups. On the supply side, we need to calibrate the average funding cost $\bar{c}$ and the risk aversion coefficient a. Next, we calibrate the speed of mean reversion of the two state variables, captured in the Γ matrix. We assume that Γ is a diagonal matrix, i.e., the predictable components of the change in the demand factor ($d\beta_{1,t}$) and dealers' funding cost depend only on their own lag. Finally, we estimate 4 parameters in the Σ matrix, which includes the loadings on the Brownian shocks to the two state variables.

[36] The empirical distribution of the coefficient has mean equal to the point estimate, and standard deviation equal to the standard error in Table 6. We truncate the coefficients at zero.

We construct the empirical moments using monthly data on swap holdings and daily flow of new transactions. We calculate swap spreads for each maturity group using the actual fixed rate observed in our data for new transactions between end-users and dealers, and subtract from it the bond (gilt) yield of equivalent maturity. Then, we aggregate the swap spreads to a monthly frequency using a notional-weighted average.[37] We define quantities, Q_t, as in Equation 1.[38] For scaling reasons and consistent with Equation 2, we consider the change in quantity as

$$\Delta q_t = \frac{Q_t - Q_{t-1}}{(|Q_t| + |Q_{t-1}|)/2}. \tag{20}$$

To calibrate the parameters, we first target the volume-weighted average swap spreads and the average net notional held by end-users in our sample period. These moments are informative about the level of the hedging needs $\theta_0(\tau)$. We then target a set of second moments related to price and quantity changes. We target the variances of swap spreads changes ($\Delta s_t(\tau)$) and the variances of scaled quantity changes ($\Delta q_t(\tau)$) for maturity groups 1-4. The dynamics of spreads and quantities are informative about the law of motion of the supply and demand factors, as well as different sectors' exposure to the demand shock. We summarize the empirical moments in Table 8. The exact expressions for the model counterparts are presented in Appendix B.[39]

Sample splits. We compare the model simulated moments with the empirical moments for the overall sample and two subsamples. The Bank of England started raising interest rates significantly at the beginning of 2022, also accompanied by quantitative tightening in later periods. Such changes in the macroeconomic environment could significantly alter the demand of end-users and dealers' supply-side constraints. At the same time, we also observe that the shape of the swap spread curve has undergone significant changes over time (see Figure A6). Motivated by these patterns, we calibrate the model under different macroeconomic environments by splitting our sample period into two subsamples. The first subsample is from Dec 2019 to Dec 2021, capturing primarily the low-interest-rate environment, while the second subsample is from Jan 2022 to Jun 2024, capturing the high-interest-rate environment. Our calibration for the different subsamples uses the same set of moment conditions as before.

[37] Some trades erroneously report the fixed rate in terms of basis points instead of percentage points. We benchmark the fixed rate in our data with the maturity-matched daily market overnight indexed swap (OIS) fixed rate sourced from the Bank of England yield curve database. We retain trades where the difference between our fixed rate and the market OIS rate falls within 2.5% to 97.5% of its distribution.

[38] We only include investors with more than half of their trading volume in their respective dominant maturity buckets. We include all the large pension funds, but we only include their positions in the maturity bucket 10 years & above.

[39] To obtain closed form results in the model, we construct the model counterpart of Equation 20 as the change in quantity scaled by the absolute value of the average quantity. Since all the variables are stationary, this approximation is close.

Simulated vs. empirical moments. Figure 6 shows the fit between the empirical and model-implied moments. The model captures the average spreads and quantities across maturity groups well. In our full sample (Dec 2019 - June 2024), the swap spread along the maturity curve features a downward-sloping pattern: it decreases from 10 bps in the first maturity group to negative 78 bps in the longest maturity group. In contrast, in the first subsample, swap spreads have a hump-shaped pattern. We find that the model implied spreads closely align with these pattern. In terms of quantities, both in the model and in the data, on average, end-users in groups one and four are receiving fixed, end-users in group two are paying fixed, and group three has little outstanding amount because it is not a preferred habitat for any of the sectors. Panel A of Table 8 reports the remaining empirical moments for the full sample, which are also broadly consistent with the model implied moments. Panels B and C of Table 8 report the empirical moments for each subsample, respectively.

3.3. Calibrated Parameters

3.3.1. Full Sample Results

Table 9 column (1) shows the calibrated parameters for the full sample. First, we estimate that $\theta_0(4) < 0$ and $\theta_0(2) > 0$, indicating that investors in the long-end of the market (10 years & above), primarily PF&Is, demand receive fixed swaps. In contrast, investors in the short-intermediate maturity group, which include banks, corporations, and funds, demand pay fixed swaps. This is consistent with our reduced-form evidence in Section 2. Importantly, these estimates are derived without imposing any parameter restrictions during the calibration process. Second, we also find that the average $\theta_1(2)$ and $\theta_1(4)$ have opposite signs, which means that investors in the short-end and long-end have opposite exposure to demand shocks. These sensitivity estimates are also qualitatively consistent with the findings in Section 2 under the interpretation that the level of interest rates is part of the demand factor. When interest rates increase, long-term investors reduce demand to receive fixed rates while short-term investors reduce demand to pay fixed rates. The opposite signs of demand intercept and exposure to the demand factor confirm that institutions trading in the short-end are natural hedging counterparties for institutions trading in the long-end. However, demand segmentation and intermediation frictions prevent them from perfectly sharing risks with each other.

On the supply side, we estimate the risk aversion parameter to be 201.29 in the full sample, which can be interpreted as risk aversion per ten billion pounds of net position. To contextualize this estimate, we benchmark it against the net equity of dealers regulated in the UK using the Common Equity Tier 1 Capital (CET1) as a proxy for capital. UK dealers on aggregate held a CET1 of about GBP 150 billion in 2023. At these capital levels, our estimated parameter translates

to a relative risk aversion of about 13 (201.29 × 10 / 150). We also estimate the average funding cost parameter for the full sample to be 1%, which closely aligns with the balance sheet cost of 81 bps in Fleckenstein and Longstaff (2020) and He et al. (2022).

3.3.2. Subsample Comparison

We next present the calibrated parameters for each subsample period in columns (2) and (3) of Table 9. Comparing the supply-side coefficients, we find that the arbitrageurs' risk aversion and balance sheet costs are significantly higher in the second subsample as compared to the first. This suggests that supply-side constraints are more binding in a monetary policy tightening environment. Our results are consistent with early evidence of increased intermediation constraints of both risk-based (Cochran et al., 2024) and risk-insensitive regulatory measures (Tunstead, 2024). As we will see in the counterfactuals section, differences in supply-side frictions matter in how demand shifts affect swap spreads across the two subsamples.

3.4. Decomposing the Swap Spread Curve

We next analyze how various supply and demand side factors affect the level and the shape of the swap spread curve. We isolate the effect of individual parameter estimates by setting each parameter to zero one at a time and assessing changes in swap spreads. Panel (a) of Figure 7 presents our results.

Funding cost. We start with the model-implied swap spreads obtained using the calibrated parameter values. We first remove the average dealer sector funding cost by setting $\bar{c} = 0$. During our sample period, on net, the dealer sector holds positive amount of swaps in aggregate across all maturity groups. Dealers therefore demand positive swap spreads to compensate for the funding cost incurred. Hence, setting the average funding cost $\bar{c}$ to 0 leads to an almost parallel downward shift (reduction in the fixed rate) in swap spreads for all maturities with a magnitude of about 13 bps. We note that this change in the swap spreads is relatively small, compared to the average swap spreads in the data which range from negative 80 bps to 10 bps. As a result, eliminating the average funding cost still leaves swap spreads to be significantly different from zero, because of dealers' risk aversion. Shutting down the risks associated with dealers' positions completely (i.e., setting the risk aversion to zero), would indeed collapse swap spreads to zero, which is the frictionless equilibrium case.

Demand parameters. We next shut down the demand pressure parameters by setting the intercepts of all the preferred-habitat investors' demand to 0, i.e., $\theta_0(\tau) = 0$ for all τ. Panel (a) of Figure 7 shows that removing demand pressure essentially brings swap spreads to zero for all maturity groups. This shows that demand pressure plays a quantitatively significant role in driving the level and the shape of the swap spread curve. Similarly, setting the demand shocks to 0, i.e.,

$\beta_{1,t} = 0$, reduces the swap spreads for all the maturities because it reduces the risks borne by the dealer sector.

Arbitrageurs' risk aversion. Our analysis highlights that the large effect of demand pressure on swap spreads relies on the dealer sector being risk averse, which plays a pivotal role in amplifying the price impact of demand imbalances on swap spreads. The calibrated risk aversion coefficient for dealers is notably high, meaning local demand shocks in specific maturity buckets translate into larger spread adjustments as dealers require greater compensation for absorbing directional exposure. Indeed, when a approaches zero, demand pressure exerts minimal influence on spreads. This demonstrates that swap spread dynamics arise from the interaction between end-user demand and dealers' risk-bearing capacity.

Regulatory constraints may further amplify this mechanism by implicitly raising dealers' effective risk aversion, as prudential rules limit balance sheet flexibility. Empirically, reducing a by half in our calibration—simulating decreased risk aversion—leads to material compression in spreads: +5 bps in short-intermediate maturities and +35 bps in long maturities (panel (b) of Figure 7). These shifts occur because less risk-averse arbitrageurs demand lower compensation for holding maturity-mismatched positions. The results underscore how post-crisis regulations, by constraining dealer risk appetite, structurally alter swap spread equilibria beyond the direct effect of persistent demand imbalances.

4. Demand Imbalance Counterfactuals and Swap Spreads

In this section, we evaluate the extent to which the distribution of demand imbalances influences the term structure of the swap spreads. The term structure determines the relative hedging costs faced by different end-users. For example, a relatively flat curve would lead different sectors to have similar hedging costs. However, as the curve deviates from this benchmark, hedging costs start to become sector-specific, varying across different maturity groups. Answering this question is inherently challenging because demand imbalances are determined in equilibrium, making it empirically difficult to distinguish whether they shape the swap spread curve or are themselves influenced by it. In other words, we require exogenous shocks that significantly change the distribution of demand imbalances. We make progress by leveraging our equilibrium framework which allows us to evaluate counterfactual scenarios where we vary the size and the composition of imbalances across maturity groups.

We proceed in 3 steps. First, we evaluate two polar cases to demonstrate that the distribution of demand imbalances is a crucial factor that determines the shape of the swap spread curve. Second, we ask how changes in the demand of one sector (which affects demand imbalances) affect the hedging costs of other sectors. Specifically, we quantify the implications of increased PF&I demand

on banks' hedging cost, and vice versa. This analysis helps trace the potential externalities of regulating specific sectors. Finally, we characterize the term structure of swap spreads in a market where PF&Is strategically shift part of their demand to a shorter maturity group in order to reduce hedging costs.

4.1. Does the Distribution of Imbalance Matter?

To quantify the impact of a shift in the distribution of demand imbalances, we change the demand of specific end-user sectors and consider the implications for swap spreads. Specifically, we alter the volume of imbalances in two key maturity groups (short-intermediate and long), which changes the *type* of imbalances that have to be borne by the dealer sector. To do so, we set the demand intercept, θ_0, to zero for the two maturity groups, one at a time. We keep all the other parameters unchanged. This means that we are able to evaluate two polar scenarios. In the first scenario, we set $\theta_0(2) = 0$, i.e. we assume that investors in the second maturity group, e.g., banks, have no demand for swaps.[40] In the second scenario, we set $\theta_0(4) = 0$, i.e. we assume that investors in the fourth maturity group, predominantly PF&I, have no demand for swaps. For each scenario, we compute the counterfactual swap spreads for every maturity group. Figure 8 shows the counterfactual swap spreads compared with the actual swap spreads. There are two key results.

When banks' demand intercept is set to zero. Our first result highlights the role of banks' swap demand in explaining the term structure of swap spreads. When banks do not demand swaps, swap spreads turn more negative across maturities, with the most pronounced effect occurring in the long maturity group. Intuitively, banks' swap demand offsets a part of PF&I positions because banks trade in the opposite direction. This reduces the aggregate net risk borne by dealers. However, in the absence of bank demand, dealers are exposed to a larger demand imbalance, which increases the risk of holding long-term pay fixed positions. As a result, dealers demand greater compensation for holding long-term pay fixed positions in the form of lower swap spreads. The same channel also reduces swap spreads in short-tenor swaps, albeit with a smaller magnitude due to lower riskiness of short-tenor positions.

One interpretation of these results is that they provide a benchmark for comparing UK swap spreads with those of other countries where, unlike the UK, the banking sector exhibits limited hedging demand in swaps. For example, McPhail et al. (2023) show that US banks do not hedge interest rate risk using swaps in a meaningful way. By setting the demand intercept of banks to zero, our analysis shows the counterfactual swap spreads in the absence of hedging demand from banks. Consistent with the empirically observed negative swap spreads in shorter maturity buckets

[40] While maturity bucket two also includes funds and corporations, in addition to banks, corporate positions are small and funds hold large positions only briefly during our sample period (Figure 3). Hence, we assume that the demand of the banking sector defines this bucket.

in the US, as shown in Figure A7, we find that the UK swap spreads also become negative in shorter maturity buckets. In other words, when we shut down the hedging demand of UK banks, the counterfactual term structure of swap spreads start to appear closer to the observed spreads in the US. This highlights the importance of the distribution of demand imbalances in potentially explaining the relative differences in the swap spread curves across countries.

When PF&Is' demand intercept is set to zero. We next consider the role of PF&I swap demand in explaining the shape of the swap curve. When PF&I do not demand long-tenor swaps, the swap spread curve becomes upward sloping with spreads turning positive across maturities. At shorter maturities, dealers now demand a higher fixed rate to supply swaps. Long-term swap spreads also rise substantially, indicating that dealers are willing to forego a higher amount to attract opposite receive fixed positions.

A lower PF&I demand could arise due to several factors. First, the PF&I sector in many countries may be substantially smaller relative to banks. For example, economies that are more bank-based than capital-market-based, economies with pay-as-you-go (PAYGO) pension systems, developing or younger economies could all have a small pension sector. In addition, even in economies with a large pension and insurance sector, the availability of substitute assets (e.g., long-term bonds) could result in lower PF&I demand for swaps.[41] These factors affect the size of PF&I demand relative to that of bands and therefore swap spreads across maturities.

