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Beyond Currency Hedging

This paper sets forth a comprehensive approach to managing currency exposure that seeks to offer a substantial return and diversification benefits for multi-asset portfolios relative to traditional naive currency hedging methodologies. Our approach centers on two key insights. First, the currency return objective should not be focused solely on carry; instead, it adopts a framework that also incorporates the economic fundamentals driving currency valuations. Second, it forgoes the rigid approach of using uniform currency hedge ratios; rather, it adopts a framework in which the constraints driving currency exposure decisions are more closely aligned with portfolio theory by seeking to exploit the diversification benefits in a multi-asset portfolio. The results of our analysis for AUD, USD, JPY and EUR based investors reveal the suboptimality of simple currency hedging strategies compared to a more holistic approach.

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1 INTRODUCTION

For most institutional investors with multi-asset portfolios, currency exposure is often determined via a hedging strategy. Currency hedging strategies often consist of simple uniform hedging rules and start by assessing the unhedged exposures stemming from foreign assets. As most investors allocate in the context of market-capitalization-weighted benchmarks, the unhedged foreign currency exposure is closely related to the relative regional weights within global public equity and fixed income markets. These implicit constraints mean that the starting point for the currency exposure decision is dominated by a select few developed market currencies, without much consideration for currencies that lie outside the G4 (USD, EUR, JPY and GBP). In addition to this market cap constraint, investors tend to fully hedge currency exposure in asset classes that are less volatile than currencies, like fixed income, regardless of the risk and return implications for the entire portfolio. This further restricts the range of the currency exposures.

A common approach to deciding on the level of currency exposure (where results are usually denominated in USD) is to use a static, uniform 50% currency hedge. Although this hedge ratio is perhaps suboptimal at any single point in time, it is generally considered a reasonable rule of thumb for the long run. However, in our recent publication on currency hedging (Guo and Ryan 2017), we conclude that it is more efficient to make hedging decisions at the portfolio[1] level on a currency-by-currency basis than to set uniform hedge ratios at the asset or portfolio level. Hedging decisions made at the asset level ignore the relationship between currency exposure in one asset and other parts

1 "Portfolio" refers to the collection of assets (for example, bonds and equities) held by the investor.

The authors thank Laura Ryan for her contribution to this research.

of the portfolio. Uniform hedge ratios at the asset or portfolio level ignore the potential differences in the portfolio risk and return implications of different currencies.

Though Guo and Ryan (2017) is primarily focused on the sub-optimality of uniform hedging rules versus a more flexible currency-by-currency framework, it does so with hypothetical currency expected return assumptions, without directly addressing how to estimate these returns. For any such model, currency carry[2] is undoubtedly an important factor to consider. However, returning to first principles, carry is just one of several pillars driving currency returns. Valuations also matter, and by incorporating a broader set of economic fundamentals as a complement to carry in a comprehensive framework – discussed in Section 3 – investors can gain a much better perspective on the overall efficacy of various currency hedging decisions.

In addition to improving currency hedging decisions by focusing on more fundamental economic models of currency expected returns, investors can seek to exploit the diversification properties of currencies in multi-asset portfolios. Traditional simple uniform currency hedging rules, discussed in Guo and Ryan (2017), reveal investors' preferences for taking currency risk in portfolios. In Section 4, we use these revealed preferences as a guide and establish a handful of simple portfolio-level constraints to develop a currency exposure strategy that ensures overall currency risk is at least as diversifying to the whole portfolio as the simple uniform hedging strategy, while limiting the stand-alone risk stemming from currencies alone.

In Section 5, we turn to analyzing the benefits of this holistic currency framework from the perspective of an Australian investor and a U.S. investor. These two investors are unique in that the currency hedging decision of an Australian investor has typically been positive carry, as Australian bond yields have generally been greater than their foreign market-cap-weighted developed market counterparts, and additive to overall portfolio risk because the AUD has been positively correlated with the equity market. Currency hedging for U.S. investors has subtracted from overall portfolio risk because the USD has traditionally performed well in times of equity market stress. The Appendix contains additional analyses for European and Japanese investors, and these findings are summarized in the conclusion.

