US Daily: When Will Balance Sheet Runoff End and How Will the Fed Know When to Stop? (Abecasis/Korapaty)

- Since last year, the Fed's balance sheet has shrunk by roughly \$1.2tn to \$7.8tn, and balance sheet runoff has proceeded smoothly so far. In today's note, we provide an update of our Fed balance sheet projections and lay out a series of indicators we are watching to track conditions in money markets.
- The FOMC will likely aim to stop balance sheet normalization when bank reserves go from "abundant" to "ample"—that is, when changes in the supply of reserves have a real but modest effect on short-term rates. We expect the FOMC to begin considering changes to the speed of runoff around 2024Q3, to slow the pace in 2024Q4, and to finish runoff in 2025Q1. At that point, we expect bank reserves to be around 12-13% of bank assets and the Fed's balance sheet to be around 22% of GDP (vs. around 30% currently and 18% in 2019). The key risk to our forecast is that the increased supply of debt that we expect in 2024 causes intermediation bottlenecks in the Treasury market that lead the Fed to stop runoff earlier.
- We continue to expect the Fed's remaining balance sheet runoff to have modest effects on interest rates, broader financial conditions, growth, and inflation—much less than the impact of interest rate hikes this cycle.
- There is substantial uncertainty over how conditions in money markets will evolve as runoff continues. We therefore introduce a number of indicators to monitor how conditions are evolving in short-term funding markets. These indicators suggest that liquidity currently remains abundant, though we expect them to signal pockets of scarcity in mid-2024.

Jan Hatzius
+1(212)902-0394 | jan.hatzius@gs.com
Goldman Sachs & Co. LLC

Alec Phillips
+1(202)637-3746 | alec.phillips@gs.com
Goldman Sachs & Co. LLC

David Mericle
+1(212)357-2619 |
david.mericle@gs.com
Goldman Sachs & Co. LLC

Spencer Hill, CFA
+1(212)357-7621 | spencer.hill@gs.com
Goldman Sachs & Co. LLC

Ronnie Walker
+1(917)343-4543 |
ronnie.walker@gs.com
Goldman Sachs & Co. LLC

Tim Krupa
+1(202)637-3771 | tim.krupa@gs.com
Goldman Sachs & Co. LLC

Manuel Abecasis
+1(212)902-8357 |
manuel.abecasis@gs.com
Goldman Sachs & Co. LLC

Praveen Korapaty
+1(212)357-0413 |
praveen.korapaty@gs.com
Goldman Sachs & Co. LLC

When Will Balance Sheet Runoff End and How Will the Fed Know When to Stop?

Since last year, the Fed's balance sheet has shrunk by $1.2tn to $7.8tn, and balance sheet runoff has proceeded smoothly so far. In today's note, we provide an update of our Fed balance sheet projections and lay out a series of indicators we are watching to track conditions in money markets.

The evolution of balance sheet runoff and our projection for the stopping point

As the Fed lets securities roll of its balance sheet, the stock of Treasury and MBS debt it used to hold needs to be absorbed by the private sector. Private savers absorb this debt by drawing on bank deposits and money market fund balances. In response, banks and money market funds reduce their holdings at the Fed, putting downward pressure on bank reserves and balances at the Fed's reverse repo (RRP) facility.[1]

Exhibit 1 breaks down the evolution of the liability side of the Fed's balance sheet. In 2022, the bulk of the reduction in the Fed's balance sheet came from a decline in bank reserves, which fell from $4.3tn in 2021, or around 19% of bank assets, to around $3.1tn in December 2022, or 13.5% of bank assets. At the same time, the Fed's reverse repo facility—where intermediaries like money market funds can deposit excess liquidity if market rates fall below the RRP rate set by the Fed—actually increased in 2022, as the rapid rise in the fed funds rate led depositors toward money market funds in search for more attractive yields and a decline in outstanding Treasury bills pushed money markets toward the RRP facility.

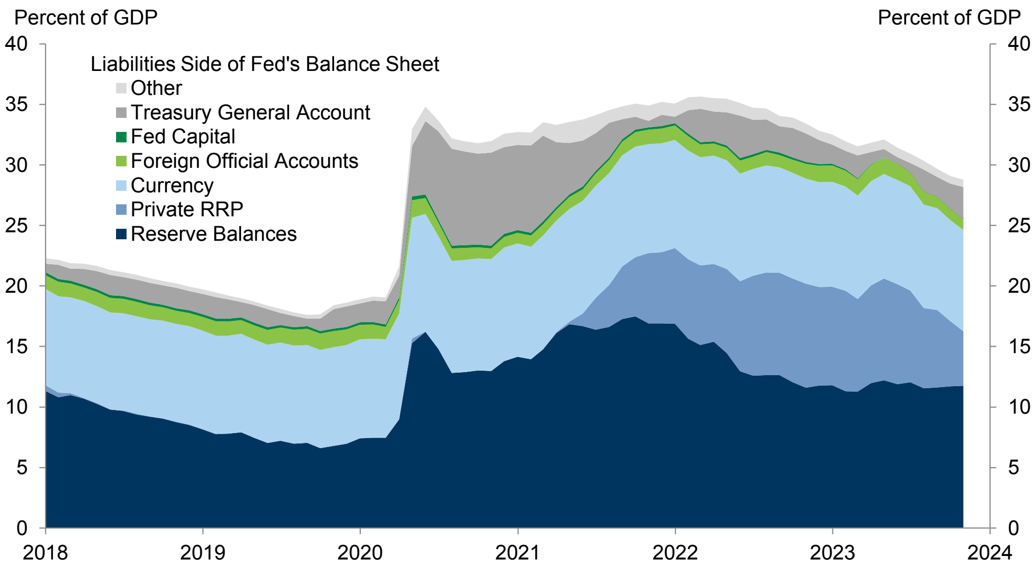
In contrast, reserve balances have been relatively flat in 2023, and the Fed's liabilities declined largely because of lower RRP use.[2] RRP balances declined by over $1.5tn to $936bn this year, as increased Treasury bill issuance and higher demand for funding by banks pushed money market funds away from the facility. Looking ahead, we expect RRP balances to continue declining and reach near-zero levels in 2024 as these dynamics continue. Lower RRP balances account for the bulk of the decline in the Fed's liabilities that we expect over the next year.

