The (par) curves they are a-changin’

Making enhancements to our Treasury & TIPS par curves

- The Treasury par curve is a fundamental component of all our US interest rate analysis. It is used as a pricing input for various spread product, helps in identifying relative value along the Treasury curve, and also aids in accurately estimating slide
- We make enhancements to the methodology for our par curve: the new model excludes very low free float bonds issued over 20 years ago, which are highly illiquid and are skewing the root mean square error of our par curve...
- ...we also double the number of knots from 6 to 12, and change the placement of these knots to align with liquidity points on the Treasury curve to adjust for the growth of the Treasury market and proliferation of CUSIPS in the post-GFC era
- We find this updated model is more stable than the previous version of our par curve, without sacrificing smoothness of our prior curve
- We also make two adjustments to our TIPS par curve: we reduce the number of knot points from 6 to 4, adjusting the placement of knots to align with liquidity points. We also exclude maturities less than 1-year from the estimation sample
- The enhanced par curve is used in the Treasury analytics reports available on JPMM. Historical par curve data as well as yield errors for individual Treasury securities can be found in DataQuery

Fixed Income Strategy

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See page 10 for analyst certification and important disclosures.

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The (par) curves they are a changin'

The Treasury par yield curve is one of the most fundamental constructs in financial markets. Its uses include estimation of richness/cheapness of specific Treasury securities, estimation of the yield slide, and as an input for pricing various spread products. The par curve in its current construction has served us well for the last 25 years, but the Treasury market has grown nine-fold over this period, and the structure of the market has changed, resulting in more benchmark points and a proliferation of securities with similar or the same maturities. Thus, we think it is appropriate time to modernize our par curve in an effort to keep pace with the growth of the Treasury market. Over the following pages, we review the methodology used to construct our par curve as well as recent changes we have made to improve the stability and robustness of this curve.

We can identify three areas for modernizing our par curve. **First**, though we aim to construct a curve of relatively uniform liquidity, we find the inclusion of very low free float off the run bonds artificially skews the output of our current model. **Second**, we have kept the number of knot points stable for the last 25 years, even though the size of the Treasury market and the number of outstanding CUSIPs has multiplied. **Finally,** given the explosive growth of the market, positioning these knots at fixed intervals of securities along the curve has resulted in reduced stability in longer maturities. In combination, making adjustments related to these three factors can improve both the fit and stability of our par curve model.

We similarly identify opportunities to improve our TIPS par curve model, based on basket construction and knot placement. **First**, the inclusion of very short maturity TIPS in the estimation sample can distort the curve fitting process, and we exclude securities less than 1 year in maturity from our estimation sample. **Second**, our legacy TIPS par curve used the same number of knot points as the nominal Treasury par curve model, despite far fewer CUSIPs used in estimation. **Third**, as with the nominal curve, we can improve stability of the curve by placing knots at liquidity points, rather than at a fixed interval between securities. Adjustments along these dimensions provide a more robust par curve estimation with smaller overall yield errors compared with our previous model.

Parametric Discounting Curve

We first discuss the basic construction of our yield curve, which involves three steps. **First**, we specify the exact basket of Treasury securities used in the estimation. **Second**, we specify a parametric model for the curve. **Finally**, we estimate model parameters by fitting a discount factor function to observed market prices of securities in the basket.

In constructing our yield curve, we aim to build a curve of relatively uniform liquidity; so, we filter out Treasury securities that have features which could distort the smoothness of our curve. We currently exclude the following securities:

- On-the-runs, olds, and double-olds in the 2-year, 3-year, 5-year, 7-year, 10-year and 20-year sectors, as these securities are actively traded and tend to exhibit a liquidity premium. We exclude current 30-year bonds, but include the old and double-old issues, since fewer securities exist at the very long end
- Treasury securities trading significantly special in the repo market. We exclude

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securities with 6-month repo rates that are 25bp or more below 6-month GC repo rates. Issues trading special in repo will exhibit a liquidity premium and could distort curve construction.

- Securities with less than 1 year to maturity. T-bills and short coupons are excluded as they are owned primarily by money market funds and other short-end investors, and tend to exhibit different supply/demand characteristics than securities that are longer maturity in nature. Instead, we use GC repo rates to model the short end, which results in more stable forward rate and carry calculations.
- Bonds with floating-rate and zero-coupon structures (TIPS, FRNs, STRIPS).

