J.P.Morgan

North America Fixed Income Strategy
11 August 2020

All that you can't leave behind

Thinking about drivers of the Treasury futures roll

- Following the significant bout of volatility in the Treasury/futures basis in March and cleanout in positioning among the leveraged fund community, there is somewhat greater uncertainty around the Treasury futures roll than previous cycles.
- With this in mind, we reassess the toolkit for trading the roll, providing some historical context for what has worked in the past and why.
- We provide a brief overview of trading the roll, including what factors tend to drive broader trends such as the pace of progression.
- Subdued leveraged fund short positioning is likely to be a key theme for long-end contracts near term, with implications for the pricing of the wildcard option.

US Fixed Income Strategy

Henry St John AC
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Colin W Paiva
(1-212) 834-2037
colin.w.paiva@jpmorgan.com

J.P. Morgan Securities LLC

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

J.P.Morgan

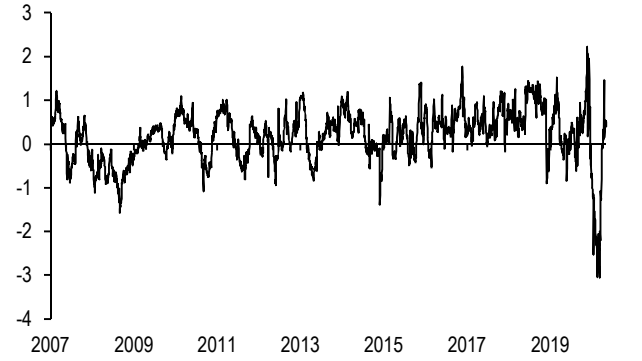
Thinking about drivers of the futures roll

Just months from the largest shakeout in the Treasury/futures basis in at least a decade, much of the market structure appears to be returning to something resembling the pre-crisis baseline: **overall open interest across the futures complex has begun to grow once more,** having experienced a record contraction in March (**Exhibit 1**), and **traded volumes in futures continue to outpace hot-run Treasuries**, though levels have moderated from the peak of the spike (**Exhibit 2**). **Net positioning among levered funds in particular has been somewhat muted since March,** but gross shorts have contracted in a far more exaggerated manner, and remain well below pre-crisis levels and suggests that basis unwinds have not clearly been replaced (**Exhibit 3**)—that is, with the exception of US and UXY, where these positions were not particularly elevated to begin with.

As the dust settles, **it's an opportune time to review and revisit some of the fundamentals of trading the futures calendar roll.** We find evidence to suggest that volatility over the roll period has grown, particularly at the long end of the futures complex (**Exhibit 4**). With positioning having shifted noticeably, and leveraged funds likely to be somewhat more conservative in aggregate in their approach to the Treasury/futures basis market for at least the near term, **we review here how we tend to approach relative and fair value for the roll** and what can be gleaned from an historical analysis of past cycles. We first provide an overview of how the roll is traded before delving into an attribution of what factors tend to drive realized price moves and how to think about each of these separate drivers in turn.

Exhibit 1: March of this year saw the most substantial pullback in Treasury futures open interest on record…

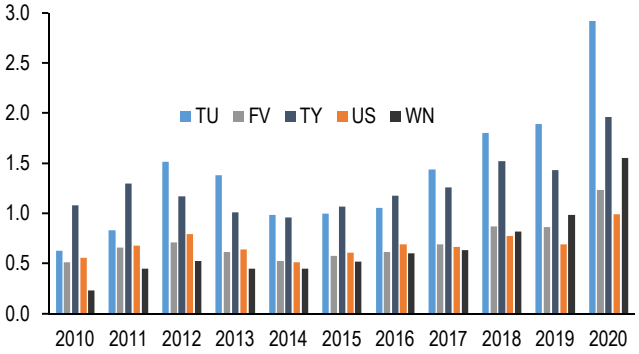
Rolling 3-month change in open interest on Treasury futures; millions of TY equivs



Source: J.P. Morgan, CME

Exhibit 2: … while traded notional in futures surged relative to current issue cash Treasuries, reaching all-time highs across the complex

Duration-adjusted trade volumes in Treasury futures versus hot-run Treasuries; unitless ratio



Note: TU related to 2s, FV relative to 5s, TY related to 10s, and both US and WN relative to 30s. Cash volumes are restricted to the BrokerTec interdealer broker platform.

Source: J.P. Morgan, CME, BrokerTec

Trading the weighted calendar spread

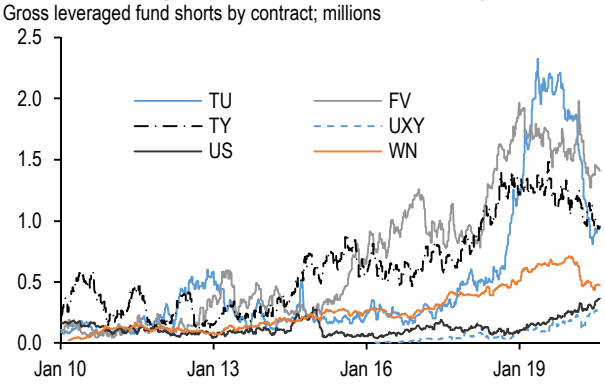
Put simply, the roll is the process by which market participants rotate open interest from the front Treasury futures contracts, which are close to expiry, into the next quarterly contract. Some participants, like asset managers and many commercial accounts, are forced early movers, often owing to operational constraints in their ability to deliver, or take delivery, of the physical bonds. Other market participants, especially levered funds, are more flexible and tactical in their approach. They may, however, be more sensitive to relative value considerations and the pricing of

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

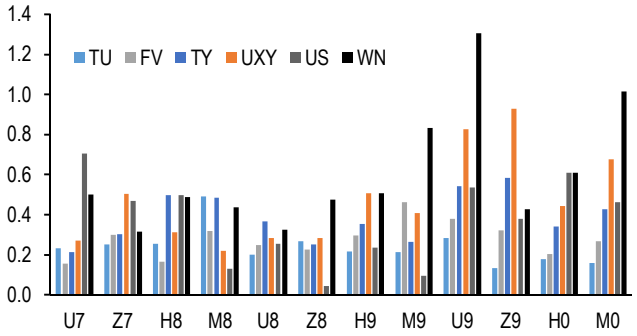
delivery options (switch, wildcard, repo calls, end of month, etc.). For this reason they tend to be less concerned with rolling positions early, but they may be more sensitive to relative value considerations. Indeed, we can see that aggregate open interest has tended to rise around roll periods over and above what normal cyclicals would tend to imply. **In this sense, one can think of real money as the primary driver of the roll but levered funds playing a key role as a pricing backstop later in the cycle.**