---

1 This simplified illustration ignores other changes that may affect banks and money market funds' incentives for holding reserves and RRP balances, such as changes in interest rates and changes in the composition of bank deposits. Acharya and Rajan (2022), for example, argue that QE shifts the composition of bank funding toward more volatile uninsured demand deposits, which increases banks' demand for reserves in order to ensure liquidity in the face of more volatile liabilities. Interest rates also change the optimal composition of bank funding—for example, time deposits have increased rapidly since the Fed started hiking, and banks may demand a different quantity of reserves to match these liabilities.

2 The Fed's balance sheet expanded somewhat in response to the banking turmoil in March 2023 but resumed its decline after conditions in the banking sector stabilized in April.

Exhibit 1: In 2022, the Fed's Balance Sheet Shrunk Through Lower Bank Reserves; In 2023, It Has Shrunk Through Lower RRP Balances



Source: Federal Reserve, Goldman Sachs Global Investment Research

The FOMC will likely aim to stop balance sheet normalization when bank reserves go from "abundant" to "ample"—that is, when changes in the supply of reserves have a real but modest effect on short-term rates relative to the Fed's administered rates. To gauge when reserves and broader conditions in money markets will start exerting upward pressure on short-term rates, we use a censored regression model that predicts the spread between the effective fed funds rate and the Fed's interest on reserve balances (IORB) rate based on reserves as a share of bank assets, our projections for bill supply, and demand for short-term financing from levered investors proxied by short positions in Treasury futures.

Our model suggests that short-term rates will start becoming more sensitive to changes in reserves around 2024Q3, and we expect the FOMC to begin considering changes to the speed of runoff at that point and then to slow the pace of balance sheet reduction in 2024Q4 by cutting the monthly runoff caps in half from $60bn to $30bn for Treasury securities and $35bn to $17.5bn for MBS securities.[3] We expect runoff to finish in 2025Q1, when bank reserves are 12-13% of bank assets (vs. 14% currently), or roughly $2.9tn (vs. $3.3tn currently), and the Fed's balance sheet is around 22% of GDP (vs. around 30% currently and 18% in 2019). As runoff progresses, we expect the spread of the fed funds rate to the IORB rate to rise by 5-10bp over the next year, from -7bp currently.

Our estimate of the level of reserves at which the Fed will stop runoff is similar to recent estimates by Fed economists. New York Fed President John Williams and other Fed economists estimate that the ample reserves region starts at around 13% of bank

[3] This should meaningfully slow the pace of Treasury runoff but have a more muted impact on the pace of MBS runoff, since higher mortgage rates have reduced mortgage prepayments substantially.

assets.[4] Estimates by economists David Lopez-Salido and Annette Vissing-Jorgensen are also consistent with reserves at around 12-13% of bank assets.[5]

We continue to expect the Fed's balance sheet runoff to have modest effects on interest rates, broader financial conditions, growth, and inflation. Our rule of thumb derived from a range of studies is that 1% of GDP of balance sheet reduction is associated with a roughly 2bp rise in 10-year Treasury yields. In total, our projections for runoff imply that balance sheet normalization will have exerted around 20bp worth of upward pressure on 10-year yields since runoff started. Together with our rule of thumb that a 25bp boost to 10-year term premia from balance sheet reduction has roughly the same impact on financial conditions and growth as a 25bp rate hike, this implies that the total runoff process should have the effect of a little under one rate hike. At this point, a large part of runoff has already occurred and most of what remains is likely already anticipated by financial markets, meaning that most of the impact on Treasury yields is likely behind us. Studies of asset purchase programs tend to find more evidence that they influence yields when they are announced or anticipated than when the flow of runoff occurs, consistent with the idea that financial markets price information about future events when they receive it, not when the event occurs.

The key risk to our forecast is that the increased supply of debt that we expect in 2024 causes intermediation bottlenecks in the Treasury market that lead the Fed to stop runoff earlier. Another possible risk is that FOMC participants decide to stop runoff early in order to avoid risking volatility in money markets. Indeed, a recent paper by President Williams and other Fed economists argues that elevated uncertainty over the shape of the demand curve for Fed reserves implies a higher optimal level of reserve supply by the Fed, all else equal.[6]

Monitoring conditions in funding markets

There is substantial uncertainty about how sensitive short-term rates will actually prove to changes in reserve balances and how conditions in money markets will evolve as runoff continues. We therefore introduce a number of indicators to monitor how conditions are evolving in short-term funding markets.

Conditions in overall funding markets

As liquidity becomes scarcer, money market rates like repo rates and the fed funds rate will start to increase relative to the Fed's administered rates. Between 2017 and 2019, as the Fed's balance sheet normalization progressed, the spread between the fed funds

4 Afonso, Gara, Domenico Giannone, Gabriele La Spada, and John C. Williams, "Scarce, Abundant, or Ample? A Time-Varying Model of the Reserve Demand Curve," May 2022 (revised June 2023).

