Goldman Sachs | Economics Research

16 May 2022 | 3:51PM EDT

Global Markets Daily: The Economics of Algorithmic Stablecoins (Rosenberg/Pandl)

Isabella Rosenberg
+1(212)357-7628 | isabella.rosenberg@gs.com
Goldman Sachs & Co. LLC

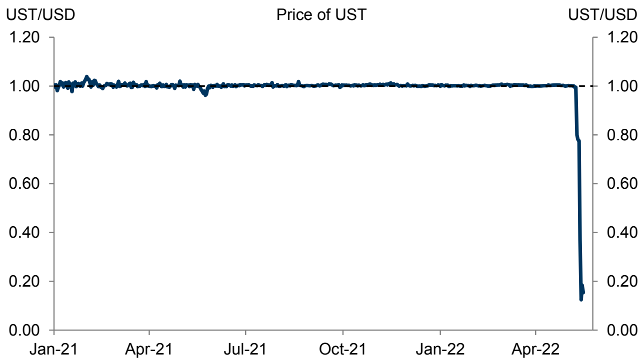
Zach Pandl
+1(212)902-5699 | zach.pandl@gs.com
Goldman Sachs & Co. LLC

- In addition to the major drop in cryptocurrency prices, digital asset markets have recently been dominated by volatility in stablecoins—cryptocurrencies intended to be pegged 1:1 with fiat currencies, most commonly the US Dollar. Within the last few weeks, two prominent "algorithmic" stablecoins have de-pegged ("broke the buck"), Terra USD and Neutrino USD.
- Like fixed exchange rates in traditional finance, algorithmic stablecoins are vulnerable to speculative attacks. They also face competitive threats from other forms of public and private money, as did similar assets in earlier experiments with private money in US history.
- While stablecoins can provide a useful service within the digital asset ecosystem, current designs can be risky. More stability could be achieved through forms of government regulation and/or deeper network effects from greater non-speculative usage of the underlying protocols.

The Economics of Algorithmic Stablecoins

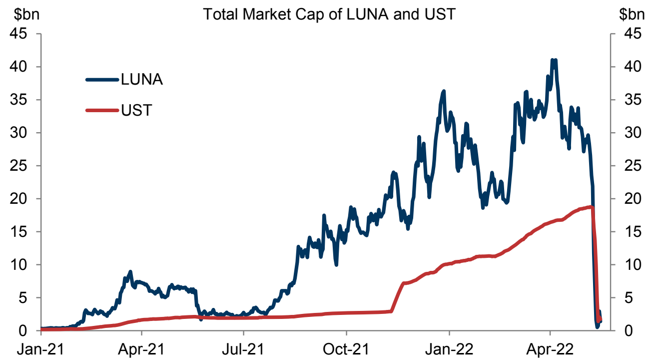
In addition to the major drop in cryptocurrency prices, digital asset markets have recently been dominated by volatility in stablecoins—cryptocurrencies intended to be pegged 1:1 with fiat currencies, most commonly the US Dollar. Within the last few weeks, two prominent "algorithmic" stablecoins have de-pegged ("broke the buck"), Terra USD and Neutrino USD (Exhibit 1 & Exhibit 2). Awareness of the risks and fragilities inherent to stablecoins has grown alongside their broader usage. While these assets are fairly new (introduced in 2014), many of the economic issues affecting stablecoins will be familiar to FX market participants and other investors. For example, algorithmic stablecoins closely resemble traditional pegged exchange rates as well as earlier forms of private money. Unlike fully-collateralized stablecoins (e.g. USDC), algorithmic stablecoins hold a volatile cryptocurrency as their reserve asset—the LUNA token in the case of the UST stablecoin—and use economic incentives to maintain the fiat peg. Unsurprisingly, algorithmic stablecoins share many of the vulnerabilities of pegged exchange rates, including the risk of speculative attacks.

Exhibit 1: Algorithmic stablecoin UST de-pegged...



