

FX Viewpoint

Predict FX Vol with PCA

Revisit PCA framework for G10 FX implied vols

We revisit the predictive capability of our PCA framework for G10 FX vols, after [initially launching it in 2016](#). Analysis of the subsequent implied vol data shows that for various tenors and most currencies there is clear negative correlation between implied vol deviations from PCA fair value versus future change in implied vols. In other words, FX implied vols trading at a discount versus the PCA framework fair value tend to rise while implied vols trading at a premium tend to fall. In addition, using 3-factor principal component decomposition of G10 FX implied vols on a 5y rolling basis to predict 10-day ahead implied vol changes shows the most significant out-of-sample correlation.

Better signals to fade vols at a large premium

Further analysis shows the out-of-sample correlations are more significant for currencies that are at a premium than at a discount to estimated fair value. Among major G10 pairs in vol market, AUDCAD, USDJPY and USDNOK vols at a premium have the most significant out-of-sample correlations. EURCHF has the most significant correlation for when implied vols are at a discount to estimated fair value. Moreover, we also find implied vols trading at a large spread to estimated fair value tend to yield better signals.

Summarizing FX vols with principal components

The first principal component vector is highly correlated with the VIX index at 79% since 2017 and 91% since 2019, meaning FX vols are highly correlated with equity vols and the sensitivity has been rising in recent years. The second principal component shows notable pre versus post-Covid shock regime change for FX vols, and is correlated with US 10y real yield at 65%. The third principal component is correlated with JPY strength at 39%, capturing risk-off drivers of FX vol. Due to its so-called “safe-haven” currency status, JPY appreciation tends to lead to higher FX vols.

PCA framework for EM FX vols

Extending the framework to major EM FX vols shows the out-of-sample correlation is more significant for a 1-factor decomposition at a 3m lookahead window. The first principal component for EM FX implied vols also shows a notable correlation with VIX.

Latest signals favor higher 3m NZDUSD vol

The latest PCA signals show 3m NZD-based implied vols are broadly underpriced, with NZDUSD implied vol below estimated fair value by -0.58. The Q4 CPI release for New Zealand at end of January could be a catalyst for higher NZDUSD implied and realized vols. The rates market currently expects 5 RBNZ rate hikes in 2022, one of the most aggressive among developed countries. Amid negative Q3 growth rate for New Zealand, the quarterly CPI release could lead to a re-price of the RBNZ rate path, subsequently contributing to higher NZDUSD vol. The risk to this view is lack of options response to the upcoming NZ CPI release and the Jan FOMC meeting.

Trading ideas and investment strategies discussed herein may give rise to significant risk and are not suitable for all investors. Investors should have experience in FX markets and the financial resources to absorb any losses arising from applying these ideas or strategies.

BofA Securities does and seeks to do business with issuers covered in its research reports. As a result, investors should be aware that the firm may have a conflict of interest that could affect the objectivity of this report. Investors should consider this report as only a single factor in making their investment decision.

Refer to important disclosures on page 11 to 12.

12373216

Timestamp: 20 January 2022 05:25PM EST

20 January 2022

G10 FX Strategy
Global

Howard Du, CFA
G10 FX Strategist
BofAS
+1 646 855 6586
yuhao.du@bofa.com

Vadim Iaralov
FX Strategist
BofAS
+1 646 855 8732
vadim.iaralov@bofa.com

Revisiting the PCA framework for G10 FX implied vols

We first launched the [principal component analysis \(PCA\) framework](#) for G10 FX implied volatility in 2016. Now in a post-Covid world, we revisit the predictive power of the framework for G10 FX implied volatility and extend to EM FX vols.

How do we apply PCA to G10 FX volatility?

We first aggregate historical implied vol time series data for all 45 G10 FX crosses. By applying principal component decomposition to the historical implied vol data, we can obtain 45 orthogonal principal components (PCs). The 45 PCs altogether can explain 100% of the variance in the implied vol data, but majority of the variance can be attributed to a select few PCs. We then regress the top principal components with the historical implied vols for each currency pair; the residuals of the regressions capture how much the actual implied vols are mispriced from the so-called PCA estimated “fair values”.

A negative residual would suggest the current implied vol is cheap and should revert higher in the near-future; while a positive residual would suggest the current implied vol is expensive and would likely decline in the near future. Moreover, the principal component vectors also allow us to identify macro variables that drive fluctuations in FX vols.

We first assess and determine the appropriate historical lookback period, the impact of additional principal components in regressions, and the forward looking horizon with suitable explanatory power.

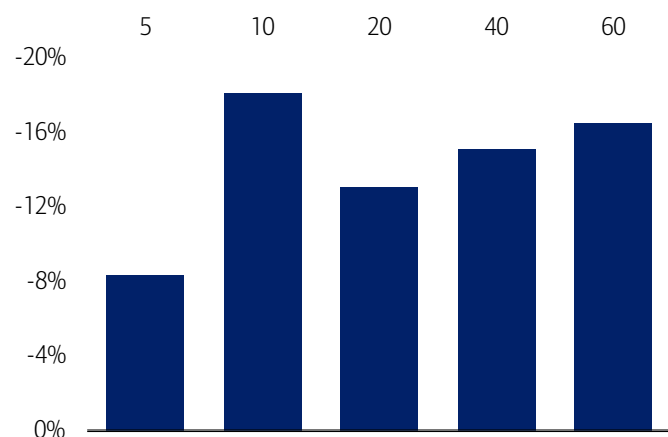
Assessment of the PCA framework

We compared 1y to 10y lookback periods, 1-week to 3-month lookahead periods, 1-PC to 5-PC decompositions, and 1m to 1y implied vol with FX implied vol data going back to 2009. For each combination of parameters, we conducted PCA decomposition to historical data on a rolling lookback basis, and calculated the out-of-sample rolling correlations between the estimated regression residuals and the future actual change of implied vol at the given lookahead period. We then looked at the average sensitivity to different parameters. For example, we ran a rolling 3-PC decomposition to historical daily 3m implied vol data at 1y lookback windows, and calculated the rolling correlation between the regression residuals and future 1-week actual change in implied vol.