Exhibit 3: Leveraged fund shorts moderated sharply in March
Gross leveraged fund shorts by contract; millions



Source: J.P. Morgan, CME, CFTC

Exhibit 4: Particularly at the long end, daily volatility during the roll period for the weighted calendar spread has been on the rise
Volatility in the weighted calendar spread by contract and roll cycle; ticks/day



Source: J.P. Morgan, CME

The price of the roll generally refers to the weighted calendar spread, the front futures contract price less the back futures contract price, multiplied by the hedge ratio (the ratio of DV01s on the two contracts).[1] Under some circumstances we also recommend an adjustment for directionality with the level of rates,[2] but that has not been a strong driver for most of the past few years.

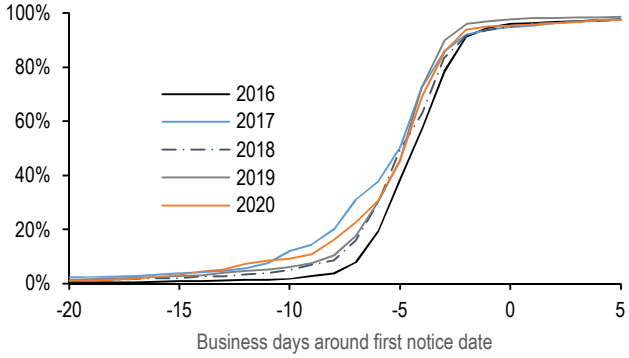
Specifically, we tend to focus on how the calendar spread changes before and after the bulk of open interest has rotated out of the front contract and into the back. Generally speaking, this transition occurs between 15 and 4 business days prior to the first notice date (**Exhibit 5**). Of course, the speed of this transition can vary across roll cycles and contracts. **One contributing factor is what fraction of the market likely needs to roll early to avoid the risk of delivery, which we tend to proxy by measuring the share of net positioning attributable to asset managers and other reportable accounts.** We also find evidence to suggest that when carry on the front contract is high, the transition of open interest tends to be somewhat more delayed (**Exhibit 6**).

[1] Formally, the weighted calendar spread = front futures price – back futures price * hedge ratio where the hedge ratio is the ratio of DV01 on the front vs. back futures. Futures DV01 itself can be the subject of some debate, but for simplicity and stability we tend to rely on parallel shifts in the deliverable basket to generate these estimates.
[2] This is generically a consequence of directionality in the curve itself, which typically arises when there is significant slope and curvature. Though a material determinant of effective/optimal hedge ratios in 2012-13, the structural flattening of USD curves has left this a weak driver.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

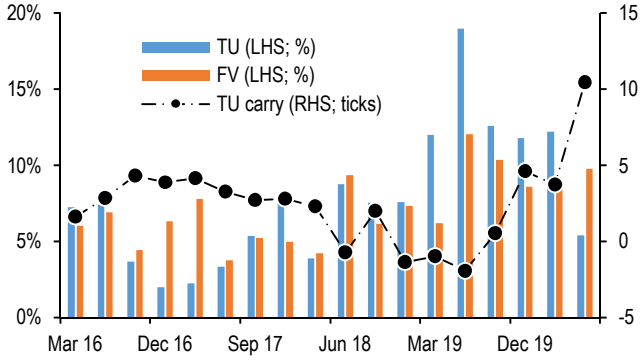
Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Exhibit 5: Most of the open interest tends to roll from the front to back contract between 10 and 4 days prior to first delivery
Fraction of open interest on the back contract averaged over the roll cycles in each respective year; %



Source: J.P. Morgan, CME

Exhibit 6: We see some evidence for the roll progressing more slowly when carry on the front contract gross basis is higher
Fraction of open interest rolled as of 10-days prior to first delivery (LHS; %) and carry on the front gross basis in TU as of that date (RHS; ticks)



Source: J.P. Morgan, CME

Drivers of calendar spreads

While simple enough to construct, the weighted calendar spread is subject to a rather large array of market forces, and these forces tend to exert different levels of influence across the futures stack. **Broadly speaking, the key drivers of the roll tend to be repo rates, positioning, relative value among the respective CTDs, relative richness/cheapness of the futures contracts, and the pricing of strategic delivery options—which given the level of rates means the wildcard specifically in practice.**[3] One way of going about assessing the relative impact of these drivers is to look at how well they work as explanatory variables on an *ex-post* basis for the weighted calendar spread over the roll period. While not necessarily predictive, this diagnostic approach is a useful way to rank different factors in order of their empirical impact on the pricing of the calendar spread over the peak roll period. Since wildcard optionality is a more recent driver, we restrict focus to a relatively short sample of roll cycles between 2015 and 2020 and construct a series of signals to proxy these aforementioned drivers.

Somewhat unsurprisingly, there is no consistent driver of the weighted calendar spreads during the roll across these contracts, perhaps with the exception of the realized change in the 1M/4M repo term structure (**Exhibit 7**). That said, some trends do stand out in different regions of the curve. At the front end, relative value between the front and back CTDs tend to be an influential driver, as well as asset manager positioning for TU. Asset manager and other reportable positioning is also relevant for US, and to a lesser extent UXY. At the very long end of the complex, WN appears rather susceptible to changes in the 10s/30s Treasury curve, suggesting that CTD micro-curve RV is often at play. Wildcard optionality is inherently more difficult to proxy given the limited time span in which it has been a relevant driver, though it is notable that the gap between implied and cash repo rates on WN is significant, since large wildcard option value can be distortive for implied repo rates via the gross basis (see *Special delivery*, J. Younger et al., 12/4/20).