The key feature of our framework that generates cross-maturity spillover effects is the presence of risk-averse arbitrageurs who jointly optimize their positions across maturities. In frictionless markets with perfectly elastic supply curves, demand imbalances would not affect asset prices. In more realistic settings, regulatory frictions (e.g., Boyarchenko et al. (2018)) and balance sheet constraints (e.g., Jermann (2020)) create inelastic supply curves, leading demand shocks to impact prices at maturities where they originate. For instance, PF&I demand, highlighted in Klingler and Sundaresan (2019), can interact with other sources of risk, such as convergence risk in long-term swap spreads (Hanson et al. (2024)), to influence prices. Despite these mechanisms, existing models do not generate cross-maturity spillovers. For example, Hanson et al. (2024) do not incorporate maturity segmentation with detailed quantity data, while other studies such as Bahaj et al. (2023) assume desk-level separation, preventing linkages across tenors. These frameworks cannot properly account for the transmission of demand shocks across maturities. In contrast, our empirical findings suggest that while end-users are preferred habitat investors, dealers actively participate across maturities. As in Vayanos and Vila (2021), dealers offset imbalances across different tenors which exposes them to the risk of non-parallel shifts in the term structure of swap spreads. This means

[41] For example, the UK gilt market is much smaller at $3 trillion relative to the size of its pension sector at $4.2 trillion (UK Debt Management Office). In contrast, the US Treasury market is valued at $28 trillion relative to the size of its pension sector at $24.5 trillion (Investment Company Institute, 2025).

that shifts in the distribution of demand imbalances—both in magnitude and origin—can influence the entire shape of swap spreads curve, generating the cross-maturity effects we document.

4.2. Quantifying the Cross-Sector Spillovers

We next quantify the impact of demand shifts for a given sector on changes in hedging costs and quantities for the other sectors. As before, we consider changes in the average level of demand, i.e., θ_0. We treat factors affecting the banking sector's hedging demand as changing the demand intercept of investors in maturity group two, which is the dominant maturity bucket for banks. Likewise, we model factors affecting pension funds' hedging demand as changing the demand intercept of investors in maturity group four, which is where the majority of pension funds' trades are. In both cases, we increase the magnitude of the demand intercept by 20%. Note that a higher demand for banks implies a smaller $\theta_0(2)$ i.e. more pay fixed positions, while a higher demand for PF&I means a larger $\theta_0(4)$, i.e. more receive fixed positions. Figure 9 and Figure 10 plot the difference between the counterfactual and the actual swap spreads for the two subsamples. We have the following results.

Cross-sector spillovers. First, when banks hedge more, swap spreads rise in all maturity groups, as seen in panels (a) and (c). This means that the hedging costs *increase* for banks, since they pay fixed, but *decrease* for PF&I, since they receive fixed. Similarly, when PF&I hedge more, swap spreads fall in all maturity groups, as seen in panels (b) and (d). That is, the hedging costs *increase* for PF&I but *decrease* for banks. In other words, in both cases, given that banks and PF&Is have offsetting positions, an increase in one sector's hedging demand *reduces* the hedging cost for the other sector.

Time-series heterogeneity. Second, comparing the magnitudes across the two subsamples, we see that the counterfactual swap spreads are much larger in the second subsample. This makes sense given the substantially higher balance sheet costs and larger risk aversion we estimate for the dealer sector in the second part of the sample. This implies that the same demand shock leads to higher swap spreads in the second subsample relative to the first subsample, reflecting the higher supply-side constraints faced by dealers.

Heterogeneity by demand elasticities. Third, we ask how end-users' demand elasticities change the impact of the demand shifts on swap spreads and investors' hedging costs. Specifically, we evaluate the case where end-users become 50% less elastic. We plot the change in the swap spreads in panels (c) and (d) for the two cases: when banks' hedging demand increase and when PF&Is' hedging demand increase for each subsample in Figure 9 and Figure 10. We find that a demand shift of the same magnitude has a greater impact on swap spreads when end-users are more inelastic. Intuitively, when investors are less responsive to price changes, quantities adjust less, causing the

demand shock to be absorbed primarily through larger adjustments in swap spreads.

Origin of demand shifts. Fourth, we evaluate whether the effect of demand shifts differs depending on where the shocks originate. Comparing panel (c) and panel (d) in Figure 9 and Figure 10, we find that the effect on swap spreads is much larger when the demand shift happens in the PF&I sector, even though the absolute magnitude of the demand change in maturity group four is smaller (because of lower average net position compared to group two). In fact, the impact of the demand shift on swap spreads is 3-4 times larger if the demand shift occurs in maturity bucket four compared to the demand shift in maturity bucket two. Intuitively, demand imbalances in longer maturity groups expose the dealer sector to more risks, hence each unit of long-maturity demand has a larger impact on asset prices compared to the demand in short-intermediate maturity swaps. Furthermore, regardless of where the demand shift originates, its impact on spreads is monotonically increasing in swaps' maturities. In both cases, the change in swap spreads in the longest maturity bucket is much larger than the change in the second maturity bucket. We conclude that the shape of the swap spreads curve reacts differently to changes in both the magnitude and the specific source of demand imbalances.

Quantifying the cross-sector hedging cost spillovers. To illustrate the economic magnitudes, we next present a simple back of the envelope estimation of the effect of the demand shifts on hedging costs of the various end-user sectors. Panel (a) of Figure 9 and Figure 10 show that a 20% increase in banks' hedging demand would raise swap spreads by 10 bps in the long maturity bucket in the first subsample and by 13 bps in the second subsample. This implies substantial savings for the PF&I sector, the primary investors in this maturity group. For example, in the second subsample, the increase in swap spreads translates to approximately GBP 2 billion ($\approx 0.13\% \times 63$ billion $\times$ 25 years) lower hedging costs over the typical life of swaps traded by this sector. In theory, part of the savings is offset because PF&I demand more swaps as hedging costs decline. However, we note that because PF&I demand is relatively inelastic, this effect is muted and the net notional exposure does not change meaningfully. The demand shock also raises swap spreads in the short-intermediate maturity group by about 4 bps, thereby increasing the hedging costs for banks themselves by approximately GBP 165 million ($\approx 0.04\% \times 151$ billion $\times$ 2.75 years) over the typical life of swaps traded.

On the other hand, a 20% increase in PF&I's hedging demand would reduce the swap spread faced by banks by about 11 bps and the swap spread faced by the PF&I sector by 43 bps in the second subsample. This leads to an estimated GBP 456 million ($\approx 0.11\% \times 151$ billion $\times$ 2.75years) reduction in average hedging costs for banks, the primary investors in the second maturity group. In contrast, the demand shock also reduces the swap spreads for the PF&I sector itself, increasing their hedging costs by an estimated GBP 6.8 billion ($\approx 0.43\% \times 63$ billion $\times$ 25 years). The effects are even larger when we consider end-users to have more inelastic demand. For example, if investors

were half as elastic as our empirical estimates suggest, then the same 20% increase in PF&I demand in the second subsample would lead to an estimated GBP 820 million reduction in average hedging costs for banks and an estimated GBP 10.2 billion increase in average hedging costs for PF&I.

4.3. Market Integration

A key friction that determines the distribution of imbalances is the mismatch in the maturities of offsetting trades, which leads dealers to absorb imbalances at various maturity points. We consider a scenario where the market is less segmented, such that dealers are able to offset a larger fraction of end-user demand *within* a given maturity group. Specifically, we consider a scenario where the swap market was more integrated on the demand-side. To do so, we shift a part of the long maturity receive fixed demand to short-intermediate maturity group, and study its impact on the term structure of swap spreads. We conduct this exercise separately for the two subsample periods.

We consider a case where $\gamma = 20\%$ of the demand from maturity group four is moved to group two. We adjust the demand parameters in the two maturity groups in the following way:

$$\theta_0'(2) = \theta_0(2) + \gamma \times \theta_0(4) \qquad \theta_0'(4) = (1-\gamma) \times \theta_0(4) \tag{21}$$

$$\theta_1'(2) = \theta_1(2) + \gamma \times \theta_1(4) \qquad \theta_1'(4) = (1-\gamma) \times \theta_1(4) \tag{22}$$

$$\alpha'(2) = \alpha(2) + \gamma \times \alpha(4) \qquad \alpha'(4) = (1-\gamma)\alpha(4) \tag{23}$$

The remaining demand parameters $\theta_1'(\tau)$, $\theta_0'(\tau)$ and $\alpha'(\tau)$ are equal to the baseline estimates for $\tau = 0, 1, 3$.

Figure 11 shows that moving a part of PF&I demand to the maturity group of banks shifts the swap spread curve upwards in both the subsamples. There are two channels behind this equilibrium pricing effect. First, there is a local effect where moving part of the PF&I demand to the same group as banks reduces the demand imbalance *within* each maturity group. This leads to a narrowing of swap spreads in both the maturity groups. Second, there is a "global" effect where dealers' overall position (negative DV01) reduces because of a reduction in long-tenor pay fixed positions that carry much higher DV01 risk relative to an increase in the short-tenor position of equal size. This leads to an upward shift in the entire swap spread curve, reinforcing the positive impact on maturity group four but offsetting the decline in swap spreads in maturity group two. We find that the global effect dominates such that for group two, swap spreads turn slightly more positive. The effects are particularly more pronounced in the second subsample given that supply-side frictions are higher.

Market integration can be motivated by situations where PF&I strategically shorten the maturity of their swaps to capture higher swap spreads. Another source of integration would arise from

banks and PF&Is operating within the same entity. This would enable internal positions to offset, allowing the entity to manage interest rate risk on a smaller net position basis, thereby reducing overall hedging costs. As our results show, a more integrated market would substantially reduce the hedging costs borne by PF&Is, with a slightly higher hedging costs for banks. At the same time, PF&I would be exposed to rollover risk, which may be large when interest rates are volatile. The extent of market integration and cost savings would therefore depend on several factors, including the regulatory treatment of intra-group exposures, the relative balance sheet sizes of banks and PF&I, and the degree to which investors are willing to bear rollover risk.

5. Conclusion

This paper provides the first large-scale empirical evidence on the extent of risk sharing in the interest rate swaps market, and quantifies how demand imbalances and frictions in the dealer sector affect swap spread dynamics. Using granular transaction-level data on both the stock and the flow of swap trades, we show that the PF&I sector emerges as a natural counterparty to banks and corporations. While PF&I mostly receive fixed, banks and corporations pay fixed. Furthermore, as rates fall, PF&I increase their net receive positions, while banks and corporations increase their net pay positions. Their trading behavior is consistent with them hedging interest rate risk from their underlying business models. The opposite positions of PF&I vis-a-vis banks and corporations imply that they are natural counterparties in the interest rate swap market, and this cross-sector netting reduces the aggregate net demand that has to be supplied by the dealers. However, the market is highly segmented across maturities: PF&I mostly hold long maturity swaps of 10 years & above, while banks and corporations mainly hold positions with maturities between 3 months to 5 years. This segmentation leaves large demand imbalances for dealers at different maturities.

We study the implications of demand imbalances on asset prices by calibrating a preferred-habitat investors model with risk-averse arbitrageurs, who face both funding cost shocks and demand side fluctuations. The richness of our data allows us to impose very little assumptions in our calibration. We find that the demand pressure, especially from the banking and PF&I sector, plays a relatively larger role than arbitrageurs' funding costs in explaining the shape of the swap spread curve. We also provide quantitative assessments of the spillover effects of sector-level demand shifts on the hedging costs of other sectors, which inform regulatory discussions on hedging requirements in light of recent events in the banking and PF&I sectors. Our results highlight the complex interactions and consequences of demand imbalances in one of the largest and most liquid financial markets in the world.

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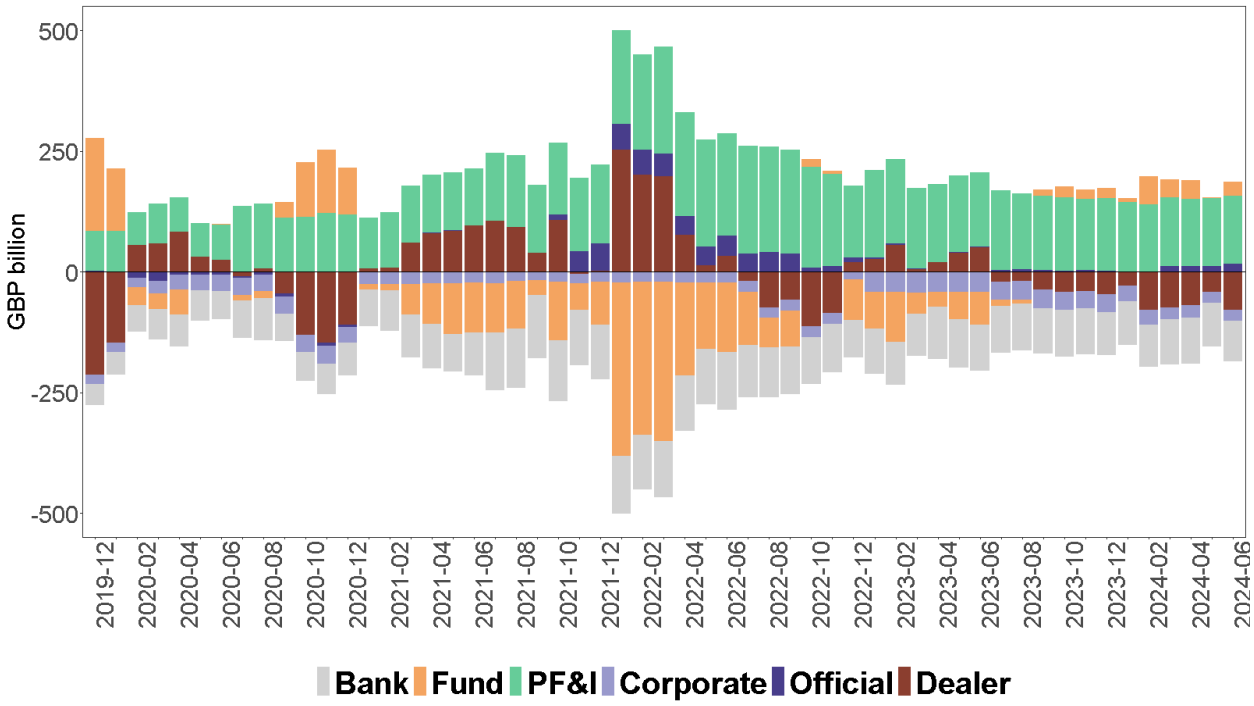
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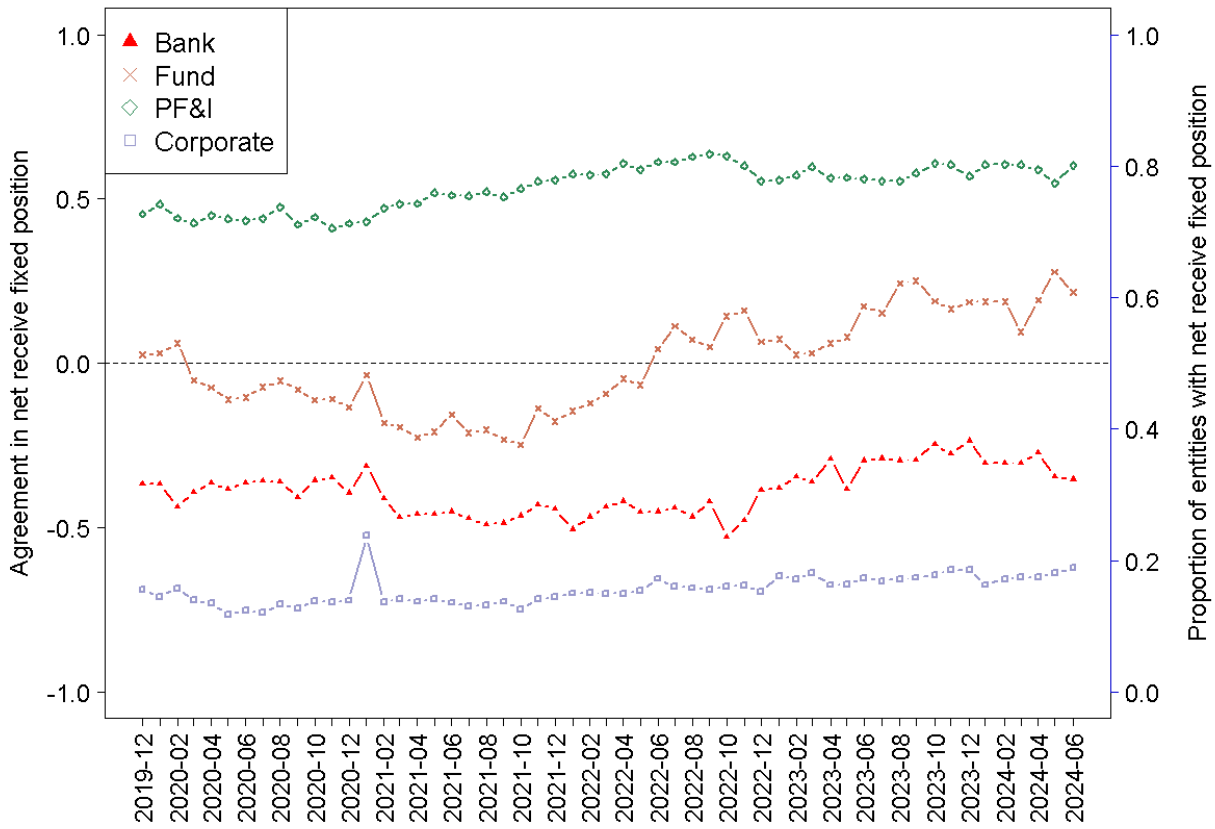
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Figure 1: Net Outstanding Positions