Source: CoinGecko, Goldman Sachs Global Investment Research

Exhibit 2: ...along with a sharp drop in LUNA's market cap below that of UST



Source: CoinGecko, Goldman Sachs Global Investment Research

Stablecoins are digital assets that are pegged to the value of a fiat currency, such as the US Dollar.[1] In their simplest form, they are virtually identical to money market fund shares: tradable claims on low-risk and short-dated securities that are nearly equivalent to cash from an economic standpoint.[2] Stablecoins have become a popular way to exit positions in volatile cryptocurrencies, while remaining within the crypto ecosystem (i.e. without transferring assets back to fiat currency via the traditional banking system). Protocols that issue "algorithmic" stablecoins may also offer high yields (often through a decentralized lending protocol) to encourage investors to hold the token. In traditional finance, these structures are analogous to high yield savings accounts or high carry currencies. Stablecoins have limited use as a payments medium at this time. If that real-world use case were to grow over time, it could create a more stable demand base for these assets.

We can classify stablecoins into three broad categories: fiat-backed, crypto-backed, and algorithmic. **Fiat-backed stablecoins** are tokens that are backed by a reserve of fiat-denominated assets held "off-chain" (i.e. in traditional securities and custody arrangements); they make up the largest share of USD stablecoin market cap among the top 14 stablecoins (Exhibit 3). These assets might include US Treasury bills, for example, if the protocol is attempting to peg to USD. In order to create a new unit of a fiat-backed stablecoin, the equivalent amount of fiat collateral needs to be added to the reserve.

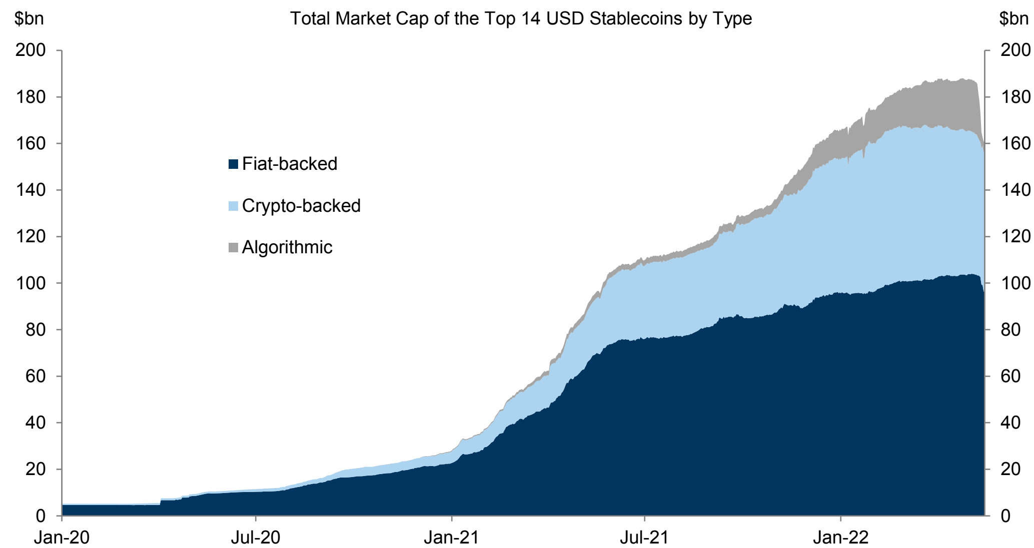
Crypto-backed stablecoins operate in a similar fashion, but rather than being fully-collateralized by a reserve of fiat-denominated assets, they are backed by an *over-collateralized* pool of cryptocurrencies. In order to create a new unit of a crypto-backed stablecoin, cryptocurrency must be added to the reserve by an amount exceeding the withdrawn stablecoin (e.g. 150%), measured at current cryptocurrency prices in US Dollar terms. For example, to generate the stablecoin DAI on the MakerDAO platform, a user must deposit 150% of the amount in Wrapped Ether at

1 Though many are pegged to fiat currencies, such as the US Dollar or Euro, they can also be pegged to commodities such as gold; in this piece, though, we will focus on those pegged to fiat currencies.