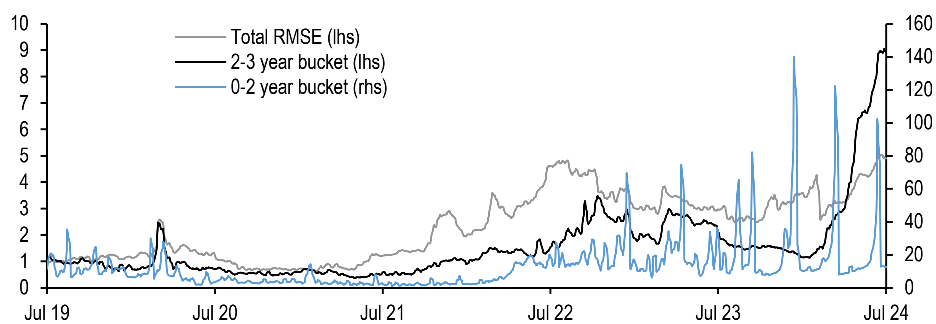
When constructing the parametric curve, we first define a bond's theoretical price by discounting the bond's cash flows by a discount factor. We model the discounting factor via a cubic spline function which is fully specified by 9 model parameters and 6 knots. The knots are determined such that there are roughly the same number of bonds between neighboring knots. Meanwhile the short end of the discounting curve is controlled by the GC repo market. Once the discounting curve is properly constructed, we can take the difference between the theoretical and dirty price to find the price error, which provides a measure to quantify the relative value of the bond. Our existing model seeks to minimize the sum of squared yield errors, where we divide each bond's price error by the product of the bond's duration and price (see *The new and improved Treasury par curve model*, 7/16/18).

Identifying ways to modernize and enhance our par curve construction

The improvements we made to our par curve in 2018 ushered in smaller yield errors and was more stable than our prior curves, but we think further enhancements are necessary in order to ensure the continued robustness of this key model. As discussed above, we observe three key areas for improvement.

Figure 1: Dispersion along our par curve has risen notably in recent months, led by the front end...

Root mean square error of J.P. Morgan Treasury par curve as well as 0-2 and 2-3 year buckets, one-week moving average; bp



Source: J.P. Morgan

First, as we have discussed recently, the root mean square error (RMSE) of our par curve, a measure of aggregate dispersion, has risen to 2-year highs, with the bulk of this move due to increased dispersion at the front end (**Figure 1**). This high RMSE largely stems from original-issue 30-year bonds issued in the late 1990s. Recall these bonds were issued during the days of small budget deficits and even surpluses, with free floats (amount issued less SOMA ownership and bonds held in stripped form) of $5bn or less, and are substantially smaller than other off-the-runs in this sector. As **Figure 2** shows, most of these small, illiquid issues are all trading exceedingly rich relative to our fitted curve, disproportionately impacting RMSE measures at the front end. Thus, the move in dispersion is being overstated by these deeply off-the-run bonds which were auctioned more than 20-years ago, are highly illiquid, and trade very infrequently. **In the spirit of creating a curve of relatively uniform liquidity, the first step in improving our model involves removing these very low free float bonds from the model basket of Treasury securities.**

Figure 2: ...and concentrated among deeply off-the-run OI 30-year bonds with very small free floats