Exhibit 1: Out-of-sample correlation is more significant for 10d look-ahead

Average of correlations for PC regression residuals vs. future implied vol changes at different look-ahead periods

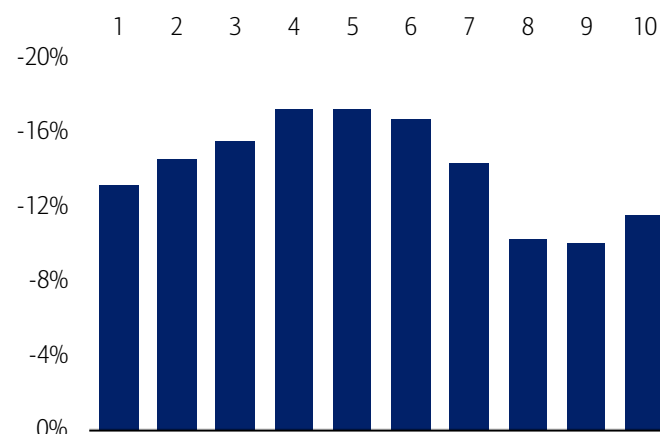


Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 2: 5y historical lookback yields more significant correlation

Average of correlations for PC regression residuals vs. future implied vol changes using different lookback periods of historical data



Source: BofA Global Research

BofA GLOBAL RESEARCH

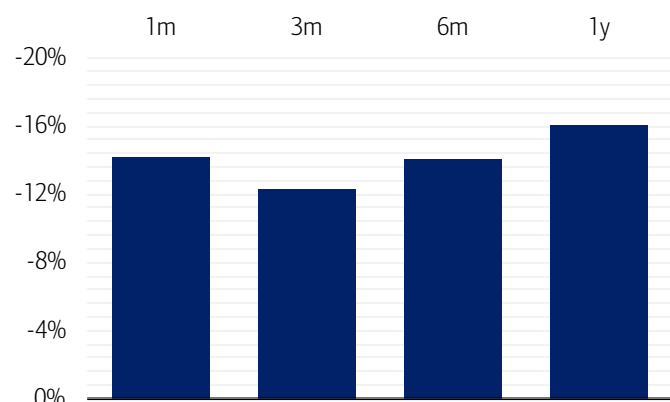
G10 PCA vol fair values significantly correlated with 10-day future vol changes

Across all of the parameters we have experimented, we find a negative out-of-sample correlation between the regression residuals and future change of implied vol. The result confirms framework validity because implied vols below estimated fair value tend to rise and implied vols above estimated fair values tend to fall. Exhibit 1 and Exhibit 2 show the backtest correlation is most significant at 10-day lookahead and about 5y lookback periods. The out-of-sample correlations are comparable across tenors, with moderately more negative correlation for the 1y tenor and correlation closer to zero for the 3m tenor (Exhibit 3).

The out-of-sample correlations are also comparable between results for the 1-PC decomposition and the 3-PC decomposition, but the correlation drops notably for the 5-PC decomposition (Exhibit 4). Compared to using a single principal components which explains 72% of the in-sample variance of implied vol data, using 3 principal components can increase the explained variance ratio to 91% (Exhibit 5). The results of the analysis confirm that the **3-PC** decomposition is suitably applied to historical implied vol data at **5y** rolling lookback windows, and use the regression residuals as signals for future **10-day** change in implied vols, in our view.

Exhibit 3: Comparable correlation significance across tenors

Average of correlations for PC regression residuals vs. future implied vol changes at different implied vol tenors

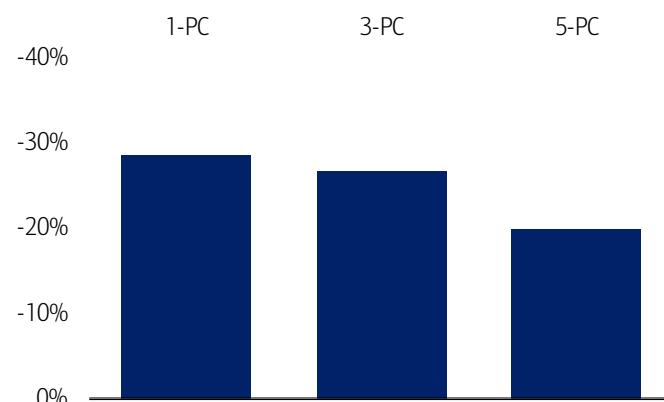


Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 4: Correlation significance is reduced at 5-PCs

Average of correlations for PC regression residuals vs. future implied vol changes using different number of principal components

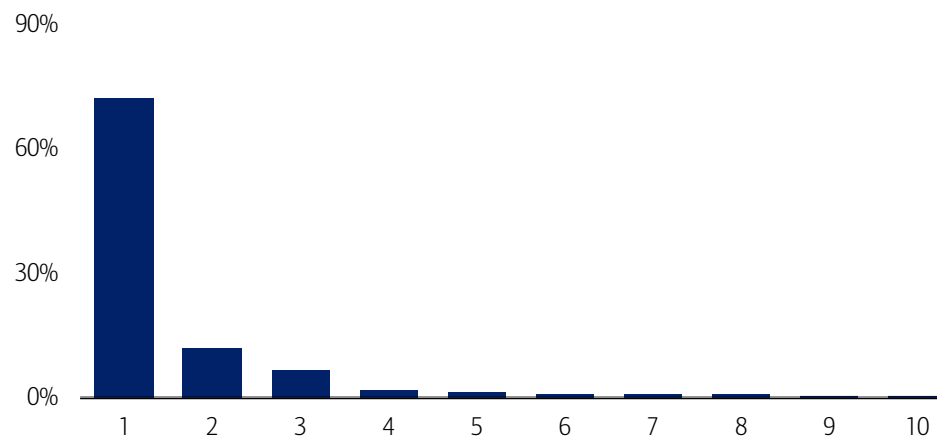


Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 5: 1-PC explains 72% and sum of top 3 PCs explains 91% of the implied vol data variance

Explained variance ratio for the top 10 principal components



Source: BofA Global Research

BofA GLOBAL RESEARCH

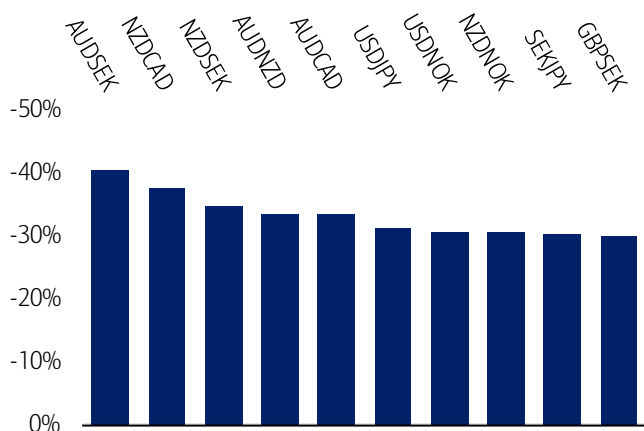
Underpriced vs overpriced implied vols**Implied vols above estimated fair value are more likely to fall**

Focusing only on the positive residuals yields more significant out-of-sample correlations, which means implied vols that are rich versus estimated fair values are more likely to fall (Exhibit 6). **AUDCAD**, **USDJPY**, and **USDNOK** are the major pairs in vol market that tend to see implied vols revert lower after trading at a premium over estimated fair value.