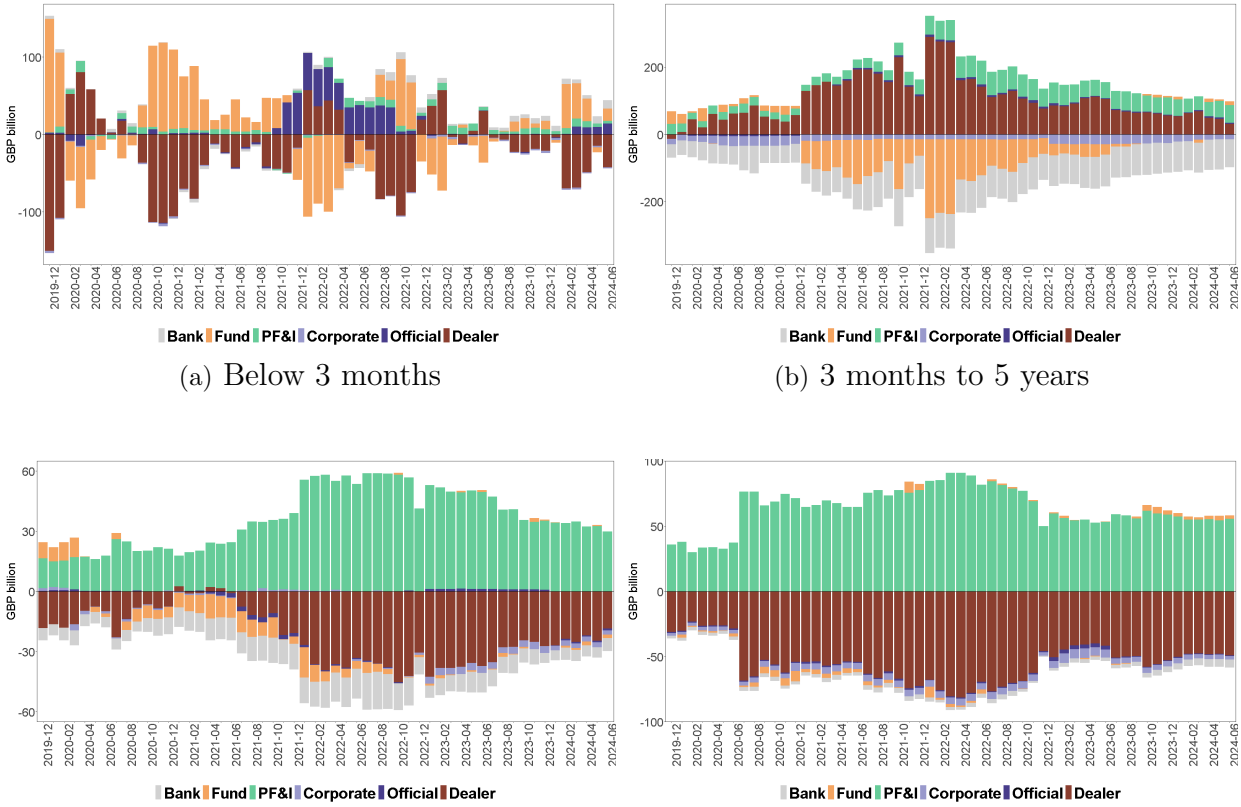
Notes: This figure shows net outstanding positions in GBP billion at the start of every month for five end-user sectors and the dealer sector. A positive value on the y-axis indicates a net receive fixed position while a negative value indicates a net pay fixed position. Net outstanding position is calculated as the difference between the outstanding notional values of receive fixed rate and pay fixed rate swaps for each legal entity as per Equation 1, and then aggregated for five end-user sectors: Bank, Fund, PF&I (pensions, liability-driven investment funds, and insurance), Corporate, and Official (sovereign and supra-national institutions). We calculate the net outstanding position for the dealer sector as the opposite side of aggregate end-user positions such that the market clears. This figure considers swaps denominated in British pound sterling (GBP), while Figure A1 considers swaps denominated across all currencies in our sample.

Figure 2: Exposure Heterogeneity within Sectors



Notes: This figure depicts within-sector heterogeneity in exposures using entity-level net positions at the start of every month. We use two measures of exposure heterogeneity. The left axis represents an agreement score, where each entity gets a score of +1 if it has a net receive fixed outstanding position, or -1 if it has a net pay fixed outstanding position. We then plot the monthly time-series of an average score across all entities within each sector. A score closer to zero indicates large disagreement within the sector, a score closer to +1 (-1) indicates that most entities hold net receive (pay) fixed position. The second measure is depicted on the right axis which shows the proportion of entities within each sector that held a net receive fixed position. About 80% of PF&I (pensions, liability-driven investment funds, and insurance) held net receive fixed positions during the sample period, while 80% of corporations and 70% of banks held net pay fixed positions. Funds displayed the largest heterogeneity with a roughly equal split between net receive and net paid positions.

Figure 3: Net Outstanding Positions by Maturity Group



(a) Below 3 months

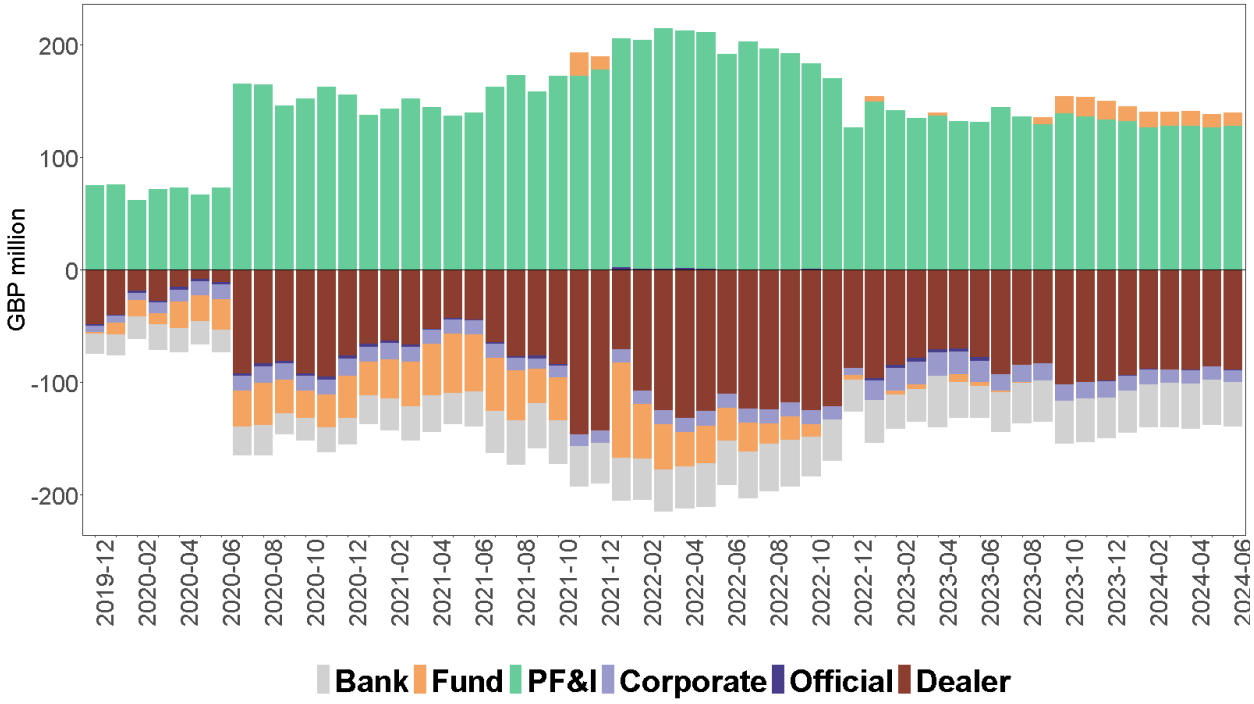
(b) 3 months to 5 years

(c) 5 years to 10 years

(d) 10 years & above

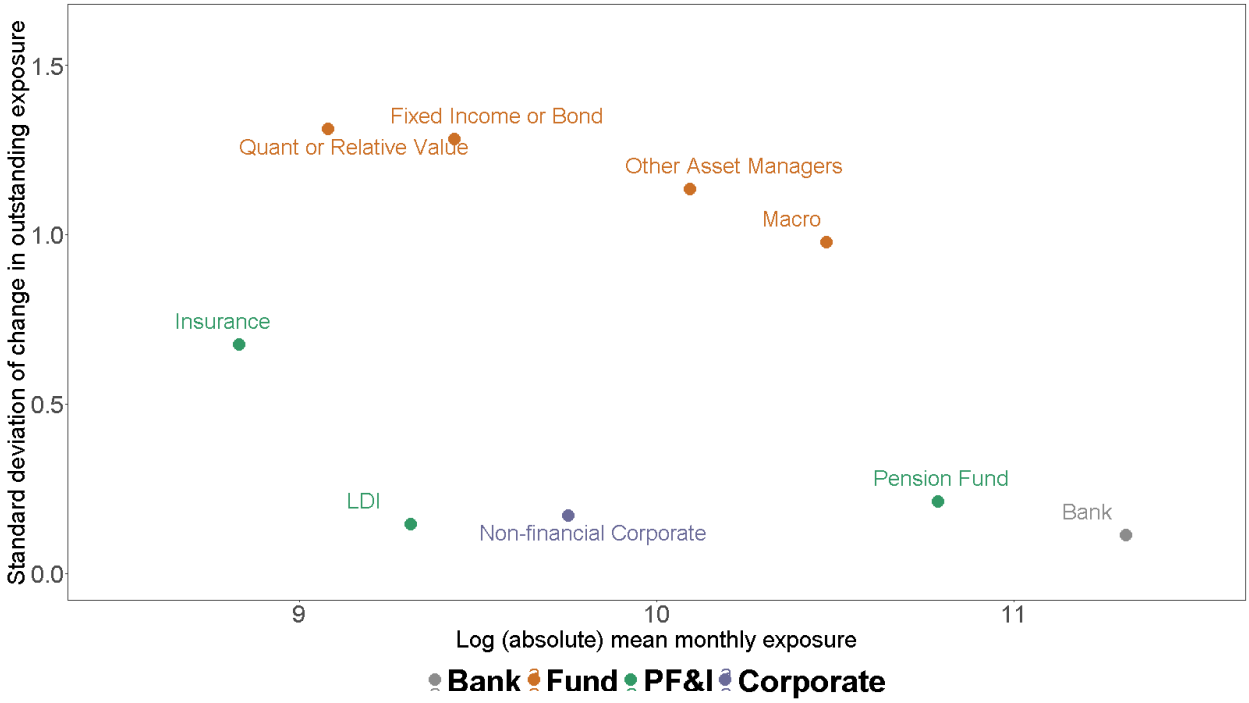
Notes: This figure shows net outstanding positions in GBP billion at the start of every month for five end-user sectors and the dealer sector, split by four maturity groups: Below 3 months in panel (a), 3 months to 5 years in panel (b), 5 years to 10 years in panel (c), and 10 years & above in panel (d). A positive value on the y-axis indicates a net receive fixed position while a negative value indicates a net pay fixed position. Net outstanding position is calculated as the difference between the outstanding notional values of receive fixed rate and pay fixed rate swaps for each legal entity as per Equation 1, and then aggregated for five end-user sectors: Bank, Fund, PF&I (pensions, liability-driven investment funds, and insurance), Corporate, and Official (sovereign and supra-national institutions). We calculate the net outstanding position for the dealer sector in each maturity group as the opposite side of aggregate end-user positions such that the market clears.