2 THE PROBLEM

2.1 A simplified example

For illustrative purposes, we begin with a simplified two-asset stylized portfolio construction problem. Suppose we have two investors, one AUD-based and the other JPY-based. Both are invested in global equities proxied by the MSCI World Index. For illustration only, we will assume the investors focus on managing the exposure to the USD while keeping the other currency exposures fully hedged.

First, we examine the AUD-based investor. The AUD is considered both a carry and a commodity currency, and is well known to be more correlated to global equities than other developed market currencies. Given that AUD investors often have large allocations to equity-like assets,[3] the decision to add USD exposure to a portfolio may reduce overall portfolio risk. Suppose there are two alternative models for the estimated returns of the USD, one based on real carry and the other based on real carry and real appreciation to the long-term fair value of the USD real exchange rate (RER), which leads to -1% and -3% annualized USD estimated returns, respectively.

Based on the assumptions shown in Exhibit 1, we can plot the portfolio's risk and return profile under different hedging ratios for the USD and the two different currency-expected-return models. Exhibit 1 tells us that USD exposure may provide diversification benefits, given the correlation of -0.46 with the MSCI World Index hedged back to AUD. Starting from 0% USD exposure (100% hedging), adding USD exposure (a reduced USD hedge ratio) reduces the volatility of the portfolio until the USD exposure reaches 55% (for a 11% hedge ratio because 55% is about 89% of the 62% total USD exposure in the unhedged

2 Investments have two potential sources of return: price changes and carry. Carry is an investment's total return assuming market conditions stay unchanged and incorporates the cost of funding the investment (carry = benefits – costs). For currency markets, the cost of investing in a foreign currency is the short-term riskless rate of the base currency; the benefit is the short-term riskless rate of the foreign currency. All else equal, an investor should not pay too much to hold an asset and should expect to earn positive carry.

3 Whether directly through allocations to public equities or implicitly through other assets, like private equity and credit

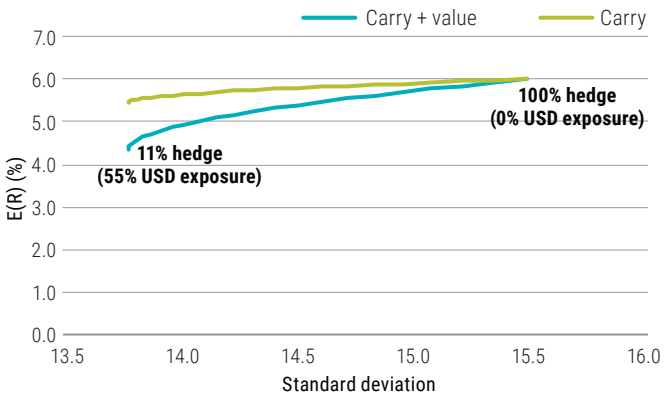
4 To construct efficient frontiers for the USD exposure or hedging, we need to drop the segment with lower return and higher risk because it is not efficient.

MSCI World Index). At this point, as there is so much USD exposure in the portfolio, that exposure would marginally increase the portfolio risk.[4] In this example, the estimated expected USD returns under the two models have the same sign, so the efficient frontiers generally look similar. However, in the next example we will show that this is not always the case.

Exhibit 1: Hypothetical example for AUD investors

	Carry	Carry + value	Estimated return	Vol	Corr	
MSCI World Index (AUD hedged)			6%	15%	1	-0.46
USD	-1%	-3%		13%	-0.46	1