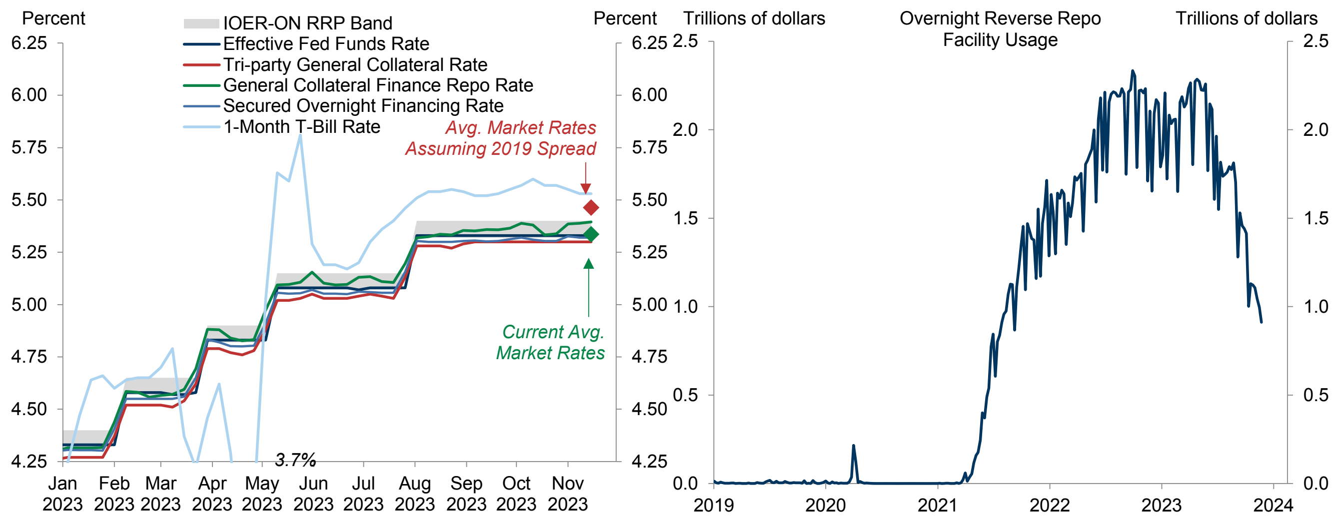
5 Lopez-Salido, David, and Annette Vissing-Jorgensen, "Reserve Demand, Interest Rate Control, and Quantitative Tightening," November 2021 (revised September 2023). We take the parameters in the paper and estimate the implied level of reserves using the latest data on deposits, which have declined somewhat since the authors published it in 2022. Their estimates imply that reserve balances equal to $2.6tn would roughly match money market conditions in September 2019 while reserve balances equal to $3.2tn would result in an IORB-fed funds spread of zero. The average of these two estimates is about $2.9tn, similar to our forecast for the stopping point.

6 See Afonso, Gara, Gabriele La Spada, Thomas M. Mertens, and John C. Williams, "The Optimal Supply of Central Bank Reserves under Uncertainty," November 2023.

rate and the IORB rate rose from around -10bp to +5bp. So far, key money market rates including the fed funds rate remain close to the lower end of the IORB-RRP band, with the fed funds rate currently 6bp below the IORB rate, indicating that liquidity remains plentiful in funding markets (left-hand side of Exhibit 2).

At the same time, short-term Treasury rates are well above other short-term money market rates (light blue line, left-hand side of Exhibit 2), suggesting that money market funds will likely continue to move assets out of the RRP facility and into bills (right-hand side of Exhibit 2).

Exhibit 2: Key Money Market Rates Remain Close to the Lower End of the IORB-RRP Band, Indicating That Liquidity Remains Plentiful; Short-Term Treasury Rates Remain Above Repo Rates, Which Should Push Money Market Funds to Continue Shifting Assets from the RRP Facility to Treasuries

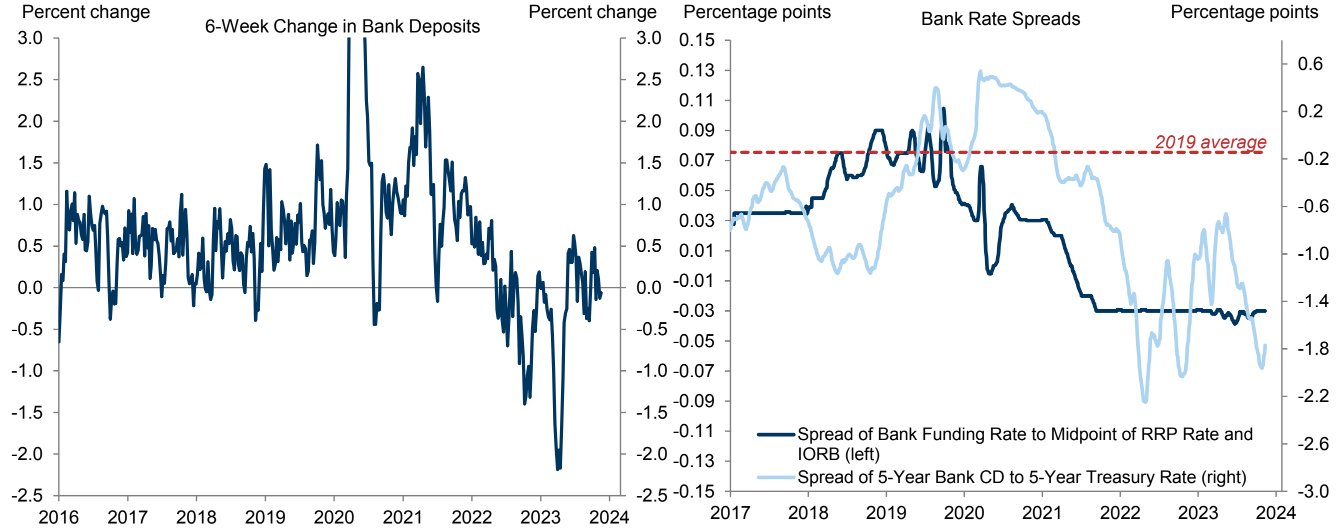


Source: Federal Reserve, Goldman Sachs Global Investment Research

Conditions for banks

Banks may demand more reserves if they need to meet unexpected deposit outflows. Deposit flows have normalized since the banking turmoil of March 2023 subsided, which has stabilized banks' immediate liquidity needs (left-hand side of Exhibit 3). Additionally, spreads on bank rates and CD rates—which increased in 2019 as banks sought to preserve funds amid increasingly scarce liquidity—remain low, suggesting that banks are not yet being forced to pay more for funds (right-hand side of Exhibit 3).