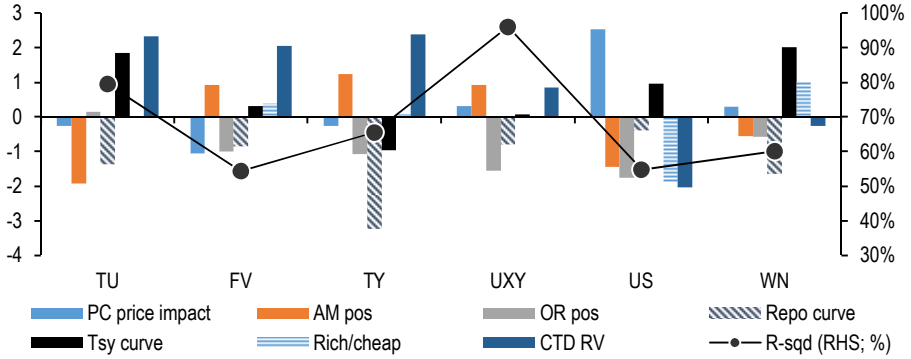
[3] A generic consequence of references yields at 6% is a very highly determined and stable CTD issue that tends to be at the short end of the deliverable basket. Further, the dollar duration of CTD contenders tends to be very similar, meaning even if there is a switch the option value is very small if not negligible.

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Exhibit 7: Repo and positioning tend to be the only consistent *ex-post* drivers of calendar spreads over roll periods

Model t-stats from regressing quarterly weighted calendar spread performance versus individual inputs by contract (LHS; unitless) and overall model fit (RHS; %)



Note: Regressions using quarterly roll for each contract from 2015 – 2Q20. Weighted calendar spread takes fixed hedge ratio as of 15 days prior to first notice, and end period for P/L taken as difference vs 4 days prior to first notice. Positioning indicators are asset manager and other reportable positioning as a % of contract open interest, repo and Tsy curve refers to the change in 1M/4M repo term structure and hot-run Tsy curve between start and end of roll period. Rich/cheap refers to the spread between implied repo and the repo to delivery before the roll commences, and CTD RV refers to the forward yield spread to OIS for the CTD on the back versus front before the roll commences.

Source: J.P. Morgan, CME, CFTC, Brokertec

Repo rates

We find that calendar spreads across the complex are often well explained on an *ex-post* basis by changes in cash financing rates between the front and back futures contracts. After the fact, it's reasonably straightforward to assign importance to the change in financing cost on the calendar spread. **Higher financing rates imply a higher cost of funding the cash bond position,** reducing the carry on holding the Treasury versus the futures short. Thus, this amounts to a narrower gross basis and therefore a richening in the futures price relative to cash. Of course, the back contract has around three months more carry left in its gross basis than the front, and this means that for a parallel shift in repo rates (i.e., a higher repo delta), **the calendar spread change is dominated by the move in the back contract relative to the front.** For example, for a parallel increase in the repo term structure, the back contract richens by more than the front, driving the calendar spread lower.[4] Our empirical beta implies that 1bp of steepening in the repo term structure cheapens the calendar spread by 1-3 ticks, with a somewhat higher beta on the longer maturity contracts, likely reflecting the wider average maturity gap between the front and back CTDs (Exhibit 7 again).

Predicting the effect of changes in repo on calendar spreads ahead of time has proven to be somewhat more elusive, and this often stems from the fact that changes in repo are rarely parallel. In fact, it tends to be far more common that changes at the front end of the money market complex, overnight and short-term repo rates, tend to drive inverse changes in the repo term structure. In practice, the beta of weekly changes in the 1M/4M repo spread to 1M GC/OIS implies that for a 1bp increase in the latter, the term structure tends to flatten by around 0.6bp. By the nature of the repo market, the risk in recent years has been more toward a short-term spike in overnight repo rates (and inversion in the repo term structure) during the roll cycle, richening the front futures contract and pushing the weighted calendar spread higher.

[4] As a rule of thumb, we tend to say that for a parallel shift in financing rates, the change in weighted calendar spread = -1 x (change in repo) / 4.

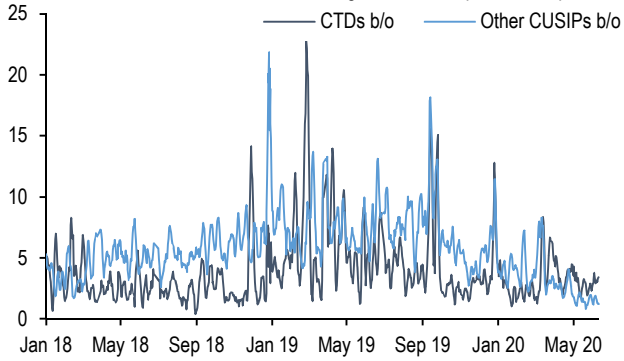
Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

The Fed's regulatory interventions, and specifically the TOMOs, have likely removed some of the tail risk of this kind of spike in repo rates for the near term at least. Liquidity conditions in repo markets have improved dramatically since the series of short-lived spikes in 2019, with brokered market bid/offer having returned to average levels last seen prior to the Fed commencing balance sheet run-off (**Exhibit 8**). It's interesting to note that repo on CTD Treasuries has shared in this improvement in conditions, with little discernable difference in terms of bid/offer between these transactions and other non-CTD Treasury CUSIPs. We don't see any evidence to suggest that the breakdown in the Treasury/futures basis market caused reverberations back to the interdealer repo market in March—the decline in volumes in CTD CUSIPs was somewhat more gradual after the March roll than in previous cycles, suggesting more activity in recycling these securities than the normal evolution of liquidity into the back basis (**Exhibit 9**). That said, these repo transactions were occurring at ever tighter rate levels to non-CTDs, which suggests that the support provided by TOMOs and Fed Treasury purchases was alleviating pressure on dealers to facilitate these trades.