Treasury securities with less than $8bn in free float*; units as indicated

CUSIP	Free float ($bn)	Issue Date	Maturity Date	Orig. issue (years)	Yield error (bp)
912810FA1	2.1	8/15/1997	8/15/2027	30	-8.7
912810EZ7	2.2	2/18/1997	2/15/2027	30	-20.8
912810EV6	2.3	8/15/1995	8/15/2025	30	-33.7
912810ET1	2.3	2/15/1995	2/15/2025	30	-58.2
912810ES3	2.5	8/15/1994	11/15/2024	30	-84.3
912810EX2	2.9	8/15/1996	8/15/2026	30	-19.8
912810FJ2	3.2	8/16/1999	8/15/2029	30	-4.9
912810EY0	3.2	11/15/1996	11/15/2026	30	-46.8
912810FG8	4.0	2/16/1999	2/15/2029	30	-12.3
912810FE3	4.1	8/17/1998	8/15/2028	30	-14.6
912810PT9	4.8	2/15/2007	2/15/2037	30	-11.2
912810EW4	5.6	2/15/1996	2/15/2026	30	-25.4
912810FM5	5.6	2/15/2000	5/15/2030	30	-2.6
912810PU6	6.0	8/15/2007	5/15/2037	30	-10.0
912810PW2	6.1	2/15/2008	2/15/2038	30	-10.1
912810FB9	6.4	11/17/1997	11/15/2027	30	-8.3
912810FT0	6.6	2/15/2006	2/15/2036	30	-14.1
912810FF0	7.1	11/16/1998	11/15/2028	30	-8.3
912810PX0	7.2	8/15/2008	5/15/2038	30	-9.0
912810FP8	7.4	2/15/2001	2/15/2031	30	-11.1

Source: J.P. Morgan, US Treasury
*Amount outstanding less the sum of SOMA holdings and the stripped amount

Second, in building our par curve for the last 25 years, we have defaulted to using 6 knot points, separated by a fixed number of CUSIPs. In its current form, we noticed shortfalls with this curve: **Figure 3** plots points on the Treasury curve, versus their model yields and the current placement of our knots. As discussed above, it's clear that the very low free float bonds are trading rich relative to surrounding maturities, but it's also notable that our curve displays a poor fit in the 7- to 10-year sector. We think this poor fit is a byproduct of current curve construction. Placing knots at fixed intervals results in a very large number of CUSIPs at the front end, but only 2 knot points past the 5-year maturity point, contributing to more variable output longer out the curve. **Thus, there is a strong case for both increasing the number of knots in our curve and changing their location.**

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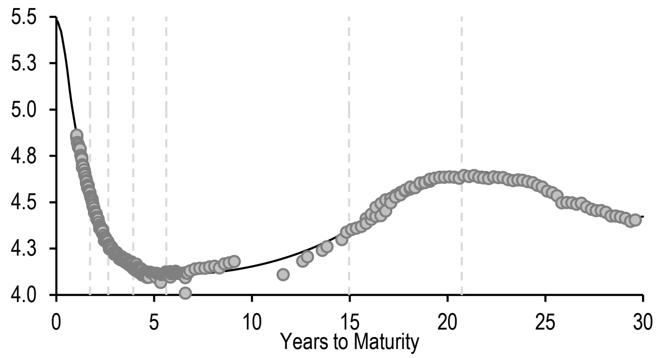
Figure 3: By construction, the legacy par curve struggles to properly fit the limited number of bonds in the 7- to 10-year space

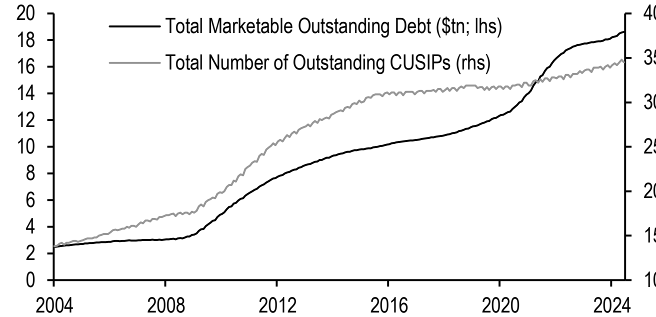
Yield errors in maturity space along the legacy par curve, alongside knot points in grey dashed lines*; %



Source: J.P. Morgan
*As of 7/12/2024

Figure 4: The size of the Treasury market has grown nine-fold and number of CUSIPs have more than doubled over the past 25 years

Total marketable outstanding Treasury debt (lhs; $tn) versus total number of outstanding Treasury CUSIPs for U.S. Treasury notes and bonds (rhs);