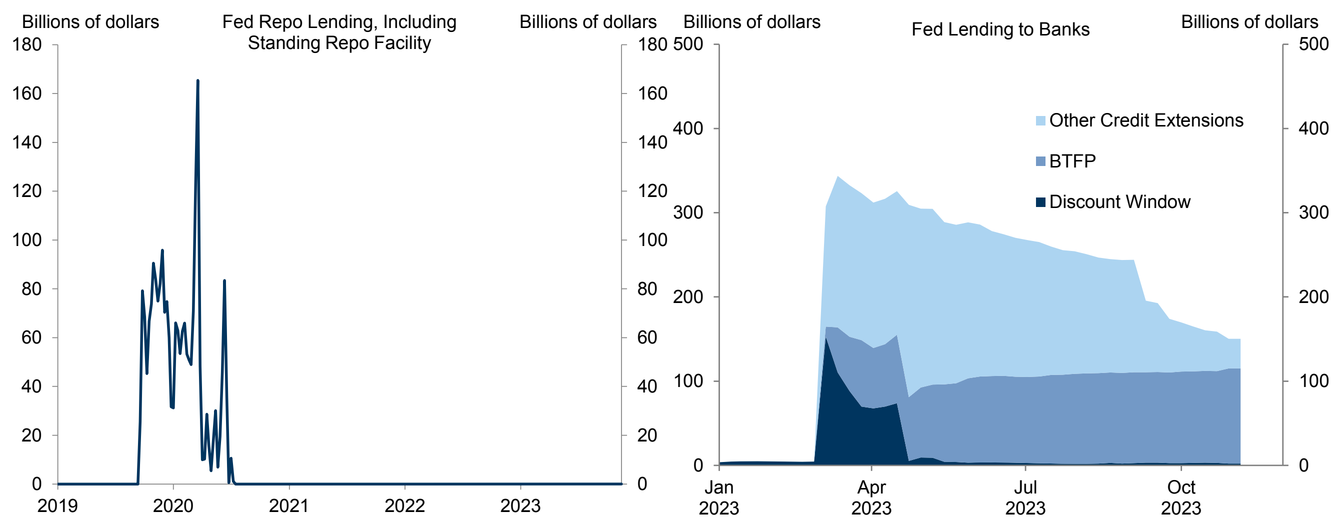
Exhibit 3: Bank Deposits Have Stabilized After the Banking Turmoil of March 2023 Subsided; Bank Rates Remain Below Market Rates, Suggesting the System Has Plenty of Liquidity



Source: Federal Reserve, Wall Street Journal, Goldman Sachs Global Investment Research

If liquidity becomes scarce, banks can borrow from the Fed through the Standing Repo Facility (SRF) and the discount window at a rate slightly above the IORB rate.[7] As a result, routine use of the SRF or the discount window would signal that liquidity has become scarce and would likely lead the Fed to slow or stop balance sheet runoff. So far, though, the SRF remains untapped (left-hand side of Exhibit 4), and while outstanding loans to banks remain elevated in the aftermath of the banking turmoil in March, banks have been paying down these loans gradually (right-hand side of Exhibit 4).

Exhibit 4: The Standing Repo Facility Remains Untapped; Banks Have Been Paying Off Discount Window and BTFP Loans Since March



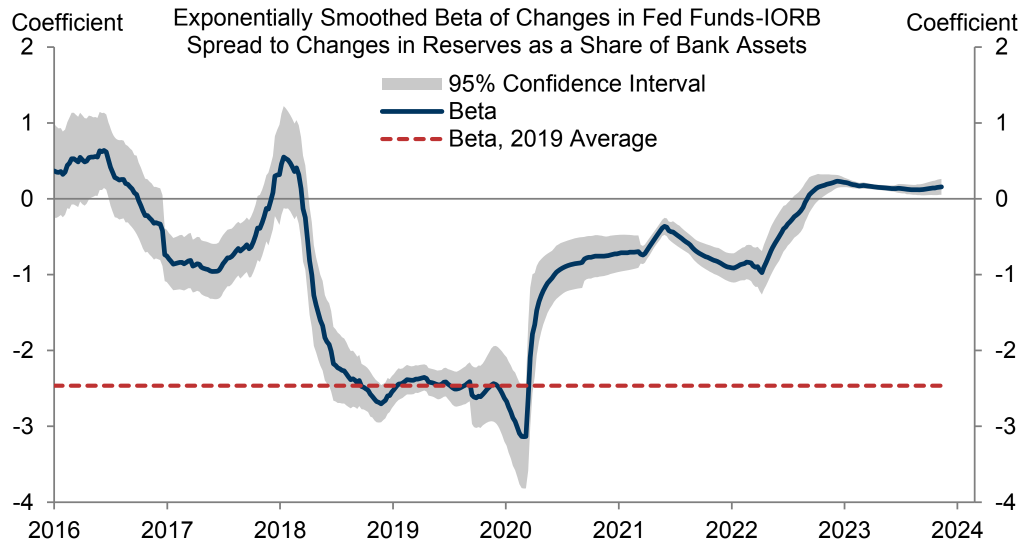
Source: Federal Reserve, Goldman Sachs Global Investment Research

Consistent with stable funding conditions for banks, changes in the spread of the fed

[7] The SRF and discount window rates are currently set at 5.50%, 10bp above the IORB rate.

funds rate to the IORB rate remain insensitive to changes in reserves (Exhibit 5). This suggests that the Fed is still supplying "abundant" reserves to the banking system.

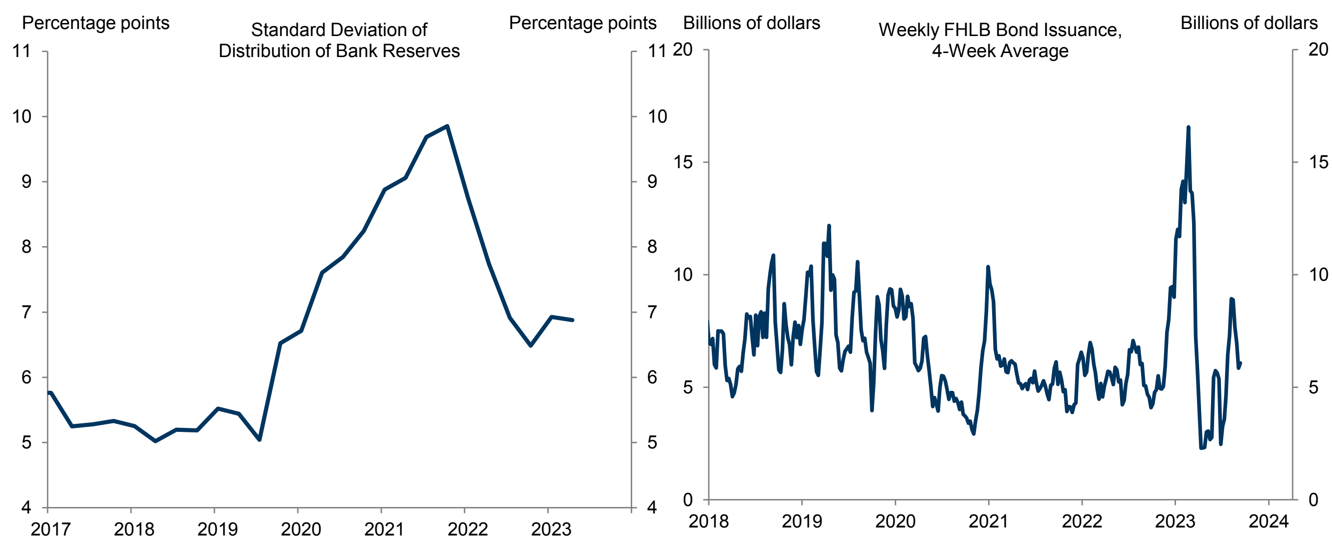
Exhibit 5: The Fed Funds Rate-IORB Spread Remains Insensitive to Changes in Reserves