By contrast, results for only the negative residuals yields correlations that are closer to zero (Exhibit 7). But in case of **EURCHF**, the implied vol is likely to rise when its level trades at a discount to estimated fair value.

Exhibit 6: Implied vols at premium are more likely to fall

Top 10 average out-of-sample correlations for implied vols at a premium vs fair value by currency

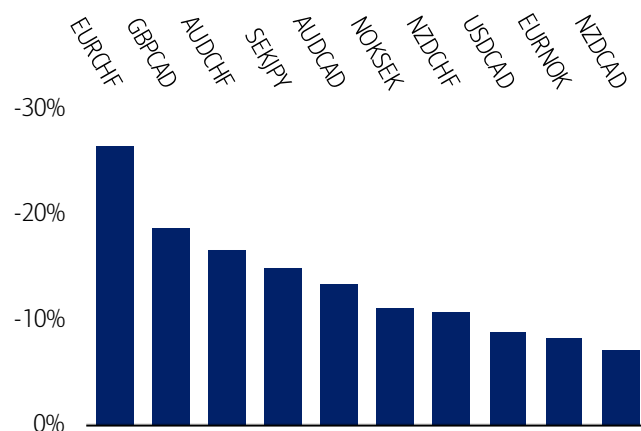


Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 7: EURCHF implied vols at discount are more likely to rise

Top 10 average out-of-sample correlations for implied vols at a discount vs fair value by currency



Source: BofA Global Research

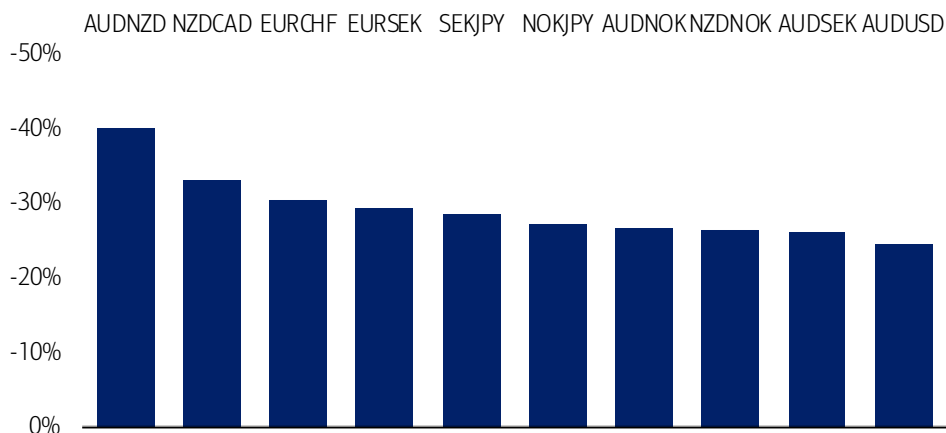
BofA GLOBAL RESEARCH

Greater signal strength for large residuals

Exhibit 8 shows the out-of-sample correlation can be more significant for regression residuals that have 1y z-score above +1 or below -1. When implied vols have large dislocation from estimated fair values, they tend to revert back towards these fair values. Among the major pairs in G10, the out-of-sample correlation is most significant for **AUDNZD**, **EURCHF**, **EURSEK** and **AUDUSD**.

Exhibit 8: Out-of-sample correlation is more significant for implied vols with large deviations from estimated fair value

Top 10 average out-of-sample correlations using regression residuals with 1y z-score beyond +/- 1



Source: BofA Global Research

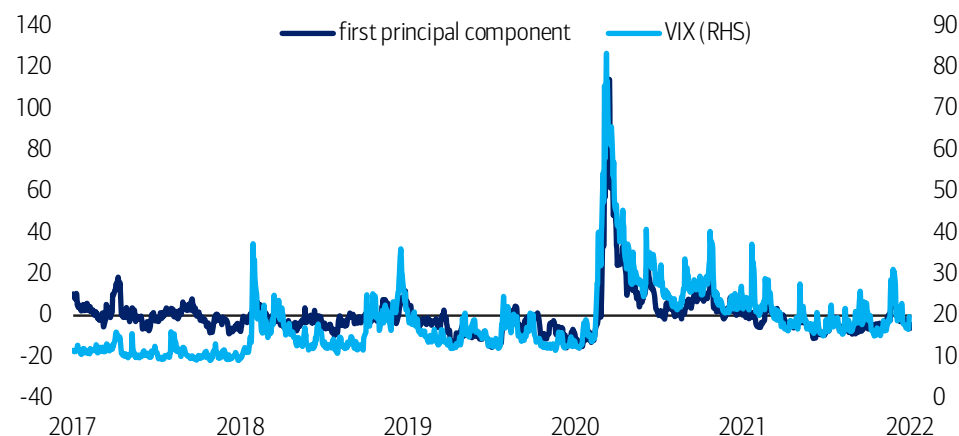
BofA GLOBAL RESEARCH

The three principal components**First principal component is highly correlated with VIX**

Exhibit 9 to Exhibit 11 illustrate the three principal component vectors for the most recent 5y lookback window. We find the first PC, which explains 72% of the variance for FX implied vols, appears to be highly correlated with the VIX index. The correlation has been 79% since 2017 and 91% since 2019 (Exhibit 9). The result FX implied vols have become more sensitive to risk spillover from the equity market over the years, making FX vol a more suitable proxy hedge for equities than in years past.