Efficient frontiers under different estimated return models for AUD investors



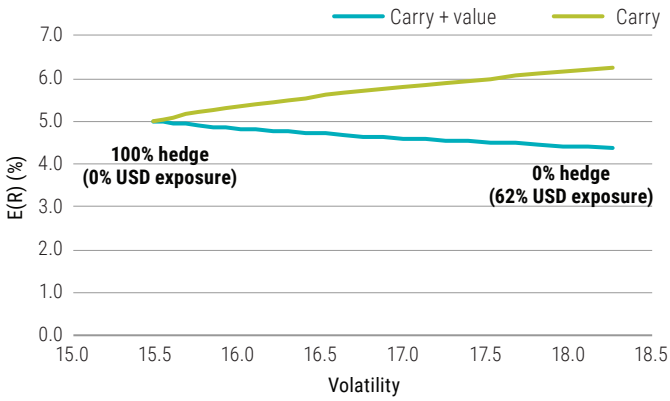
Source: PIMCO. **Hypothetical example for illustrative purposes only.**

We now examine an example for JPY investors. Historically, JPY has been the most risk-off, or the safest safe-haven, currency, even more so than USD. Therefore, we assume USD/JPY has a positive correlation of 0.22 with the MSCI World Index (JPY hedged). Exhibit 2 shows the assumptions for this example. Specifically, we assume that the expected estimates of USD returns under the two alternative models are of different signs.

Exhibit 2: Hypothetical example for JPY investors

	Carry	Carry + value	Estimated return	Vol	Corr	
MSCI World Index (JPY hedged)			5%	15%	1	0.22
USD	2%	-1%		11%	0.22	1

Resk-return trade-offs under different estimated return models for JPY investors



Source: PIMCO. **Hypothetical example for illustrative purposes only.** The expected USD/JPY returns of different signs under the two alternative models are purely hypothetical. They are not based on actual model outputs for any historical point in time.

In this example, the risk/return profiles under the carry-only and carry+value models are quite different and will likely lead to materially different currency decisions. Under the carry-only model, there is an efficient frontier for USD exposure/hedging: Starting from 0% USD exposure (100% USD hedging), the investor can increase return while increasing risk by adding USD exposure (reducing the USD hedge ratio). Under the carry+value model, only the 0% USD exposure (100% USD hedge ratio) point is efficient, because it dominates the other choices.

We can see that while both AUD- and JPY-based investors have the same assets in their portfolios, the risk implication of currency exposure can be very different. Incorporating valuation into the estimation for currency expected returns can potentially lead to completely different decisions. These examples highlight not only the importance of including valuations when determining expected returns, but the need to consider the inter-relationships among the base currency, foreign currency and any other assets in the portfolio.[5]

5 Other assets include other currencies. We examine the implications of uniform hedge ratios versus currency-specific hedge ratios in the Appendix.

2.2 Understanding currency expected returns: The basic framework

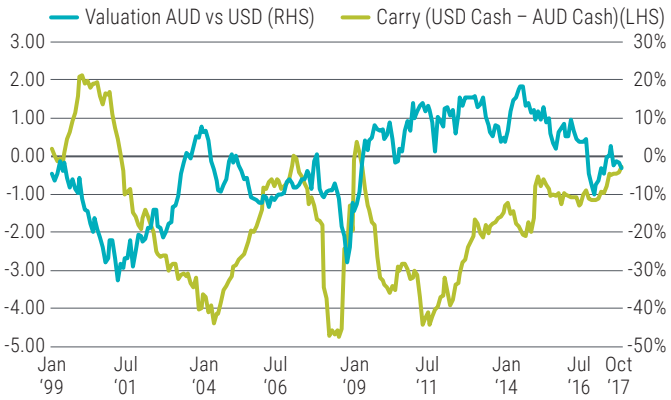
Interest rate differentials and valuations are important components of estimating the expected return on currencies. Following Rennison, Davis and Dorsten (2016), we posit the following framework for estimating expected returns in currencies:

$$E(r_t) = E^C(r_t) + E^{\Delta P}(r_t)$$

where $E^C(r_t)$ is the expected real carry and $E^{\Delta P}(r_t)$ is the expected real appreciation or depreciation due to the (partial) convergence of the price to the fair value.