Source: Goldman Sachs Global Investment Research

While there is abundant liquidity in the aggregate banking system, the distribution of reserves remains uneven (left-hand side of Exhibit 6). Banks can acquire reserves by borrowing in repo markets and taking out advances from the Federal Home Loan Banks (FHLBs), whose bonds can be purchased by market participants like money market funds. FHLB bond issuance has picked up slightly in recent weeks but remains well below its March levels, suggesting that banks' funding needs remain broadly stable (right-hand side of Exhibit 6).

Exhibit 6: The Distribution of Bank Reserves Remains Uneven; FHLB Issuance Has Picked Up Slightly in Recent Weeks but Remains Well Below Its March Level

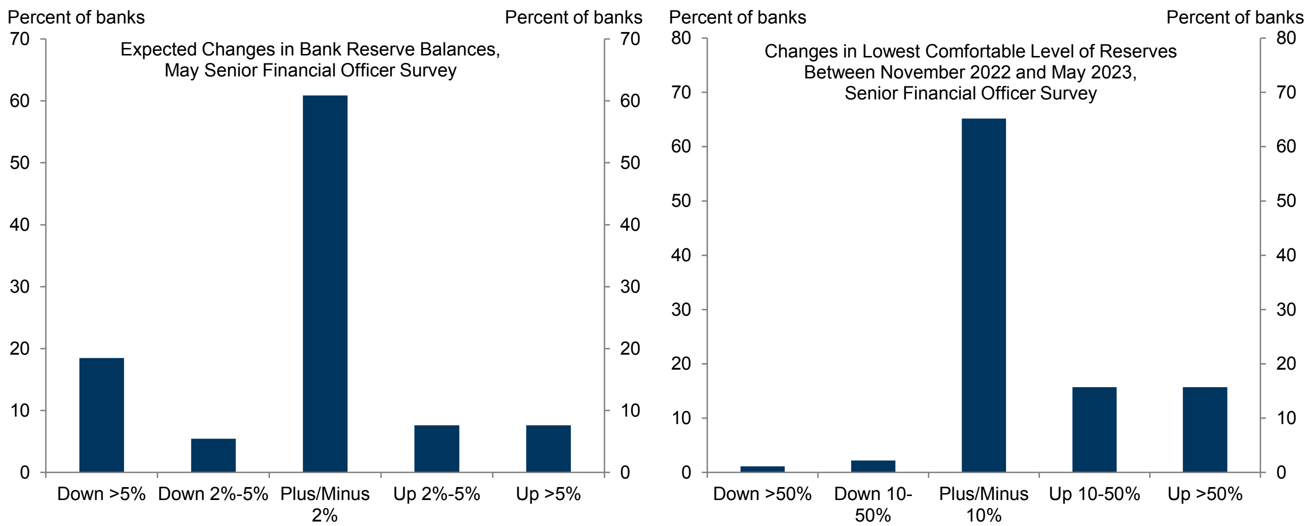


Source: Federal Financial Institutions Examination Council, Department of the Treasury, Goldman Sachs Global Investment Research

Looking ahead, the Fed's most recent Senior Financial Officer Survey shows that a net

10% of bank financial officers expect reserves at their banks to decline further, while 56% expect reserves to remain roughly where they are now (left-hand side of Exhibit 7). These results are broadly consistent with our expectation that bank reserves will decline modestly before the Fed stops runoff. Bank financial officers have also signaled that the lowest level of reserves they are comfortable with has mostly risen since last year (right-hand side of Exhibit 7).

Exhibit 7: Most Banks Expect Reserve Balances to Remain Near Current Levels and Report That the Lowest Level of Reserves They're Comfortable With Has Risen Since Last Year



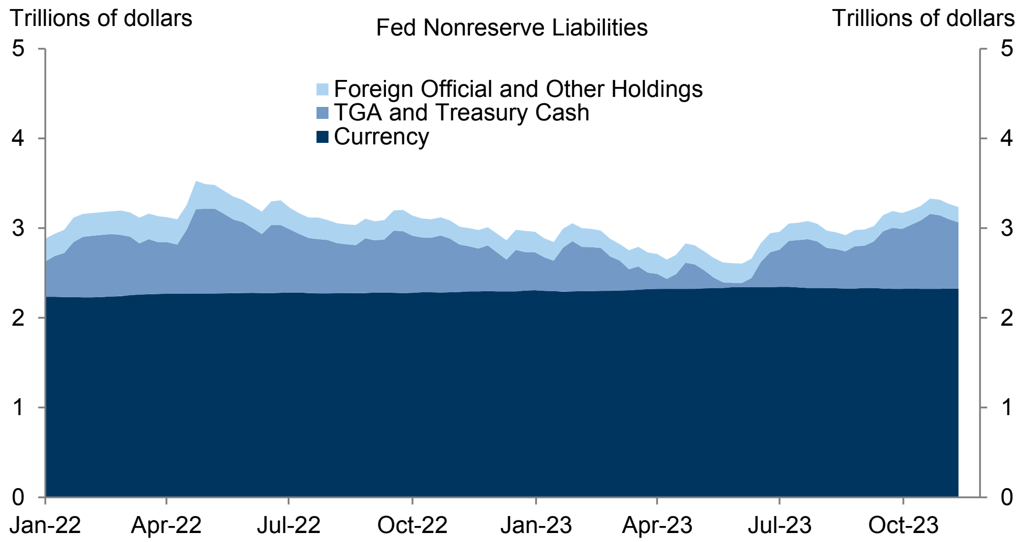
Source: Federal Reserve, Goldman Sachs Global Investment Research

The evolution of non-reserve liabilities

As runoff continues, changes in the Fed's non-reserve liabilities can lead to fluctuations in liquidity available to banks and money market funds. For example, the suspension of the debt ceiling in June allowed Treasury to replenish the Treasury General Account (TGA) at the Fed, which absorbed funds from the RRP facility and lowered the Fed's supply of liquidity to the private sector. TGA balances rose to $850bn in October but have since fallen to $740bn, and we expect them to remain at $700-750bn over the next few months.