Exhibit 8: The peak to trough widening in bid/offer was somewhat higher for CTDs in March, though overall volatility had already compressed substantially thanks to Fed TOMOs…

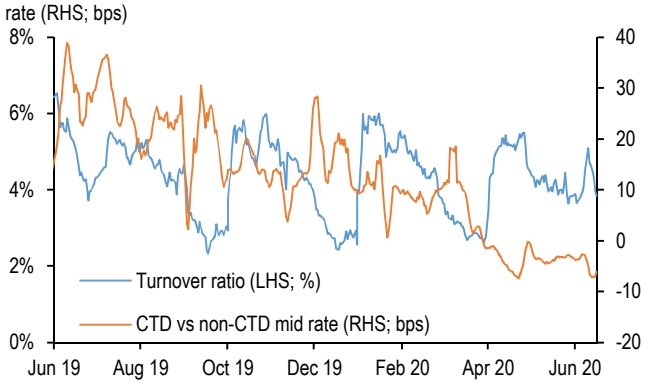
CTD and non-CTD CUSIP bid/offer in overnight brokered repo trades; bps



Source: J.P. Morgan

Exhibit 9: … and while we saw a cyclical pickup in specialness around the contract month, these gaps have also been smoothed out since March

Turnover ratio of CTD vs non-CTD repo trades (LHS, %) and CTD vs non-CTD mid-rate (RHS; bps)



Source: J.P. Morgan

Wildcard optionality

One area that has garnered significant focus in recent years is wildcard optionality. The timing mismatch between the daily futures settlement at 3pm EST and the time by which the futures short must give notice of intent to deliver at 7pm EST[5] creates an opportunity to monetize large post-close moves in the cash market. Since the invoice amount is fixed as of futures close, large price increases in the CTD allow the shorts to cover their tail at a higher price than invoice, allowing them to make delivery while profiting from this residual value, provided they're willing to forgo the promise of earning the gross basis to expiry.[6] Though not all investors are set up to actually exercise this option, it can still be an important determinant of pricing due to the involvement of levered funds and dealers in taking the other side of real money flows.

[5] Although in practice, trading activity after 5pm EST is rare, trading activity can extend beyond this point, including the beginning of the Tokyo session.

[6] This decision of whether to exercise can be simplified for the short futures position holder to:

$$\text{Gross basis} * (CF / (1 - CF)) < P_{late} - P_{3pm}$$

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

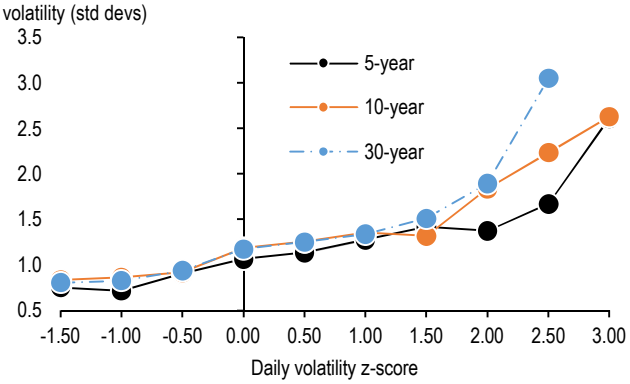
Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

In effect, value in holding the futures short to monetize the wildcard option (or the market fairly pricing its value) depends on the conversion factor on the likely CTD bond being sufficiently low, and to a lesser extent the foregone carry being low or negative, which has become a more frequent occurrence in recent years' as CTD coupons have drifted lower relative to financing costs (see *Good things come to those who wait*, J. Younger et al., 5/18/20). The value also depends on having sufficiently high price moves relative to the size of the "tail"—that means the longer end of the futures complex, with low conversion factors CTDs and higher price volatility, tends to exhibit the most wildcard option value. When the Treasury/futures basis market is not policing the wildcard option value in the gross basis, this has made it a relatively cheap source of convexity (see *Wild at Heart*, H. St John et al., 4/30/20), particularly to position for higher inter-day volatility (**Exhibit 10**).

An interesting note is that, while market focus on the wildcard option has certainly increased in recent years, we actually see relatively weak evidence of consistent monetization of the wildcard option (see *Special delivery*, J. Younger et al., 12/4/20). Aside from a late flurry of mid- and late-cycle delivery by futures shorts in late 2018 and early 2019, delivery activity in more recent cycles looks more similar to prior years, although late-cycle delivery is a slightly greater share of overall deliveries (**Exhibit 11**). The positioning squeeze in March likely explains some of the story here, with a significantly smaller fraction of leveraged fund shorts holding H0 futures positions for this kind of trade (Exhibit 3 again). A broader explanation is that the market has become more adept at reflecting wildcard optionality via a wider net basis in higher vol regimes. Admittedly, this is difficult to measure empirically, given the endogeneity between moves in the net basis and vol in March. In any case, closer scrutiny of wildcard option value likely puts more onus on correctly calling the post-close vol regime, something that we have focused on more recently via mapping market microstructure measures to delivered volatility to infer correct pricing assumptions (see *US Treasury Futures Rollover Outlook*, J. Younger et al., 5/14/20).

Exhibit 10: Post-close vol tends to move higher with general inter-day delivered volatility, making it a source of convexity exposure to the market

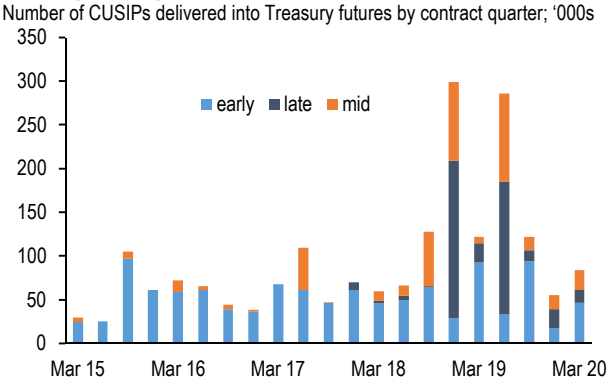
Post-close volatility (bp/2hr) versus the z-score of inter-day delivered monthly volatility (std devs)



Source: J.P. Morgan, Brokertec

Exhibit 11: Despite significant volatility in March, we saw relatively low early delivery behavior consistent with wildcard monetization

Number of CUSIPs delivered into Treasury futures by contract quarter; '000s



Source: J.P. Morgan, CME

Positioning

As we have already discussed, certain investor types are constrained in their ability to take physical delivery of Treasuries and as such tend to reliably roll their long futures exposures well ahead of the first notice date as a precaution. Those investor types tend to be commercial accounts, specifically asset managers and other reportables (which likely includes some of the reserve manager community). The former in