2 We will abstract from decentralization in this discussion.

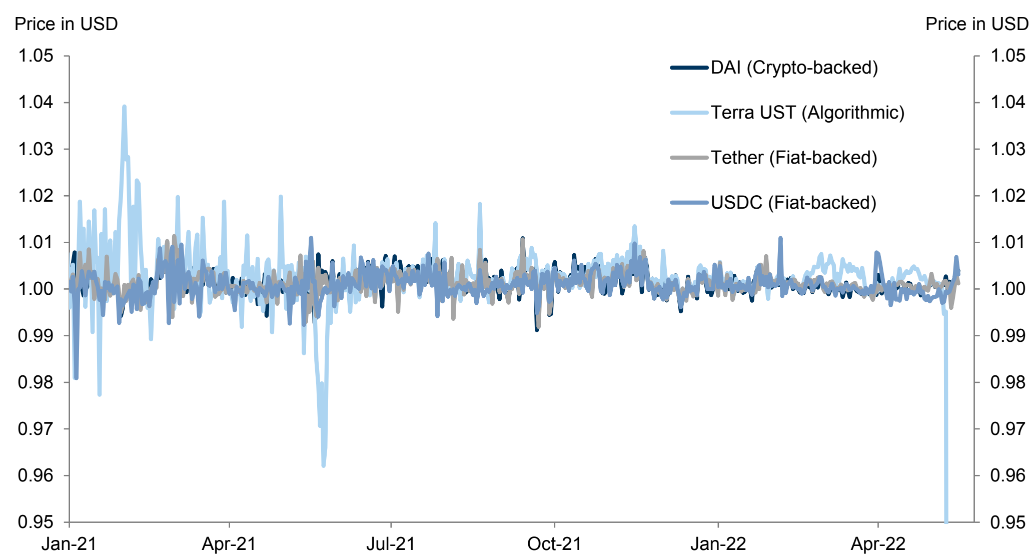
current market prices. If the market price of Ether declines, pushing the market value of assets below the minimum collateralization ratio, the smart contract will automatically sell the assets and consider the claim settled. Through this mechanism, crypto-backed stablecoins have remained generally stable, despite holding volatile cryptocurrency assets (Exhibit 4).

Exhibit 3: Fiat-backed stablecoins account for the largest share of market cap among the top 14 USD stablecoins



Source: CoinGecko, Goldman Sachs Global Investment Research

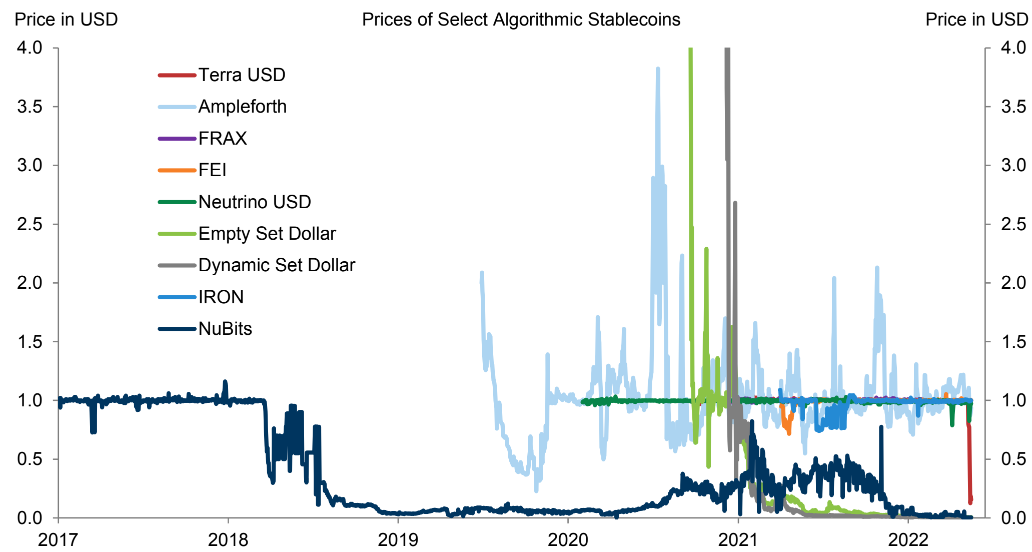
Exhibit 4: Many Types of Stablecoin Structures