Exhibit 9: 1st PC is highly correlated with VIX at 79% since 2017 and 91% since 2019

First principal component vector and VIX index



Source: BofA Global Research

BofA GLOBAL RESEARCH

Second principal component show Covid regime shift for FX vol

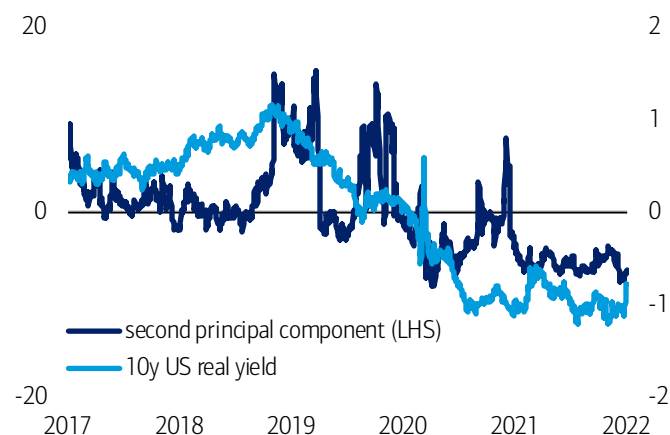
The second principal component was positive most of the time before the March 2020 Covid-19 shock, but has since then averaged negative (Exhibit 10). We find the US 10y real rate correlates with the 2nd PC at 65% but not conforming to all of the spikes in the 2nd PC. If the second PC turned positive like it did briefly in Sep and Dec 2020, then we would expect FX vols could broadly move higher in 2022.

Third principal component correlates with JPY strength

Lastly, we find the third PC has a notable correlation of 39% with the Bloomberg correlation-weighted JPY index over the past 5 years capturing risk-off drivers of FX vol (Exhibit 11). Given its so-called “safe-haven” currency status, JPY appreciation tends to occur amid rising FX vols.

Exhibit 10: 2nd PC has been suppressing FX vol since the Covid shock

Second principal component vector correlates with US 10y real rate at 65%

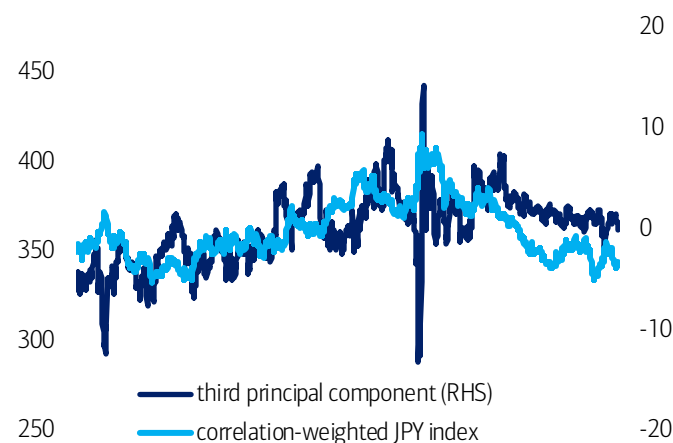


Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 11: 3rd PC correlates with JPY strength at 39%

Third principal component vector



Source: BofA Global Research

BofA GLOBAL RESEARCH

PCA framework for EM FX implied FX vols**Higher correlation for EM FX vols using 1-PC and 3m lookahead**

We further extend the PCA decomposition framework to 10 pairs of major EM FX vols across major regions. We find the out-of-sample correlations between PCA residuals and future implied vol changes are most significant for a 1-PC decomposition using 6 years of lookback window and 3-month lookahead window. Additional principal components

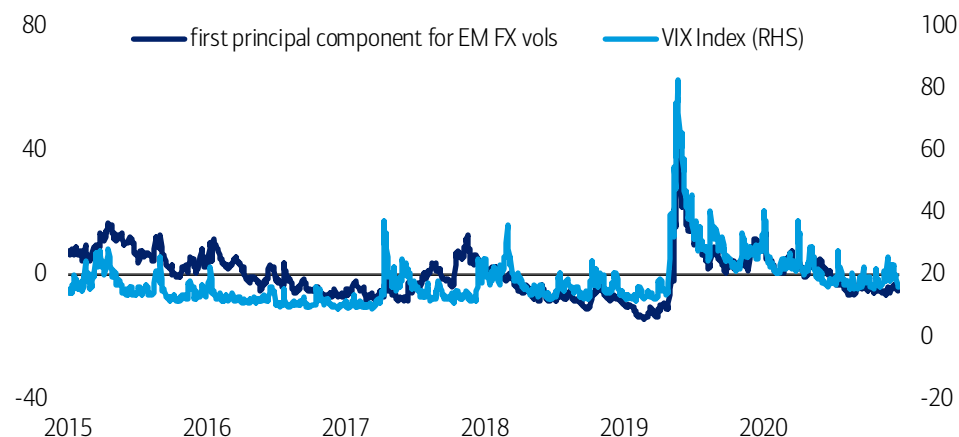


and applying the framework to shorter lookahead windows tend to notably reduce the out-of-sample correlation for EM FX vols.

The first principal component vector for EM FX vols explains 76% of the historical data variance. It is also correlated with the VIX index at 60% (Exhibit 12), and correlated with the first PC for G10 FX at 81%. These results suggest idiosyncratic local risks affect EM FX vols more than G10 FX vols, and the PCA framework has more explanatory power over medium term than short-term for EM FX vols.

Exhibit 12: 1st PC for EM FX vols has explained variance ratio of 76% and is 60% correlated with VIX

First principal component vector for EM FX vols vs VIX Index



Source: BofA Global Research, Bloomberg. The first principal component is generated using historical FX implied vol values for MXN, BRL, ZAR, HUF, PLN, RUB, KRW, TWD, SGD, and INR.

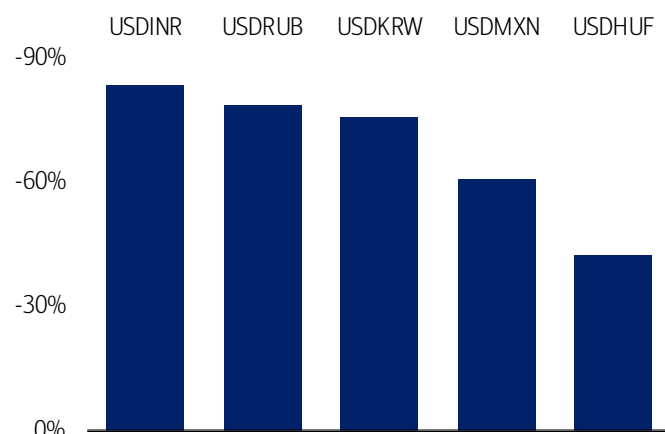
BofA GLOBAL RESEARCH

Implied vols at premium are also more likely to fall for EM FX

We break down the out-of-sample correlation between implied vols at a premium versus at a discount for EM FX pairs. Similar to G10 FX vols, EM FX implied vols are also more likely to fall when the levels are at a premium versus PCA fair values than to rise when levels are at a discount. INR, RUB, and KRW vols tend to fall the most when they are richer than estimated fair values (Exhibit 13). When EM FX implied vols are at a discount against PCA fair values, they tend to rise more for BRL and MXN (Exhibit 14).