It is important to distinguish between real and nominal carry when determining expected currency returns. If the real exchange rate is fair and stable, we would expect nominal exchange rates to adjust quickly to inflation differentials based on purchasing power parity (PPP), which offsets the nominal interest rate differential so that the investor, on average, earns real carry rather than nominal carry. But real carry is not the whole story. Valuations also matter. There will be instances when positive carry coincides with expectations of positive spot returns, and times when a high carry currency is overvalued and expected to depreciate – or, worse, when the currency is overvalued and has large negative carry. Exhibit 3 shows that in 2010–2013, from an Australian investor's perspective, carry was large (and negative) and AUD was overvalued relative to USD. However, at the end of 2017 carry was low and AUD was closer to fair value. For this reason, our analysis will also consider currency valuation as part of the currency exposure decision.

Exhibit 3: Carry versus valuation



Source: PIMCO as of November 2017. **Hypothetical example for illustrative purposes only.**

3 UNDERSTANDING CURRENCY EXPECTED RETURNS BEYOND PPP

3.1 Key factors for the real exchange rate valuation model

Although many economists believe some variant of PPP serves as an anchor for real exchange rates in the long run,[6] not all large fluctuations in real exchange rates indicate fundamental misalignment. Factors such as real interest rate differential and productivity differential may play key roles in determining the equilibrium fair value of real exchange rates.

Ex ante real interest rate differentials have been linked to real exchange rates (see, for example, Baxter 1994 and Clarida and Galí 1994). Higher real interest rate differentials are associated with a currency's stronger fair value over the medium-term horizon. The empirical relationship has become stronger over the past decade.

Productivity differential is another important factor for the long-run fair value of real exchange rates. Technical progress may cause fluctuations in the prices of tradables relative to those of nontradables (the "Harrod-Balassa-Samuelson effect"; see Harrod 1933, Balassa 1964 and Samuelson 1964) and therefore move the equilibrium real exchange rate. This factor is especially important in capturing the trends in high growth emerging market currencies.

The theoretical and empirical literature of international economics suggests a range of additional economic variables for real exchange rate valuation. For example, from an AUD perspective, one key factor is terms of trade. AUD is a commodity currency because of Australia's heavy dependence on the export of raw materials such as iron ore, bauxite, alumina and aluminum. The country also produces coal, copper, gold and zinc, and is a significant exporter of agricultural commodities.

Chen and Rogoff (2003) focused on three OECD economies with commodity currencies (Australia, Canada and New Zealand) and found that terms of trade had a strong and stable influence on their floating real exchange rates.

Menkhoff et al. (2017) considered four macroeconomic fundamentals that can influence future real rate differentials and/or long-run RER: productivity, the quality of a country's

6 The empirical literature on PPP suggests long half-lives of real exchange rate shocks in the presence of high short-run exchange rate volatility, which is difficult to explain for most models in international macroeconomics (the PPP puzzle). See Rogoff (1996) and Obstfeld and Rogoff (2000) for more details.

exports,[7] net foreign assets and the output gap. Corte et al. (2016) investigated the relation between currency excess returns and sovereign risk, as measured by the credit default swap (CDS) spread. A widened CDS is associated with a weaker currency in real terms in the medium run.

Li et al. (2015) showed that economic fundamentals can generate reliable out-of-sample forecasts for exchange rates, based on a "kitchen sink" regression with multiple predictors and a shrinkage method to reduce the effect of less informative predictors.

In this paper, we use output from PIMCO's proprietary currency valuation model. It is beyond the scope of this paper to go into further detail on the exact econometric procedures and present the battery of robustness tests that would be typical of a paper focused solely on currency valuation models. Two references in the literature that are similar in spirit to PIMCO's approach are Stupnytska et al. (2009) and Menkhoff et al. (2017). These ex ante expected return estimates will be the inputs for the currency optimization in the next section.

4 A FRAMEWORK FOR OPTIMAL CURRENCY EXPOSURE IN PORTFOLIO CONSTRUCTION

Using our model for ex ante expected return estimates, we can simulate the impact currency exposure has on the risk/return profile of multi-asset investors with varying base currencies. For the purposes of this study, we assume an exogenous asset allocation for four base currencies (AUD, USD, JPY and EUR). We construct a global 60/40 portfolio with 30% global equities, 30% domestic equities, 20% global bonds and 20% domestic bonds. Our portfolio construction problem also considers seven major currencies that in total represent more than 95% of the MSCI World Index and the Bloomberg Barclays Global Aggregate Index (as of 30 June 2018): USD, EUR, JPY, GBP, CAD, AUD and CHF.