Figure 4: Net Outstanding DV01



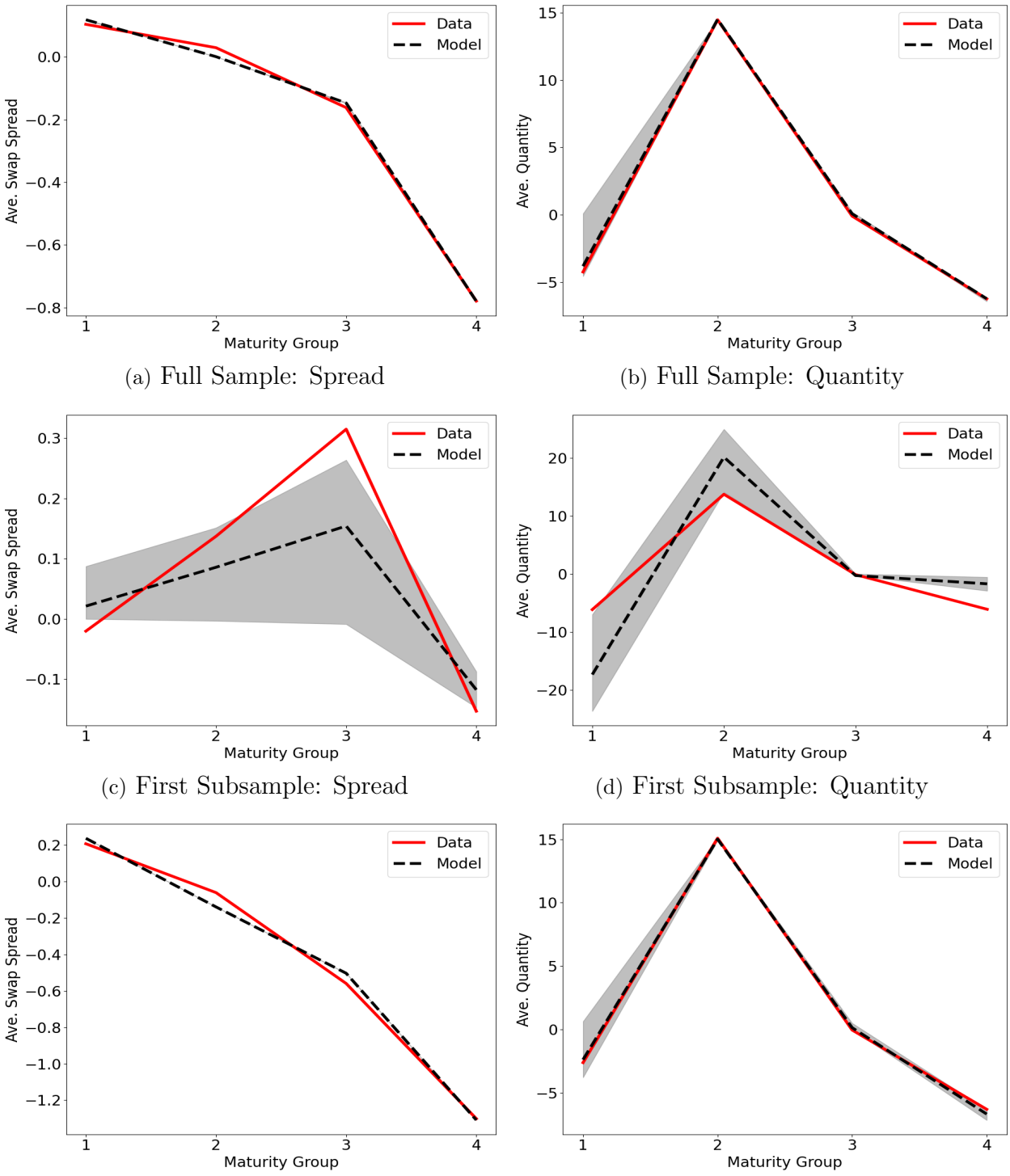
Notes: This figure shows net outstanding DV01 in GBP million at the start of every month for five end-user sectors and the dealer sector. DV01 refers to the change in dollar value of swaps for one basis point parallel shift in the interest rate curve. A positive value on the y-axis indicates a net positive DV01 (i.e., the value of swap increases with a downward shift in the interest rate curve) while a negative value indicates a net negative DV01. The net outstanding DV01 for the dealer sector is calculated as the opposite side of aggregate end-user positions such that the market clears. We fix the duration measure as at the beginning of our sample period such that the variation depicted in this figure reflects active trading by investors. This figure considers swaps denominated in British pound sterling (GBP), while Figure A1 considers swaps denominated across all currencies in our sample.

Figure 5: Investor Size and Exposure Volatility



Notes: This figure plots the relationship between size of sub-sectors and volatility in their outstanding positions. Sub-sectors include the four types of Funds and three types of PF&I, with a single representation each from Bank and Corporate. The x-axis reports the size of each sub-sector, calculated as the log of mean (absolute) net monthly exposure observed during our sample period. The y-axis represents the corresponding standard deviation of the change in monthly outstanding positions within the dominant maturity group for that sector. Dominant maturity groups are: 3 months to 5 years for Bank and Corporate, below 3 months for Fund, and 10 years & above for PF&I. Changes in monthly outstanding positions are scaled to enable comparison and mitigate the effect of outliers. This variable is defined in Equation 2 and is bounded between -2 and +2. All sub-sectors are represented on the plot using the color of the overall sector as reported in the legend.

Figure 6: Comparing Model Simulated Moments with Empirical Moments



(a) Full Sample: Spread

(b) Full Sample: Quantity

(c) First Subsample: Spread

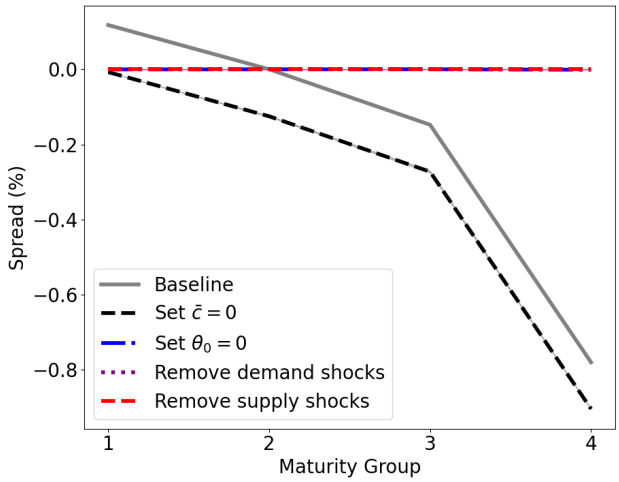
(d) First Subsample: Quantity

(e) Second Subsample: Spread

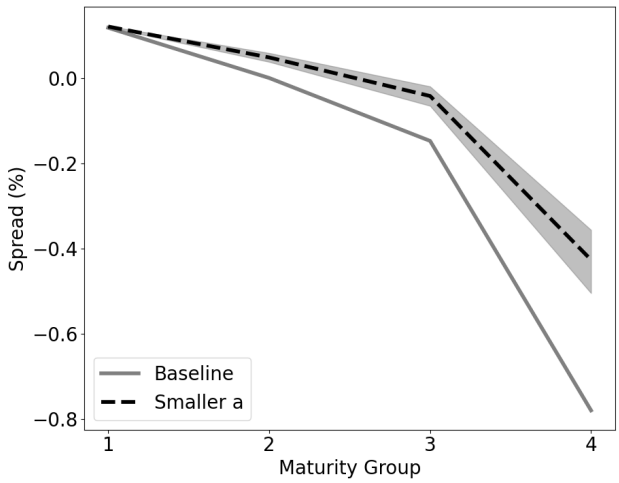
(f) Second Subsample: Quantity

Notes: This figure compares the model simulated moments with the corresponding empirical moments from the data. The shaded region indicates the 90th percentile confidence interval. All the spreads and yields are quoted in percentage terms.

Figure 7: Decomposing the Swap Spread Curve



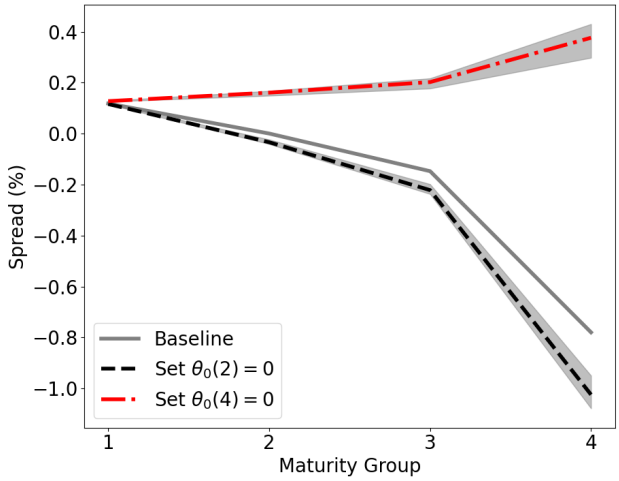
(a) Shut down funding costs and demand shocks



(b) Halve arbitrageurs' risk aversion

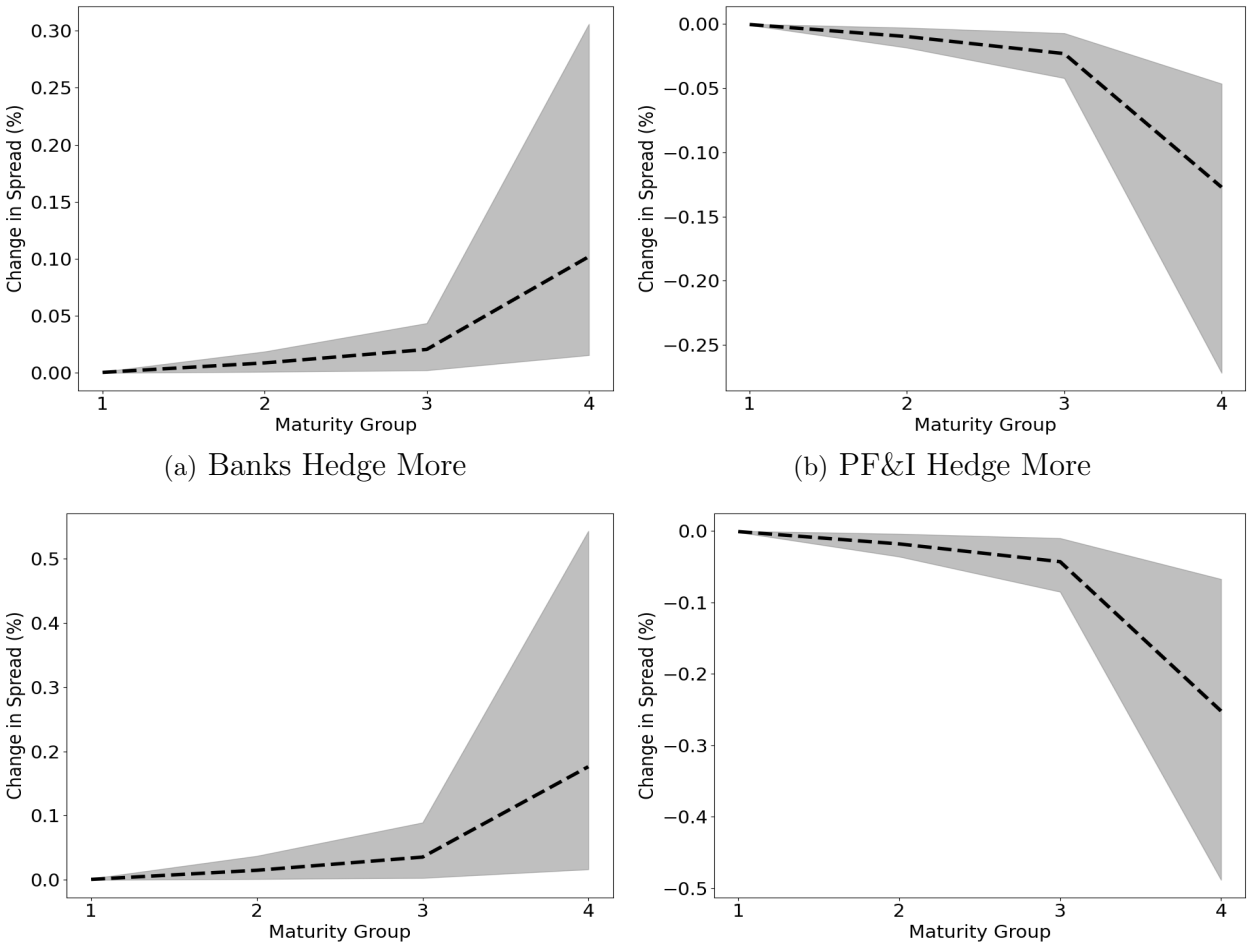
Notes: This figure plots the average swap spreads for different scenarios. In panel (a), we start with the baseline swap spreads (in grey), then we set $\bar{c} = 0$ and recalculate the swap spreads in equilibrium. Next, we set $\theta_0(\tau) = 0$ for all τ. We then remove demand side shocks, i.e. $d\beta_{1,t} = 0$ and finally remove all supply side shocks $dc_t = 0$. Spreads are quoted in percentage terms. In panel (b), we consider a scenario where the arbitrageurs become half as risk averse as in the baseline case, and recalculate the equilibrium swap spreads. The shaded area indicates 90th percentile confidence interval.

Figure 8: Distribution of Imbalances and Swap Spreads



Notes: This figure plots the average swap spreads when demand of one sector is set to zero one at a time. We set $\theta_0 = 0$ for one maturity group at a time and recalculate the equilibrium swap spreads. Spreads are quoted in percentage terms. The shaded area indicates the 90th percentile confidence interval.

Figure 9: Counterfactual Analysis on Demand Pressure — First Subsample



(a) Banks Hedge More

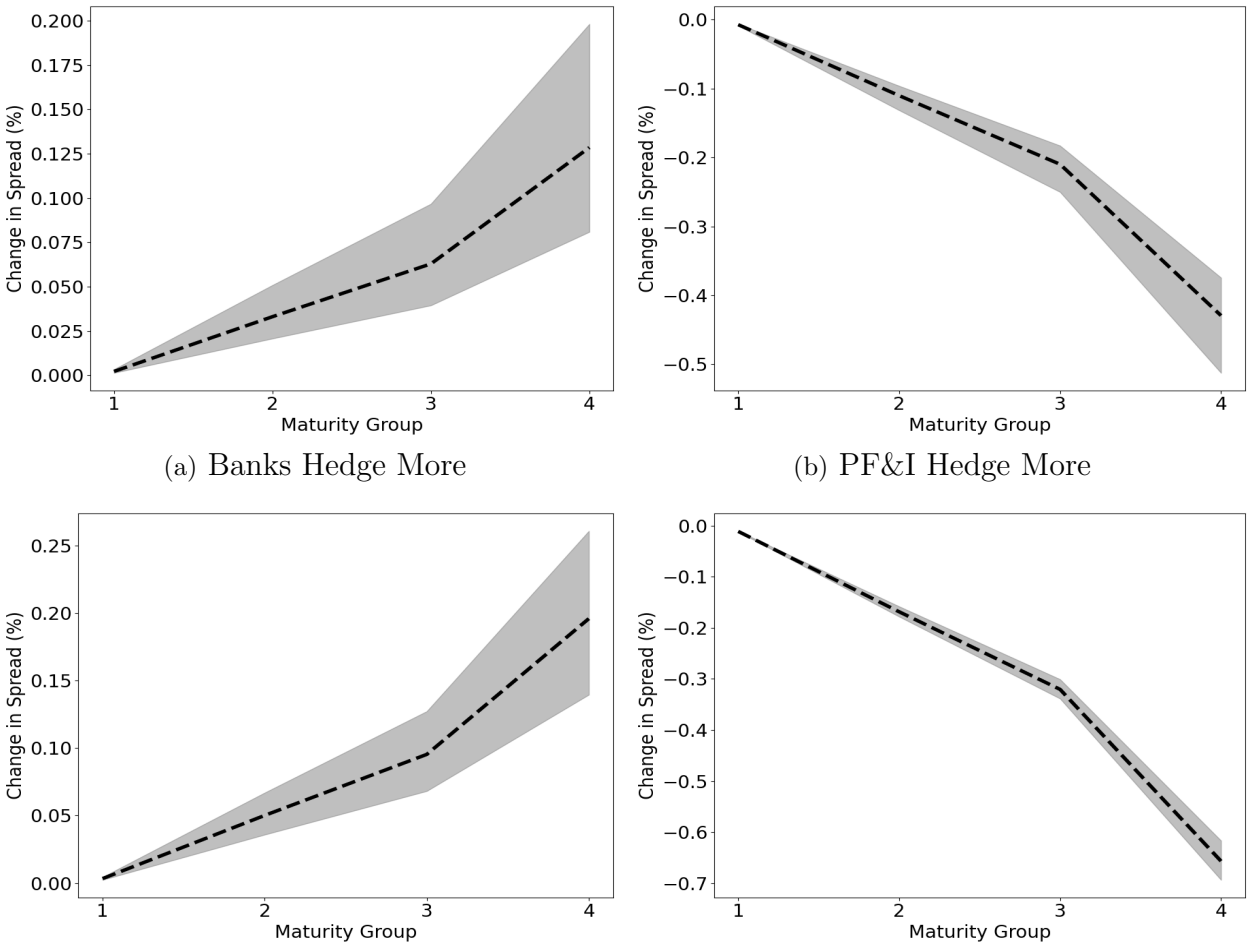
(b) PF&I Hedge More

(c) Banks Hedge More (Inelastic Demand)

(d) PF&I Hedge More (Inelastic Demand)

Notes: Panels (a) and (b) plot the counterfactual change in swap spreads when the magnitudes of $\theta_0(2)$ and $\theta_0(4)$ increase by 20% respectively. Panels (c) and (d) plot the changes in spreads for the two counterfactuals when demand elasticities for all sectors decrease by a half. The sample period for this analysis is December 2019 through December 2021.