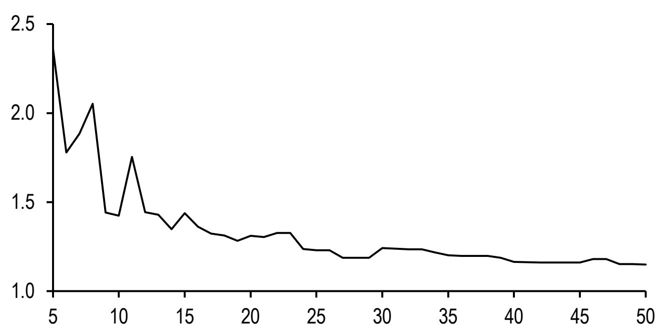


Source: U.S. Treasury

On the former, the Treasury market has grown nine-fold, and the number of CUSIPs has more than doubled over the last 25 years (**Figure 4**). Accordingly, it's imperative to add knots to keep pace with the proliferation of securities since the turn of the century. Importantly, we find the RMSE of the par curve declines with the addition of more knots (**Figure 5**). However, there are diminishing benefits to using a large number of knot points, as the incremental decline in RMSE is negligible when we use more than 10 to 15 knots. While adding additional knot points helps to increase the fit of the model, it can also come at the cost of the smoothness: **Figure 6** shows the absolute value of the difference of differences between various tenors on the curve. Smaller values indicate smaller changes in the slope of the curve over its length and thus would suggest a smoother curve, and vice versa. The curvature tends to increase as the number of knots increase, indicating that more knots result in a less smooth curve. Moreover, the figure shows there is a real increase in curvature, and thus overfitting, between 15 and 20 knot points. **Given the growth in the size of the Treasury market and the results from these empirical tests, we double the number of knot points from 6 to 12.**

Figure 5: The RMSE of the par curve declines with additional knot points, with diminishing benefits beyond 10-15 knots...

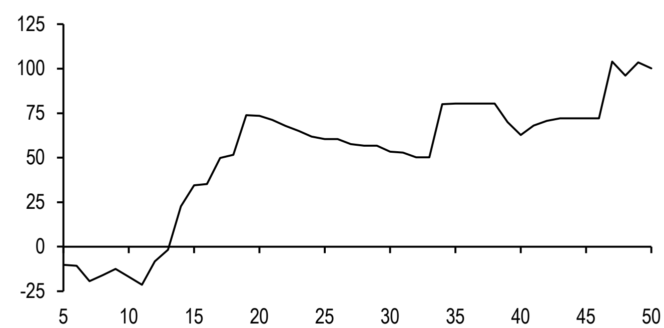
RMSE versus number of knot points*; bp



Source: J.P. Morgan
*As of 7/12/2024

Figure 6: ...around the same number at which the model begins to display overfitting

Percent change in curvature following shock* versus number of knot points**; %



Source: J.P. Morgan
*Curvature measure represents the absolute value of second-order differences at various maturity points along the re-estimated curve following a N~(20,5) shock to 5% of bonds
**As of 7/11/2024

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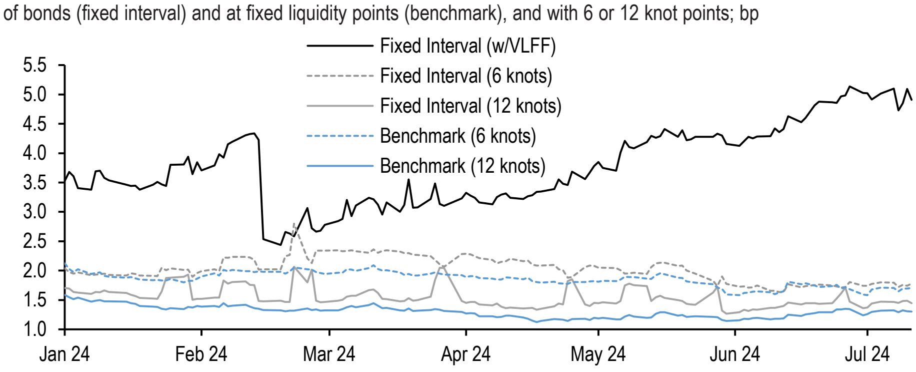
Finally, knot placement also matters, and in the current construction, there are only two knot points after the 5-year maturity point along the curve and they are placed at relatively illiquid points on the curve. Therefore, there is a rationale for moving the knot points to benchmark points, which are natural liquidity points. We think there's also a case to space the new knots at midpoints between benchmark points, where off the runs transition from trading off a longer maturity point to trading off a shorter maturity point. **As such we move the placement of knot points to align with on-the-run maturities as well as their midpoints.**