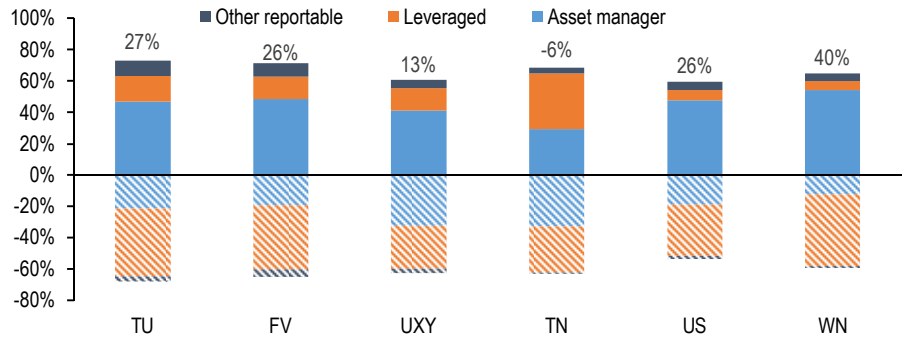
Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

particular tend to be persistently long Treasury futures across the complex—likely a result of index replication and other duration management strategies that rely on derivatives to maintain liquidity (**Exhibit 12**). As a result of these operational constraints, these net longs point to a structural cheapening bias in weighted calendar spreads as the need for asset managers and others to close out their positions in the front futures contracts (short) and open new positions in the back (long) is less elastic with respect to price. In recent years, we've tended to see the implied beta from positioning through to realized changes in the weighted calendar spread decline. We see this tendency empirically in the *ex-post* performance of various weighted calendar spreads relative to *ex-ante* commercial account, asset manager, and other reportable positions across a range of contracts. That said, it is worth noting that the magnitude of this sensitivity has declined over the past few years. It is difficult to attribute this effect to any one driver, but it does suggest greater price sensitivity and tactical trading of the roll on the part of these investors.

Another element of this may simply be improving depth as asset manager net longs have remained reasonably stable at high levels, but overall open interest has trended higher. All else equal, that would likely reduce the price impact of these rolls on any given day. In this context, it tends to be more useful to think of positioning and subsequent rolling demand as a function of overall market size when assessing calendar spread impacts. By contrast, build-up of leveraged fund short-positioning can be a useful tool for assessing the roll progression. Leveraged funds are more likely to hold positions for longer through the roll, either to take full advantage of the convergence in the Treasury/futures basis, trade optionality, or position for anticipated flows. A sharp withdrawal in leveraged fund net short positioning is also likely to drive a faster roll progression and more of a bearish move in the weighted calendar spread as the asset manager side dominates.

Exhibit 12: Despite having moderated substantially for shorter contracts since March, leveraged fund net shorts are still fairly significant at the long end as a share of market open interest
Asset manager, other reportables and leveraged fund gross longs and shorts as a fraction of contract open interest; % and leveraged fund net short position in each contract as of August 2020 (data labels; %)



Source: J.P. Morgan, CME, CFTC

Relative value

Value in the front and back CTDs relative to their surrounding bonds can drive reciprocal changes in their respective CTD basis and in turn affect the weighted calendar spread. As such, we can use a variety of tools to assess potential relative value opportunities in the spread between the front and back CTD, which may drive price action over the roll period. RV signals can be difficult to identify, with varying degrees of effectiveness between cycles. However, it is easier to observe the degree to which CTD price action matters for the weighted calendar spread. We find that for somewhere on average between 50-60% of roll cycles since 2015, the directional

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

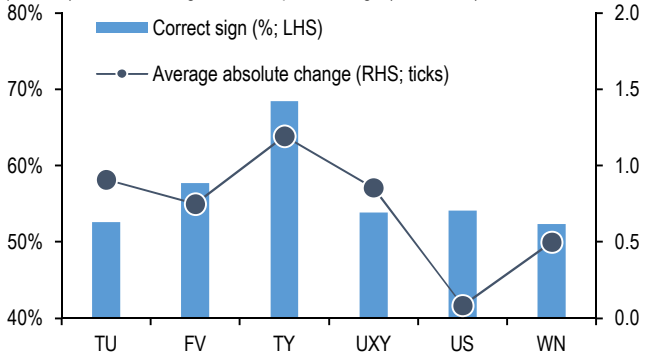
bias that comes from the front/back CTD spread lines up with the ultimate change in the weighted calendar spread (**Exhibit 13**). For TY, this fraction jumps to a fairly impressive 68%. Across the stack, we find that the change in price imparts on average 0.5-1.5 ticks of bias on the calendar spread. The exception to this rule has been the US contract, which has persistently had the same front and back CTD in more recent roll cycles. With the re-introduction of the hot-run 20-year, and more supplying coming in this region of the curve, this is likely to change.

One form of CTD RV we tend to focus on is the impulse imparted by the broader Treasury curve. The back CTD tends to have a slightly longer maturity than the front contract CTD, meaning that the sensitivity between these two points to the local region of the curve can impart a bearish or bullish bias on the calendar spread, what we refer to as "micro-curve RV." To predict the potential impact, we usually take the historical beta between the specific likely CTDs and the hot-run Treasury curve (e.g., for TU we would regress on the 2s/5s curve), and then use our Treasury strategy colleagues' rate forecasts and bond DV01s to infer a bias in ticks. Sensitivity of the calendar spread to these curve moves works well on back-test, particularly for the front end of the futures complex (Exhibit 7 again).

Another RV strategy is to simply look at rich/cheap measures for Treasury yields. One approach is to look at likely CTD forward yields spread to OIS on a maturity matched basis. We find strong evidence to suggest that, particularly for longer-maturity futures, the CTD box spread to OIS (on a forward basis to deliver) is highly mean-reverting during roll periods in recent years (**Exhibit 14**). In a similar vein, one could also look at the yield error on CTDs relative to a fitted par curve for similar information content. We've also looked to auction cyclicals between current hot-run and olds, or first versus second olds, as a measure for potential cheapening bias on one CTD relative to the other. These metrics tend to come and go in terms of relevance but often bear consideration wherever applicable in assessing potential risks to the weighted calendar spread.