Figure 10: Counterfactual Analysis on Demand Pressure — Second Subsample



(a) Banks Hedge More

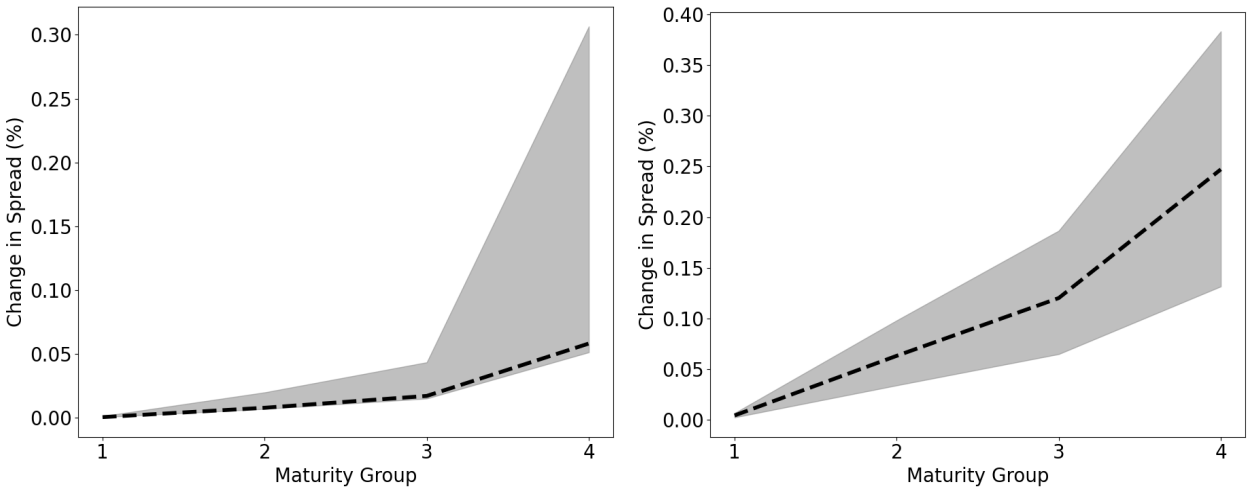
(b) PF&I Hedge More

(c) Banks Hedge More (Inelastic Demand)

(d) PF&I Hedge More (Inelastic Demand)

Notes: Panels (a) and (b) plot the counterfactual change in swap spreads when the magnitudes of $\theta_0(2)$ and $\theta_0(4)$ increase by 20% respectively. Panels (c) and (d) plot the changes in spreads for the two counterfactuals when demand elasticities for all sectors decrease by a half. The sample period for this analysis is December 2021 through June 2024.

Figure 11: Counterfactual Analysis on Market Integration



(a) First Subsample (b) Second Subsample

Notes: This figure considers the counterfactual in which we move 20% of the demand in group 4 to group 2. For group 1 and 3 we do not change the demand parameter. For group 2 and 4, we adjust the demand parameters according to Equation 21 through Equation 23.

Table 1: Outstanding Positions and Transaction Volume

	Outstanding Positions (GBP billion, as on Feb 1, 2022)			Transaction Volume (GBP billion, monthly average)	
	Gross notional	Net notional	Net DV01	Gross notional	Net notional
	(1)	(2)	(3)	(4)	(5)
Bank	364	-112	-37	41	-2
Fund	1,187	-317	-48	1,322	9
PF&I	1,007	197	203	73	9
Corporate	68	-21	-12	3	-1
Official	73	53	1	13	0

Notes: This table reports the outstanding positions and new transaction volumes in GBP billion for five end-user sectors: Bank, Fund, PF&I (pensions, liability-driven investment funds, and insurance), Corporate, and Official (sovereign and supra-national institutions). Column (1) reports the gross outstanding notional as on February 1, 2022, column (2) reports the net outstanding notional, and column (3) reports the net DV01. A positive value indicates a net receive fixed position while a negative value indicates a net pay fixed position. Column (4) reports the average monthly gross notional traded by each sector throughout our sample period, and column (5) reports the average monthly net notional traded. All values are for swaps denominated in British pound sterling (GBP).

Table 2: Changes in Interest Rates and Swap Exposure

Panel A	Δ Quantity (scaled)			
	Bank	Fund	PF&I	Corporate
Δ Rate (PC1, t-1)	0.063***	0.011	-0.050***	0.114***
	(0.024)	(0.019)	(0.011)	(0.014)
Δ Rate (30Y yield, t-1)	0.135***	-0.032	-0.084***	0.213***
	(0.047)	(0.035)	(0.021)	(0.026)
Δ Rate (10Y yield, t-1)	0.099**	0.004	-0.083***	0.190***
	(0.043)	(0.033)	(0.019)	(0.025)
Δ Rate (5Y yield, t-1)	0.065*	0.026	-0.074***	0.161***
	(0.037)	(0.030)	(0.017)	(0.022)
Δ Rate (3M yield, t-1)	0.093**	0.072**	-0.060***	0.114***
	(0.036)	(0.032)	(0.018)	(0.022)
N	6,264	22,536	29,901	13,965
Investor FE	Yes	Yes	Yes	Yes
Panel B	Δ DV01 (scaled)			
	Bank	Fund	PF&I	Corporate
Δ Rate (PC1, t-1)	0.041*	0.030	-0.042***	0.116***
	(0.024)	(0.019)	(0.012)	(0.015)
N	6,244	22,456	29,879	13,824
Investor FE	Yes	Yes	Yes	Yes

Notes: This table reports estimates of a fixed-effects panel regression for a model of the form in Equation 2. In Panel A, the dependent variable is the change in monthly outstanding net position held by an investor within a sector, while in panel B it is the net DV01 of these positions. Both the dependent variables are scaled to reflect approximate percentage changes and are bounded between +/- 2. Panel A presents separate estimation results using 5 regressors: the first principal component (PC1) of 3 month, 5 year, 10 year, and 30 year GBP bond (gilt) yields, and then each of these yields individually. For brevity, panel B shows estimates using PC1 only. All regressors are expressed as monthly changes and lagged by one period. All columns include investor fixed effects. Standard errors clustered by investor are reported in parentheses. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 3: Monetary Policy Shocks and Swap Exposure

Panel A	Δ Quantity (scaled)			
	Bank	Fund	PF&I	Corporate
MPS (10Y yield, t-1)	0.677**	-1.01***	-0.366**	0.067
	(0.277)	(0.237)	(0.144)	(0.165)
MPS (5Y yield, t-1)	0.755***	-0.725***	-0.257**	0.338**
	(0.247)	(0.202)	(0.121)	(0.157)
MPS (2Y yield, t-1)	0.605***	-0.634***	-0.105	0.150
	(0.219)	(0.183)	(0.108)	(0.140)
N	4,055	14,489	19,353	8,989
Investor FE	Yes	Yes	Yes	Yes
Panel B	Δ DV01 (scaled)			
	Bank	Fund	PF&I	Corporate
MPS (10Y yield, t-1)	0.584**	-1.03***	-0.405***	0.029
	(0.269)	(0.242)	(0.141)	(0.173)
MPS (5Y yield, t-1)	0.634**	-0.784***	-0.285**	0.280*
	(0.245)	(0.200)	(0.121)	(0.165)
MPS (2Y yield, t-1)	0.500**	-0.725***	-0.142	0.100
	(0.221)	(0.178)	(0.109)	(0.145)
N	4,039	14,438	19,339	8,898
Investor FE	Yes	Yes	Yes	Yes

Notes: This table reports estimates of a fixed-effects panel regression for a model of the form in Equation 3. In Panel A, the dependent variable is the change in monthly outstanding net position held by an investor within a sector, while in panel B it is the net DV01 of these positions. Both the dependent variables are scaled to reflect approximate percentage changes and are bounded between +/- 2. Both panels present separate estimation results using monetary policy shocks (MPS) reflected in gilt yields of tenors 2 year, 5 year, and 10 year, respectively. All regressors are lagged by one period. All columns include investor fixed effects. Standard errors clustered by investor are reported in parentheses. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 4: Investor Maturity Preference

Panel A	Fraction of investors trading in one maturity group					
	Equally-weighted			Notional-weighted		
Bank	0.94			0.92		
Fund	0.91			0.97		
PF&I	0.74			0.79		
Corporate	0.97			0.94		
Panel B	**Fraction of trades in the dominant maturity group**					
	N	Mean	SD	p25	p50	p75
Bank	179	0.82	0.18	0.70	0.86	1.00
Fund	1,415	0.80	0.20	0.62	0.85	1.00
PF&I	533	0.66	0.20	0.50	0.63	0.82
Corporate	305	0.91	0.17	0.90	1.00	1.00
Panel C			**Fraction of trades by maturity group**			
			Below 3M	3M to 5Y	5Y to 10Y	10Y & above
Bank			0.11	0.70	0.16	0.03
Fund			0.65	0.27	0.04	0.04
PF&I			0.06	0.26	0.17	0.51
Corporate			0.04	0.63	0.15	0.18

Notes: This table shows that end-users in the interest rate swaps market exhibit preferred habitat behavior. Panel A reports the equally-weighted and notional-weighted fraction of investors within each sector that trade at least 50% of their total transaction volume of GBP swaps in a single maturity group. Maturity groups are defined as: below 3 months, 3 months to 5 years, 5 years to 10 years, and 10 years & above. Panel B reports the distribution of the proportion of notional-weighted trades that fall under each investor's own dominant maturity group. Investor-level shares are calculated at legal entity identifier (LEI) level and the distribution is constructed at the sector level. In panel B, "N" refers to the number of unique investors within a sector that traded GBP swaps during our sample period. Panel C reports the share of (gross) transaction volume in each of the four maturity groups by investors across each sector.

Table 5: Descriptive Statistics for Compression Trades and Investor-Dealer Stickiness

Panel A	Compression					
	N	Mean	SD	p25	p50	p75
Compression ratio (dealer-week)	2,763	0.19	0.15	0.08	0.15	0.24
Inter-dealer or CCP-facing (share)	74,103	0.93	0.26	1	1	1
Centrally cleared (share)	74,111	1	0.04	1	1	1
Panel B	Investor-month share of trades with its top dealer					
	N	Mean	SD	p25	p50	p75
Bank	3,343	0.77	0.22	0.56	0.79	1
Fund	19,218	0.87	0.20	0.73	1	1
PF&I	7,642	0.87	0.20	0.76	1	1
Corporate	651	0.79	0.24	0.56	1	1

Notes: This table describes compression-related variables and confirms that investors predominantly trade with a single dealer. Panel A reports the distribution of dealer-week compression ratio, defined as the fraction of trades tagged as compressed out of all the outstanding swaps as on a given date. Panel A also describes the economic characteristics of trades tagged as compressed as on February 1, 2022. Panel B reports the fraction of investor-month trades facing the dealer with whom an investor trades most frequently in that month. We calculate this measure of investor-dealer "stickiness" where we observe at least two trades within the investor-month combination because the share is mechanically one for a single trade.

Table 6: Demand Elasticities

First stage	Δ Swap spread	
	3M to 5Y	10Y & above
Δ Compression ratio	-0.373***	0.400***
	(0.080)	(0.109)
Δ Quantity (scaled, t-1)	0.006	-0.020
	(0.013)	(0.041)
N	2,537	1,834
Dealer FE	Yes	Yes
Time FE	Yes	Yes
Instrument F-statistic	21.86	13.46
Adj. R^2	0.10	0.17
Second stage	**Δ Quantity (scaled)**	
	3M to 5Y	10Y & above
$\Delta\widehat{\text{Swap spread}}$	0.826***	0.252
	(0.198)	(0.411)
Δ Quantity (scaled, t-1)	-0.229***	-0.203***
	(0.067)	(0.052)
N	2,537	1,834
Dealer FE	Yes	Yes
Time FE	Yes	Yes

Notes: This table reports estimates of a two-stage least squares regression for models of the form in Equation 5 (first stage) and Equation 6 (second stage). Panel A reports the first stage where the dependent variable is the change in maturity-wise swap spreads and the instrument is the weekly change in the fraction of trades tagged as "compressed" against each dealer. The columns represent each of the two maturity groups. In Panel B, the dependent variable is the scaled change in the weekly outstanding net position facing a dealer and the regressor of interest is the instrumented change in swap spreads for the respective maturity group. We control for the changes in past week's quantities and include dealer and time fixed effects. Standard errors clustered by dealer and time are reported in parentheses. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table 7: Maturity Groups and Relevant Parameters

	Values
Maturity groups $\tau = 0, 1, ..., 4$	$\{(0, 0.05), [0.05, 0.25), [0.25, 5), [5, 10), [10, \infty)\}$
Ave. maturity $\bar{m}(\tau)$	$\{0.025, 0.15, 2.75, 7.5, 25\}$
Transition prob. $\delta(\tau)$	$\{20, 6.67, 0.38, 0.21, 0.06\}$

Notes: This table summarizes the maturity groups, and the average maturity we use for each maturity group in the calibration.