Building a better par curve

Incorporating these changes and re-estimating our par curve, **Figure 7** illustrates the incremental improvement in RMSE from these various changes. As expected, removing the very low free float bonds significantly improves the fit and stability of the par curve model, with the average RMSE YTD falling from 3.8bp to 2bp and the standard deviation shrinking from 0.66bp to 0.21bp. Changing the distribution of the knot points between a fixed interval of bonds ('fixed interval') to placement at a fixed number of liquid points ('benchmark') further reduces RMSE by roughly 0.2bp and decreases the standard deviation by 0.08bp, under both a 6- and 12-knot model. Finally, expanding the number of knot points from 6 to 12 further increases the fit of the model on the margin, reducing average RMSE by approximately 0.5bp, under both the fixed interval and benchmark models. **Overall, we can observe that re-estimating the par curve after removing very low free floats, increasing the number of knot points to 12, and positioning these at and between liquid on-the-run tenors deliver the greatest increase in fit and stability to our par curve.** On net these changes help to reduce average RMSE by 2.5bp, or 65% compared to the legacy model, and decrease the standard deviation by 0.56bp, or 85% compared to the legacy model, YTD.

Figure 7: Removing very low free float bonds, expanding the number of knot points to 12, and anchoring these at and between liquid on-the-run points all help to increase the fit and reduce the variability of our par curve model

RMSE by various model construction, including with and without very low free floats, setting knots between fixed number of bonds (fixed interval) and at fixed liquidity points (benchmark), and with 6 or 12 knot points; bp



Source: J.P. Morgan

Away from total RMSE, we can see that in the new construction, there are more knots points at the long end, and these knot points run through more liquid points , the 10-, 15-, 20-, and 25-year sectors. This change drive a better fit in the 7- to 10-year sector and in the 15- to 25-year sector, which should help in more accurately identifying relative value opportunities (**Figure 8**) . Cumulatively, these changes show that RMSE has been relatively stable along the curve this year, and the outsized increases at the front end have disappeared, leaving dispersion closer to average levels in most maturity buckets

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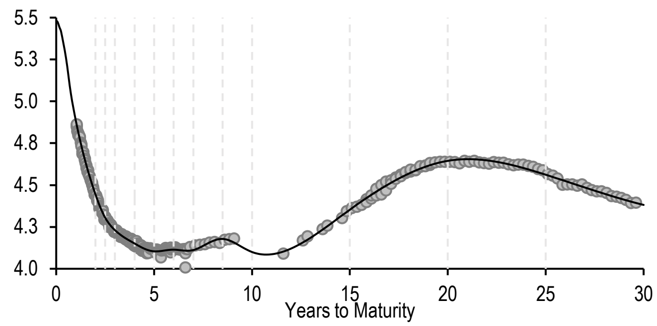
(**Figure 9**).

Figure 8: The updated par cure provides a closer fit in the 7-10 and 15-25 year sectors...

Yield errors in maturity space along the new J.P. Morgan par curve, alongside knot points in grey dashed lines*; %



Source: J.P. Morgan
*As of 7/12/2024

Figure 9: ...and shows that dispersion is closer to average across most tenors, rather than elevated in the front-end

RMSE of new and legacy J.P. Morgan par curve by maturity bucket with 1 year statistics; bp unless otherwise indicated

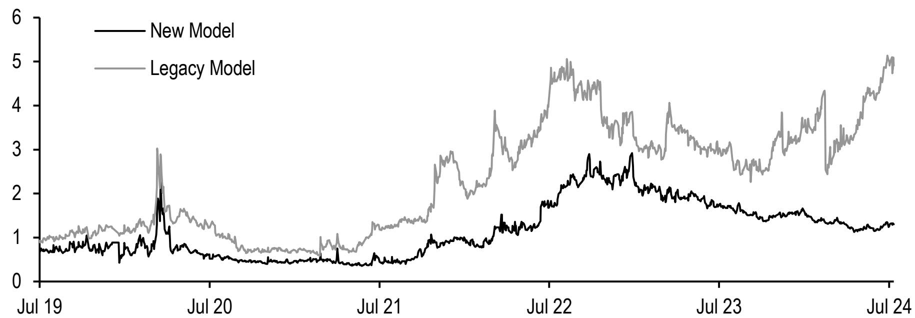
	Legacy Model				New Model			
Maturity	Last	Avg	%	Std Dev	Last	Avg	%	Std Dev
0-2y	12.4	23.1	55%	36.6	0.9	1.2	13%	0.3
2-3y	8.9	2.9	97%	2.3	0.8	1.1	27%	0.3
3-5y	3.1	2.3	97%	0.3	1.1	0.9	63%	0.2
5-7y	2.3	2.5	21%	0.2	2.1	2.3	17%	0.2
7-10y	5.1	4.7	62%	1.0	1.6	2.3	20%	0.6
10-20y	2.2	3.3	7%	0.7	1.5	1.4	71%	0.5
20-30y	1.1	1.3	28%	0.3	1.3	1.1	92%	0.1