Exhibit 13: The implied impact of price changes tends to align with the directional move of the weighted calendar spread

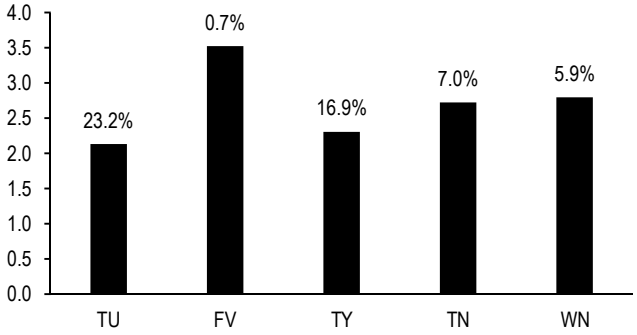
Fraction of calendar spreads since 2015 where the price change on the front/back CTD is correctly aligned with the change in the calendar spread over the roll period (LHS; %) and the average absolute price change (RHS; ticks)



Source: J.P. Morgan

Exhibit 14: The CTD box spread to OIS is highly mean-reverting during roll periods

Absolute value of the Dickey-Fuller test statistic (bars) and p-value (label) for various contracts*



* We perform a Dickey-Fuller test on the difference between the back and front contract CTDs' spread to OIS during rollover periods from H14 until M20, testing only on data between 15 and 3 business days until delivery of the front contract. We then take the absolute value of the statistic for ease of viewing and include the p-value above each test statistic.

Source: J.P. Morgan

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Appendix

Summary of key calendar spread drivers

	Bullish	Bearish	Rationale
Positioning	AM less net long or net short	Heavy AM net longs	Asset managers tend to roll earlier, and extended net long positioning tends to therefore create early selling pressure on the front contract
Optionality	Fairly valued/rich wildcard	Wildcard undervalued	An undervalued wildcard is likely to drive leveraged fund short interest on the front contract, either to reflect anticipated future pricing, or to monetize potential delivery opportunities
Repo	lower repo rates, flatter curve	higher repo rates, steeper curve	Higher repo rates, imply higher cost of funding the cash bond position, which means a narrower gross basis and richer futures position relative to cash
RV	Back CTD cheapens vs front	Back CTD richens vs front	Changes in the CTD micro-curve carry through to the front and back CTD basis, driving moves in the calendar spread

Source: J.P. Morgan

Joshua Younger
(1-212) 270-1323
joshua.d.younger@jpmorgan.com

Henry St John
(1-212) 834-5669
henry.stjohn@jpmorgan.com

Analyst Certification: The research analyst(s) denoted by an "AC" on the cover of this report certifies (or, where multiple research analysts are primarily responsible for this report, the research analyst denoted by an "AC" on the cover or within the document individually certifies, with respect to each security or issuer that the research analyst covers in this research) that: (1) all of the views expressed in this report accurately reflect the research analyst's personal views about any and all of the subject securities or issuers; and (2) no part of any of the research analyst's compensation was, is, or will be directly or indirectly related to the specific recommendations or views expressed by the research analyst(s) in this report. For all Korea-based research analysts listed on the front cover, if applicable, they also certify, as per KOFIA requirements, that their analysis was made in good faith and that the views reflect their own opinion, without undue influence or intervention.

All authors named within this report are research analysts unless otherwise specified. In Europe, Sector Specialists may be shown on this report as contacts but are not authors of the report or part of the Research Department.

Important Disclosures

Company-Specific Disclosures: Important disclosures, including price charts and credit opinion history tables, are available for compendium reports and all J.P. Morgan–covered companies by visiting https://www.jpmm.com/research/disclosures, calling 1-800-477-0406, or e-mailing research.disclosure.inquiries@jpmorgan.com with your request. J.P. Morgan's Strategy, Technical, and Quantitative Research teams may screen companies not covered by J.P. Morgan. For important disclosures for these companies, please call 1-800-477-0406 or e-mail research.disclosure.inquiries@jpmorgan.com.

Analysts' Compensation: The research analysts responsible for the preparation of this report receive compensation based upon various factors, including the quality and accuracy of research, client feedback, competitive factors, and overall firm revenues.

Other Disclosures

J.P. Morgan is a marketing name for investment banking businesses of JPMorgan Chase & Co. and its subsidiaries and affiliates worldwide.

Any data discrepancies in this report could be the result of different calculations and/or adjustments.

Any long form nomenclature for references to China; Hong Kong; Taiwan; and Macau within this research report are Mainland China; Hong Kong SAR, China; Taiwan, China; Macau SAR, China.

Options and Futures related research: If the information contained herein regards options or futures related research, such information is available only to persons who have received the proper options or futures risk disclosure documents. Please contact your J.P. Morgan Representative or visit https://www.theocc.com/components/docs/riskstoc.pdf for a copy of the Option Clearing Corporation's Characteristics and Risks of Standardized Options or http://www.finra.org/sites/default/files/Security_Futures_Risk_Disclosure_Statement_2018.pdf for a copy of the Security Futures Risk Disclosure Statement.

Changes to Interbank Offered Rates (IBORs) and other benchmark rates: Certain interest rate benchmarks are, or may in the future become, subject to ongoing international, national and other regulatory guidance, reform and proposals for reform. For more information, please consult: https://www.jpmorgan.com/global/disclosures/interbank_offered_rates

Principal Trading: J.P. Morgan trades or may trade as principal in the derivatives or the debt securities (or related derivatives) that are the subject of this report.

Private Bank Clients: Where you are receiving research as a client of the private banking businesses offered by JPMorgan Chase & Co. and its subsidiaries ("J.P. Morgan Private Bank"), research is provided to you by J.P. Morgan Private Bank and not by any other division of J.P. Morgan, including but not limited to the J.P. Morgan corporate and investment bank and its research division.

Legal entity responsible for the production of research: The legal entity identified below the name of the Reg AC research analyst who authored this report is the legal entity responsible for the production of this research. Where multiple Reg AC research analysts authored this report with different legal entities identified below their names, these legal entities are jointly responsible for the production of this research.