Source: CoinGecko, Goldman Sachs Global Investment Research

In contrast, **algorithmic stablecoins** are typically pegged not through the use of reserves, but through an expansion and contraction of the supply of the stablecoin (note that the terminology on these topics varies across the industry). The exact mechanism through which algorithmic stablecoin pegs are maintained can be quite different, and multiple different models have emerged over the past few years, with most eventually de-pegging or adopting a fiat- or crypto-backed reserve model (Exhibit 5).[3]

Exhibit 5: A Volatile History for Algorithmic Stablecoins



Source: Coin Gecko

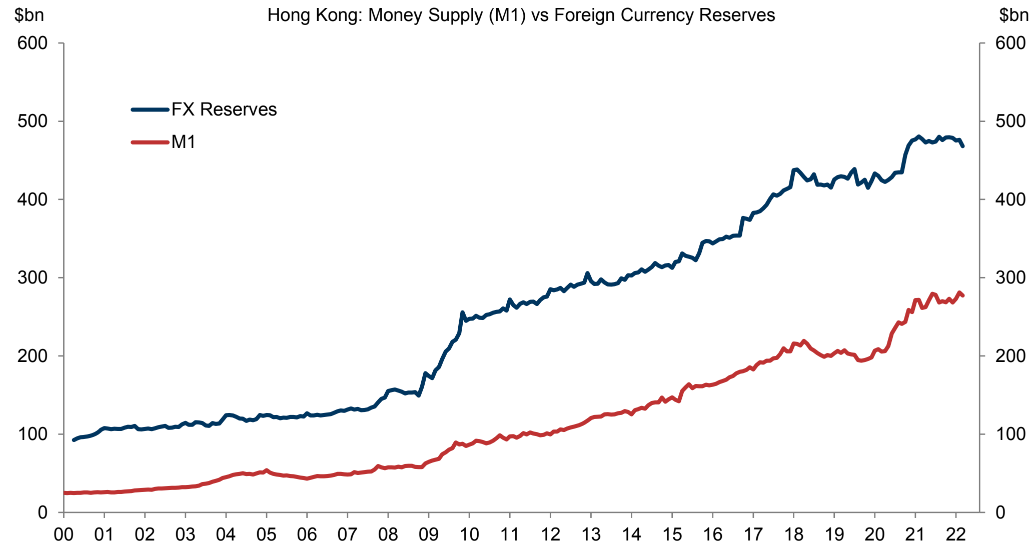
The ill-fated Terra USD (UST) had a relatively simple stability mechanism. When users create (or "withdraw", "convert fiat into") UST, an equivalent amount of the blockchain's native LUNA token is "burned" (destroyed). When users redeem UST (or "pay back", "convert back into fiat"), an equivalent amount of the LUNA token is "minted" (issued). This creates the incentive mechanism intended to maintain UST's peg to the US Dollar. For example, if the market price of UST falls below $1, an arbitrageur could purchase it in the open market, then redeem it through a smart contract for $1 of LUNA. After selling LUNA in the open market, assuming the steps happen simultaneously, the trader would net the different between the market price of UST and the $1 gained from selling LUNA. The same arbitrage incentives are intended to keep the market price of LUNA from rising above $1. Similar algorithmic stablecoins include USDN, IRON, and USDD. Most of these structures have no other "reserve" asset, but some, including UST and FRAX, are partly fiat-backed or crypto-backed.