Exhibit 13: INR, RUB, and KRW vols at premium are more likely to fall

Top 5 average out-of-sample correlations for EM FX implied vols at a premium vs fair value by currency

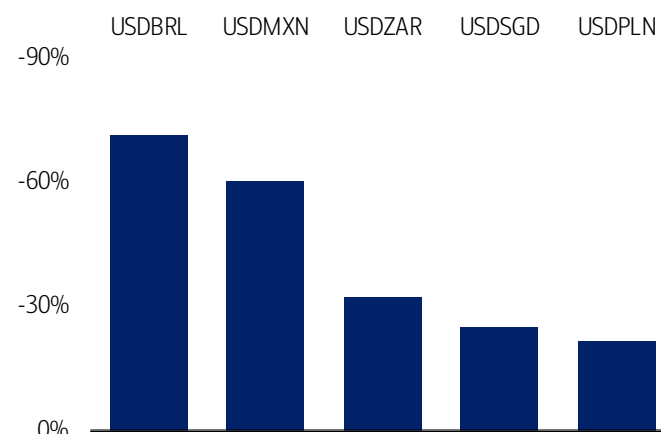


Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 14: BRL and MXN vols at discount are more likely to rise

Top 5 average out-of-sample correlations for EM FX implied vols at a discount vs fair value by currency



Source: BofA Global Research

BofA GLOBAL RESEARCH

Latest PCA signals favor higher 3m NZD implied vols**NZD-based implied vols are broadly underpriced**

The latest PCA signals show 3m NZD-based implied vols are cheap relative to PCA estimated fair values. NZDUSD implied vol is the most underpriced by 0.58 vols (Exhibit 15). The actual implied vol minus estimated fair value spread is also below -1 z-scores (Exhibit 16).

JPY-cross volatilities appear at a premium, with CADJPY as the richest at 0.92 vols given imminent Bank of Canada meeting. The premiums are in excess of what can be explained by the variation within G10 FX alone. The JPY-based vol premiums may be a market response to the recent global equity sell-off, in our view.

Exhibit 15: NZD-based implied vol are underpriced by 0.5 spread

3m implied vol – PCA estimated fair value spread

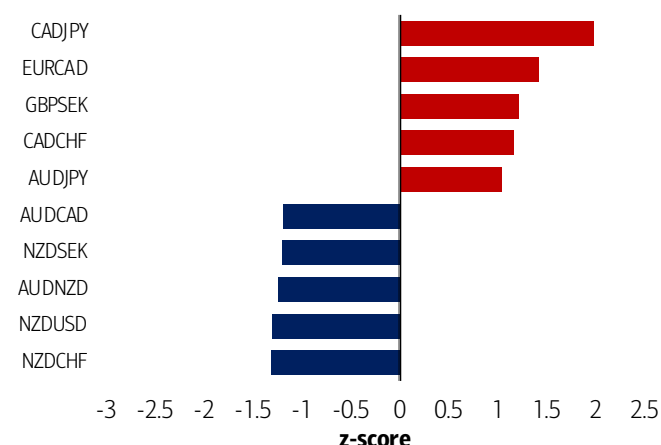
Vols	EUR/	GBP/	AUD/	NZD/	USD/	CAD/	CHF/	NOK/	SEK/
/GBP	-0.14								
/AUD	-0.04	-0.13							
/NZD	-0.30	-0.31	-0.48						
/USD	-0.35	-0.18	-0.29	-0.58					
/CAD	0.50	0.02	-0.38	-0.48	0.20				
/CHF	-0.02	-0.25	-0.35	-0.55	-0.07	0.45			
/NOK	0.30	0.29	-0.31	-0.32	-0.21	0.02	0.24		
/SEK	0.24	0.39	-0.19	-0.55	-0.04	0.17	0.21	0.20	
/JPY	-0.05	0.34	0.64	0.45	-0.02	0.92	0.18	0.23	0.17

Source: BofA Global Research

BofA GLOBAL RESEARCH

Exhibit 16: NZD actual-PCA estimated vol spreads are below -1 z-score

Top and bottom 1y z-scores of implied vol-PCA estimated fair value spread



Source: BofA Global Research

BofA GLOBAL RESEARCH

Q4 CPI release amid aggressive 2022 rate hike pricing to move NZD vol higher

3m NZDUSD implied vol is currently trading close to the 2021 low. It has not moved higher largely because NZDUSD realized vol has remained subdued, in our view (Exhibit 17). We expect both 3m NZDUSD implied and realized vols to move higher from current levels, and we see the Q4 2021 NZ CPI release at end of January as a potential catalyst. Unlike the US CPI which has had above 3% YoY monthly prints since June 2021, the NZ

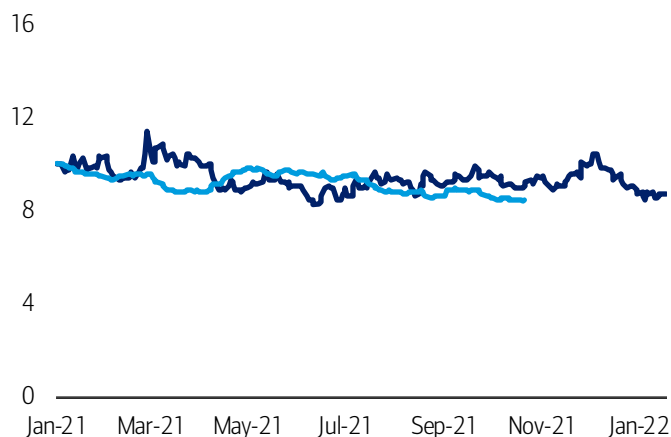


CPI is released quarterly and latest value still only covers data up to Q3 2021 ([New Zealand Economic Watch: 18 October 2021](#)).

The rates market currently has priced in 5 RBNZ rate hikes in 2022 (Exhibit 18), which is one of the most aggressive among all developed countries. Most of the hikes are also expected to occur in within the first half of 2022. Any re-pricing of the monetary policy decisions on the back of uncertain Q4 CPI amid contracting Q3 growth ([New Zealand Economic Watch: 16 December 2021](#)) would likely lead to a rise in NZD vols. The risk to this view is lack of options response to the upcoming NZ CPI release and the Jan FOMC meeting.