Legal Entities Disclosures
U.S.: JPMS is a member of NYSE, FINRA, SIPC and the NFA. JPMorgan Chase Bank, N.A. is a member of FDIC. **Canada**: J.P. Morgan Securities Canada Inc. is a registered investment dealer, regulated by the Investment Industry Regulatory Organization of Canada and the Ontario Securities Commission and is the participating member on Canadian exchanges. **U.K.**: JPMorgan Chase N.A., London Branch, is authorised by the Prudential Regulation Authority and is subject to regulation by the Financial Conduct Authority and to limited regulation by the Prudential Regulation Authority. Details about the extent of our regulation by the Prudential Regulation Authority are available from J.P. Morgan on request. J.P. Morgan Securities plc (JPMS plc) is a member of the London Stock Exchange and is authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority. Registered in England & Wales No. 2711006. Registered Office 25 Bank Street, London, E14 5JP. **Germany**: This material is distributed in Germany by J.P. Morgan Securities plc, Frankfurt Branch which is regulated by the Bundesanstalt für Finanzdienstleistungsaufsich and also by J.P. Morgan AG (JPM AG) which is a member of the Frankfurt stock exchange and is regulated by the Federal Financial Supervisory Authority (BaFin), JPM AG is a company incorporated in the Federal Republic of Germany with registered office at Taunustor 1, 60310 Frankfurt am Main, the Federal Republic of Germany. **South Africa**: J.P. Morgan Equities South Africa Proprietary Limited is a member of the

Johannesburg Securities Exchange and is regulated by the Financial Services Board. **Hong Kong**: J.P. Morgan Securities (Asia Pacific) Limited (CE number AAJ321) is regulated by the Hong Kong Monetary Authority and the Securities and Futures Commission in Hong Kong and/or J.P. Morgan Broking (Hong Kong) Limited (CE number AAB027) is regulated by the Securities and Futures Commission in Hong Kong. JP Morgan Chase Bank, N.A., Hong Kong is organized under the laws of U.S.A. with limited liability. **China**: J.P. Morgan Securities (China) Company Limited has been approved by CSRC to conduct the securities investment consultancy business. **Korea**: This material is issued and distributed in Korea by or through J.P. Morgan Securities (Far East) Limited, Seoul Branch, which is a member of the Korea Exchange(KRX) and is regulated by the Financial Services Commission (FSC) and the Financial Supervisory Service (FSS). **Australia**: J.P. Morgan Securities Australia Limited (JPMSAL) (ABN 61 003 245 234/AFS Licence No: 238066) is regulated by ASIC and is a Market, Clearing and Settlement Participant of ASX Limited and CHI-X. **Taiwan**: J.P. Morgan Securities (Taiwan) Limited is a participant of the Taiwan Stock Exchange (company-type) and regulated by the Taiwan Securities and Futures Bureau. **India:** J.P. Morgan India Private Limited (Corporate Identity Number - U67120MH1992FTC068724), having its registered office at J.P. Morgan Tower, Off. C.S.T. Road, Kalina, Santacruz - East, Mumbai – 400098, is registered with Securities and Exchange Board of India (SEBI) as a 'Research Analyst' having registration number INH000001873. J.P. Morgan India Private Limited is also registered with SEBI as a member of the National Stock Exchange of India Limited and the Bombay Stock Exchange Limited (SEBI Registration Number – INZ000239730) and as a Merchant Banker (SEBI Registration Number - MB/INM000002970). Telephone: 91-22-6157 3000, Facsimile: 91-22-6157 3990 and Website: www.jpmipl.com. For non local research reports, this material is not distributed in India by J.P. Morgan India Private Limited. **Thailand**: This material is issued and distributed in Thailand by JPMorgan Securities (Thailand) Ltd., which is a member of the Stock Exchange of Thailand and is regulated by the Ministry of Finance and the Securities and Exchange Commission and its registered address is 3rd Floor, 20 North Sathorn Road, Silom, Bangrak, Bangkok 10500. **Indonesia**: PT J.P. Morgan Sekuritas Indonesia is a member of the Indonesia Stock Exchange and is regulated by the OJK a.k.a. BAPEPAM LK. **Philippines**: J.P. Morgan Securities Philippines Inc. is a Trading Participant of the Philippine Stock Exchange and a member of the Securities Clearing Corporation of the Philippines and the Securities Investor Protection Fund. It is regulated by the Securities and Exchange Commission. **Brazil**: Banco J.P. Morgan S.A. is regulated by the Comissao de Valores Mobiliarios (CVM) and by the Central Bank of Brazil. **Mexico**: J.P. Morgan Casa de Bolsa, S.A. de C.V., J.P. Morgan Grupo Financiero is a member of the Mexican Stock Exchange and authorized to act as a broker dealer by the National Banking and Securities Exchange Commission. **Singapore:** This material is issued and distributed in Singapore by or through J.P. Morgan Securities Singapore Private Limited (JPMSS) [MCI (P) 018/04/2020 and Co. Reg. No.: 199405335R], which is a member of the Singapore Exchange Securities Trading Limited and/or JPMorgan Chase Bank, N.A., Singapore branch (JPMCB Singapore) [MCI (P) 070/09/2019], both of which are regulated by the Monetary Authority of Singapore. This material is issued and distributed in Singapore only to accredited investors, expert investors and institutional investors, as defined in Section 4A of the Securities and Futures Act, Cap. 289 (SFA). This material is not intended to be issued or distributed to any retail investors or any other investors that do not fall into the classes of "accredited investors," "expert investors" or "institutional investors," as defined under Section 4A of the SFA. Recipients of this document are to contact JPMSS or JPMCB Singapore in respect of any matters arising from, or in connection with, the document. **Japan**: JPMorgan Securities Japan Co., Ltd. and JPMorgan Chase Bank, N.A., Tokyo Branch are regulated by the Financial Services Agency in Japan. **Malaysia**: This material is issued and distributed in Malaysia by JPMorgan Securities (Malaysia) Sdn Bhd (18146-X) which is a Participating Organization of Bursa Malaysia Berhad and a holder of Capital Markets Services License issued by the Securities Commission in Malaysia. **Pakistan**: J. P. Morgan Pakistan Broking (Pvt.) Ltd is a member of the Karachi Stock Exchange and regulated by the Securities and Exchange Commission of Pakistan. **Dubai**: JPMorgan Chase Bank, N.A., Dubai Branch is regulated by the Dubai Financial Services Authority (DFSA) and its registered address is Dubai International Financial Centre - Building 3, Level 7, PO Box 506551, Dubai, UAE. **Russia:** CB J.P. Morgan Bank International LLC is regulated by the Central Bank of Russia. **Argentina:** JPMorgan Chase Bank Sucursal Buenos Aires is regulated by Banco Central de la República Argentina ("BCRA"- Central Bank of Argentina) and Comisión Nacional de Valores ("CNV"- Argentinian Securities Commission")