Algorithmic stablecoins, like other stablecoins, resemble pegged exchange rates (for this discussion we will abstract from capital controls). In order to maintain a fixed exchange rate, a central bank must always stand ready to buy and sell the national currency at a stated price in foreign currency terms (i.e. at a stated exchange rate). Central banks support this mechanism by maintaining reserve assets denominated in the foreign currency. In a currency board, the most stable structure, these reserve

[3] One of the earliest examples of an algorithmic stablecoin is NuBits, issued in 2014, which functioned through a "seignorage-style" mechanism. This model inspired several other seignorage-style stablecoins, such as Basis, Empty Set Dollar, and Dynamic Set Dollar, which also relied on bond- or option-like instruments to push the value of the stablecoin up if it fell below parity.

assets exceed the nation's monetary base and are invested in low-risk assets denominated in the target currency, effectively guaranteeing that the central bank cannot run out of reserves. For example, the Hong Kong Monetary Authority, which operates under a currency board regime, holds low-risk USD assets exceeding the nation's monetary base (Exhibit 6). This system resembles "fiat-backed" stablecoins in crypto markets.

Exhibit 6: Currency Boards are More Stable than Other Fixed FX Regimes



Source: Haver Analytics, Goldman Sachs Global Investment Research

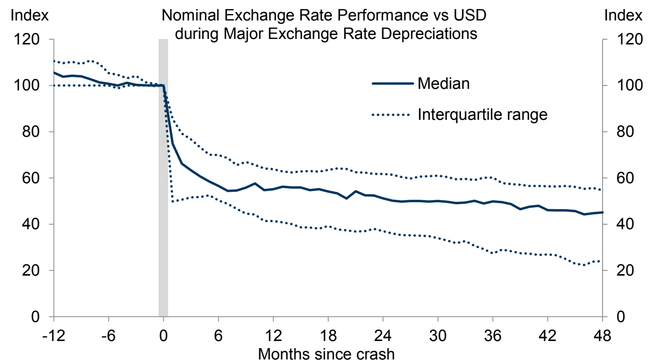
In most other fixed exchange rate regimes there will be higher uncertainty about the stability of the peg: reserve assets may not cover net balance of payments outflows in all possible future scenarios. These structures are typically evaluated along a spectrum, using indicators of reserve adequacy. Although fixed exchange rate regimes can be stable over long periods of time (sometimes supported by capital controls), most countries will not hold reserves sufficient to cover all possible tail-risk events, and there will always be some probability that the peg could break. As a result, these systems are vulnerable to runs, crashes, and speculative attacks. In our dataset covering 109 major currency crashes, many of which are peg breaks, nominal USD crosses depreciate by 45% in the median case over 48 months (Exhibit 7).

Balance of payments crises/currency crises typically occur when market participants expect that a fixed exchange rate will eventually be abandoned, leading to capital flows out of the domestic currency and a decline in foreign exchange reserves. One key element to currency crises is that they can be partly self-fulfilling.[4] If investors begin to sell a currency because they expect it to be devalued in the future, their speculation can, in fact, be the dominant source of balance of payments pressure on the currency. Once this pressure has been applied, it can be costly for a government or organization to defend the pegged exchange rate—it can require sharply higher interest rates, a large

[4] Krugman, Rockoff, Fischer, & McDonough, "Currency Crises," 1999.

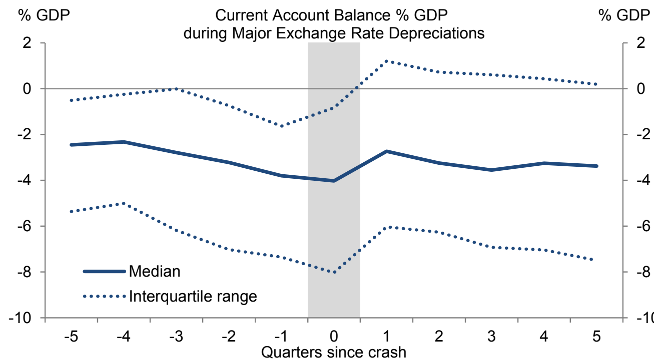
decline in reserve assets, and/or capital controls.[5] Therefore, a sufficiently large speculative attack can in fact trigger a peg break. As a result, pegged exchange rates are especially vulnerable if a country runs a current account deficit funded with short-term portfolio financial account liabilities—in other words, funding that can exit quickly (Exhibit 8).

Exhibit 7: Pegged Exchange Rates Can be Subject to Large Crashes ...



