

Finance and Economics Discussion Series

Federal Reserve Board, Washington, D.C.

ISSN 1936-2854 (Print)

ISSN 2767-3898 (Online)

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2026-057

Please cite this paper as:

Banegas, Ayelen, Lucas Devigne, Mulalo Mamburu, Kleopatra Nikolaou, Anna Samarina, and Fabio Tamburrini (2026). "Government bond-backed repo markets: between resilience and vulnerability," Finance and Economics Discussion Series 2026-057. Washington: Board of Governors of the Federal Reserve System, <https://doi.org/10.17016/FEDS.2026.057>.

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Government bond-backed repo markets: between resilience and vulnerability¹

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Abstract

This paper synthesizes the literature on vulnerabilities in government bond-backed repo markets, focusing on the features that contribute to both the fragility and stability of these markets. The literature shows that the same features that enable efficient liquidity provision, including short-term funding, dealer intermediation, extensive collateral reuse, and low haircuts, can also create channels for rapid transmission of stress. The review documents tight linkages between repo and government bond markets, highlighting how repos are key to the build-up of leverage and can propagate stress across funding, cash, and derivatives markets, particularly through dealers and nonbank financial intermediaries such as investment firms, hedge funds, and money market funds. Evidence from recent stress episodes illustrates how these vulnerabilities materialize in practice. The review also examines post-crisis regulatory reforms and central bank interventions, identifying how these measures have enhanced market resilience while also creating trade-offs for market dynamics, with implications for liquidity and collateral availability.

Keywords: repo markets; government bonds; vulnerabilities; financial stability.

JEL codes: G10, G12, G15, G20.

¹ We thank Erik Heitfield, Shahzad Gitay, and Will Kerry for their leadership of the FSB-AGV repo market working group whose work motivated this research. We are grateful to Sebastian Infante, Jay Kahn, Andrea Deghi, and Erik Heitfield for their helpful comments. The analysis and conclusions set forth are solely those of the authors and do not necessarily reflect the views of the Board of Governors, the staff of the Federal Reserve System, Banque de France, South African Reserve Bank, De Nederlandsche Bank, the European Central Bank, the Eurosystem, the Financial Stability Board or the International Monetary Fund, its Executive Board, or IMF management.

1. Introduction

Repurchase agreement (repo) markets form a central pillar of modern financial systems. A repo transaction is a secured borrowing arrangement between two counterparties, predominantly short-term, structured as a temporary asset sale, followed by a subsequent re-purchase at a pre-agreed price. By enabling collateralized borrowing -- primarily against government securities -- repo markets provide an essential and low-cost source of liquidity to dealers, asset managers, and a broad range of wholesale market participants. At the same time, repo markets serve as an important source of collateral for liquidity providers and securities investors, while offering a safe short-term investment opportunity for cash-rich entities. The scale of repo markets alone reflects their systemic importance: by end-2024, outstanding government bond-backed repos reached roughly \$16 trillion globally, with the U.S. accounting for nearly 60 percent of this activity (FSB, 2026). While repo market structures vary across jurisdictions, they share a common set of features that shape their functioning, vulnerabilities, and role in the transmission of financial conditions both domestically and across borders. However, these same structural features that enable efficient liquidity provision can also create channels for rapid stress transmission.

Recent episodes of severe market stress in repo markets illustrate this duality. In September 2019 and March 2020 in the U.S. and in September 2022 in the UK, repo markets experienced disruptions that intensified focus on understanding the vulnerabilities of government bond repo markets. While an extensive body of research examines individual aspects of repo markets -- from dealer intermediation to collateral dynamics to regulatory impacts -- a comprehensive synthesis of how structural features generate both resilience and fragility, how stress transmits between repo and government bond markets, and how policy interventions have reshaped market dynamics remains lacking. This literature review contributes to closing this gap by synthesizing evidence across these dimensions and identifying areas for future research.

The review draws on the academic research and policy analysis of government bond-backed repos across major jurisdictions. It synthesizes evidence on the factors that contribute to repo market fragility and resilience, as well as the interlinkages and transmission channels between repo and government debt markets. It also assesses research on policy measures proposed or implemented to directly or indirectly address

repo market vulnerabilities, including Basel III regulatory reforms, market-based regulations, and central bank liquidity interventions. While the review covers key contributions from international evidence where available, research has focused predominantly on the U.S. repo market, largely reflecting data availability.

The remainder of the paper is structured as follows. Section 2 describes the structure of government bond-backed repo markets, including key participants, collateral, clearing arrangements, and cross-border linkages. Section 3 reviews the literature on core repo market characteristics -- such as networks of counterparties, collateral quality, haircuts, and collateral reuse -- and discusses how these features contribute to both market resilience and vulnerability. Section 4 examines the links between repo markets and government bond markets, covering liquidity provision, transmission mechanisms, and the role of non-bank financial intermediaries (NBFIs). Section 5 reviews evidence from major stress episodes to illustrate how repo market vulnerabilities materialize in practice. Section 6 discusses the impact of regulatory reforms and policy interventions on repo markets. Finally, Section 7 concludes and outlines directions for future research.

2. Key features in global repo market architecture

Repo market structures vary across jurisdictions, yet they share common features that shape their functioning and vulnerability to stress. These features present a trade-off: the characteristics that enable efficient liquidity provision and collateral transformation -- short maturities, dealer centralization, high-quality collateral, and integrated clearing -- can also concentrate risk and create channels for rapid stress transmission. FSB (2026) describes a global repo market structure whose design delivers both resilience and fragility. Understanding this duality is important for interpreting the literature reviewed in subsequent sections.

Repo transactions remain overwhelmingly short-term, with roughly half maturing overnight and most others within days or weeks. This maturity structure is central to the market's strength: it enables continuous liquidity provision, supports efficient redistribution of cash and collateral, and allows dealers to rapidly adjust balance sheets in response to changing market conditions. However, such very short-maturity funding renders the system vulnerable to rollover risk, where even a modest withdrawal by cash

providers or an increase in haircuts can trigger deleveraging, forced sales of government securities, and a contraction in market-making capacity.

The network of participants further reinforces this duality. Repo markets draw cash from money market funds (MMF), asset managers, corporate treasuries, and -- in the U.S. -- government-sponsored enterprises, while collateral is supplied by banks and leveraged investors, most prominently hedge funds. The market's reliance on large, globally active dealer banks at the center of this network underpins market efficiency: dealers intermediate heterogeneous preferences, redistribute liquidity, and transform collateral at scale. Yet the same structure generates concentration risks and creates channels through which balance-sheet constraints, whether market-driven or regulatory, can potentially restrict overall repo intermediation during stress, precisely when liquidity is most needed.

A further structural feature is the dominant reliance on government securities as collateral (around 80 percent of total repo outstanding, as of end-2024 (FSB, 2026)), including U.S. Treasuries, which serve as the global benchmark safe asset. This reliance mitigates credit concerns, enhances collateral liquidity, and supports robust pricing in the general collateral (GC) segment. However, this creates tight linkages between markets: disruptions in sovereign bond markets, especially in the U.S. Treasury market, can propagate immediately into repo pricing, haircuts, and collateral availability. Episodes of Treasury market dysfunction have shown how quickly stresses in one market segment transmit to the other, reinforcing the repo–sovereign bond nexus.

Clearing and settlement arrangements shape market resilience in similarly nuanced ways. The coexistence of bilateral and centrally cleared repos reflects differences in netting benefits, balance-sheet usage, and counterparty risk management. Central clearing, dominant in Japan and expanding in the U.S., can reduce bilateral exposures and improve transparency, strengthening systemic resilience and providing a mechanism for mutualizing losses, through CCP default funds and other shared loss-allocation arrangements. Yet this creates potential single points of failure: central-clearing counterparties (CCPs) themselves become systemically important, while liquidity and collateral pressures are likely to be redistributed (rather than eliminated) across market participants. Tri-party arrangements, particularly prominent in the U.S., improve operational efficiency and

collateral management but can concentrate intraday credit exposures at clearing banks, a vulnerability observed in earlier stress episodes.

Finally, repo markets are deeply international: an estimated 40 percent of outstanding positions are cross-border, and the same major dealers intermediate across the U.S., European, and Asian markets. This integration supports global collateral mobility and enhances the elasticity of liquidity across jurisdictions. However, international integration also creates pathways for the cross-border transmission of stress, as observed during episodes of sudden dollar funding shortages or disruptions in sovereign bond markets.

More recently, repo activity has begun to expand into the tokenized space. Current implementations suggest that the main value proposition lies less in changing the economic structure of repo than in improving operational efficiency, collateral mobility, and liquidity management. In many cases, the underlying collateral remains conventional and immobilized in custody accounts, while smart contracts are used to automate matching, collateral management, ownership transfer, and settlement (Patel et al., 2026). While tokenized repo has attracted growing interest from market participants and policymakers, empirical evidence remains limited so far, and this emerging area remains outside the scope of this review.

Taken together, the structural characteristics of global repo markets -- short maturities, high-quality collateral, dealer-centric intermediation, heterogeneous clearing arrangements, and extensive international linkages -- provide the foundation for their essential role in modern financial markets. Yet these same features embed vulnerabilities, including run dynamics, liquidity drying up under stress, impaired dealer intermediation, and propagation of shocks across markets and borders. In what follows, the paper examines how the literature assesses these structural features and their implications for market resilience and fragility.

3. Structural sources of fragility and resilience

3.1. Network of repo market participants

Repo lies at the center of the modern market-based credit system, linking banks, dealers, hedge funds, MMFs, and other NBFIs. Its structure naturally creates dense

networks of exposures through which market liquidity can be supported. At the same time these networks can act as channels along which shocks can spread and amplify.