Country and Region Specific Disclosures

U.K. and European Economic Area (EEA): Unless specified to the contrary, issued and approved for distribution in the U.K. and the EEA by JPMS plc. Investment research issued by JPMS plc has been prepared in accordance with JPMS plc's policies for managing conflicts of interest arising as a result of publication and distribution of investment research. Many European regulators require a firm to establish, implement and maintain such a policy. Further information about J.P. Morgan's conflict of interest policy and a description of the effective internal organisations and administrative arrangements set up for the prevention and avoidance of conflicts of interest is set out at the following link https://www.jpmorgan.com/jpmpdf/1320742677360.pdf. This report has been issued in the U.K. only to persons of a kind described in Article 19 (5), 38, 47 and 49 of the Financial Services and Markets Act 2000 (Financial Promotion) Order 2005 (all such persons being referred to as "relevant persons"). This document must not be acted on or relied on by persons who are not relevant persons. Any investment or investment activity to which this document relates is only available to relevant persons and will be engaged in only with relevant persons. In other EEA countries, the report has been issued to persons regarded as professional investors (or equivalent) in their home jurisdiction. **Australia:** This material is issued and distributed by JPMSAL in Australia to "wholesale clients" only. This material does not take into account the specific investment objectives, financial situation or particular needs of the recipient. The recipient of this material must not distribute it to any third party or outside Australia without the prior written consent of JPMSAL. For the purposes of this paragraph the term "wholesale client" has the meaning given in section 761G of the Corporations Act 2001. J.P. Morgan's research coverage universe spans listed securities across the ASX All Ordinaries index, securities listed on offshore markets, unlisted issuers and investment products which Research management deem to be relevant to the investor base from time to time. J.P. Morgan seeks to cover companies of relevance to the domestic and international investor base across all GIC sectors, as well as across a range of market capitalisation sizes. **Germany:** This material is distributed in Germany by J.P. Morgan Securities plc, Frankfurt Branch which is regulated by the Bundesanstalt für Finanzdienstleistungsaufsicht. **Korea:** This report may have been edited or contributed to from time to time by affiliates of J.P. Morgan Securities (Far East) Limited, Seoul Branch. **Singapore:** As at the date of this report, JPMSS is a designated market maker for certain structured warrants listed on the Singapore Exchange where the underlying securities may be the securities discussed in this report. Arising from its role as designated market maker for such structured warrants, JPMSS may conduct hedging activities in respect of such underlying securities and hold or have an interest in such underlying securities as a result. The updated list of structured warrants for which JPMSS acts as designated market maker may be found on the website of the Singapore Exchange Limited: http://www.sgx.com. In addition, JPMSS and/or its affiliates may also have an interest or holding in any of the securities discussed in this report – please see the Important Disclosures section above. For securities where the holding is 1% or greater, the holding may be found in the Important Disclosures section above. For all other securities mentioned in this report, JPMSS and/or its affiliates may have a holding of less than 1% in such securities and may trade them in ways different from those discussed in this report. Employees of JPMSS and/or its affiliates not involved in the preparation of this report may have investments in the securities (or derivatives of such securities) mentioned in this report and may trade them in ways different from those discussed in this report. **Taiwan**: Research relating to equity securities is issued and distributed in Taiwan by J.P. Morgan Securities (Taiwan) Limited, subject to the license scope and the applicable laws and the regulations in Taiwan. According to Paragraph 2, Article 7-1 of Operational Regulations Governing Securities Firms Recommending Trades in Securities to Customers (as amended or supplemented)

and/or other applicable laws or regulations, please note that the recipient of this material is not permitted to engage in any activities in connection with the material which may give rise to conflicts of interests, unless otherwise disclosed in the “Important Disclosures” in this material. **India:** For private circulation only, not for sale. **Pakistan:** For private circulation only, not for sale. **New Zealand:** This material is issued and distributed by JPMSAL in New Zealand only to "wholesale clients" (as defined in the Financial Advisers Act 2008). The recipient of this material must not distribute it to any third party or outside New Zealand without the prior written consent of JPMSAL. **Canada:** This report is distributed in Canada by or on behalf of J.P.Morgan Securities Canada Inc. The information contained herein is not, and under no circumstances is to be construed as an offer to sell securities described herein, or solicitation of an offer to buy securities described herein, in Canada or any province or territory thereof. The information contained herein is under no circumstances to be construed as investment advice in any province or territory of Canada and is not tailored to the needs of the recipient. **Dubai:** This report has been distributed to persons regarded as professional clients or market counterparties as defined under the DFSA rules. **Brazil:** Ombudsman J.P. Morgan: 0800-7700847 / ouvidoria.jp.morgan@jpmorgan.com.

General: Additional information is available upon request. Information has been obtained from sources believed to be reliable but JPMorgan Chase & Co. or its affiliates and/or subsidiaries (collectively J.P. Morgan) do not warrant its completeness or accuracy except with respect to any disclosures relative to JPMS and/or its affiliates and the analyst's involvement with the issuer that is the subject of the research. All pricing is indicative as of the close of market for the securities discussed, unless otherwise stated. Opinions and estimates constitute our judgment as of the date of this material and are subject to change without notice. Past performance is not indicative of future results. This material is not intended as an offer or solicitation for the purchase or sale of any financial instrument. The opinions and recommendations herein do not take into account individual client circumstances, objectives, or needs and are not intended as recommendations of particular securities, financial instruments or strategies to particular clients. The recipient of this report must make its own independent decisions regarding any securities or financial instruments mentioned herein. JPMS distributes in the U.S. research published by non-U.S. affiliates and accepts responsibility for its contents. Periodic updates may be provided on companies/industries based on company specific developments or announcements, market conditions or any other publicly available information. Clients should contact analysts and execute transactions through a J.P. Morgan subsidiary or affiliate in their home jurisdiction unless governing law permits otherwise.

"Other Disclosures" last revised July 04, 2020.