Source: J.P. Morgan

Figure 10 displays a longer history of our legacy and new par curves. The new model generally tracks the old model, but with a lower RMSE, for the reasons listed above. However, the two models diverge in 2024, where the aggressive richening of very low very float original-issue 30-year bonds becomes more pronounced in our legacy model. Meanwhile, the new curve would be consistent with relatively stable market functioning, which we also observe across a host of other liquidity metrics as well (see *This one's optimistic Broad improvements in Treasury market liquidity trends in 2024*, 6/21/24).

Figure 10: Updating our par curve reveals that dispersion along the curve has in fact been declining, not rising, over the past two years

RMSE of new and legacy J.P. Morgan par curves; %



Source: J.P. Morgan

Revisions to our TIPS par curve

Turning to our TIPS par curve construction, we use a similar approach to the piece-wise cubic spline model described above, in which we estimate parameters by minimizing yield errors, though there are a few differences worth highlighting. **First**, we model a discount function on future cashflows by first adjusting for the value of the floor option in TIPS, as well as the seasonality of CPI. The option adjustment is straightforward: we

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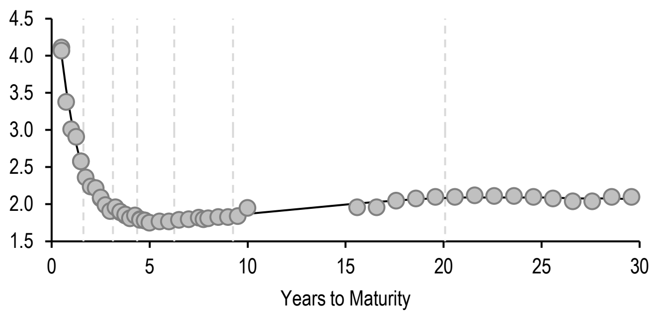
model the value of the option via standard swaption pricing models with OIS discounting and subtract it from the observed real market price for each TIPS in our basket. Additionally, we use monthly multiplicative seasonal factors from BLS to calculate daily seasonal adjustment factors, based on linear interpolation, which are applied to each cashflow (see *Revising our fitting TIPS curve*, 8/15/19). **Second**, when building our nominal Treasury par curve, we filter out securities that trade with a liquidity premium, including on-the-run and near off-the-run securities. We do not filter these securities out of our TIPS estimation sample given that on-the-run TIPS rarely trade with a substantial liquidity premium and given the limited number of outstanding securities. However, in our existing curve construction, we filter out securities with less than 0.4 years in maturity, given that the lagged indexation process in TIPS results in erratic pricing of very short-maturity TIPS.

Going forward, we introduce two improvements to this model. **First**, we believe that a 0.4-year maturity filter is too short, and still leaves a number of short-maturity TIPS in the estimation sample, which can distort the curve fitting process. Thus, in our revised par curve, we exclude TIPS with less than 1-year in maturity from the estimation. **Second**, consistent with the exercise discussed above, we adjust the number and placement of knot points used in the par curve construction. In the existing model, the TIPS par curve uses 6 knot points, with placement determined such that there is roughly the same number of securities between neighboring knots—the same approach as the existing nominal Treasury par curve. However, there are only 54 TIPS CUSIPs used in the current TIPS par curve estimation, a small fraction of the nearly 400 CUSIPs used in the estimation of the nominal par curve, and this number drops to just 48 when we extend our maturity filter to 1 year. Moreover, in contrast to the nominal Treasury market, where the number of benchmark points has expanded in recent decades, Treasury has maintained just 3 TIPS benchmark tenors. These considerations argue for a smaller number of knot points in our TIPS par curve model.