At the same time, the demand for currency has risen slowly but consistently over time. We don't expect slowly-rising currency demand to have material effects over the next few months, but we do expect it to put a modest amount of upward pressure on the equilibrium size of the balance sheet as a share of GDP over time.

Exhibit 8: The Fed's Nonreserve Liabilities Have Grown in Recent Months as the Treasury Replenished the TGA and Currency Demand Continues to Increase



Source: Federal Reserve, Goldman Sachs Global Investment Research

Manuel Abecasis

Praveen Korapaty

Disclosure Appendix

Reg AC

We, Jan Hatzius, Alec Phillips, David Mericle, Spencer Hill, CFA, Ronnie Walker, Tim Krupa, Manuel Abecasis and Praveen Korapaty, hereby certify that all of the views expressed in this report accurately reflect our personal views, which have not been influenced by considerations of the firm's business or client relationships.

Unless otherwise stated, the individuals listed on the cover page of this report are analysts in Goldman Sachs' Global Investment Research division.

Disclosures

Regulatory disclosures

Disclosures required by United States laws and regulations

See company-specific regulatory disclosures above for any of the following disclosures required as to companies referred to in this report: manager or co-manager in a pending transaction; 1% or other ownership; compensation for certain services; types of client relationships; managed/co-managed public offerings in prior periods; directorships; for equity securities, market making and/or specialist role. Goldman Sachs trades or may trade as a principal in debt securities (or in related derivatives) of issuers discussed in this report.

The following are additional required disclosures: **Ownership and material conflicts of interest:** Goldman Sachs policy prohibits its analysts, professionals reporting to analysts and members of their households from owning securities of any company in the analyst's area of coverage. **Analyst compensation:** Analysts are paid in part based on the profitability of Goldman Sachs, which includes investment banking revenues. **Analyst as officer or director:** Goldman Sachs policy generally prohibits its analysts, persons reporting to analysts or members of their households from serving as an officer, director or advisor of any company in the analyst's area of coverage. **Non-U.S. Analysts:** Non-U.S. analysts may not be associated persons of Goldman Sachs & Co. LLC and therefore may not be subject to FINRA Rule 2241 or FINRA Rule 2242 restrictions on communications with subject company, public appearances and trading securities held by the analysts.

Additional disclosures required under the laws and regulations of jurisdictions other than the United States

The following disclosures are those required by the jurisdiction indicated, except to the extent already made above pursuant to United States laws and regulations. **Australia:** Goldman Sachs Australia Pty Ltd and its affiliates are not authorised deposit-taking institutions (as that term is defined in the Banking Act 1959 (Cth)) in Australia and do not provide banking services, nor carry on a banking business, in Australia. This research, and any access to it, is intended only for "wholesale clients" within the meaning of the Australian Corporations Act, unless otherwise agreed by Goldman Sachs. In producing research reports, members of Global Investment Research of Goldman Sachs Australia may attend site visits and other meetings hosted by the companies and other entities which are the subject of its research reports. In some instances the costs of such site visits or meetings may be met in part or in whole by the issuers concerned if Goldman Sachs Australia considers it is appropriate and reasonable in the specific circumstances relating to the site visit or meeting. To the extent that the contents of this document contains any financial product advice, it is general advice only and has been prepared by Goldman Sachs without taking into account a client's objectives, financial situation or needs. A client should, before acting on any such advice, consider the appropriateness of the advice having regard to the client's own objectives, financial situation and needs. A copy of certain Goldman Sachs Australia and New Zealand disclosure of interests and a copy of Goldman Sachs' Australian Sell-Side Research Independence Policy Statement are available at: https://www.goldmansachs.com/disclosures/australia-new-zealand/index.html. **Brazil:** Disclosure information in relation to CVM Resolution n. 20 is available at https://www.gs.com/worldwide/brazil/area/gir/index.html. Where applicable, the Brazil-registered analyst primarily responsible for the content of this research report, as defined in Article 20 of CVM Resolution n. 20, is the first author named at the beginning of this report, unless indicated otherwise at the end of the text. **Canada:** This information is being provided to you for information purposes only and is not, and under no circumstances should be construed as, an advertisement, offering or solicitation by Goldman Sachs & Co. LLC for purchasers of securities in Canada to trade in any Canadian security. Goldman Sachs & Co. LLC is not registered as a dealer in any jurisdiction in Canada under applicable Canadian securities laws and generally is not permitted to trade in Canadian securities and may be prohibited from selling certain securities and products in certain jurisdictions in Canada. If you wish to trade in any Canadian securities or other products in Canada please contact Goldman Sachs Canada Inc., an affiliate of The Goldman Sachs Group Inc., or another registered Canadian dealer. **Hong Kong:** Further information on the securities of covered companies referred to in this research may be obtained on request from Goldman Sachs (Asia) L.L.C. **India:** Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (India) Securities Private Limited, Research Analyst - SEBI Registration Number INH000001493, 951-A, Rational House, Appasaheb Marathe Marg, Prabhadevi, Mumbai 400 025, India, Corporate Identity Number U74140MH2006FTC160634, Phone +91 22 6616 9000, Fax +91 22 6616 9001. Goldman Sachs may beneficially own 1% or more of the securities (as such term is defined in clause 2 (h) the Indian Securities Contracts (Regulation) Act, 1956) of the subject company or companies referred to in this research report. Investment in securities market are subject to market risks. Read all the related documents carefully before investing. Registration granted by SEBI and certification from NISM in no way guarantee performance of the intermediary or provide any assurance of returns to investors. Goldman Sachs (India) Securities Private Limited Investor Grievance E-mail: india-client-support@gs.com. Compliance Officer: Anil Rajput |Tel: + 91 22 6616 9000 | Email: anil.m.rajput@gs.com. **Japan:** See below. **Korea:** This research, and any access to it, is intended only for "professional investors" within the meaning of the Financial Services and Capital Markets Act, unless otherwise agreed by Goldman Sachs. Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (Asia) L.L.C., Seoul Branch. **New Zealand:** Goldman Sachs New Zealand Limited and its affiliates are neither "registered banks" nor "deposit takers" (as defined in the Reserve Bank of New Zealand Act 1989) in New Zealand. This research, and any access to it, is intended for "wholesale clients" (as defined in the Financial Advisers Act 2008) unless otherwise agreed by Goldman Sachs. A copy of certain Goldman Sachs Australia and New Zealand disclosure of interests is available at: https://www.goldmansachs.com/disclosures/australia-new-zealand/index.html. **Russia:** Research reports distributed in the Russian Federation are not advertising as defined in the Russian legislation, but are information and analysis not having product promotion as their main purpose and do not provide appraisal within the meaning of the Russian legislation on appraisal activity. Research reports do not constitute a personalized investment recommendation as defined in Russian laws and regulations, are not addressed to a specific client, and are prepared without analyzing the financial circumstances, investment profiles or risk profiles of clients. Goldman Sachs assumes no responsibility for any investment decisions that may be taken by a client or any other person based on this research report. **Singapore:** Goldman Sachs (Singapore) Pte. (Company Number: 198602165W), which is regulated by the Monetary Authority of Singapore, accepts legal responsibility for this research, and should be contacted with respect to any matters arising from, or in connection with, this research. **Taiwan:** This material is for reference only and must not be reprinted without permission. Investors should carefully consider their own investment risk. Investment results are the responsibility of the individual investor. **United Kingdom:** Persons who would be categorized as retail clients in the United Kingdom, as such term is defined in the rules of the Financial Conduct Authority, should read this research in conjunction with prior Goldman Sachs research on the covered companies referred to herein and should refer to the risk warnings that have been sent to them by Goldman Sachs International. A copy of these risks warnings, and a glossary of certain financial terms used in this report, are available from Goldman Sachs International on request.