The literature has established that these networks are organized in relationship structures that dominate trading patterns and promote more stable repo markets. Researchers have found that dealers and their clients approach relationship building strategically. Typically, while forming trade agreements with several counterparts, they concentrate their activities on a much smaller number (Han et al., 2022). They do so in part because trading relationships can positively affect terms of trade, such as haircuts, repo prices and volumes (Copeland et al., 2012; Han et al., 2022; Huber 2023; Eisenschmidt et al., 2024; Andreeva et al., 2025; Julliard et al. 2026). Expanding on these pricing dynamics, Paddrik and Ramírez (2025) find that search frictions and counterparty diversification determine price variation in tri-party repo; for instance, borrowers who search for more lenders may signal liquidity strains, which reduces their bargaining power and results in higher rates. Bittner and Jank (2025) demonstrate that the same bank will require lower haircuts from hedge funds that maintain a larger network of established banking relationships. Research has also found that relationships can provide a liquidity buffer during liquidity shocks. In other words, stronger relationships help reduce rate dispersion and maintain funding stability during liquidity shocks, be it regular ones such as quarter ends (Anbil and Senyuz, 2018; Han et al., 2022), regulatory induced (Kotidis and van Horen, 2018) or in crisis periods (Anbil et al., 2022). In Mexico, López et al. (2017) show that relationships in the repo market extend to unsecured funding markets, with relationships affecting terms of trade and buffering liquidity shocks across markets. They also find a high degree of interconnectedness among repo counterparts in Mexican repo market.

While relationships support normal market functioning, the literature highlights that the highly concentrated nature of these networks around a few central hubs creates important vulnerabilities, with this core-periphery structure amplifying instability when key intermediaries face stress. The presence of diverse investor types can allow shocks in one part of the financial system to be amplified and transmitted to others, while collateralization, although enhancing micro-level safety for individual lenders, tightens balance sheet interconnections and propagates risk to agents not directly exposed to the original source of stress, thus increasing macro-level fragility (Czech et al., 2021; Kappes, 2025).

Market structure and strategic interactions among dealers can further exacerbate this dynamic: the theoretical model by Chang et al. (2025) illustrates that when a sudden contraction in funding supply meets inelastic funding demand, imperfect competition allows dealers to restrict their onward supply of funding to extract higher profit margins. This means that supply shocks may be amplified rather than absorbed by dealer balance sheets, and whether dealer responses act as stabilising substitutes or destabilising complements depends critically on how trading networks are wired. The authors argue that this is consistent with the September 2019 repo market disruption, characterized by large supply shocks interacting with inelastic dealer demand.

Moreover, research suggests that dealer market power and network position can distort prices and liquidity conditions more broadly. Cañón Salazar et al. (2025) show that persistent shocks to highly connected dealers propagate through trading networks and can drive persistent bond price deviations, while dispersion in bargaining power can generate aggregate liquidity frictions and amplify mispricing through network spillovers. Shocks thus transmit not only through balance sheet constraints but through the structure of dealer intermediation relationships themselves.

In addition, the literature identifies interconnectedness and fire sales as a key channel through which local funding pressures become market-wide stress. Stressed borrowers sell securities to raise liquidity, and lenders sell collateral following a default (Baklanova et al., 2015). Dislocated fire sale prices can then trigger further margin calls, forcing additional sales and propagating turmoil from initially constrained borrowers to otherwise sound institutions, even beyond the repo market itself (Adrian et al., 2013).

Finally, the international dimension of repo markets means that fragility is not contained within borders. Hermes et al. (2025a) document that euro area entities' U.S. dollar repo activity alone accounts for 40 percent of total outstanding volumes, comparable in scale to the euro repo market itself. They argue that this evidence challenges the traditional view that repo markets remain primarily segmented along geographical lines. Instead, global secured funding markets appear tightly interconnected through the balance sheet structure of internationally active dealers. In their analysis, a major driver of cross-border integration is the internal capital market of global banking groups. Intragroup transactions across jurisdictions add a further €700 billion in euro and \$350 billion in dollar volumes, with UK-based entities playing a

central intermediating role to continental European banking institutions.² "Window dressing" in the U.S. tri-party market is primarily driven by foreign (specifically European and Japanese) dealers (Bostrom et al., 2025), and sizeable cross-border activity more generally means that regulatory or liquidity pressures in one jurisdiction manifest as global shifts in funding availability and pricing (Bassi et al., 2024).

3.2. Collateral

Collateral quality

Repo transactions are secured by collateral, primarily government securities. The use of highly liquid and low risk collateral can support financial stability by ensuring that collateral can be quickly converted to cash if needed (Paddrik et al., 2021). Moreover, such collateral can help maintain market confidence in periods of stress and prevent liquidity crises (Mancini et al., 2016; Hüser et al., 2024). Collateral quality also shapes pricing and liquidity in repo markets. Empirical work on bilateral repo markets finds that lower-quality or less liquid collateral tends to carry higher repo rates and larger haircuts, while very high-quality, scarce collateral can even support negative spreads relative to general collateral because of its special repo value (Baklanova et al., 2019; Hempel et al., 2023).

A central strand of the literature shows that collateral risk and liquidity are central drivers of haircut dynamics, particularly under market stress. Evidence from the Global Financial Crisis (GFC) shows how rising concerns over the liquidity and valuation of securitized collateral led to sharp increases in haircuts on structured products, effectively rationing funding and triggering deleveraging (Gorton and Metrick, 2010a, 2010b, and 2012). Bilateral repo transactions backed by private asset-backed securities collapsed to near zero in the crisis, although the reduction was more limited when viewed against the size of the broader repo market (Krishnamurthy et al., 2014). Data from the U.S. triparty repo market further indicate that more illiquid collateral commands higher haircuts, while haircuts on Treasuries and agency debentures have been low and relatively stable even through the GFC (Copeland et al., 2014).

² Evidence from the ICMA European Repo Market Survey (2025b) further supports this trend, reporting that cross-border transactions into and out of the euro area reached a historical high of 41.7% of outstanding positions in mid-2025.

Consistent patterns also emerge in granular UK data, where measures of collateral quality and collateral liquidity are shown to be systematic determinants of haircuts, with riskier or more illiquid securities requiring larger overcollateralization and exhibiting more sensitive terms at longer maturities (Julliard et al., 2026).

The literature suggests that tighter availability of high-quality collateral can alter market behavior in ways that may amplify fragility and systemic risk. Demand for safe assets had already been rising ahead of the GFC, driven by financial sector developments and the expansion of repo markets. Regulatory reforms, including the liquidity coverage ratio (LCR), have reinforced this demand (Accornero, 2020). Central banks' asset purchase programs can further constrain effective collateral supply by absorbing high-quality securities, although their overall effect on collateral availability depends on central bank operations' design and mitigating measures (D'Amico et al., 2018; Arrata et al., 2020; see Section 6.4). When high-quality collateral becomes scarce, markets may respond by using less liquid or riskier assets as collateral, which can heighten fragility. At the same time, while collateral re-use can improve market efficiency, research shows that it can also increase interconnectedness and leverage. These vulnerabilities become more pronounced when high-quality assets are scarce, adding to systemic risk (Fuhrer et al., 2016; Infante and Vardoulakis, 2021). However, the repo mechanism itself can partially offset safe asset scarcity by transforming long-term safe assets into short-term claims and, under certain conditions, generating a net increase in safe assets even from lower-quality collateral through the private money creation process (Infante, 2020).

Nonetheless, collateral constraints may arise even in the absence of an aggregate shortage of safe assets. Individual institutions often face "qualitative shortages", where their holdings do not match counterparties' eligibility requirements (Capel and Levels, 2014). In response to these mismatches, the financial sector and international markets have increasingly relied on collateral optimization and collateral transformation, whereby lower-quality assets can be exchanged for high-grade collateral via repo or securities lending. While these practices can support liquidity management, they introduce additional interdependencies and concentration risks along the collateral chain.

The literature also highlights how elevated demand for specific high-quality securities can generate collateral specialness, potentially contributing to inefficient repo

market segmentation, particularly during periods of stress. ‘Special’ repo rates, as defined by Duffie (1996), refer to situations where specific securities trade at rates significantly below prevailing risk-free benchmarks, indicating elevated demand. Work on repo ‘specialness’ shows that particular sovereign issues can trade at significantly lower repo rates than general collateral, reflecting their value in meeting short-selling, hedging, or regulatory needs. Strong demand for safe, pledgeable collateral allows intermediaries to optimally choose which bonds to deliver into general versus special collateral repos. However, specialness can lead to market segmentation across special versus general collateral segments, which can become more pronounced during stress, when demand for specific safe bonds spikes and their repo rates fall relative to money market benchmarks (Ballensiefen et al., 2023).

When the specialness wedge becomes large and persistent, repo rates increasingly reflect the scarcity value of specific collateral rather than broad funding conditions, which may weaken price signals and complicating arbitrage (Duffie, 1996; Corradin and Maddaloni, 2020; D’Amico and Pancost, 2022; Ballensiefen et al., 2023). While some GC-special differentiation reflects efficient sorting across heterogeneous liquidity and hedging needs, the literature shows this wedge is not always benign (e.g., Coen et al., 2024). First, when collateral demand is correlated with funding needs -- particularly for core intermediaries -- it can reduce gains from trade and impair market functioning, especially in stress (Arrata et al., 2020; Jank et al., 2022). Second, excessively large specialness wedges can distort price discovery in the broader bond market. Specifically, exorbitant costs to borrow specific collateral can raise the cost of trades requiring specific collateral, thereby limiting arbitrageurs’ ability to correct mispricing via short-selling. Third, specialness premia can further amplify funding stress when demand concentrates in a narrow set of securities, increasing vulnerability to hoarding dynamics and abrupt unwinds (Brunnermeier and Pedersen, 2009; Infante and Vardoulakis, 2021).