Exhibit 17: 3m NZD implied versus lagged realized vol

NZD implied and realized vols are both at or close to a bottom since 2021

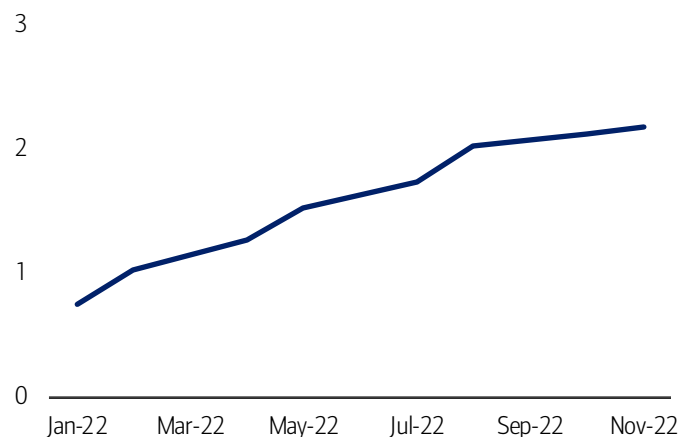


Source: BofA Global Research, Bloomberg

BofA GLOBAL RESEARCH

Exhibit 18: NZ OIS market currently sees 5 RBNZ rate hikes in 2022

NZ OIS implied rate in 2022



Source: BofA Global Research, Bloomberg

BofA GLOBAL RESEARCH

Options Risk Statement

Potential risk at expiry and options limited duration risk

Unlike owning or shorting a stock, employing any listed options strategy is by definition governed by a finite duration. The most severe risks associated with general options trading are total loss of capital invested and delivery/assignment risk...all of which can occur in a short period.

Investor suitability

The use of standardized options and other related derivatives instruments are considered unsuitable for many investors. Investors considering such strategies are encouraged to become familiar with the "Characteristics and Risks of Standardized Options" (an OCC authored white paper on options risks). U.S. investors should consult with a FINRA Registered Options Principal. For detailed information regarding the risks involved with investing in listed options:

<http://www.theocc.com/about/publications/character-risks.jsp>

Disclosures

Important Disclosures

Due to the nature of the market for derivative securities, the issuers or securities recommended or discussed in this report are not continuously followed. Accordingly, investors must regard this report as providing stand-alone analysis and should not expect continuing analysis or additional reports relating to such issuers and/or securities.

BofA Global Research personnel (including the analyst(s) responsible for this report) receive compensation based upon, among other factors, the overall profitability of Bank of America Corporation, including profits derived from investment banking. The analyst(s) responsible for this report may also receive compensation based upon, among other factors, the overall profitability of the Bank's sales and trading businesses relating to the class of securities or financial instruments for which such analyst is responsible.

BofA Securities fixed income analysts regularly interact with sales and trading desk personnel in connection with their research, including to ascertain pricing and liquidity in the fixed income markets.

Other Important Disclosures

Prices are indicative and for information purposes only. Except as otherwise stated in the report, for the purpose of any recommendation in relation to: 1) an equity security, the price referenced is the publicly traded price of the security as of close of business on the day prior to the date of the report or, if the report is published during intraday trading, the price referenced is indicative of the traded price as of the date and time of the report; or 2) a debt security (including equity preferred and CDS), prices are indicative as of the date and time of the report and are from various sources including BofA Securities trading desks.

The date and time of completion of the production of any recommendation in this report shall be the date and time of dissemination of this report as recorded in the report timestamp.

Recipients who are not institutional investors or market professionals should seek the advice of their independent financial advisor before considering information in this report in connection with any investment decision, or for a necessary explanation of its contents.

Officers of BofAS or one or more of its affiliates (other than research analysts) may have a financial interest in securities of the issuer(s) or in related investments.

Refer to [BofA Global Research policies relating to conflicts of interest](#).

"BofA Securities" includes BofA Securities, Inc. ("BofAS") and its affiliates. Investors should contact their BofA Securities representative or Merrill Global Wealth Management financial advisor if they have questions concerning this report or concerning the appropriateness of any investment idea described herein for such investor. "BofA Securities" is a global brand for BofA Global Research.

Information relating to Non-US affiliates of BofA Securities and Distribution of Affiliate Research Reports:

BofAS and/or Merrill Lynch, Pierce, Fenner & Smith Incorporated ("MLPF&S") may in the future distribute, information of the following non-US affiliates in the US (short name: legal name, regulator): Merrill Lynch (South Africa): Merrill Lynch South Africa (Pty) Ltd., regulated by The Financial Service Board; MLI (UK): Merrill Lynch International, regulated by the Financial Conduct Authority (FCA) and the Prudential Regulation Authority (PRA); BofASE (France): BofA Securities Europe SA is authorized by the Autorité de Contrôle Prudentiel et de Résolution (ACPR) and regulated by the ACPR and the Autorité des Marchés Financiers (AMF). Note that BofA Securities Europe SA has registered address at 51 rue la Boétie, 75008 Paris, is registered under no. 842 602 690 RCS Paris, and its share capital can be found on [BofASE's disclaimer webpage](#); BofA Europe (Milan): Bank of America Europe Designated Activity Company, Milan Branch, regulated by the Bank of Italy, the European Central Bank (ECB) and the Central Bank of Ireland (CBI); BofA Europe (Frankfurt): Bank of America Europe Designated Activity Company, Frankfurt Branch regulated by BaFin, the ECB and the CBI; BofA Europe (Madrid): Bank of America Europe Designated Activity Company, Sucursal en España, regulated by the Bank of Spain, the ECB and the CBI; Merrill Lynch (Australia): Merrill Lynch Equities (Australia) Limited, regulated by the Australian Securities and Investments Commission; Merrill Lynch (Hong Kong): Merrill Lynch (Asia Pacific) Limited, regulated by the Hong Kong Securities and Futures Commission (HKSF); Merrill Lynch (Singapore): Merrill Lynch (Singapore) Pte Ltd, regulated by the Monetary Authority of Singapore (MAS); Merrill Lynch (Canada): Merrill Lynch Canada Inc, regulated by the Investment Industry Regulatory Organization of Canada; Merrill Lynch (Mexico): Merrill Lynch Mexico, SA de CV, Casa de Bolsa, regulated by the Comisión Nacional Bancaria y de Valores; Merrill Lynch (Argentina): Merrill Lynch Argentina SA, regulated by Comisión Nacional de Valores; BofAS Japan: BofA Securities Japan Co., Ltd., regulated by the Financial Services Agency; Merrill Lynch (Seoul): Merrill Lynch International, LLC Seoul Branch, regulated by the Financial Supervisory Service; Merrill Lynch (Taiwan): Merrill Lynch Securities (Taiwan) Ltd., regulated by the Securities and Futures Bureau; BofAS India: BofA Securities India Limited, regulated by the Securities and Exchange Board of India (SEBI); Merrill Lynch (Indonesia): PT Merrill Lynch Sekuritas Indonesia, regulated by Otoritas Jasa Keuangan (OJK); Merrill Lynch (Israel): Merrill Lynch Israel Limited, regulated by Israel Securities Authority; Merrill Lynch (Russia): OOO Merrill Lynch Securities, Moscow, regulated by the Central Bank of the Russian Federation; Merrill Lynch (DIFC): Merrill Lynch International (DIFC Branch), regulated by the Dubai Financial Services Authority (DFSA); Merrill Lynch (Brazil): Merrill Lynch S.A. Corretora de Títulos e Valores Mobiliários, regulated by Comissão de Valores Mobiliários; Merrill Lynch KSA Company: Merrill Lynch Kingdom of Saudi Arabia Company, regulated by the Capital Market Authority.