European Union and United Kingdom: Disclosure information in relation to Article 6 (2) of the European Commission Delegated Regulation (EU)

(2016/958) supplementing Regulation (EU) No 596/2014 of the European Parliament and of the Council (including as that Delegated Regulation is implemented into United Kingdom domestic law and regulation following the United Kingdom's departure from the European Union and the European Economic Area) with regard to regulatory technical standards for the technical arrangements for objective presentation of investment recommendations or other information recommending or suggesting an investment strategy and for disclosure of particular interests or indications of conflicts of interest is available at https://www.gs.com/disclosures/europeanpolicy.html which states the European Policy for Managing Conflicts of Interest in Connection with Investment Research.

Japan: Goldman Sachs Japan Co., Ltd. is a Financial Instrument Dealer registered with the Kanto Financial Bureau under registration number Kinsho 69, and a member of Japan Securities Dealers Association, Financial Futures Association of Japan Type II Financial Instruments Firms Association, The Investment Trusts Association, Japan, and Japan Investment Advisers Association. Sales and purchase of equities are subject to commission pre-determined with clients plus consumption tax. See company-specific disclosures as to any applicable disclosures required by Japanese stock exchanges, the Japanese Securities Dealers Association or the Japanese Securities Finance Company.

Global product; distributing entities

Goldman Sachs Global Investment Research produces and distributes research products for clients of Goldman Sachs on a global basis. Analysts based in Goldman Sachs offices around the world produce research on industries and companies, and research on macroeconomics, currencies, commodities and portfolio strategy. This research is disseminated in Australia by Goldman Sachs Australia Pty Ltd (ABN 21 006 797 897); in Brazil by Goldman Sachs do Brasil Corretora de Títulos e Valores Mobiliários S.A.; Public Communication Channel Goldman Sachs Brazil: 0800 727 5764 and / or contatogoldmanbrasil@gs.com. Available Weekdays (except holidays), from 9am to 6pm. Canal de Comunicação com o Público Goldman Sachs Brasil: 0800 727 5764 e/ou contatogoldmanbrasil@gs.com. Horário de funcionamento: segunda-feira à sexta-feira (exceto feriados), das 9h às 18h; in Canada by Goldman Sachs & Co. LLC; in Hong Kong by Goldman Sachs (Asia) L.L.C.; in India by Goldman Sachs (India) Securities Private Ltd.; in Japan by Goldman Sachs Japan Co., Ltd.; in the Republic of Korea by Goldman Sachs (Asia) L.L.C., Seoul Branch; in New Zealand by Goldman Sachs New Zealand Limited; in Russia by OOO Goldman Sachs; in Singapore by Goldman Sachs (Singapore) Pte. (Company Number: 198602165W); and in the United States of America by Goldman Sachs & Co. LLC. Goldman Sachs International has approved this research in connection with its distribution in the United Kingdom.

Goldman Sachs International ("GSI"), authorised by the Prudential Regulation Authority ("PRA") and regulated by the Financial Conduct Authority ("FCA") and the PRA, has approved this research in connection with its distribution in the United Kingdom.