While collateralization generally supports market resilience, concentration of repo collateral in a narrow set of high-quality liquid assets may itself become a source of vulnerability. As government securities play a central role across multiple funding and derivatives markets, shocks to their valuation, availability, or market liquidity can propagate widely through the financial system. Brunnermeier and Pedersen (2009) show that the collateralized structure of repo funding implies that changes in collateral

values directly affect borrowing capacity and margin requirements, creating a direct link between funding and securities markets, and potentially reinforcing liquidity spirals and amplifying stress episodes.

Collateral reuse

Collateral quality, counterparty credit risk, and collateral reuse are closely intertwined, with rehypothecation, the practice whereby a collateral recipient reuses the received collateral in other transactions, emerging as a core feature of modern repo market intermediation. Collateral quality and counterparty credit risk are tightly linked to collateral reuse because rehypothecation turns collateral from a simple credit-risk mitigant into a shared, system-wide funding resource, whose value and safety depend on both asset risk and solvency of every intermediary in the reuse chain. Gottardi et al. (2019) explain that, as haircuts increase with counterparty risk and collateral risk, in equilibrium, lenders choose to re-use collateral. The empirical literature suggests that rehypothecation practice is widespread in the repo market: for the U.S., Infante et al. (2020) document an 85 percent re-use rate for the nine largest primary dealers; with a broader sample, Hempel et al. (2024) show that dealers re-lend 65 percent of repo collateral in other transactions; for Germany, Jank et al. (2022) report a re-use rate of 75 percent; for the European market, Inhoffen and van Lelyveld (2023) find an average re-use of 53 percent.

Higher-quality collateral can safely support longer and more intense reuse, but the literature suggests that long chains of reuse simultaneously magnify exposure to counterparty default and amplify the consequences of any deterioration in the underlying collateral's quality. In line with this trade-off, the literature emphasizes that collateral reuse both relaxes collateral constraints and generates new channels of fragility. On the benefit side, some studies find that collateral reuse improves market liquidity (Andolfatto et al., 2017; Infante, 2019; Infante et al., 2020), as it allows dealers to more efficiently distribute securities, effectively increases supply of available safe assets and mitigates safe asset scarcity, for example at times of central banks' asset purchases (Jank et al. 2022). Beyond increasing aggregate safe asset supply, reuse distributes these benefits to heterogeneous investors, particularly risk-averse agents seeking short-term claims without interest rate risk (Infante and Saravay, 2025).

However, rehypothecation can give rise to important financial vulnerabilities through its effects on leverage, interconnectedness, and crisis dynamics. A substantial volume of work focused on financial vulnerabilities created by rehypothecation (FSB, 2017). First, rehypothecation can lead to the build-up of excessive leverage in the market (Singh, 2011; Bottazzi et al., 2012; Capel and Levels, 2014). Second, high reuse rates amplify interconnectedness, as several agents are counting on the same collateral pool to secure their transactions: Eren (2014) shows how re-use may expose a hedge fund to a dealer's default, while Infante (2019) and Infante et al. (2020) note that rehypothecation has the potential to undermine financial stability in times of stress due to the associated collateral, counterparty and maturity risks involved in these practices. Third, increased leverage and higher interconnectedness can amplify market disruptions in crisis periods. Singh and Aitken (2009) document how the collapse in rehypothecation following Lehman's failure contributed to global deleveraging. Adrian and Shin (2010) model a system in which collateral is repeatedly pledged and re-pledged, showing that cumulative haircuts (or margin spirals) can become severe in downturns. Evidence from the U.K., suggests that the potential for unlimited rehypothecation offers a platform for higher swings in leverage (Singh and Aitken, 2010).

More recent work highlights the role of network structure and collateral concentration in amplifying systemic risk. Luu et al. (2021) show that concentrated collateral held by densely connected dealers increases their vulnerability to cascades of collateral hoarding triggered by localized liquidity shocks. These hoarding dynamics can in turn generate or amplify collateral scarcity, creating the conditions under which collateral runs become more likely. Infante and Vardoulakis (2021) and Infante (2019) formalize this mechanism showing how collateral runs may arise when re-used collateral becomes scarce with the resulting scramble for collateral propagating stress through the network.

Acknowledging the trade-off between market liquidity and financial stability risks, Brumm et al. (2023) argue that some degree of regulation, such as limits to the re-use of collateral, are welfare optimal, allowing some risk-sharing benefits while preventing excessive leverage (see Section 6.3).

3.3. Counterparty credit risk

Despite repo being a secured transaction and the key role of collateral quality, a robust body of evidence shows that counterparty risk remains economically important and is often priced, particularly in bilateral markets. Haircut levels vary systematically with counterparty type: riskier borrowers, such as hedge funds, face significantly higher haircuts, while non-hedge funds, large borrowers, and borrowers with repeated relationships receive lower haircuts (Julliard et al., 2026). Repo pricing also embeds counterparty-specific risk premia on the funding side, as dealers receive higher compensation (spreads) when they borrow cash from more creditworthy lenders, such as banks, compared to lending to less creditworthy ones, such as hedge funds, embedding counterparty-specific risk premia directly into repo rates (Barth and Kahn, 2025).

In contrast, the triparty repo market has exhibited muted responses to counterparty risk: Copeland et al. (2014) and Krishnamurthy et al. (2014) found that investors rarely adjust haircuts or collateral quality in response to adverse news, including during the GFC. Yet this evidence does not imply that counterparty risk is irrelevant in the triparty repo; rather, it manifests on the extensive margin, as investors respond to severe credit concerns by adjusting volumes, namely withdrawing entirely from trades, rather than tightening terms for certain investors. Adrian et al. (2013) note that Bear Stearns and Lehman Brothers lost access to repo financing as lenders reacted to a perceived increase in counterparty risk during the GFC, contributing to their bankruptcy. Together, this evidence highlights that the pricing and transmission of counterparty risk differ across repo segments.

3.4. Haircuts

Having established how collateral characteristics and market structure shape both the likelihood and severity of losses in repo transactions, haircuts can be viewed as the key parameter through which risks are priced and controlled. In practice, they determine how far the market is willing to leverage a given collateral pool and therefore map directly into both funding capacity in normal times and the speed of deleveraging in stress.

Haircuts in repo contracts can be used to limit leverage and protect lenders against credit and market risk. Theoretical work shows that haircuts are designed to absorb potential declines in collateral value over a liquidation horizon, and in practice, they are calibrated to collateral quality, borrower characteristics, and market liquidity conditions. Weymuller (2013) and Julliard et al. (2026) show that haircuts adjust dynamically with market conditions, underscoring the importance of adaptive margining frameworks that can pre-emptively counteract procyclical tendencies. However, recent empirical evidence suggests that observed haircut levels are shaped not only by collateral risk but also by institutional frictions. Using transaction-level euro area data, Ballensiefen et al. (2025) show that balance sheet constraints, collateral heterogeneity, and dealer market power distort margin setting, implying that haircuts may deviate from levels consistent with purely risk-based pricing. Using data from the non-centrally cleared bilateral repo market in the U.S., Hempel et al. (2023a) document that 74 percent of Treasury repo volume transacts at zero haircut, a stark contrast to the tri-party market where Treasury haircuts have consistently been around 2 percent. This prevalence of zero haircuts in bilateral transactions suggests that margining practices in this segment reflect factors beyond standalone collateral risk, including netting arrangements. Hermes et al. (2025a) also document frequent zero and even negative repo haircuts, especially in collateral-driven trades: they attribute this to collateral scarcity rather than risk. They also find that haircut levels vary across currencies and counterparties, with intragroup and transactions by large players with market power receiving particularly low haircuts. Kahn and McCormick (2025) propose a framework for understanding haircut patterns through "proportionate margining", where margins align with portfolio-level counterparty default risk rather than individual transaction risk. Under this approach, zero or negative haircuts on individual repos can be rationalized when viewed within a broader portfolio context that includes netting and cross-margining considerations, as the relevant risk is not the standalone transaction but the net exposure across all positions. From a theoretical perspective, Infante (2019) shows that haircut sign and magnitude depend on the economic motive for the trade. When the primary objective is to source collateral rather than funding, negative haircuts can be optimal to protect the collateral provider against cash reinvestment risk, analogous to overcollateralization in securities lending contracts. Furthermore, in centrally cleared segments where long and short positions are netted, portfolio-level risk may be minimal, supporting zero haircuts even when individual positions might appear under-margined.

More broadly, the literature suggests that when dealers intermediate repo, differences in haircuts and other contracting terms between the two legs of the transaction, including haircuts, can generate windfall profits for the dealer while simultaneously concentrating counterparty exposures on the intermediary.

The prevalence of zero or even negative haircuts documented in the empirical literature has raised concerns because, theoretically, they could lead to infinite leverage. Hermes et al. (2025b) argue that prevailing haircut levels are often insufficient to constrain leverage and may not fully reflect systemic risk. To address such vulnerabilities, the FSB published a regulatory framework introducing numerical haircut floors for non-centrally cleared securities financing transactions (FSB, 2014). Designed to limit the build-up of excessive leverage outside the banking system and reduce its procyclicality, the framework mandates minimum haircuts ranging from 0.5 percent to 10 percent for transactions where financing is provided to non-banks against collateral other than government securities. Grill et al. (2025) provide empirical support for these recommendations by documenting that market haircuts often fall below the levels recommended by the FSB, enabling higher repo leverage by NBFIs and increasing fragility in stress periods. The authors further show that introducing minimum haircut requirements in line with the FSB framework would significantly reduce repo leverage, especially among larger and more highly leveraged non-banks, supporting the view that well-calibrated haircut floors can function as an effective macroprudential tool. Similarly, Banegas and Monin (2023) show that imposing a hypothetical 200-basis-point haircut floor on Treasury repos would substantially reduce effective leverage on basis trades, increasing loss-absorbing capacity, but potentially affecting the profitability and scale of relative-value strategies.