There are a number of different methods for determining the level of currency exposure in a multi-asset portfolio. We consider the following four approaches in this paper:

1) **Uniform hedging.** Many institutional investors impose a uniform hedge ratio across currencies at the portfolio level. This ratio remains constant and does not account for any forward-looking valuations. Financial literature often reports results using a 50% uniform hedge ratio.

2) **Asset-specific hedging.** Under this approach, investors tend to fully hedge the currency exposure in asset classes that are less volatile than currencies, such as fixed income. The average Australian superannuation fund, for example, imposes a 34% hedge on international equity exposure and a 100% hedge on international bond exposure.[8]

3) **Optimal currency-specific hedging.** An optimal hedge ratio of between 0% and 100% is determined for each currency. The maximum exposure to any currency is the percentage of the total portfolio invested in assets domiciled in that currency.

4) **Optimal exposure strategy with constraints.** We allow each currency to vary between -20% and 20% of total portfolio-level exposure. We choose 20% because this is approximately the maximum currency exposure many investors are comfortable with, as indicated by the current hedging practices of institutional investors. We then impose further constraints to ensure the "risk" of the strategy is no more than that of a "benchmark" hedging strategy. The benchmark strategy is the hedging strategy most often implemented by institutional investors. We define risk using three different metrics: overall portfolio volatility, currency risk and equity beta risk.[9]

To show the risk/return trade-offs under different strategies, mean-variance efficient frontiers can be constructed by maximizing a portfolio's expected return subject to a maximum volatility constraint and other constraints above except for the volatility constraint. The Appendix provides further elaboration of the portfolio frontier calculation algorithm and constraints. Here we provide an illustrative example of the different efficient frontiers resulting from the four different approaches for AUD-based investors. We highlight the potential return pickup from looking at the currency problem through an exposure lens rather than a hedging lens. In the next section, we look at whether implementing a time-varying dynamic currency exposure strategy can consistently increase returns without increasing risk, compared with the benchmark currency hedging strategy for Australian investors.

7 An example of high quality exports: Switzerland's manufactured goods, such as watches.

8 Chant, Warren, Mano Mohankumar, and Geoffrey J. Warren. "MySuper: A New Landscape for Default Superannuation Funds." CIFR Paper No. 020/2014, 2014. Available at SSRN: https://ssrn.com/abstract=2442663 or http://dx.doi.org/10.2139/ssrn.2442663

9 In an environment where valuations on equities may be overstretched, adding no extra equity beta is an important consideration. Further, allowing each currency exposure to be long or short and driven by its unique risk/return characteristics, the exposure strategy may provide diversification benefits over and above the benchmark hedging strategy.

5 RESULTS

5.1 AUD

5.1.1 AUD dynamic optimal exposure strategy versus a benchmark hedging strategy

We compare the cumulative performance differential of a dynamic optimal exposure strategy with the static uniform hedging policy usually implemented by Australian institutional investors. The optimal currency-specific exposure in each month is determined by maximizing the expected ex ante return estimates to the portfolio for any given level of risk and the expected currency return estimates are a function of carry and currency valuations.

As mentioned previously, Australian investors usually implement static and uniform hedge ratios at the asset level: 100% for international bonds and 34% for international equities. We model the benchmark portfolio for Australian investors as shown in Exhibit 4. The total benchmark currency exposure listed in the bottom row of the table incorporates the country-specific hedging strategy. The benchmark portfolio will be the basis on which we compare the performance of the dynamic optimal exposure strategy with constraints.