Source: Haver Analytics, Goldman Sachs Global Investment Research

Exhibit 8: ... Usually Resulting from Sudden Capital Flight



Source: Haver Analytics, Goldman Sachs Global Investment Research

These types of self-fulfilling crises can also occur in algorithmic stablecoins. Investor confidence in a fixed exchange rate can be rattled for a number of reasons. In the case of UST, the broader drawdown in digital assets may have raised investors' subjective probabilities of the risk that LUNA's market cap could fall below the supply of UST, such that it might be insufficient to cover all redemptions. If investors rush to sell/redeem UST, new LUNA will be minted, adding to LUNA supply and potentially weighing on its price. The peg is intended to self-stabilize by incentivizing arbitrageurs to buy UST if selling pressure pushes its price below $1. But if the price of LUNA is crashing market participants may be unwilling to make this arbitrage, such that prices of both the stablecoin and the blockchain-native cryptocurrency can spiral downward. Raising deposit rates can help slow capital outflows—as in traditional currency markets—but these steps may be insufficient against overwhelming capital outflow pressure.

Hypothetically, an algorithmic stablecoin could survive in the long-run, if it were to have ongoing transaction-related demand (similar to a fiat currency). However, stablecoins have competitors, such that demand for any one asset may prove unstable. One of the best historical analogues for the current state of stablecoins is the circulation of private bank notes as money during the US Free Banking Era (1837-1863), as Gorton and Zhang (2021) explain. During this Era, US banks were able to issue private bank notes, which circulated as money and were payable in specie on demand at the issuing bank; however, they importantly did not trade at par away from the issuing bank, but rather at a discount, given the large number of different banks' notes in circulation (branch banking was limited during this period[6]) and the difficulty of ascertaining bank-specific risk across the entire system. Ultimately, the US took control of the money system with

5 Krugman & Obstfeld, *International Economics*, 7th ed., 2006.

6 Rockoff, "Banking and Finance, 1789-1914," *The Cambridge Economic History of the United States*, 2008.

the National Banking Act, producing national bank notes, and, much later, Federal Reserve Notes took over.

There are two main lessons that the US (and Canadian[7]) experience with private money can teach us about the future of stablecoins. First is Gorton and Zhang's claim that private money generally does a worse job of acting like money than public money. To this point, stablecoins often trade at a discount, likely related to protocol-specific risk, much like bank notes did in response to bank-specific risk. Additionally, there are a large number of alternative stablecoins that can coexist, each with its own risk profile, making them difficult to use across platforms, much like private money once was away from issuing banks. The second key lesson from this experience is that while private and public money can coexist for a time, the private money system is eventually regulated and/or later supplanted by public money.

Stablecoins provide a useful service within the digital asset ecosystem: users need a less volatile base asset in these markets—ideally without converting back to fiat currency and the traditional banking system, given the frictions and transaction costs involved—and stablecoins have filled this need. However, algorithmic stablecoins in particular are vulnerable to self-fulfilling crises, as is now obvious after the decline of UST and LUNA. Regulation seems likely, in our view, and appropriate regulation could improve stability and lower risk in the stablecoin market (or possibly displace stablecoins through an alternative government-backed medium). Within the digital asset market, positive network effects from greater non-speculative use cases for these protocols could contribute to a more stable demand base over time.

Isabella Rosenberg

Zach Pandl

[7] Fung, Hendry & Weber, "Canadian Bank Notes and Dominion Notes: Lessons for Digital Currencies," 2017.

Disclosure Appendix

Reg AC

We, Isabella Rosenberg and Zach Pandl, 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 the Global Investment Research Division 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. **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 and Type II Financial Instruments Firms 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

The Global Investment Research Division of Goldman Sachs 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.

Effective from the date of the United Kingdom's departure from the European Union and the European Economic Area ("Brexit Day") the following information with respect to distributing entities will apply:

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, the Republic of Cyprus and the Republic of Ireland; GS -Succursale de Paris (Paris branch) which, from Brexit Day, will be 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 our Global Investment Research Division. 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 the Global Investment Research division of GS 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.