A recurring theme in the literature is that when haircuts are set too low ex ante, they can become an amplification mechanism in periods of stress, rather than a buffer. Gorton and Metrick (2012) exploit bilateral U.S. repo data and document a sharp rise in margins during the GFC, which they interpret as a “run on the repo” market, analogous to a traditional bank run. They show that in securitized financing, low haircuts can exacerbate vulnerabilities by failing to absorb shocks from deteriorating asset values. The authors show that insufficient margining not only increases the probability of fire sales but also propagates contagion among interconnected financial institutions, thereby amplifying systemic risk. Subsequent work by Gorton et al. (2020) shows that

collateral subject to larger haircut increases is more likely to be brought to Federal Reserve emergency liquidity facilities, providing evidence that rising haircuts force deleveraging and shift funding onto the central bank's balance sheet. Infante and Vardoulakis (2021) introduce a model where insufficient margin buffers lead to a cascade of forced asset sales during market stress. They show that rapid margin calls can precipitate a downward spiral in collateral values, triggering a contagion effect that jeopardizes financial stability. These patterns are consistent with models in which rapid, procyclical margin calls produce "margin spirals," as in Adrian and Shin (2010).

Notably, the literature suggests that the shock transmission does not require large changes in haircuts. Mann (2025) identifies a "repo rate spillover" channel whereby exogenous funding shocks in the Treasury repo market propagate to other asset classes through dealers' balance sheets. In segments where haircuts are relatively rigid, such as tri-party repo, dealers may instead manage pressures by raising rates and compressing repo volumes across collateral classes, transforming localized funding stress into broader market-wide liquidity deterioration without a sharp increase in margin requirements.

Calibrating "appropriate" haircut levels is, however, challenging, especially in segments where very low or zero haircuts are prevalent. In repos backed by government collateral, haircuts, when applied, are typically modest and relatively stable. For example, repo with U.S. Treasury collateral has standard haircuts in the triparty market segment, which is typically 2 percent at the overnight segment (Huber, 2023). Copeland et al. (2014) provide evidence that margins for repos collateralized by U.S. Treasuries and agency debentures did not change throughout the GFC. At the same time, supervisory evidence for hedge funds shows that a large share of their Treasury repo borrowing is estimated to occur at zero or even negative haircuts, allowing a small set of highly leveraged funds to build very large gross positions in U.S. Treasuries (Banegas and Monin, 2023). Bejarano et al. (2025) show that large U.S. dealer banks lend at an average negative haircut of -0.19 percent against Treasury collateral implying leverage frequently exceeds 100 percent and argue that this can reflect a form of regulatory arbitrage whereby a secured loan is bundled with an effectively unsecured exposure, enabling counterparty credit provision with lower capital intensity than pure unsecured lending.

Consistent with a proportionate margining framework, FSB (2026) acknowledges the use of zero or negative haircuts as part of a portfolio margining procedure (as also argued by ICMA, 2025a), or for special repos, yet it emphasizes that limited understanding remains about how haircuts are set in practice. Overall, this combination of theory and evidence suggests that while haircuts are central to controlling leverage and pricing risk, observed haircut levels may partly reflect institutional features of dealer intermediation, margining practices (including portfolio margining and netting arrangements), market power and balance sheet costs, meaning that low haircuts do not necessarily signal low underlying risk. In some segments, limited margin buffers may therefore leave the system more exposed to sudden deleveraging pressures, complicating the task of designing haircut regimes that both preserve liquidity and contain systemic risk. Given the limited understanding of the extent to which haircut and margining practices properly reflect underlying risks, this appears to be a promising area for future research.

3.5. Central clearing

The role of central clearing, where a central clearing counterparty (CCP) novates trades, has been expanding in global repo markets in recent years, although at varying speed across countries. A growing strand of literature suggested system-wide benefits from central clearing over other types of clearing. CCPs act as intermediaries in repo transactions, becoming the buyer to every seller and the seller to every buyer, a process known as novation. Approximately one-third of outstanding repo transactions are cleared through a CCP, though this proportion differs widely by jurisdiction: all repos in India and the majority in Japan are centrally cleared, while the U.S. and Europe have substantial but not dominant shares, and some markets like Mexico, South Africa, and Switzerland have little or no central clearing (FSB, 2026). The U.S. is the first jurisdiction that mandated central clearing of certain eligible U.S. Treasury cash and repo trades and is currently in the process of implementing this mandate.

Beyond central clearing, repo markets have been traditionally using bilateral and, in some cases, tri-party settlement methods (FSB, 2026). In bilateral repos, two counterparties negotiate and settle directly, managing collateral and risk themselves, which offers flexibility but can increase opacity and counterparty risk. Tri-party repos involve a third-party agent (typically a custodian bank) that manages collateral

selection, valuation, and settlement on behalf of both parties, streamlining operations and reducing operational risk, while counterparty risk remains bilateral. Tri-party arrangements are especially common among non-bank investors and facilitate larger, more efficient transactions (Baklanova et al., 2015).

From a system perspective, novation can reduce credit risk in the form of counterparty risk and the risk of default, as now all counterparties face the CCP. Moreover, the CCP has enhanced risk management mechanisms and settlement failure procedures. This process can further reduce systemic risk, as it limits the potential for a single default to cascade through the financial system. In addition, the increased transparency and standardization brought by central clearing can facilitate better regulatory oversight and market discipline (Domanski et al., 2015; Duffie, 2020; Fleming and Keane, 2021; Aquilina et al., 2024).

In repo trades, a key benefit of central clearing comes from netting of positions. Literature shows that novation allows for netting positions, letting market makers effectively manage their balance sheet space and decrease capital requirements (Chen et al., 2022; Aquilina et al., 2024). Estimates from central clearing in the U.S. cash Treasury market and the UK and Canadian repo markets suggest potentially large netting efficiencies, though these estimates depend critically on the extent of participant coverage and the degree to which exposures are offsetting (Chen et al., 2022; Fleming and Keane, 2022; Baranova et al., 2023; Bowman et al., 2024). Using netting, central clearing can lower the costs associated with the supplementary leverage ratio³ (SLR) by optimizing balance sheet usage, ultimately expanding the intermediation capacity of market makers (Kotidis and van Horen, 2018; Infante et al., 2020; He et al., 2022; Chen et al., 2022; Baranova et al., 2023; Di Luigi et al., 2024). Literature also suggests that central clearing enhances the operational efficiency of repo markets and fortifies their resilience against financial shocks (Hempel et al., 2024).

However, the benefits of central clearing are not distributed evenly across market participants. While CCPs generate substantial netting efficiencies for dealer-

³ The Supplementary Leverage Ratio (SLR) is a non-risk-weighted capital requirement that measures a bank's Tier 1 capital against its total leverage exposure. Because repo transactions expand a dealer's gross balance sheet, they consume SLR capacity regardless of the underlying collateral's safety. Netting repo and reverse repo positions through a CCP reduces these gross reported exposures, thereby freeing up balance sheet space.

banks operating matched books, netting benefits can be constrained by low volumes of centrally cleared trades or by trades dominated by one-directional exposures (Bowman et al., 2024; Bardoscia et al., 2025). In such cases, the scope for meaningful multilateral netting may remain limited and the costs of central clearing could even offset their benefits. Specifically, one-directional investors such as MMFs, which mainly act as structural cash lenders, or net cash borrowers have few offsetting positions, and can therefore face higher central clearing costs, associated with margin requirements and default fund contributions (Hempel et al., 2023a; Di Luigi et al., 2024). Non-centrally cleared segments may also remain more economically attractive for buy-side participants, notably because they allow greater flexibility in terms of collateral and maturities.

Central clearing can also increase liquidity risk, as counterparties become subject to margin requirements that may bind during stress (Aramonte and Huang, 2019; Bardoscia et al., 2025). While CCPs tend to reduce counterparty risk in normal times, the literature suggests that they can become a focal point of systemic risk during crises, meaning CCPs can be both stabilizing and functioning as a new locus of systemic risk (Domanski et al., 2015; Duffie, 2020).

Evidence from the Eurozone sovereign crisis shows that centrally cleared repo markets at times of systemic stress became highly sensitive to sovereign risk despite CCP protection, suggesting concerns about the resilience of clearing houses, especially when collateral quality deteriorated (Boissel et al., 2017). The policy and academic literature further notes that CCPs -- by concentrating risk into a single node -- raise the risk of “single point of failure”, akin to “too-big-to-fail” concerns (Duffie and Zhu, 2013).

An additional challenge posed by central clearing is margin procyclicality, that is, the tendency of CCP collateral calls to increase with risk. This can be potentially destabilizing, particularly in times of stress, when margin requests are greatest, as it can lead to a system-wide liquidity squeeze (Bakoush et al., 2019; King et al., 2023). For this reason, policy efforts are being made to limit the procyclicality of the CCP margin (BCBS-CPMI-IOSCO, 2022) as well as market participants’ preparedness to margin and collateral calls (FSB, 2024b).