This information has been approved for publication and is distributed in the United Kingdom (UK) to professional clients and eligible counterparties (as each is defined in the rules of the FCA and the PRA) by MLI (UK), which is authorized by the PRA and regulated by the FCA and the PRA - details about the extent of our regulation by the FCA and PRA are available from us on request; has been approved for publication and is distributed in the European Economic Area (EEA) by BofASE (France), which is authorized by the ACPR and regulated by the ACPR and the AMF; has been considered and distributed in Japan by BofAS Japan, a registered securities dealer under the Financial Instruments and Exchange Act in Japan, or its permitted affiliates; is issued and distributed in Hong Kong by Merrill Lynch (Hong Kong) which is regulated by HKSF; is issued and distributed in Taiwan by Merrill Lynch (Taiwan); is issued and distributed in India by BofAS India; and is issued and distributed in Singapore to institutional investors and/or accredited investors (each as defined under the Financial Advisers Regulations) by Merrill Lynch (Singapore) (Company Registration No 198602883D). Merrill Lynch (Singapore) is regulated by MAS. Merrill Lynch Equities (Australia) Limited (ABN 65 006 276 795), AFS License 235132 (MLEA) distributes this information in Australia only to 'Wholesale' clients as defined by s.761G of the Corporations Act 2001. With the exception of Bank of America N.A., Australia Branch, neither MLEA nor any of its affiliates involved in preparing this information is an Authorised Deposit-Taking Institution under the Banking Act 1959 nor regulated by the Australian Prudential Regulation Authority. No approval is required for publication or distribution of this information in Brazil and its local distribution is by Merrill Lynch (Brazil) in accordance with applicable regulations. Merrill Lynch (DIFC) is authorized and regulated by the DFSA. Information prepared and issued by Merrill Lynch (DIFC) is done so in accordance with the requirements of the DFSA conduct of business rules. BofA Europe (Frankfurt) distributes this information in Germany and is regulated by BaFin, the ECB and the CBI. BofA Securities entities, including BofA Europe and BofASE (France), may outsource/delegate the marketing and/or provision of certain research services or aspects of research services to other branches or members of the BofA Securities group. You may be contacted by a different BofA Securities entity acting for and on behalf of your service provider where permitted by applicable law. This does not change your service provider. Please refer to the [Electronic Communications Disclaimers](#) for further information.

This information has been prepared and issued by BofAS and/or one or more of its non-US affiliates. The author(s) of this information may not be licensed to carry on regulated activities in your jurisdiction and, if not licensed, do not hold themselves out as being able to do so. BofAS and/or MLPF&S is the distributor of this information in the US and accepts full responsibility for information distributed to BofAS and/or MLPF&S clients in the US by its non-US affiliates. Any US person receiving this information and wishing to effect any transaction in any security discussed herein should do so through BofAS and/or MLPF&S and not such foreign affiliates. Hong Kong recipients of this information should contact Merrill Lynch (Asia Pacific) Limited in respect of any matters relating to dealing in securities or provision of specific advice on securities or any other matters arising from, or in connection with, this information. Singapore recipients of this information should contact Merrill Lynch (Singapore) Pte Ltd in respect of any matters arising from, or in connection with, this information. For clients that are not accredited investors, expert investors or institutional investors Merrill Lynch (Singapore) Pte Ltd accepts full responsibility for the contents of this information distributed to such clients in Singapore.

General Investment Related Disclosures:

Taiwan Readers: Neither the information nor any opinion expressed herein constitutes an offer or a solicitation of an offer to transact in any securities or other financial instrument. No part of this report may be used or reproduced or quoted in any manner whatsoever in Taiwan by the press or any other person without the express written consent of BofA Securities.

This document provides general information only, and has been prepared for, and is intended for general distribution to, BofA Securities clients. Neither the information nor any opinion expressed constitutes an offer or an invitation to make an offer, to buy or sell any securities or other financial instrument or any derivative related to such securities or instruments (e.g., options,



futures, warrants, and contracts for differences). This document is not intended to provide personal investment advice and it does not take into account the specific investment objectives, financial situation and the particular needs of, and is not directed to, any specific person(s). This document and its content do not constitute, and should not be considered to constitute, investment advice for purposes of ERISA, the US tax code, the Investment Advisers Act or otherwise. Investors should seek financial advice regarding the appropriateness of investing in financial instruments and implementing investment strategies discussed or recommended in this document and should understand that statements regarding future prospects may not be realized. Any decision to purchase or subscribe for securities in any offering must be based solely on existing public information on such security or the information in the prospectus or other offering document issued in connection with such offering, and not on this document.

Securities and other financial instruments referred to herein, or recommended, offered or sold by BofA Securities, are not insured by the Federal Deposit Insurance Corporation and are not deposits or other obligations of any insured depository institution (including, Bank of America, N.A.). Investments in general and, derivatives, in particular, involve numerous risks, including, among others, market risk, counterparty default risk and liquidity risk. No security, financial instrument or derivative is suitable for all investors. Digital assets are extremely speculative, volatile and are largely unregulated. In some cases, securities and other financial instruments may be difficult to value or sell and reliable information about the value or risks related to the security or financial instrument may be difficult to obtain. Investors should note that income from such securities and other financial instruments, if any, may fluctuate and that price or value of such securities and instruments may rise or fall and, in some cases, investors may lose their entire principal investment. Past performance is not necessarily a guide to future performance. Levels and basis for taxation may change.