Table 8: Targeted Moments

Panel A: Full Sample	Data
Ave. swap spreads in group 1-4	[0.104, 0.029, -0.162, -0.779]
Ave. quantity in group 1-4	[-4.236, 14.466, -0.095, -6.224]
Variances of swap spread changes in group 1-4	[0.038, 0.091, 0.399 , 0.145]
Variances of scaled quantity changes in group 1-4	[0.058, 0.003, 0.087, 0.001]

Panel B: First Subsample	Data
Ave. swap spreads in group 1-4	[-0.02, 0.137, 0.315, -0.153]
Ave. quantity in group 1-4	[-6.172, 13.719, -0.146, -6.123]
Variances of swap spread changes in group 1-4	[0.002, 0.043, 0.039 , 0.045]
Variances of scaled quantity changes in group 1-4	[0.02, 0.003, 0.084, 0.002]

Panel C: Second Subsample	Data
Ave. swap spreads in group 1-4	[0.207, -0.061 , -0.56, -1.30]
Ave. quantity in group 1-4	[-2.623, 15.088, -0.053, -6.31]
Variances of swap spread changes in group 1-4	[0.067, 0.132, 0.698 , 0.285]
Variances of scaled quantity changes in group 1-4	[0.089, 0.002, 0.091, 3.6×10^{-4}]

Notes: This table summarizes the empirical moments that we target in our calibration. Panel A uses monthly data from Dec 2019 through Jun 2024. Panel B uses data from Dec 2019 to Dec 2021, and Panel C uses data from Jan 2022 to Jun 2024. Swap spreads are in percentages and quantities are in 10 billion GBP. The swap spreads are the volume weighted average swap spreads for a given maturity group. The changes in quantities are calculated according to Equation 20.

Table 9: Calibrated Parameters

Parameters	**Value (median)**		
	(1) Full Sample	(2) First subsample	(3) Second subsample
Arbitrageur risk aversion coeff. a	201.29	82.92	786.78
Arbitrageur ave. cost $\bar{c}$	0.01	0.001	0.02
Demand intercepts θ_0	$[4.17, 14.47, 0, -8.08]$	$[7.75, 15.18, 0.06, -6.17]$	$[7.3, 13.26, 0.02, -9.93]$
Demand sensitivities to aggregate demand factor θ_1	$[0.1, 1.22, 0, -0.9]$	$[0.27, -7.53, 0, -6.43]$	$[0, -0.84, 0, 0.18]$
Speed of mean reversion Γ	$(9.58 \times 10^{-4}, 9.63 \times 10^{-4})$	$(4.3 \times 10^{-5}, 4.33 \times 10^{-5})$	$(6.66 \times 10^{-2}, 6.66 \times 10^{-2})$
Variances of supply and demand shocks Σ	$\begin{pmatrix} 1.78 & -0.81 \\ 0.24 & -0.11 \end{pmatrix}$	$\begin{pmatrix} 1.9 & -0.87 \\ 0.23 & -0.1 \end{pmatrix}$	$\begin{pmatrix} 1.78 & -0.8 \\ 0.24 & -0.11 \end{pmatrix}$

Notes: This table summarizes the calibrated parameter values in the model, for the full sample and each subsample.

Internet Appendix

"The Market for Sharing Interest Rate Risk: Quantities and Asset Prices"

Umang Khetan Jian Li Ioana Neamțu Ishita Sen

April 2025

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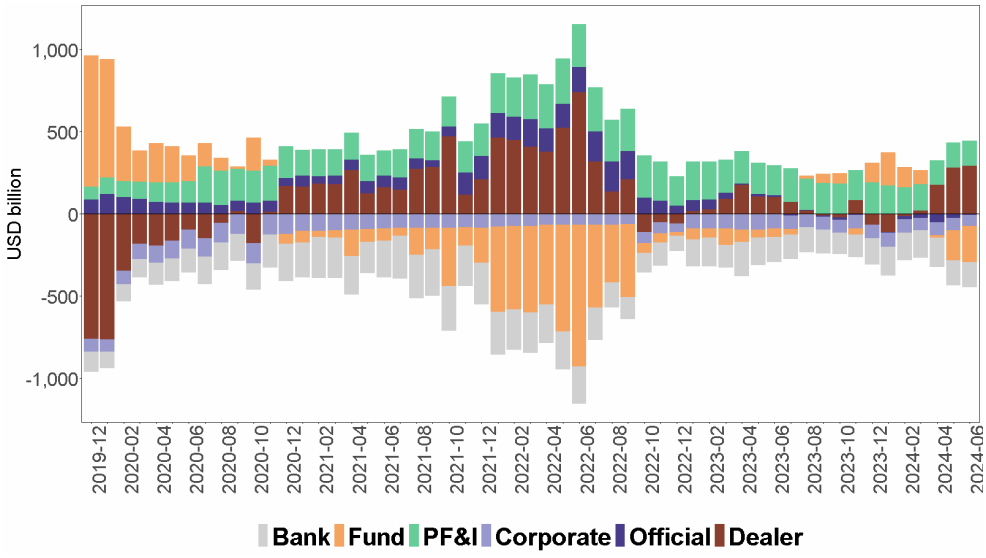
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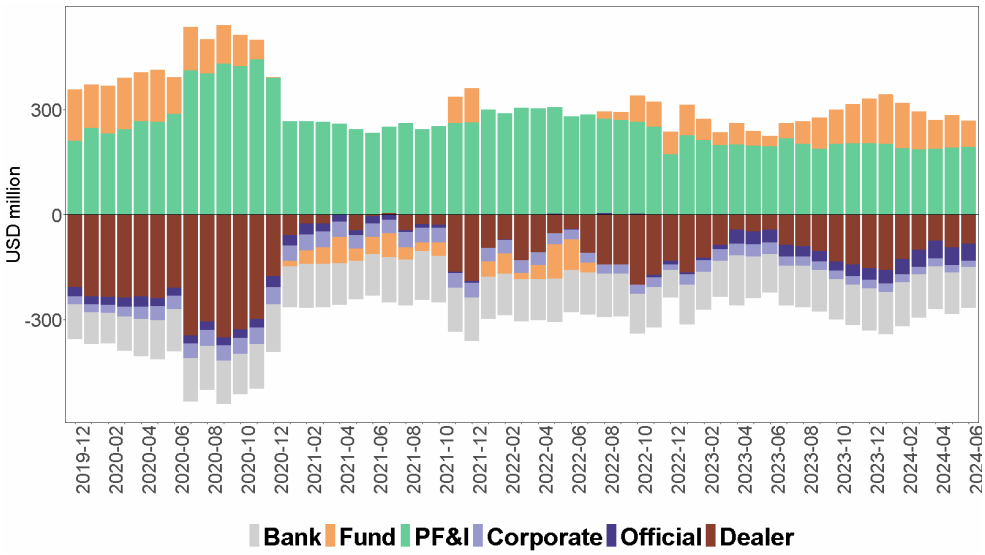
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A. Additional Figures and Tables

Figure A1: Net Outstanding Positions and DV01 (All Currencies)



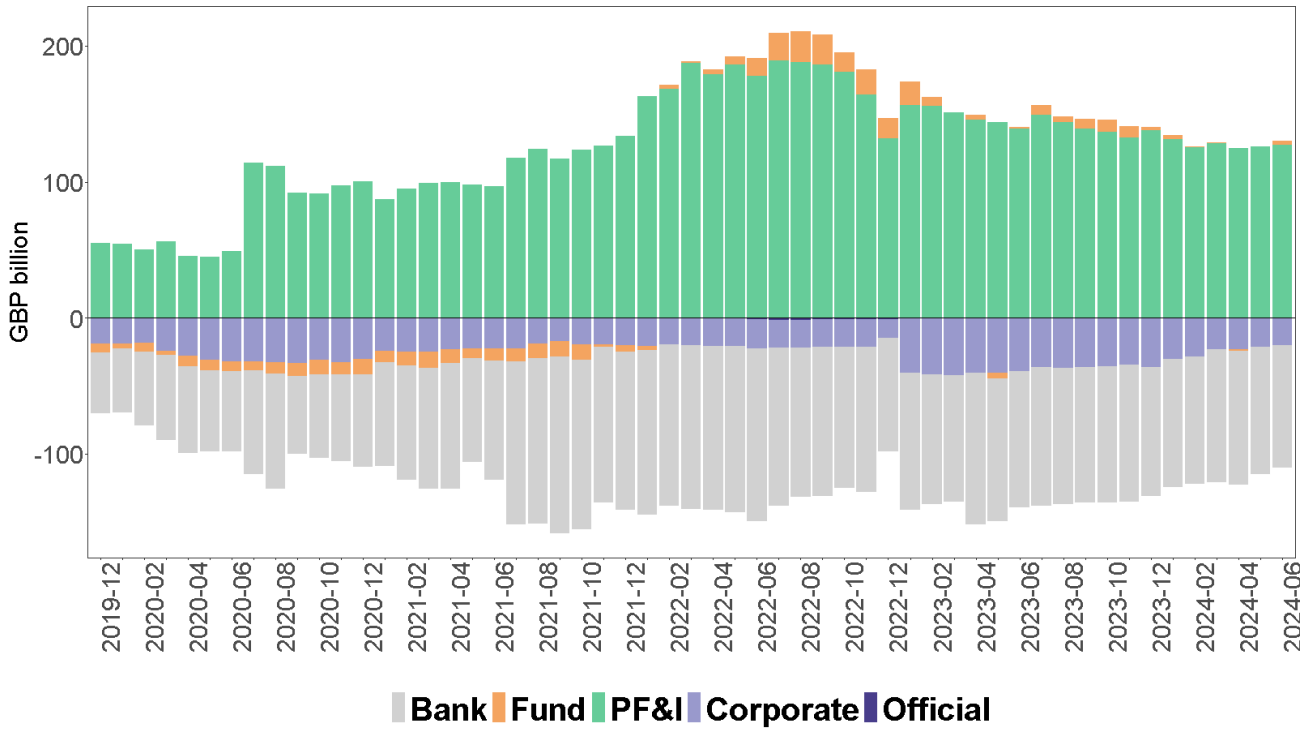
(a) Notional



(b) DV01

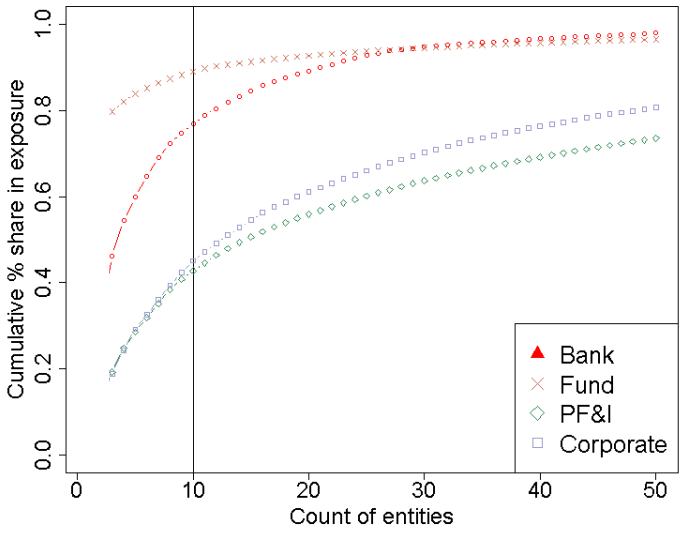
Notes: Panel (a) shows the net outstanding positions in USD billion at the start of every month for five end-user sectors and the dealer sector, and panel (b) shows the corresponding DV01. A positive value on the y-axis indicates a net receive fixed position (or positive duration) while a negative value indicates a net pay fixed position (or negative duration). This figure considers swaps denominated across all currencies in our sample, while Figure 1 plots the notional of GBP swaps and Figure 4 plots the DV01 of GBP swaps.

Figure A2: Net Outstanding Positions (UK Entities)

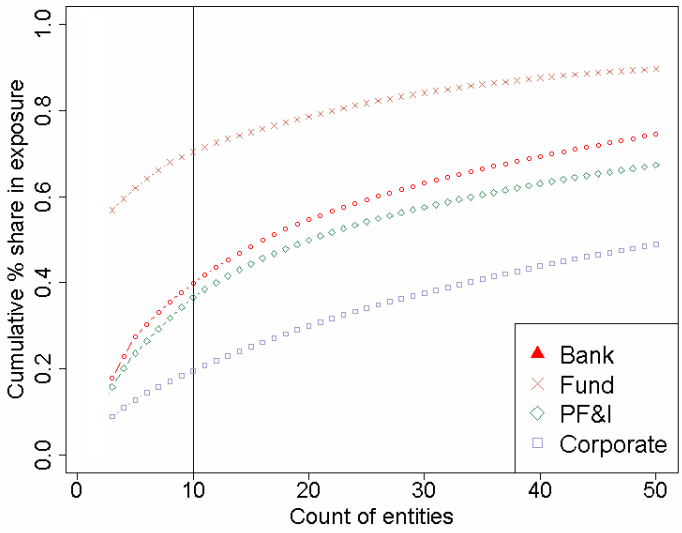


Notes: This figure shows net outstanding positions in GBP billion at the start of every month for five end-user sectors, where each entity is located in the United Kingdom (UK). A positive value on the y-axis indicates a net receive fixed position while a negative value indicates a net pay fixed position. Net outstanding position is calculated as the difference between the outstanding notional values of receive fixed rate and pay fixed rate swaps for each legal entity as per Equation 1, and then aggregated for five end-user sectors: Bank, Fund, PF&I (pensions, liability-driven investment funds, and insurance), Corporate, and Official (sovereign and supra-national institutions). This figure considers swaps denominated in British pound sterling (GBP).