4. The role of repo in government debt markets

4.1. Market liquidity

A substantial literature documents the close link between repo markets and the liquidity and resilience of government debt markets. At a basic level, repo markets facilitate the circulation of both cash and collateral: they allow market participants to raise short-term liquidity in exchange for (generally high-quality) collateral like government bonds, helping to absorb shocks and mitigate disorderly sales. The functioning of government bond markets is therefore closely tied to the efficiency and resilience of repo markets (Mancini et al., 2016; DNB, 2023). Repos play a critical role in primary markets by enabling dealers to finance Treasury auction purchases at low cost, thereby supporting efficient price discovery in auctions and reducing government borrowing costs for taxpayers. In secondary (cash) markets, repo markets allow market participants to fund positions in government bonds without resorting to outright sales. By enabling the temporary exchange of high-quality collateral for short-term funding, repos provide "liquidity without liquidation" (Coen et al., 2024), thereby supporting continuous trading, price discovery, and market stability (Di Luigi et al., 2024). Furthermore, the repo market facilitates hedging and liquidity in underlying markets, including government debt (Bassi et al., 2024). The ability to readily convert government bonds into cash via repo, and vice versa, ensures a continuous and efficient functioning of the government debt market. In normal conditions, repo markets underpin dealers' and investors' willingness to hold inventories of government bonds by ensuring reliable access to funding. In periods of stress, this role becomes even more critical.

A key channel through which repos affect government bond market liquidity operates via dealer balance sheet capacity. Empirical evidence shows that liquidity deteriorates sharply when dealers' balance sheets become constrained. Duffie et al. (2023), document a significant loss in U.S. Treasury market liquidity and functioning when intensive use of dealer balance sheets is needed to intermediate markets, consistent with the existence of binding constraints on the intermediation capacity of dealers, as observed in March 2020. Favara et al. (2025) similarly find that shocks to banks' balance sheet -- proxied by credit line drawdown from nonfinancial firms -- reduce dealer subsidiary's participation in Treasury markets, with the response being concentrated in reverse repo activity, exacerbating liquidity stress. More broadly,

Adrian et al. (2025) argue that increased dealer perceptions of risk can reduce market-making activity and amplify illiquidity in government bond markets.

Foundational models (e.g., Duffie, 1996; Brunnermeier and Pedersen, 2009) show that repos enable market makers and primary dealers to finance large inventories of government bonds through collateralized borrowing, relaxing capital constraints and enhancing market liquidity and price discovery. Within this framework, the concept of “specialness” emerges: when a particular government bond becomes scarce (or “special”) in the repo market, its repo rate falls below the general collateral (GC) rate.

This specialness premium reflects both a scarcity effect and the benefits of low-cost funding. Krishnamurthy (2002) shows that specialness premiums represent equilibrium pricing rather than exploitable arbitrage. Analyzing convergence trades between on-the-run and off-the-run 30-year Treasuries, he finds zero average profits once differential repo financing costs are incorporated, establishing that Treasury pricing depends on leveraged returns that incorporate repo financing costs, not cash yields alone. Adrian et al. (2013) further illustrate that repo markets not only facilitate financing but also help in the allocation of risk across financial institutions. By converting illiquid government bond positions into liquid funding, repos support market resilience.

Moreover, the “specialness” of government bonds emerges as a critical determinant, capturing endogenous variation in the funding cost of holding government bonds. Corradin and Maddaloni (2020) find that specialness becomes more pronounced during periods of stress, which may temporarily support funding but can also introduce fragility if the premium unwinds abruptly. Empirical studies confirm that tighter repo conditions are associated with deteriorating government bond market liquidity. Pinter (2023) and Coen et al. (2024) show that higher haircuts and wider repo spreads coincide with lower trading volumes and wider bid–ask spreads, as dealers and investors scale back inventories when repo financing becomes more expensive or scarce. Central bank interventions can influence this nexus by affecting collateral availability (see Section 6.4).

4.2. Repo-bond market transmission

Beyond their role in liquidity provision, repo markets act as a key transmission channel between funding markets and government bond markets. Because government bonds

are widely used as collateral, shocks can propagate rapidly across these markets, with implications for financial stability and monetary policy.

Several studies highlight the potential for amplification and contagion. Accornero (2020) notes that the use of government bonds as repo collateral links funding and securities' markets, potentially increasing contagion risk. During the European sovereign debt crisis, rising sovereign risk translated into higher repo haircuts set by CCPs on peripheral government bonds in repo markets, tightening funding conditions and amplifying market stress in these jurisdictions (Armakolla et al., 2019).

At the same time, other research emphasizes that centrally cleared repo markets can also absorb shocks and preserve market functioning during periods of stress. CCPs can mitigate some contagion risk by centralizing and managing counterparty exposures, facilitating multilateral netting, and supporting the redistribution of liquidity across market participants (Di Luigi et al., 2024). In addition, Mancini et al. (2016) document that the centrally cleared euro repo market remained resilient during crisis episodes, including the European sovereign debt crisis, with repo lending increasing and without a significant rise in spreads, maturities, or haircuts at the aggregate market level. They argue that CCP-based market structure, the use of safe collateral, and the absence of a daily unwind mechanism avoiding intraday funding gaps helped preserve secured funding activity and reduce run risks during the crisis. By contrast, the paper also highlights weaker resilience for repos backed by riskier sovereign collateral, illustrating how centrally cleared repo markets may simultaneously preserve overall market functioning while amplifying stress for specific sovereign securities through procyclical haircuts and margin adjustments.

4.3. Monetary policy implementation

Repo markets play a central role in the implementation and transmission of monetary policy. Through repo-based open market operations, central banks can efficiently redistribute liquidity across banks and non-banks, thereby effectively steering short-term interest rates (Arrata et al., 2020; Di Luigi et al., 2024). Furthermore, some studies have shown that central bank facilities, such as the Fed's reverse repo facility, can contribute to the stability of the repo market by providing a floor for overnight funding rates, as noted by Anbil and Senyuz (2018). Frost et al. (2015) argue that a lender-of-last-resort function for non-bank investors via repo markets can reduce the likelihood

of runs. Fatouh et al. (2025) find that quantitative easing (QE) can improve liquidity provision in repo markets, although effects may depend on the scale of interventions and prevailing market conditions. By contrast, Mancini et al. (2016) show a substitution effect from private to public liquidity at high levels of excess liquidity, implying that large central bank liquidity provision may crowd out secured interbank lending by weakening incentives for banks to lend to each other. Overall, the effectiveness of monetary policy implementation is closely intertwined with repo market functioning.

4.4. Key market participants

4.4.1. Dealer balance sheet constraints and market liquidity

Dealers serve as essential intermediaries between borrowers and lenders in government bond markets and are key to safeguarding their liquidity and well-functioning (Adrian et al. 2025). Dealers typically intermediate across cash, futures, and repo segments. Repo intermediation is a core dealer function, where dealers channel cash and securities from lenders to borrowers, facilitating the smooth flow of cash and collateral, and maintaining stable short-term funding in financial markets.

A growing body of evidence shows that dealer balance sheet constraints can be a key source of liquidity stress in government bond and repo markets. While government bond liquidity generally worsens with higher volatility, dealer balance sheet constraints explain liquidity breakdowns beyond what volatility alone would predict (Duffie et al., 2023; Adrian et al., 2025). Shocks to banks' balance sheets reduce the activity of their dealer subsidiaries in both Treasury cash markets and reverse repo, weakening market liquidity, as demonstrated during the March 2020 Treasury market dysfunction (Favara et al., 2025). Furthermore, dealer constraints can interact with rising non-bank demand for leverage and bargaining dynamics, generating persistent funding stress in secured overnight markets (Adams et al., 2025).

Balance sheet constraints can also increase intermediation costs and steepen the yield curve. Constrained dealers demand higher compensation from leveraged investors for expanding their balance sheets, leading to higher reverse repo rates and a steepening of the yield curve during periods of stress (He et al., 2022; Barth and Kahn, 2025). Repo frictions can then weaken Treasury rate transmission along the curve. Higher reverse repo funding costs limit levered investors' ability to absorb

Treasury supply, generating a wedge between long-term Treasury yields, which are affected by dealer balance sheet constraints, and risk-neutral expectations of short rates (OIS rates), which are not (He et al., 2022).

4.4.2. Hedge funds and the Treasury cash-futures basis trade

Hedge funds play an increasingly important role in repo markets through their leveraged arbitrage strategies. While hedge funds employ various fixed-income arbitrage trades,⁴ the Treasury cash-futures basis trade has received particular attention in the literature due to its rapid growth and central role in the March 2020 turmoil. Banegas et al. (2021) and Barth and Kahn (2025) document that hedge fund repo market activity increased significantly in the years prior to the pandemic driven largely by the rise of this basis trade. The trade arbitrages small price differentials (the “basis”) between government bond futures contracts and the underlying deliverable securities, typically involving a short position in futures contract and a long position in the government bond security, which is usually financed through repo markets.⁵ In the case of the US, asset managers' demand for long futures positions to efficiently gain interest rate exposure though futures generally enables hedge funds' basis trade arbitrage (Kashyap et al., 2025). In normal times, this arbitrage activity enhances price discovery and supports the law of one price across Treasury cash, repo, and futures markets.

However, the Treasury cash-futures basis trade creates financial vulnerabilities through several channels. First, it can link several markets at a time, including government bond repo, cash, and futures markets, creating potential contagion pathways. Second, it involves significant leverage from both repo financing of the cash Treasury position and the embedded low margins on the government bond futures contract. Third, as repo financing supporting these trades is typically short-term and futures margins can change, hedge funds are exposed to margin risk and rollover risk inherent in maintaining the trade.

⁴ Duarte et al. (2007) document risk and return characteristics of various fixed-income arbitrage strategies employed by hedge funds, including swap spread arbitrage.