Figure 11: Our current par curve construction is distorted by erratic pricing in very short-maturity TIPS and suffers from overfitting due to a smaller number of CUSIPS

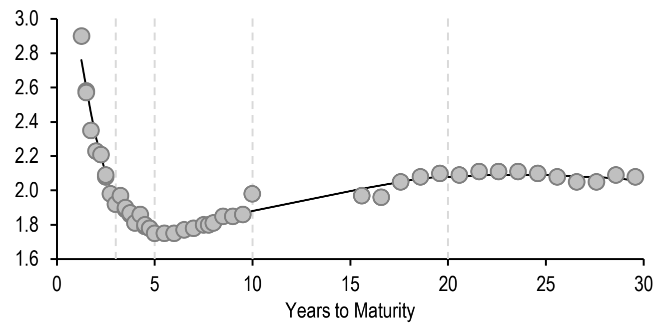
Legacy TIPS par curve versus par yield + yield error for bonds in estimation sample (knot points in grey dashed lines*); %



Source: J.P. Morgan

Figure 12: By excluding maturities less than 1 year and reducing the number of knots, we believe our revised par curve serves as a better valuation tool...

Revised TIPS par curve versus par yield + yield error for bonds in estimation sample (knot points in grey dashed lines*); %



Source: J.P. Morgan

Figure 11 plots model yields for outstanding TIPS relative to the fitted par curve and illustrates both of these shortcomings. The shape of the curve is dominated by very high real yields for TIPS with less than 1-year to maturity, likely obscuring the ability to model curve shape at the front end. Additionally, we see that the current model there are 5 knot points between 1 and 10 years. In contrast, **Figure 12** plots the revised curve, in

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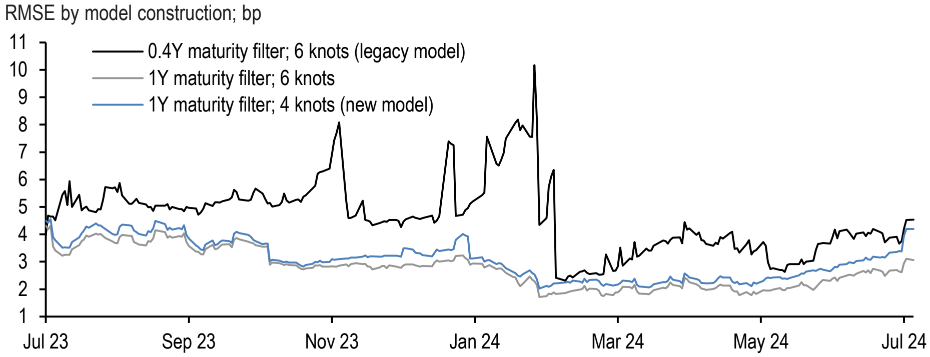
which the 1-year maturity filter is applied, and the number of knot points is reduced to just four. Consistent with the approach described above for the nominal curve, we choose to place knot points at benchmark maturities. We also add one midpoint knot at the 3-year maturity, given the highest concentration of CUSIPS in this bucket.

Overall, by excluding maturities less than 1 year and reducing the number of knot points, we believe our revised par curve serves as a better valuation tool compared with our legacy model. Notably, the RMSE of the revised curve has historically been far more stable at a lower level, driven primarily by the change in maturity filter (**Figure 13**). We acknowledge there is a tradeoff between overfitting and smoothness, and we sacrifice slightly lower curve dispersion by reducing the number of knot points, in order to better capture the broad contours of the real yield curve.

Figure 13: ...and the RMSE of the revised par curve model is historically more stable, while capturing the broad contours of the real yield curve

RMSE by model construction; bp



Source: J.P. Morgan

We have rolled out these changes to both par curves. The updated models are used within the T*reasury Carry, Roll, and Relative Value Report* and the *TIPS Fitted Curve Relative Value Report* within our US Cash Interest Rate Products Analytics Package, which can be found on JPMM. Historical par curve data as well as yield errors for individual Treasury securities and maturity buckets can be found in our DataQuery analytical tool.

We would like to extend a special thanks to Dylan Dong for his contributions to this piece.

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