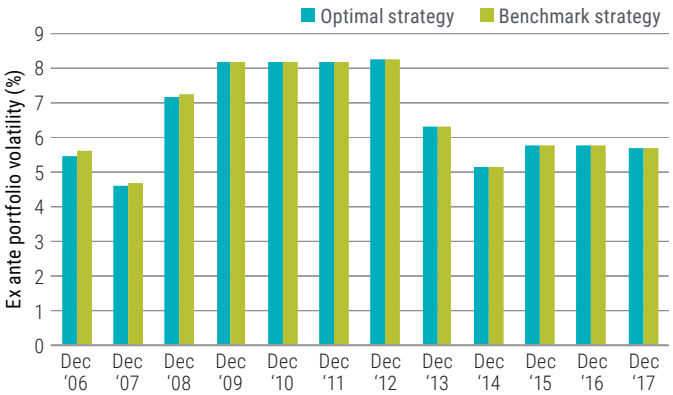
Exhibit 4: AUD benchmark portfolio and exposures by currency

Asset	Proxy	60/40 portfolio	USD	EUR	JPY	GBP	CAD	CHF
Global equities	MSCI World Ex Australia	30%	62%	12%	9%	7%	4%	3%
Global bonds	Bloomberg Barclays Global Agg	20%	45%	26%	16%	5%	3%	1%
Domestic equities	S&P/ASX300	30%						
Domestic bonds	Bloomberg Ausbond Index	20%						
Total benchmark exposure			12%	2%	2%	1%	1%	1%

Currency exposures in the benchmark portfolio are calculated as currency exposures in global equities × portfolio weight in global equities × (1-hedge ratio for global equities) + currency exposures in global bonds × portfolio weight in global bonds × (1-hedge ratio for global bonds).
Source: Bloomberg

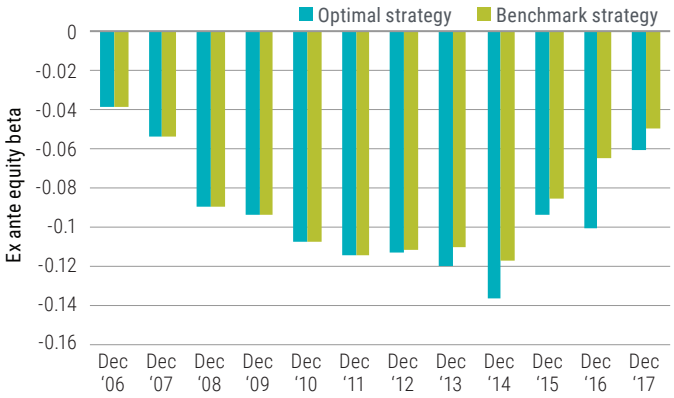
Exhibit 5 shows the ex ante portfolio volatilities of the optimal exposure strategy and the static strategy as a benchmark at the end of each year (for January in the next year) from December 2006 through 2017. The constraint that the optimal strategy should have lower or equal portfolio volatility compared with the benchmark strategy is binding for most of the dates examined, except for the first few, when the ex ante portfolio volatility under the optimal strategy is slightly lower. Similarly, Exhibit 6 shows the equity beta constraint is binding for the first half of the sample period and nonbinding for the second half (i.e., the optimal exposure strategy is adding more diversification than the benchmark strategy). Because equity risk typically dominates in a 60/40 portfolio, the constraints on portfolio volatility and on the equity beta of currency exposures may be substitutes, to some extent. The third ex ante risk constraint on the tracking error of the currency exposures is always binding, so we will not show it here.

Exhibit 5: AUD ex ante portfolio volatilities



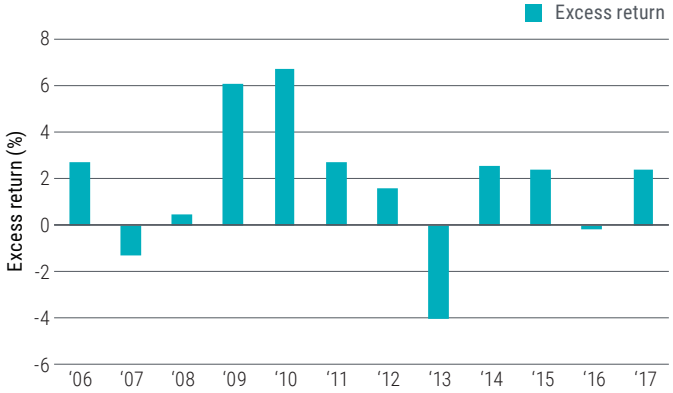
Source: PIMCO. as of June 2018. **Hypothetical example for illustrative purposes only.** Exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Exhibit 6: AUD ex ante equity beta of net currency exposures