⁵ We focus on the “long” basis trade. However, hedge funds also engage in “short” basis trading. In this case, the hedge fund will go long a government bond futures contract and short a government bond security, reflecting their prior that government bond futures are relatively less expensive than the cash securities.

The March 2020 episode illustrates these dynamics (Vissing-Jorgensen, 2021; Barth and Kahn, 2025; Kruttli et al., 2025). As volatility in U.S. Treasury markets widened the cash-futures basis spreads, hedge funds experienced significant losses and unwound their trades, amplifying disruptions in the Treasury market. However, despite the significant fall in hedge funds' U.S. Treasury exposures, Kruttli et al. (2025) find that repo lending volumes to hedge funds remained stable over the turmoil and that financing terms, including haircuts, did not change materially, indicating that funding constraints operated through price and margin pressure rather than through a quantity withdrawal of repo credit. Consistent with this, Barth and Kahn (2025) document that repo spreads for large basis traders expanded by at least 30 percent at the peak of market stress and show that elevated financing costs and wider repo spreads correlated with increased Treasury liquidations. Together, these findings suggest that repo funding remained available in quantity terms, but rising funding costs and futures margin pressure interacted with internal risk constraints as the transmission mechanism through which stress translated into position reductions. In the UK gilt repo market, Hüser et al. (2024) show that hedge funds were the only non-bank sector to increase borrowing in the overnight gilt repo market during the Covid-19 crisis, as their demand for short-term liquidity rose.

Since late 2022, the basis trade has reemerged in the U.S. Barth et al. (2023) and Glicoes et al. (2024) document renewed growth in hedge funds' basis trading activity, consistent with the rise of hedge funds' net repo exposure, a proxy for hedge fund U.S. Treasury cash-futures basis trade activity. Such growth can exert upward pressure on repo rates even in normal times, as leveraged demand for repo financing increases pressure on dealer balance sheets, raising the cost of intermediation in government bond repo markets (Nikolaou, 2026). Kashyap et al. (2025) develop a model showing how the incentives and constraints of dealers, hedge funds, and asset managers interact to create fragility in the Treasury market. They identify the cash-futures basis trade as an important source of instability and show that a rapid growth in the U.S. Treasury market should be expected to further increase the footprint of highly levered funds engaging in basis trading, increasing vulnerabilities in the cash, repo, and futures markets for U.S. Treasuries. They propose that in a future episode of U.S. Treasury market dysfunction, government bond purchases by the central bank should be conducted on a fully hedged basis to separate financial stability interventions from

monetary policy objectives, although removing basis-trade risk would introduce moral hazard and full hedging would add significant operational complexity to central bank purchases.⁶

4.4.3. Money market funds and funding supply

Money market funds (MMFs) are major cash lenders, notably in the US repo market, providing substantial short-term secured funding to dealers and other market participants. Through tri-party and bilateral repo transactions, MMFs channel cash from retail and institutional investors into the financial system, supporting dealer intermediation activities essential for government bond market liquidity and overall functioning. However, despite their important role as funding providers, MMFs face structural vulnerabilities that can impair their capacity to supply liquidity during stress periods.

These vulnerabilities stem from two key, mutually reinforcing factors, namely exposure to sudden investor redemptions and, in some cases, reliance on structurally illiquid assets. By offering daily redemptions against portfolios concentrated in private short-term instruments, such as commercial papers (CPs) and certificates of deposit (CDs), MMFs perform liquidity transformation, which leaves them vulnerable to runs when confidence falters. At the same time, secondary markets for such assets are thinly traded even in normal times, and dealers have limited capacity to absorb sales during stress. These features create incentives for early withdrawals and restrict funds' ability to meet outflows without curtailing their lending, thereby reducing dealer intermediation capacity (FSB, 2021; Bouveret et al., 2022; Baes et al., 2025).

The March 2020 “dash for cash” illustrated how these vulnerabilities materialized. Non-government MMFs in the U.S., UK and Europe, particularly prime and low-volatility NAV funds, faced significant outflows that forced them to conserve liquidity, shorten maturities, and withdraw from repo markets, while government MMFs experienced historic inflows as investors sought safety (Eren et al., 2020; Czech et al., 2021). Non-government MMFs shed longer-dated assets, rolled investments into overnight instruments, and liquidated CPs and CDs to build precautionary buffers. In

⁶ See Annette Vissing-Jorgensen's and Hyun-Song Shin's comments of the same paper.

the UK gilt markets, MMFs cut term repo lending and concentrated lending in overnight funding to retain next-day cash availability (Hüser et al., 2024). Beyond redemption pressures, MMFs' pullback from repo markets reflected heightened risk aversion and market segmentation. By concentrating in the safest, shortest maturities, funds preserved liquidity for redemptions but withdrew term funding from banks and dealers, constraining system-wide liquidity exactly when demand for secured funding spiked (Czech et al. 2021; Hüser et al., 2024).

The systemic implications of MMFs' retrenchment are significant given their large market footprint.⁷ The defensive behavior of MMFs -- such as halting term repo lending, conserving liquidity assets, and concentrating in government securities -- limits their ability to act as cash lenders in periods of stress. As documented by Bouveret et al. (2022), the March 2020 episode showed that MMFs withdraw from their role as liquidity providers when they themselves face funding pressures from investor redemptions, contributing to severe stress in U.S. short-term funding markets. Recent evidence suggests that MMFs have continued to attract substantial inflows during the post-pandemic monetary tightening cycle, driven primarily by yield-seeking behavior rather than flight-to-safety motives, further increasing their footprint and systemic relevance in short-term funding markets (Nikolaou, 2025).

5. Market dynamics during stress episodes

Over the past decade, repo markets have experienced several episodes of stress that illustrate key vulnerability channels in market dynamics, such as sell-offs, reserve scarcity, settlement frictions, and spillovers from leveraged liquidity demand.

The spikes in repo rates observed in the U.S. in September 2019 illustrate how a combination of factors such as corporate tax payments, Treasury issuance, and declining reserve balances can trigger significant market disruptions (Anbil et al., 2021; Kahn et al., 2023; Copeland et al., 2025). Kahn et al. (2023) note that these elements, while manageable individually, became disruptive when they occurred together, with limited price transparency contributing to the severity of the episode. Chang et al.

⁷ MMFs hold around one-fifth of U.S. CPs and over two-thirds of euro area CPs outstanding, therefore their collective withdrawal can significantly amplify shocks to short-term funding markets (FSB, 2024a; Baes et al., 2025).

(2025) argue that the episode was driven by a large supply shock meeting inelastic dealer funding demand, amplified by strategic interactions among dealers. Building on the broader mechanism of reserve depletion, Dao et al. (2025) identify brinkmanship around the U.S. debt ceiling as an amplifier of short-term funding instability. They show that rapid inflows into the Treasury General Account following a debt-ceiling lift-off can drain reserves and cause repo spreads to swing by 20-30 basis points, particularly when aggregate bank reserves are low. This highlights how fiscal cash-management dynamics can exacerbate dealer-bank balance sheet constraints and distort repo supply.

The March 2020 shock showed how a global "dash for cash" triggered urgent demand for liquidity and disrupted repo markets across multiple currencies. In the UK, Czech et al. (2021) document how rapid sales of even safe assets by NBFIs -- driven by margin calls and investor redemption -- strained dealers' willingness and capacity to intermediate, contributing to dysfunction in both cash gilt and repo markets. Hüser et al. (2024) document that stress was marked by sharp increases in repo rates and a notable shift toward central clearing: volumes cleared through CCPs rose, while most non-bank participants (except hedge funds) reduced borrowing and faced wider spreads in the bilateral segment, reflecting a preference for the security offered by central clearing. In the U.S., Duffie (2020) and Kashyap et al. (2025) document that dealer balance sheets were overwhelmed in March 2020, leading to broader Treasury-market dysfunction. Further evidence on the March 2020 episode highlights how stress among key cash-investor segments amplified liquidity withdrawals and intensified funding pressures. Cipriani and La Spada (2020) show that institutional ("sophisticated") investors in prime money market funds withdrew pre-emptively when funds' weekly liquid assets approached regulatory thresholds associated with redemption gates and fees, while retail ("unsophisticated") investors reacted mainly through informational contagion, increasing redemptions after observing institutional withdrawals within the same fund family. These dynamics contributed to a contraction in the supply of cash to short-term funding markets, reinforcing the liquidity strains observed during the dash for cash.

The 2022 gilt-market crisis shows how leveraged nonbanks can act as amplifiers of repo market stress. Using transaction-level data, Pinter (2023) shows that firms employing Liability Driven Investment (LDI) strategies were forced to liquidate gilts

rapidly in September 2022 as their repo and derivative positions deteriorated. LDI firms with larger pre-crisis repo and swap exposures, particularly in index-linked gilts, experienced more severe forced selling. Their heavy reliance on short-term repo funding amplified market stress, impairing market liquidity and triggering contagion across market segments that necessitated intervention by the Bank of England.

Taken together, these episodes illustrate how repo markets are exposed to sudden liquidity demands and rate volatility, and how initial shocks can escalate through fire-sale dynamics and intermediation constraints, producing spillovers well beyond the original source of stress. Moreover, these episodes show notable heterogeneity in their triggers but significant consistency in their transmission mechanisms, reflecting the structural features and market linkages documented in Sections 3 and 4.

6. Regulation and central bank policy in repo markets

6.1. Liquidity standards

The Basel III reforms introduced two international liquidity standards -- the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR) -- to reduce banks' overreliance on short-term wholesale financing. A number of studies highlight financial stability benefits of these standards, arguing that stronger liquidity buffers have increased banks' resilience to market stress and reduced the likelihood of systemic crises (Gerba and Katsoulis, 2021; BCBS, 2022). Alongside these benefits, the literature also examines how the standards may affect repo market participation and market functioning, including during periods of elevated liquidity demand.