Figure A3: Concentration in Exposures



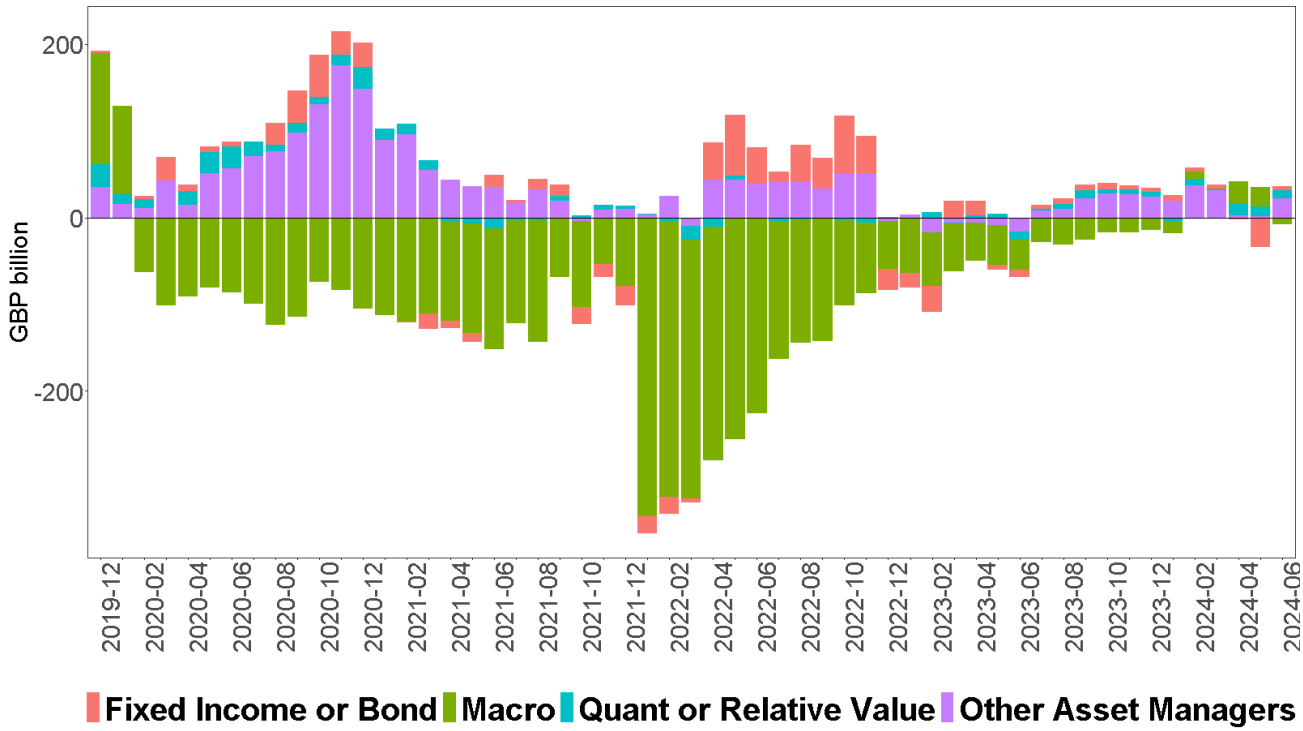
(a) GBP



(b) All currencies

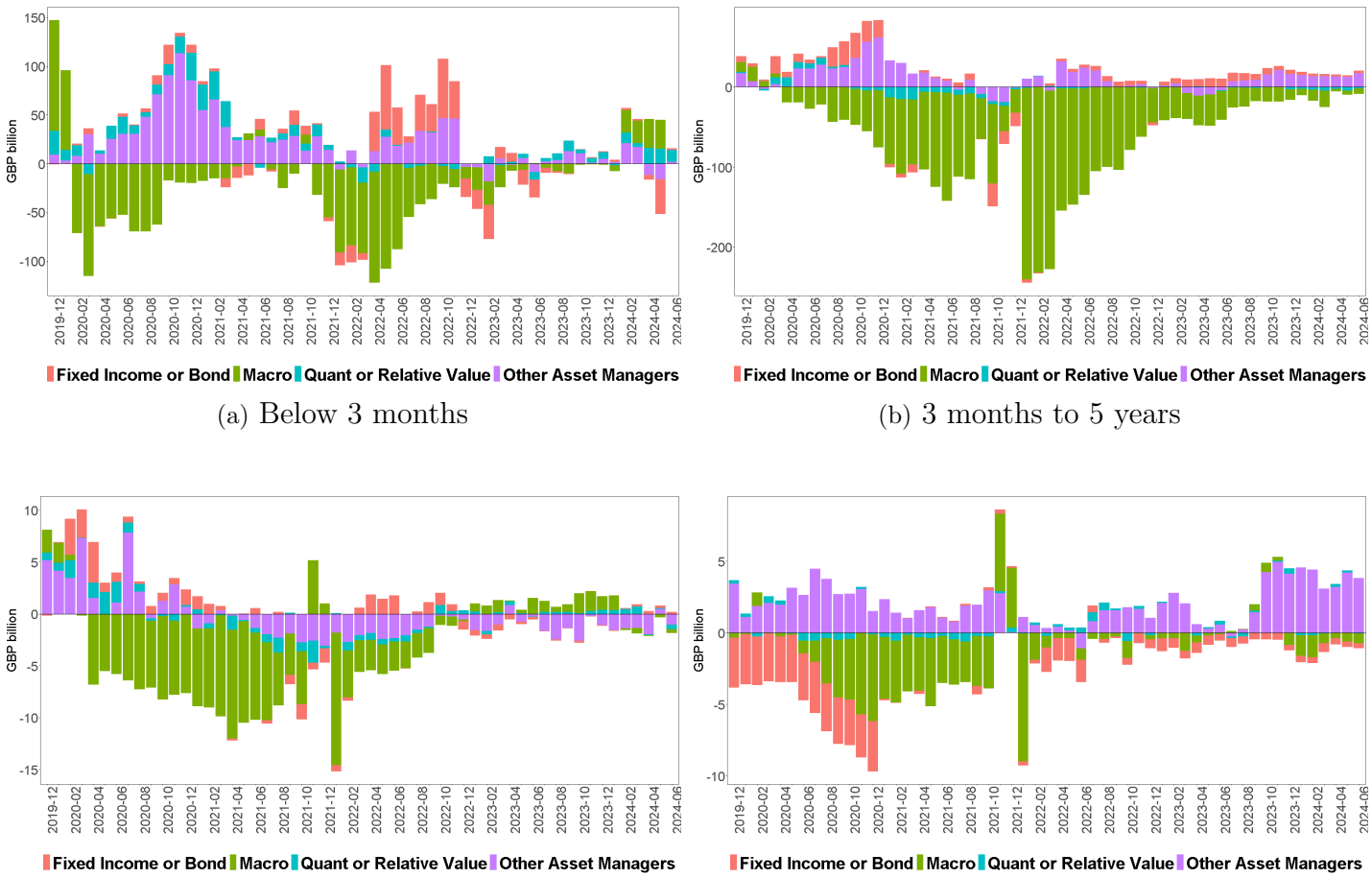
Notes: This figure shows that net exposures are concentrated within a few entities, particularly in the fund sector. The figure plots the cumulative share of net (absolute) position held by top 50 investors within each sector as on February 1, 2022, for GBP swaps in panel (a) and swaps across all currencies in panel (b). Vertical line in black traces the top 10 investors in each sector with their corresponding cumulative share on the y-axis. The first point in both plots shows the share of top 3 entities put together in each sector.

Figure A4: Net Outstanding Positions by Fund Type



Notes: This figure shows net outstanding positions in GBP billion at the start of every month for four fund types: Fixed Income or Bond, Macro, Quantitative or Relative Value, and Other Asset Managers. We identify fund types at a legal entity level using string matching on their names with common investment strategies. A positive value on the y-axis indicates a net receive fixed position while a negative value indicates a net pay fixed position. Net outstanding position is calculated as the difference between the outstanding notional values of receive fixed rate and pay fixed rate swaps for each legal entity as per Equation 1, and then aggregated for the four fund types.

Figure A5: Net Outstanding Positions by Maturity Group and Fund Type



(a) Below 3 months

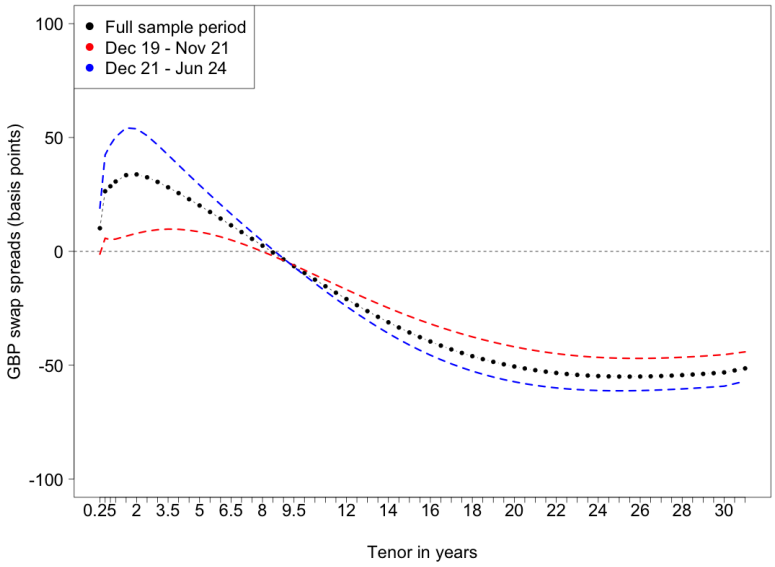
(b) 3 months to 5 years

(c) 5 years to 10 years

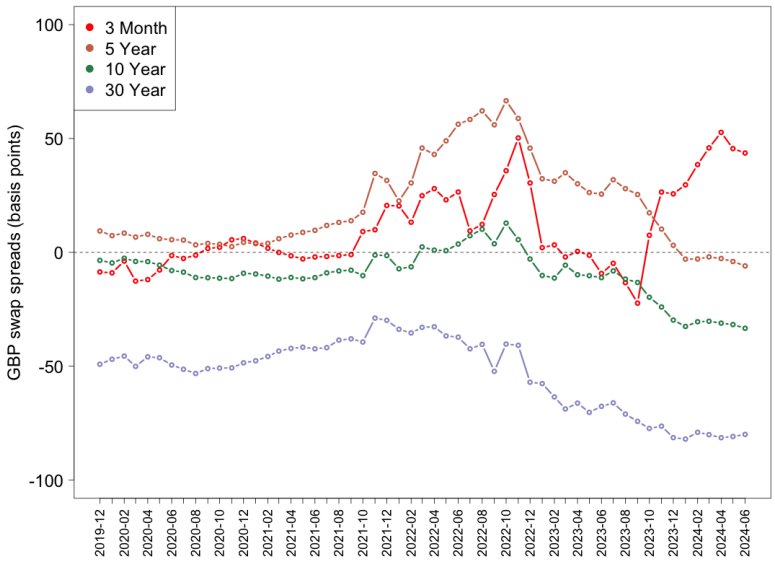
(d) 10 years & above

Notes: This figure shows net outstanding positions in GBP billion at the start of every month for four fund types, split by four maturity groups: below 3 months in panel (a), 3 months to 5 years in panel (b), 5 years to 10 years in panel (c), and 10 years & above in panel (d). A positive value on the y-axis indicates a net receive fixed position while a negative value indicates a net pay fixed position. Net outstanding position is calculated as the difference between the outstanding notional values of receive fixed rate and pay fixed rate swaps for each legal entity as per Equation 1, and then aggregated for the four fund types: Fixed Income or Bond, Macro, Quant or Relative Value, and Other Asset Managers. We identify fund types at a legal entity level using string matching on their names with common investment strategies.

Figure A6: Swap Spreads



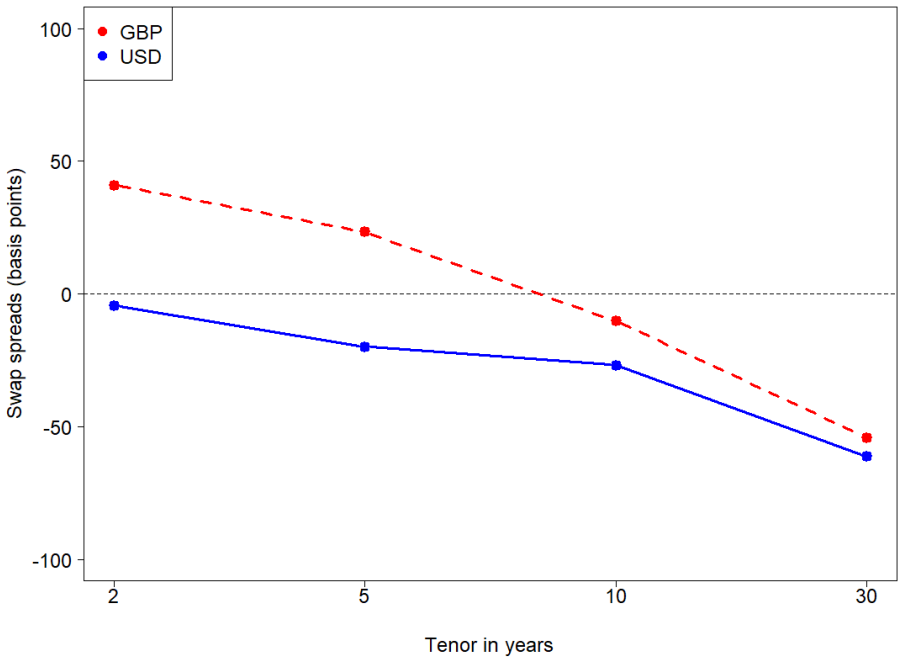
(a) Average term structure



(b) Time series

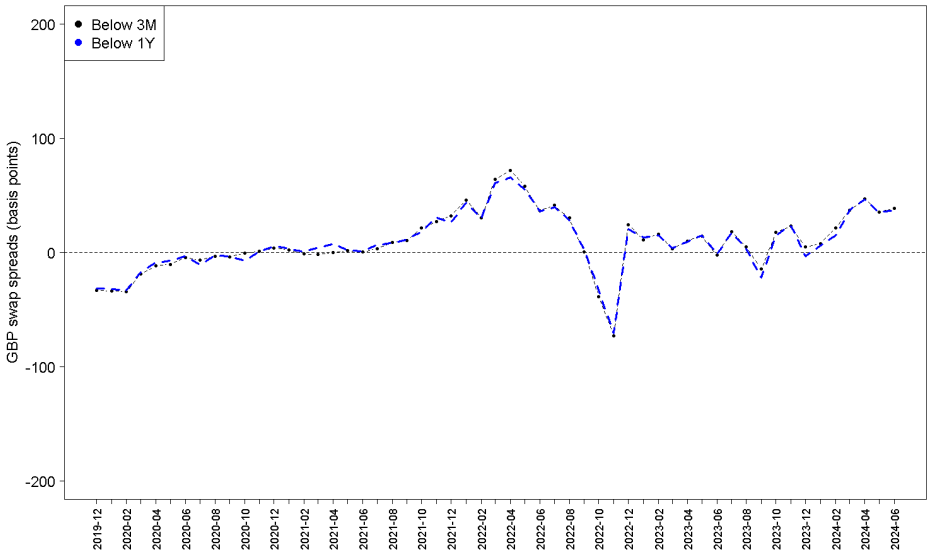
Notes: This figure plots the term structure of GBP swap spreads in panel (a) and the time series of 3 month, 5 year, 10 year, and 30 year swap spreads in panel (b). Swap spread is defined as the difference between swap fixed rate and the maturity-matched bond (gilt) yield. Panel (a) shows the average term structure using 3-monthly maturity intervals up to one year, and 6-monthly thereafter. The underlying data for these plots is sourced from the Bureau van Dijk Bank of England bond and overnight indexed swap (OIS) database.