European Economic Area: GSI, authorised by the PRA and regulated by the FCA and the PRA, disseminates research in the following jurisdictions within the European Economic Area: the Grand Duchy of Luxembourg, Italy, the Kingdom of Belgium, the Kingdom of Denmark, the Kingdom of Norway, the Republic of Finland and the Republic of Ireland; GSI - Succursale de Paris (Paris branch) which is authorised by the French Autorité de contrôle prudentiel et de resolution ("ACPR") and regulated by the Autorité de contrôle prudentiel et de resolution and the Autorité des marches financiers ("AMF") disseminates research in France; GSI - Sucursal en España (Madrid branch) authorized in Spain by the Comisión Nacional del Mercado de Valores disseminates research in the Kingdom of Spain; GSI - Sweden Bankfilial (Stockholm branch) is authorized by the SFSA as a "third country branch" in accordance with Chapter 4, Section 4 of the Swedish Securities and Market Act (Sw. lag (2007:528) om värdepappersmarknaden) disseminates research in the Kingdom of Sweden; Goldman Sachs Bank Europe SE ("GSBE") is a credit institution incorporated in Germany and, within the Single Supervisory Mechanism, subject to direct prudential supervision by the European Central Bank and in other respects supervised by German Federal Financial Supervisory Authority (Bundesanstalt für Finanzdienstleistungsaufsicht, BaFin) and Deutsche Bundesbank and disseminates research in the Federal Republic of Germany and those jurisdictions within the European Economic Area where GSI is not authorised to disseminate research and additionally, GSBE, Copenhagen Branch filial af GSBE, Tyskland, supervised by the Danish Financial Authority disseminates research in the Kingdom of Denmark; GSBE - Sucursal en España (Madrid branch) subject (to a limited extent) to local supervision by the Bank of Spain disseminates research in the Kingdom of Spain; GSBE - Succursale Italia (Milan branch) to the relevant applicable extent, subject to local supervision by the Bank of Italy (Banca d'Italia) and the Italian Companies and Exchange Commission (Commissione Nazionale per le Società e la Borsa "Consob") disseminates research in Italy; GSBE - Succursale de Paris (Paris branch), supervised by the AMF and by the ACPR disseminates research in France; and GSBE - Sweden Bankfilial (Stockholm branch), to a limited extent, subject to local supervision by the Swedish Financial Supervisory Authority (Finansinpektionen) disseminates research in the Kingdom of Sweden.

General disclosures

This research is for our clients only. Other than disclosures relating to Goldman Sachs, this research is based on current public information that we consider reliable, but we do not represent it is accurate or complete, and it should not be relied on as such. The information, opinions, estimates and forecasts contained herein are as of the date hereof and are subject to change without prior notification. We seek to update our research as appropriate, but various regulations may prevent us from doing so. Other than certain industry reports published on a periodic basis, the large majority of reports are published at irregular intervals as appropriate in the analyst's judgment.

Goldman Sachs conducts a global full-service, integrated investment banking, investment management, and brokerage business. We have investment banking and other business relationships with a substantial percentage of the companies covered by Global Investment Research. Goldman Sachs & Co. LLC, the United States broker dealer, is a member of SIPC (https://www.sipc.org).

Our salespeople, traders, and other professionals may provide oral or written market commentary or trading strategies to our clients and principal trading desks that reflect opinions that are contrary to the opinions expressed in this research. Our asset management area, principal trading desks and investing businesses may make investment decisions that are inconsistent with the recommendations or views expressed in this research.

We and our affiliates, officers, directors, and employees will from time to time have long or short positions in, act as principal in, and buy or sell, the securities or derivatives, if any, referred to in this research, unless otherwise prohibited by regulation or Goldman Sachs policy.

The views attributed to third party presenters at Goldman Sachs arranged conferences, including individuals from other parts of Goldman Sachs, do not necessarily reflect those of Global Investment Research and are not an official view of Goldman Sachs.

Any third party referenced herein, including any salespeople, traders and other professionals or members of their household, may have positions in the products mentioned that are inconsistent with the views expressed by analysts named in this report.

This research is focused on investment themes across markets, industries and sectors. It does not attempt to distinguish between the prospects or performance of, or provide analysis of, individual companies within any industry or sector we describe.

Any trading recommendation in this research relating to an equity or credit security or securities within an industry or sector is reflective of the investment theme being discussed and is not a recommendation of any such security in isolation.

This research is not an offer to sell or the solicitation of an offer to buy any security in any jurisdiction where such an offer or solicitation would be illegal. It does not constitute a personal recommendation or take into account the particular investment objectives, financial situations, or needs of individual clients. Clients should consider whether any advice or recommendation in this research is suitable for their particular circumstances and, if appropriate, seek professional advice, including tax advice. The price and value of investments referred to in this research and the income from them may fluctuate. Past performance is not a guide to future performance, future returns are not guaranteed, and a loss of original capital may occur.

Fluctuations in exchange rates could have adverse effects on the value or price of, or income derived from, certain investments.

Certain transactions, including those involving futures, options, and other derivatives, give rise to substantial risk and are not suitable for all investors. Investors should review current options and futures disclosure documents which are available from Goldman Sachs sales representatives or at https://www.theocc.com/about/publications/character-risks.jsp and https://www.fiadocumentation.org/fia/regulatory-disclosures_1/fia-uniform-futures-and-options-on-futures-risk-disclosures-booklet-pdf-version-2018. Transaction costs may be significant in option strategies calling for multiple purchase and sales of options such as spreads. Supporting documentation will be supplied upon request.

Differing Levels of Service provided by Global Investment Research: The level and types of services provided to you by Goldman Sachs Global Investment Research may vary as compared to that provided to internal and other external clients of GS, depending on various factors including your individual preferences as to the frequency and manner of receiving communication, your risk profile and investment focus and perspective (e.g., marketwide, sector specific, long term, short term), the size and scope of your overall client relationship with GS, and legal and regulatory constraints. As an example, certain clients may request to receive notifications when research on specific securities is published, and certain clients may request that specific data underlying analysts' fundamental analysis available on our internal client websites be delivered to them electronically through data feeds or otherwise. No change to an analyst's fundamental research views (e.g., ratings, price targets, or material changes to earnings estimates for equity securities), will be communicated to any client prior to inclusion of such information in a research report broadly disseminated through electronic publication to our internal client websites or through other means, as necessary, to all clients who are entitled to receive such reports.

All research reports are disseminated and available to all clients simultaneously through electronic publication to our internal client websites. Not all research content is redistributed to our clients or available to third-party aggregators, nor is Goldman Sachs responsible for the redistribution of our research by third party aggregators. For research, models or other data related to one or more securities, markets or asset classes (including related services) that may be available to you, please contact your GS representative or go to https://research.gs.com.

Disclosure information is also available at https://www.gs.com/research/hedge.html or from Research Compliance, 200 West Street, New York, NY 10282.