One strand of research focuses on banks' incentives to participate in repo markets under these regulations. Grill et al. (2017) explain that the NSFR treats short-term repo and reverse repo transactions asymmetrically: reverse repos require stable funding, whereas repos are not recognized as stable funding. They also emphasize that LCR effects depend on the collateral quality, counterparty type, and haircut levels. Empirical findings are mixed. For the euro area, Grill et al. (2017) find mostly insignificant effects of the LCR and NSFR on repo volumes. In contrast, Gerba and Katsoulis (2021) document more visible adjustments in the UK, with banks prioritizing HQLA-backed transactions to optimize LCR buffers. They further find that in low-

volatility conditions the LCR is more likely to discourage long-term trades, as banks avoid longer-term repos to build up HQLA stock and boost LCR buffers in normal times.

The literature also documents broader effects on market liquidity. A review by the Committee on the Global Financial System (CGFS, 2017) finds that Basel III has contributed to a general decline in repo market liquidity, with some of the effect attributed to the LCR. For the U.S., Macchiavelli and Pettit (2020) report that after the LCR implementation banks extended repo maturities for lower-quality collateral, reducing their reliance on repos to finance HQLA holdings. Other research finds that the effects of liquidity regulations are particularly pronounced during stress periods. Gerba and Katsoulis (2021) show that banks with jointly binding LCR and leverage ratio constraints reduce repo activity more than banks constrained by a single ratio and even more than unconstrained banks, exacerbating liquidity shortages during market stress.

Beyond volumes, research shows that liquidity regulations can reshape the structure of repo transactions and collateral transformation. Examining UK data, Gerba and Katsoulis (2021) find that a stricter LCR is associated with less reverse repo lending against low-quality collateral beyond 30 days, reduced repo borrowing against gilts of similar maturities, fewer collateral swaps downgrades, and more upgrades -- patterns consistent with banks' incentives to protect LCR buffers and internalize HQLA funding.

6.2. Leverage ratio and intermediation capacity

The regulatory minimum leverage ratio (LR) under Basel III was introduced to mitigate the build-up of excessive leverage in the banking system. The BCBS (2022) argues that the LR has strengthened the financial system and improved the resilience of financial institutions. Research shows, however, that the LR can affect money markets, particularly repo (Grill et al., 2017; CGFS, 2017; Andreeva et al., 2025), by attaching a balance sheet cost to holding reserves and to transactions that expand reported assets.

A prominent manifestation is “window-dressing” around reporting dates. Bank-affiliated dealers tend to temporarily shrink their balance sheets by reducing securities and reserve holdings and market activity, thereby generating sharp, predictable declines in market volumes and downward spikes in rates, introducing seasonal effects (Corradin et al., 2020; Bassi et al., 2024). Such effects are particularly visible in the overnight repo segment. Evidence across jurisdictions confirms these patterns.

Munyan (2017) and Anbil and Senyuz (2022) find that in the U.S. tri-party market, window-dressing is linked to European and Japanese banks that report LR at quarter-ends. Similarly, Allahrakha et al. (2018) show that the 2012 U.S. SLR introduction is associated with reduced tri-party repo borrowing by broker-dealers affiliated with bank holding companies. In the UK, banks with tighter LR constraints reduced repo borrowing and offered lower rates to smaller clients (Kotidis and van Horen, 2018). In the euro area, banks closer to the regulatory LR minimum cut money market borrowing at quarter-ends, with the strongest effect in the overnight secured segment (Corradin et al., 2020). Bassi et al. (2024) confirm these findings and show that lower-LR banks reduce repo exposures more forcefully at reporting dates. Baldo et al. (2018) show that while repo balances fall at reporting dates, overall market activity outside these dates is largely unaffected.

Beyond volumes, the LR can influence the pricing and composition of secured funding. Where exposures are not netted -- most notably in non-CCP-cleared transactions -- LR constraints are associated with higher intermediation costs. In the UK gilt repo market, LR constraints increased repo borrowing costs, with stronger effects for trades that are not nettable via CCPs (Noss and Patel, 2019).⁸ Similarly, research on euro area overnight repo markets finds that banks with higher LRs offer deposits at higher rates, with weaker effects for CCP-cleared trades, consistent with netting benefits (Andreeva et al., 2025). Grill et al. (2017) argue that the LR creates incentives for a shift toward nettable transactions, incentivizing a greater use of central clearing in the repo market.

A growing U.S.-focused literature links the SLR to dealer intermediation capacity in Treasury and repo markets (Adrian et al., 2025). Some studies show that in normal times, the SLR may discourage repo market intermediation even against very safe collateral, such as U.S. Treasuries, and can raise intermediation markups (Duffie, 2018; Andersen et al. 2019; Huh and Infante, 2021). These constraints appear more salient during stress periods. He et al. (2022) find that during the March 2020 “dash for cash,” SLR requirements constrained dealers’ ability to absorb large Treasury sales and expand repo lending; temporary exemptions for Treasuries from the SLR calculation

⁸ This aligns with Rinaldo et al. (2021), who note that joint effects of Basel III and the European Market Infrastructure Regulation (EMIR) led to lower repo rates by increasing reverse repo supply from CCPs and reducing repo demand from banks.

eased banks' balance-sheet pressure and supported market functioning. Other evidence indicates that in high market volatility conditions, banks price netted and non-netted repo differently, lowering margins on netted trades while charging more on non-netted ones (Gerba and Katsoulis, 2021). Similarly, Fatouh et al. (2025) find that while the LR supports bank resilience, it raises the cost of repos due to its risk-insensitive nature, affecting spreads.

The magnitude and persistence of LR effects on repo markets remain debated. According to the BCBS (2022) Covid evaluation, aggregate bank repo intermediation in March 2020 remained stable or rose, implying that the LR "was not a binding constraint for most banks during the pandemic". Cochran et al. (2023) find no clear evidence that SLR relief boosted intermediation. Similarly, evidence for the euro area points to limited effects on overall repo volumes relative to banks' total exposures (Bucalossi and Scalia, 2016; Grill et al., 2017). Corradin et al. (2020) attribute most of the post-2015 secured-market rate dispersion to QE-induced collateral scarcity rather than to the LR.

A complementary literature emphasizes alternative and not strictly regulatory drivers of dealer intermediation constraints in stress. Adrian et al. (2025) show that in times of crisis when market volatility increases, dealer risk tolerance also tightens, making intermediation more costly. Li et al. (2025), using confidential trading-desk Value-at-Risk data, show that internal and self-imposed risk limits limit dealers' appetite for risks and their capacity to intermediate in Treasury markets in times of market stress and conclude that "deregulation alone may not be sufficient to induce risk-taking by dealer intermediaries in times of crisis." Bräuning and Stein (2024) separately identify a quantitatively significant internal-VaR channel using supervisory microdata. Beyond the crisis scenario, Boyarchenko et al. (2020) found that VaR constraints were more binding than regulatory constraints during the pre-SLR period, underscoring that the LR and internal risk limits are difficult to separate empirically.

While the jury remains open on the magnitude of LR effects on repo markets, literature has emerged examining the solutions to mitigate the potential side-effects of the LR requirement while preserving prudential objectives. Proposals include using reporting-period averages (rather than point-in-time snapshots) to attenuate window-dressing (Grill et al., 2017), and temporary exemptions for central bank reserves and specific assets from the LR exposure measure in exceptional circumstances (as in the

Covid-19 pandemic) to support monetary policy implementation and market functioning. These exemptions, however, entail a trade-off between supporting market functioning in stress and maintaining the full risk-insensitive scope of the LR (He et al., 2022; Andreeva et al., 2025). Expanding central clearing is another avenue, as greater netting -- facilitated by central clearing -- can reduce balance sheet pressures (Noss and Patel, 2019; Di Luigi et al., 2024). However, the evidence on netting benefits of central clearing is mixed; some studies project large reductions in settlement obligations and meaningful netting efficiencies (Fleming and Keane, 2021; Baranova et al., 2023), while other research finds only modest reductions in balance-sheet costs (Bowman et al., 2024). The literature suggests that actual netting benefits crucially depend on the specific market structure, notably the extent to which end repo borrowers such as non-bank investors would participate in central clearing, thereby expanding the aggregate nettable set relative to the status quo.

6.3. Market-based regulations

In addition to globally relevant regulations, the literature identifies several market-based measures aimed at enhancing the resilience of repo markets. Among these, stricter collateral requirements and restrictions on naked short selling have been widely studied.

Stricter collateral requirements can limit dealers' accumulation of excessive collateral liabilities and prevent liquidity windfalls from being allocated to high-risk investments (Infante and Vardoulakis, 2021). This rationale is reinforced by empirical evidence suggesting that haircut-setting practices may not fully internalize systemic risk considerations. Using transaction-level data on the euro area repo market, Grill et al. (2025) identify inconsistencies between observed haircuts and the calibration proposed under the FSB minimum haircut framework, pointing to a potential market failure in the private determination of margins. Their analysis shows that minimum haircut requirements would primarily bind for the largest and most leveraged non-bank entities, which tend to obtain comparatively low haircuts and therefore operate with higher initial leverage. By increasing ex ante margin buffers, such floors could reduce excessive leverage and mitigate the risk of destabilizing deleveraging cycles. Minimum haircut requirements are thus presented as a potentially effective macroprudential instrument targeting systemic vulnerabilities associated with leverage in NBFIs. The literature also

highlights a trade-off. While such measures may reduce repo vulnerabilities, they can also affect market functioning and liquidity, as collateral reuse is central to repo market efficiency.