Figure A7: USD and GBP Swap Spreads

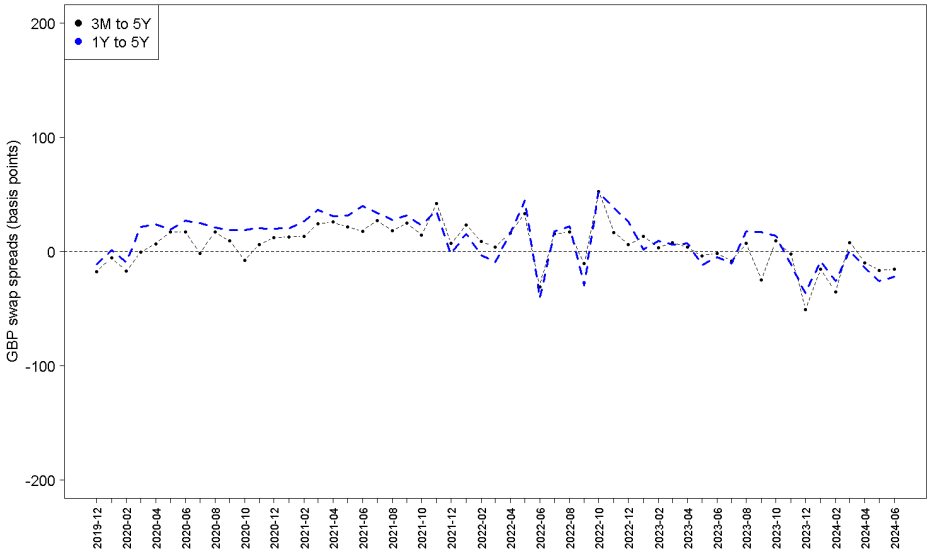


Notes: This figure plots the term structure of GBP swap spreads (red dashed line) and USD swap spreads (blue solid line) for swaps of tenors 2 year, 5 year, 10 year and 30 year. Swap spread is defined as the difference between swap fixed rate and the maturity matched bond yield. The underlying data for these plots is sourced from the Bureau van Dijk Bank of England bond and overnight indexed swap (OIS) database for GBP swaps, and Bloomberg for USD swaps. The sample period over which the swap spreads are averaged is October 2020 through June 2024, because SOFR-benchmarked USD swap spreads are not available prior to October 2020.

Figure A8: Swap Spreads for Alternative Maturity Groups



(a) Short tenor



(b) Intermediate tenor

Notes: This figure plots the time series of volume-weighted GBP swap spreads in our data for the baseline and alternative definitions of short and intermediate maturity groups. Panel (a) compares swap spreads for below 3 months with below 1 year. Panel (b) compares swap spreads for 3 months to 5 years with 1 year to 5 years.

Table A1: Estimated Coverage of Transactions Activity

	Average daily turnover in April 2022		
	Our data ($ billion)	BIS benchmark ($ billion)	Coverage
All currencies	3,425	4,987	69%
Pound sterling (GBP)	287	341	84%
Euro (EUR)	1,328	1,688	79%
US dollar (USD)	1,460	2,209	66%
Australian dollar (AUD)	141	279	51%
Other currencies	209	470	44%

Notes: This table reports the estimated coverage of interest rate swap transactions observed in our data using the April 2022 Bank for International Settlements (BIS) over-the-counter interest rate derivatives turnover survey as the benchmark. BIS data can be accessed here. Our sample includes all trades where at least one of the counterparties is a UK entity. We adjust for double counting arising out of the dual reporting of trades with same unique identifier, as well as duplication on account of centralized clearing of trades with different unique trade identifiers. We calculate the adjusted turnover in the month of April 2022 and divide it by 19, the number of trading days in that month. We compare our average daily turnover to the BIS benchmark that includes all interest rate derivatives except options and complex derivatives, and report the estimated share for all currencies put together and for some of the major currency pairs separately.

Table A2: Descriptive Statistics for Investor-level Outstanding Positions

	Investor-level net absolute position (GBP million)					
	N	Mean	SD	p25	p50	p75
Bank	105	1,411	4,119	34	163	755
Fund	365	1,328	17,699	5	30	142
PF&I	576	435	1,573	21	61	217
Corporate	258	165	403	14	40	106
Official	16	3,446	12,798	28	166	405

Notes: This table reports the distribution of net (absolute) outstanding positions for investors within each end-user sector as on February 1, 2022. Units are in GBP million except the count of entities. We calculate the net exposure at the investor level as the difference between the notional values of receive fixed and pay fixed swaps outstanding on a date, and report the distribution of its absolute value within the sector. "N" refers to the number of unique investors that had any outstanding exposure in GBP swaps as on February 1, 2022 in our sample. All sectors in general and funds in particular display the presence of a few large investors as evidenced by the large difference in the mean and median positions.

Table A3: Gross and Net Outstanding Positions by Maturity Group and Fund Type

Panel A	Gross position (GBP billion)					
	Below 3M	3M to 5Y	5Y to 10Y	10Y & above	Total	Share
Fixed Income or Bond	121	77	11	4	213	0.18
Macro	254	268	7	3	532	0.45
Quant or Relative Value	108	28	6	3	145	0.12
Other Asset Managers	147	109	17	23	297	0.25
Panel B	Net receive fixed position (GBP billion)					
	Below 3M	3M to 5Y	5Y to 10Y	10Y & above	Net-to-gross	Share
Fixed Income or Bond	-17	-1	0	0	0.08	0.05
Macro	-80	-232	-5	-2	0.60	0.85
Quant or Relative Value	-4	0	-1	0	0.03	0.01
Other Asset Managers	14	13	-3	1	0.08	0.08

Notes: This table reports the outstanding gross positions (panel A) and net receive fixed positions (panel B) as on February 1, 2022, held within each of the four maturity groups by four fund types: Fixed Income or Bond, Macro, Quantitative or Relative Value, and Other Asset Managers. We identify fund types at a legal entity level using string matching on their names with common investment strategies. The second-to-last column in panel A reports the total position of the fund type across all maturities, and the last column reports the share of each fund type in the overall outstanding gross positions. The second-to-last column in panel B reports the ratio of net position to gross notional for each fund type using positions aggregated across maturity groups, and indicates the extent of two-sided exposures held by each fund type. The last column in panel B reports the share of each fund type in the net (absolute) positions in aggregate across all maturity groups.

Table A4: Determinants of Compression

	Δ Compression ratio				
	(1)	(2)	(3)	(4)	(5)
Δ Quantity (Below 3M, t-1)	-0.001	-0.001	-0.001	-0.002	-0.003
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Δ Quantity (3M - 5Y, t-1)	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.007)
Δ Quantity (5Y - 10Y, t-1)	0.002	0.002	0.002	0.0006	0.0008
	(0.002)	(0.002)	(0.002)	(0.003)	(0.004)
Δ Quantity (10Y & Above, t-1)	-0.0004	-0.0003	-0.0003	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.002)	(0.005)
Δ Rate (10Y, t-1)		0.006	0.006		
		(0.004)	(0.004)		
Δ Rate volatility (10Y, t-1)		-0.018	-0.019		
		(0.015)	(0.015)		
Δ Assets (log)					-0.008
					(0.026)
Δ CET1/RWA					0.060
					(0.073)
N	2,609	2,573	2,573	2,573	1,929
Adj. R^2	0.00	0.00	0.00	0.13	0.17
Dealer FE	N	N	Y	Y	Y
Time FE	N	N	N	Y	Y

Notes: This table reports estimates for a model of the form:

$$\Delta\text{Compression Ratio}_{i,t} = \sum_{m=1}^{4} \beta_m \Delta q_{m,i,t-1} + \text{Controls} + \alpha_i + \alpha_t + \varepsilon_{i,t}. \qquad (24)$$

The dependent variable is the weekly change in compression ratio for each dealer in our sample. The regressors include scaled changes in net quantities facing the dealer across four maturity groups in the previous week. Columns (2) and (3) additionally include lagged changes in the 10Y gilt yield and its squared term that represents interest rate volatility. Column (5) includes the quarterly balance sheet variables of each dealer: changes in log assets and in common equity tier 1 (CET1) capital scaled by risk-weighted assets (RWA). Columns (3) through (5) progressively add dealer and time fixed effects. Standard errors clustered by dealer and time are reported in parentheses. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Table A5: Demand Elasticities - Alternative Specifications

Panel A	3M to 5Y	10Y & above
$\Delta\widehat{\text{Swap spread}}$	0.651*	-0.023
	(0.386)	(0.384)
Δ Quantity (scaled, t-1)	-0.227***	-0.199***
	(0.067)	(0.049)
Δ Rate (10Y, t-1)	0.009	-0.058
	(0.068)	(0.101)
N	2,501	2,436
Dealer FE	Yes	Yes
Instrument F-statistic	239.08	17.07
Panel B	**3M to 5Y**	**10Y & above**
$\Delta\widehat{\text{Swap spread}}$	0.839**	-0.096
	(0.289)	(0.416)
Δ Quantity (scaled, t-1)	-0.310***	-0.200**
	(0.079)	(0.076)
Δ Rate (10Y, t-1)	0.055	0.001
	(0.079)	(0.093)
Δ Rate volatility (10Y, t-1)	-0.570	-0.024
	(0.368)	(0.151)
Δ Assets (log)	-0.042	-0.057
	(0.101)	(0.069)
Δ CET1/RWA	-0.493	-0.339
	(0.824)	(0.518)
N	1,891	1,862
Dealer FE	Yes	Yes
Instrument F-statistic	73.36	8.33

Notes: This table reports estimates for a model of the form in Equation 6 (second stage). In both panels, the dependent variable is the scaled change in weekly outstanding net position facing a dealer. The regressor of interest is the change in maturity-wise swap spreads, instrumented using portfolio compression. Panel A controls for changes in lagged quantities and 10 year bond (gilt) yield. Panel B additionally controls for the squared term of yield changes to capture interest rate volatility, changes in (log) assets of dealers, and changes in dealers' common equity tier 1 (CET1) scaled by risk-weighted assets (RWA). The dealer-level controls pertain to the respective quarter for which the data are available. All columns include dealer fixed effects. Standard errors clustered by dealer and time are reported in parentheses. $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$.

B. Equilibrium Derivation

To solve the equilibrium, apply Ito's lemma to the equilibrium price Equation 14 and plug in the expression of dg_t in Equation 20, we get the expected return,

$$\begin{aligned} dP_t(\tau) =& -A(\tau)^\top P_t(\tau)\left(-\Gamma(g_t-\bar{g})dt+\Sigma dB_t\right)+\frac{1}{2}A(\tau)^\top\Sigma\Sigma^\top A(\tau)P_t(\tau)dt \\ & (A'(\tau)g_t+C'(\tau))P_t(\tau)dt \\ \frac{dP_t(\tau)}{P_t(\tau)} =& -A(\tau)^\top\left(-\Gamma(g_t-\bar{g})dt+\Sigma dB_t\right)+\frac{1}{2}A(\tau)^\top\Sigma\Sigma^\top A(\tau)dt \\ & A'(\tau)g_t dt+C'(\tau)dt \end{aligned}$$

Collecting the terms in front of dt, we get

$$\mu_t(\tau) = A(\tau)^\top\Gamma(g_t-\bar{g})+\frac{1}{2}A(\tau)^\top\Sigma\Sigma^\top A(\tau)+A'(\tau)g_t+C'(\tau) \tag{25}$$

Dealer's problem is

$$\max_{X_t(\tau)}\left[\int_0^\infty X_t(\tau)(\mu_t(\tau)-c_t)d\tau-\frac{a}{2}Var(\int_0^\infty X_t(\tau)A(\tau)^\top\Sigma d\tau dB_t)\right]$$

Take first order condition with respect to $X_t(\tau)$, we get

$$\mu_t(\tau)-c_t = aA(\tau)^\top\Sigma\Sigma'\left[\int_0^\infty X_t(\tau)A(\tau)d\tau\right] \tag{26}$$

Plug in the expression for $X_t(\tau)$ from the market clearing condition (assuming $K=1$)

$$\begin{aligned} X_t(\tau) &= -Q_t(\tau) = \alpha(\tau)log(P_t(\tau))+\beta_t(\tau) \\ &= -\alpha(\tau)[A(\tau)g_t+C(\tau)]+\theta_0(\tau)+\theta_1(\tau)\beta_{1,t} \end{aligned}$$

Furthermore, plug in the expression for $\mu_t(\tau)$ from Equation 25 into Equation 26. Matching the coefficients in front of g_t, we get Equation 15. Matching the coefficients in front of the constant terms, we get Equation 16.

To get the moments, the average spread for maturity bucket τ is

$$E[s_t(\tau)] = \left[A(\tau)^\top\begin{pmatrix}\bar{c}\\0\end{pmatrix}+C(\tau)\right]/\tau \tag{27}$$

The average quantity from the client's perspective for maturity bucket τ is

$$E[Q_t(\tau)] = \alpha(\tau)[A(\tau)^\top\begin{pmatrix}\bar{c}\\0\end{pmatrix}+C(\tau)]-\theta_0(\tau) \tag{28}$$

The change in spread is

$$ds_t(\tau) = \frac{A(\tau)}{\tau} dg_t \tag{29}$$

Hence the variance is

$$Var(ds_t(\tau)) = \frac{A(\tau)^\top}{\tau} Var(dg_t) \frac{A(\tau)}{\tau} \tag{30}$$

We define $\tilde{A}$ to be a $T \times 2$ matrix, where the τth row is $\frac{A(\tau)}{\tau}$.

Plug in

$$dg_t = -\Gamma g_t + \Sigma dB_t \tag{31}$$

$$Var(dg_t) = \Gamma Var(g_t)\Gamma^\top + \Sigma\Sigma^\top \tag{32}$$

$$Var(g_t) = \rho \tag{33}$$

where ρ is the solution to

$$-\Gamma\rho - \rho^\top\Gamma^\top + \Sigma\Sigma^\top = 0 \tag{34}$$

we get the formula for variance of spread changes.

Furthermore, to match the empirical counterpart, we define the change in quantities as the change in Q_t scaled by the absolute average quantity, i.e.,

$$\frac{dQ_t(\tau)}{|E[Q_t(\tau)]|} = \frac{\alpha(\tau)A(\tau)^\top dg_t - (0, \theta(\tau))dg_t}{|E[Q_t(\tau)]|} = \frac{[\alpha(\tau)A(\tau)^\top - (0, \theta(\tau))]dg_t}{|E[Q_t(\tau)]|} \tag{35}$$

The variance of this object is

$$Var\left(\frac{dQ_t(\tau)}{|E[Q_t(\tau)]|}\right) = \frac{[\alpha(\tau)A(\tau)^\top - (0, \theta(\tau))]Var(dg_t)[\alpha(\tau)A(\tau)^\top - (0, \theta(\tau))]^\top}{|E[Q_t(\tau)]|^2} \tag{36}$$

We define $\tilde{M}$ to be a $T \times 2$ matrix, where the τth row is $[\alpha(\tau)A(\tau)^\top - (0, \theta(\tau))]/|E[Q_t(\tau)]|$.

Furthermore, define

$$\Lambda = \begin{pmatrix} \tilde{A} \\ \tilde{M} \end{pmatrix} \tag{37}$$

Hence, the variance-covariance matrix of spread changes and quantity changes is

$$Var\left(\begin{pmatrix} ds_t \\ \frac{dQ_t}{|E[Q_t]|} \end{pmatrix}\right) = \Lambda Var(dg_t)\Lambda^\top = \Lambda\left(\Gamma Var(g_t)\Gamma^\top + \Sigma\Sigma^\top\right)\Lambda^\top \tag{38}$$