Futures and options are not appropriate for all investors. Such financial instruments may expire worthless. Before investing in futures or options, clients must receive the appropriate risk disclosure documents. Investment strategies explained in this report may not be appropriate at all times. Costs of such strategies do not include commission or margin expenses.

BofA Securities is aware that the implementation of the ideas expressed in this report may depend upon an investor's ability to "short" securities or other financial instruments and that such action may be limited by regulations prohibiting or restricting "shortselling" in many jurisdictions. Investors are urged to seek advice regarding the applicability of such regulations prior to executing any short idea contained in this report.

Foreign currency rates of exchange may adversely affect the value, price or income of any security or financial instrument mentioned in this report. Investors in such securities and instruments effectively assume currency risk.

BofAS or one of its affiliates is a regular issuer of traded financial instruments linked to securities that may have been recommended in this report. BofAS or one of its affiliates may, at any time, hold a trading position (long or short) in the securities and financial instruments discussed in this report.

BofA Securities, through business units other than BofA Global Research, may have issued and may in the future issue trading ideas or recommendations that are inconsistent with, and reach different conclusions from, the information presented herein. Such ideas or recommendations may reflect different time frames, assumptions, views and analytical methods of the persons who prepared them, and BofA Securities is under no obligation to ensure that such other trading ideas or recommendations are brought to the attention of any recipient of this information.

In the event that the recipient received this information pursuant to a contract between the recipient and BofAS for the provision of research services for a separate fee, and in connection therewith BofAS may be deemed to be acting as an investment adviser, such status relates, if at all, solely to the person with whom BofAS has contracted directly and does not extend beyond the delivery of this report (unless otherwise agreed specifically in writing by BofAS). If such recipient uses the services of BofAS in connection with the sale or purchase of a security referred to herein, BofAS may act as principal for its own account or as agent for another person. BofAS is and continues to act solely as a broker-dealer in connection with the execution of any transactions, including transactions in any securities referred to herein.

Copyright and General Information:

Copyright 2022 Bank of America Corporation. All rights reserved. iQDatabase® is a registered service mark of Bank of America Corporation. This information is prepared for the use of BofA Securities clients and may not be redistributed, retransmitted or disclosed, in whole or in part, or in any form or manner, without the express written consent of BofA Securities. BofA Global Research information is distributed simultaneously to internal and client websites and other portals by BofA Securities and is not publicly-available material. Any unauthorized use or disclosure is prohibited. Receipt and review of this information constitutes your agreement not to redistribute, retransmit, or disclose to others the contents, opinions, conclusion, or information contained herein (including any investment recommendations, estimates or price targets) without first obtaining express permission from an authorized officer of BofA Securities.

Materials prepared by BofA Global Research personnel are based on public information. Facts and views presented in this material have not been reviewed by, and may not reflect information known to, professionals in other business areas of BofA Securities, including investment banking personnel. BofA Securities has established information barriers between BofA Global Research and certain business groups. As a result, BofA Securities does not disclose certain client relationships with, or compensation received from, such issuers. To the extent this material discusses any legal proceeding or issues, it has not been prepared as nor is it intended to express any legal conclusion, opinion or advice. Investors should consult their own legal advisers as to issues of law relating to the subject matter of this material. BofA Global Research personnel's knowledge of legal proceedings in which any BofA Securities entity and/or its directors, officers and employees may be plaintiffs, defendants, co-defendants or co-plaintiffs with or involving issuers mentioned in this material is based on public information. Facts and views presented in this material that relate to any such proceedings have not been reviewed by, discussed with, and may not reflect information known to, professionals in other business areas of BofA Securities in connection with the legal proceedings or matters relevant to such proceedings.

This information has been prepared independently of any issuer of securities mentioned herein and not in connection with any proposed offering of securities or as agent of any issuer of any securities. None of BofAS or any of its affiliates or their research analysts has any authority whatsoever to make any representation or warranty on behalf of the issuer(s). BofA Global Research policy prohibits research personnel from disclosing a recommendation, investment rating, or investment thesis for review by an issuer prior to the publication of a research report containing such rating, recommendation or investment thesis.

Any information relating to the tax status of financial instruments discussed herein is not intended to provide tax advice or to be used by anyone to provide tax advice. Investors are urged to seek tax advice based on their particular circumstances from an independent tax professional.

The information herein (other than disclosure information relating to BofA Securities and its affiliates) was obtained from various sources and we do not guarantee its accuracy. This information may contain links to third-party websites. BofA Securities is not responsible for the content of any third-party website or any linked content contained in a third-party website. Content contained on such third-party websites is not part of this information and is not incorporated by reference. The inclusion of a link does not imply any endorsement by or any affiliation with BofA Securities. Access to any third-party website is at your own risk, and you should always review the terms and privacy policies at third-party websites before submitting any personal information to them. BofA Securities is not responsible for such terms and privacy policies and expressly disclaims any liability for them.

All opinions, projections and estimates constitute the judgment of the author as of the date of publication and are subject to change without notice. Prices also are subject to change without notice. BofA Securities is under no obligation to update this information and BofA Securities ability to publish information on the subject issuer(s) in the future is subject to applicable quiet periods. You should therefore assume that BofA Securities will not update any fact, circumstance or opinion contained herein.

Certain outstanding reports or investment opinions relating to securities, financial instruments and/or issuers may no longer be current. Always refer to the most recent research report relating to an issuer prior to making an investment decision.

In some cases, an issuer may be classified as Restricted or may be Under Review or Extended Review. In each case, investors should consider any investment opinion relating to such issuer (or its security and/or financial instruments) to be suspended or withdrawn and should not rely on the analyses and investment opinion(s) pertaining to such issuer (or its securities and/or financial instruments) nor should the analyses or opinion(s) be considered a solicitation of any kind. Sales persons and financial advisors affiliated with BofAS or any of its affiliates may not solicit purchases of securities or financial instruments that are Restricted or Under Review and may only solicit securities under Extended Review in accordance with firm policies.

Neither BofA Securities nor any officer or employee of BofA Securities accepts any liability whatsoever for any direct, indirect or consequential damages or losses arising from any use of this information.