The literature stresses that the design of rehypothecation restrictions is crucial. Andolfatto et al. (2017) and Brumm et al. (2023) show that intermediate reuse limits -- where the amount of borrowed securities that can be rehypothecated is tied to the amount of cash lent -- can be welfare-enhancing by raising cash demand when liquidity is low and facilitating risk-sharing without encouraging excessive leverage. By contrast, overly stringent rehypothecation limits -- particularly those that restrict reuse without linking to the cash borrowed -- are typically welfare-reducing, potentially impairing market liquidity and efficiency without addressing underlying demand for real cash balances.

The practice of naked (uncovered) short selling has also been debated given its potential to amplify market volatility: selling securities without first borrowing them raises the risk of failed deliveries and intensifies downward price pressures. Major jurisdictions -- including the EU, the UK, and the U.S. -- ban or restrict naked short selling, but evidence on their effectiveness is mixed (Barardehi et al., 2023; Edwards et al., 2023). Some studies argue that restrictions can curb destabilizing price spirals and enhance market integrity, whereas others find that such measures may inadvertently reduce market liquidity and hinder price discovery. Coen et al. (2024) suggest that policies reducing collateral demand, including rules on uncovered short selling, could improve repo market functioning by increasing trading volumes and realized gains, given the observed positive correlation between funding and collateral demand across firms. The effect could be particularly large in times of financial stress. Their findings further suggest that any such policy should be designed with particular attention to dealers and banks, who simultaneously face high funding demand and high collateral demand in stress as they seek to hedge interest rate risk.

6.4. Central bank liquidity provision and interventions

The literature examines various tools central banks employ to restore and support repo market functioning. These interventions can improve market liquidity and reduce systemic risk, but their design also matters because interventions may have side effects, necessitating complementary measures (Aldridge et al., 2023). Central banks

rely on two broad types of liquidity-providing facilities to address market dysfunction: lending operations and asset purchases. Lending operations provide liquidity directly to financial institutions against collateral, helping to contain funding stress that could otherwise trigger fire sales or liquidity spirals (Gorton et al., 2020; Carlson et al., 2025). These facilities can be deployed rapidly with existing counterparties (Czech et al., 2021). Asset purchases inject liquidity at scale and influence market prices by shifting the supply-demand balance for government bonds and other high-quality assets, thereby addressing wider market dysfunctions, such as asymmetric information and impaired price discovery (Aldridge et al., 2023).

Research suggests that central bank interventions have played a key role in stabilizing repo markets. Gorton et al. (2020) document how the Federal Reserve's emergency liquidity programs during the GFC alleviated collateral shortages, improved market functioning, and reduced the risk of a broader financial collapse. Carlson et al. (2025) provide empirical evidence that dealers continued to transmit Fed repo liquidity to the broader financial system during March 2020, though with a shift toward lending to affiliated entities. For the UK, Czech et al. (2021) find that the Bank of England's Contingent Term Repo Facility (CTRF) helped stabilize repo markets and ease financial conditions during the March 2020 'dash for cash' episode.

A large body of literature examines central bank asset purchases in supporting repo markets during stress. Research shows that QE programs are typically launched during periods of heightened market stress when repo markets show strain (Hüser et al., 2024). Studies conclude that by enhancing liquidity provision, QE can stabilize and improve repo market functioning under stress. Fatouh et al. (2025) find that QE supported liquidity in the UK repo market by increasing bank reserves, part of which flowed into short-term funding markets, reducing spreads; related work shows that gilt purchases were effective in restoring market functioning during the 2020 dash-for-cash and the 2022 LDI crisis (Czech et al., 2021; Pinter, 2023). In the U.S., the Fed's purchases of Treasuries helped alleviate market disruptions during the Covid-19 crisis (He et al., 2022). In the euro area, large-scale asset purchases stabilized and supported repo markets during episodes of stress by lowering yields, alleviating liquidity tensions, and reducing fragmentation (Eser and Schwaab, 2016; Arrata et al., 2020; ECB, 2022).

At the same time, the literature identifies channels through which central bank interventions can alter repo-market incentives and conditions. Asset purchase

programs may contribute to collateral scarcity by removing large amounts of high-quality securities (primarily government bonds) from the market, increasing specialness premia and potentially affecting repo rates (D'Amico et al., 2018; Arrata et al., 2020; Dufour et al., 2020; Corradin and Maddaloni, 2020; D'Amico et al., 2022). D'Amico et al. (2018) and Arrata et al. (2020) show that this can elevate funding costs and dampen market liquidity. In response, banks may increase collateral re-use, which can amplify market fragilities (Inhoffen and Lelyveld, 2023). Schaffner et al. (2019) also document a shift in the euro repo market toward collateral-driven activity, reinforcing market segmentation. More broadly, recurrent interventions may raise concerns about moral hazard (encouraging financial institutions to take on excessive risks) and reduce incentives to self-insure, potentially weakening market resilience (Czech et al., 2021; Aldridge et al., 2023). The literature discusses several measures to mitigate these side effects of central bank interventions. Securities-lending programs -- lending out government bonds from central bank portfolios -- can increase collateral availability and reduce scarcity, improving repo market functioning (Arrata et al., 2020; Aldridge et al., 2023; Greppmair and Jank, 2023; Pelizzon et al., 2023).⁹ Coen et al. (2024) additionally suggest that accepting a broad range of collateral in lending operations could help financial institutions manage liquidity and interest-rate risks.

Another mitigating measure concerns remuneration and absorption, including reserve tiering and other tools for managing excess reserves (Logan and Bindseil, 2019). In the U.S., the Fed's Overnight Reverse Repo (ON RRP) facility -- introduced to support rate control -- helped constrain funding spreads by offering cash lenders an alternative secured investment and reducing dealer market power (Anbil and Senyuz, 2018; Afonso et al., 2022; Huber, 2023; Hempel et al., 2023b). Relatedly, Eisenschmidt et al. (2024) argue that giving OTC market participants access to a secured central bank deposit facility akin to the RRP could strengthen their bargaining position and reduce funding stress. Chang et al. (2025) extend the analysis on the lending side by modelling repo intermediation as a network and assessing the role of the Fed's

⁹ Grasso and Poinelli (2025) highlight the importance of flexible implementation in the day-to-day execution of asset purchases. They find that Eurosystem asset managers mitigate policy-induced scarcity by tilting purchases away from the most "special" bonds. In their estimates, deviations from a market-neutral allocation are associated with a normalization of day-to-day repo conditions in 2015-2019, illustrating that implementation choices can reduce the footprint of balance sheet policies on money markets.

Standing Repo Operations (SRP). They find that the SRP act as an effective backstop, dampening rate volatility arising from large, transitory imbalances such as in September 2019. They also highlight a policy trade-off: higher SRP caps strengthen the backstop but may crowd out private relationships by weakening dealers' incentives to maintain diverse funding links with cash lenders.

Finally, an expanding literature emphasizes the growing role of NBFIs in repo markets and the vulnerabilities they introduce. Several studies therefore advocate for extending central bank backstops to a wider set of nonbank counterparties, provided they meet specific requirements, while pairing such ex-post liquidity support with measures to reduce underlying fragilities ex-ante (Hall, 2021; Hauser, 2021; Hüser et al., 2024).

7. Conclusion

This paper synthesizes the academic and policy literature on the structure, functioning, and potential vulnerabilities of government-bond backed repo markets. The literature shows that repo markets play a central role in modern financial systems by supporting liquidity provision, price discovery, and the efficient circulation of cash and collateral. However, the structural features that enable their efficiency -- short-term funding, extensive collateral reuse, dealer-centric intermediation, and tight links to government bond markets -- also generate systemic vulnerabilities that have been extensively documented in the literature. Evidence from recent stress episodes (2019, 2020, 2022) shows how dealer balance-sheet constraints, non-bank leverage, and the interaction of market structure with regulatory frameworks contribute to episodes of market stress. While post-crisis regulatory reforms and central bank interventions have addressed some vulnerabilities and enhanced resilience in important ways, the literature also identifies trade-offs and open questions about optimal policy design. By integrating findings on market structure, transmission channels, stress episodes, and policy responses, this review offers a comprehensive view of the factors shaping repo market resilience and fragility.

Despite this substantial body of work, important research questions remain underexplored. The long-term implications of operating with large central bank balance sheets and new monetary policy frameworks for repo market functioning warrant further

study. The literature highlights how asset purchase programs can lead to collateral scarcity, affecting repo rates and potentially increasing market fragility, but questions remain about how persistently elevated central bank holdings influence market dynamics and the optimal strategies for central banks to manage collateral scarcity while ensuring market liquidity and stability. In addition, the optimal design of haircut and margin requirements for non-bank repo participants remains an open question, including whether they would reduce systemic risk or shift leverage to unregulated venues. Finally, the literature documents that post-Basel III leverage and liquidity requirements may have led to structural changes in the functioning of repo markets and possibly may have constrained dealer intermediation capacity during recent stress episodes. However, the magnitude of these effects and whether these constraints represent a permanent feature of repo markets or a transitional adjustment period as dealers adapt their business models remains unclear.

Looking ahead, the emergence of digital assets, tokenization, and distributed ledger technologies raises new questions about the future structure of repo markets. For instance, central bank digital currencies and tokenized securities could fundamentally reshape collateral usage and risk management in repo markets. Whether these innovations will enhance efficiency or introduce new risks remains an open question. Research examining the feasibility, regulatory implications, and systemic consequences of digitalized repo market infrastructure will become increasingly relevant as these technologies evolve.

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