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Exhibit 7: AUD realized annual excess returns (optimal strategy over benchmark strategy)



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product. Model performance figures do not reflect the deduction of investment advisory fees and would be lower if applied.

Exhibit 7 shows the realized portfolio returns for each year under the two different strategies. The annualized cumulative portfolio return between 2006 and 2018 under the optimal strategy is 164 basis points (bps) higher than that under the benchmark strategy. This is a very significant return pickup, given that the optimal currency exposure strategy does not add extra risk to the portfolio, compared with the benchmark strategy ex ante.

5.2 USD

5.2.1 USD dynamic optimal exposure strategy versus a benchmark hedging strategy

The benchmark hedging strategy is 100% hedged bonds and 100% unhedged equities. Exhibit 8 shows the currency exposure in the underlying assets (unhedged), as well as the benchmark currency exposure at the portfolio level, assuming the benchmark hedging strategy.

Exhibit 8: USD benchmark portfolio

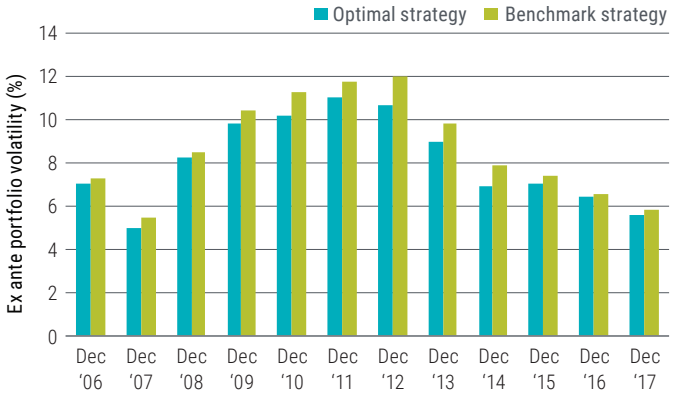
Asset	Proxy	60/40 portfolio	AUD	EUR	JPY	GBP	CAD	CHF
Global equities	MSCI World ex US	30%	5%	23%	17%	12%	6%	5%
Global bonds	Bloomberg Barclays Global Agg	20%	2%	46%	30%	9%	5%	1%
Domestic equities	S&P 500	30%						
Domestic bonds	FTSE BIG US	20%						
Total benchmark exposure			1%	7%	5%	4%	2%	2%

Currency exposures in the benchmark portfolio are calculated as currency exposures in global equities × portfolio weight in global equities × (1-hedge ratio for global equities) + currency exposures in global bonds × portfolio weight in global bonds × (1-hedge ratio for global bonds).

Source: PIMCO

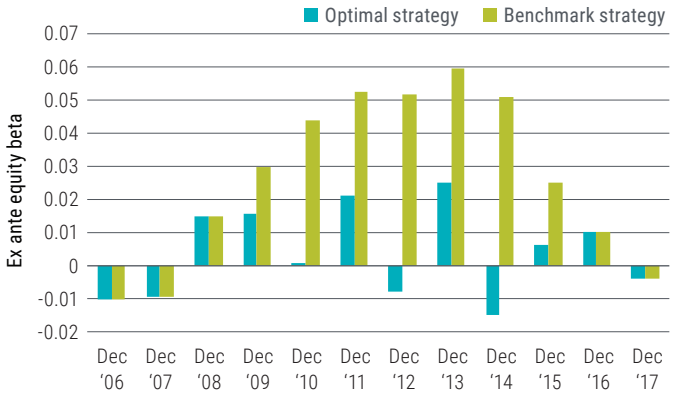
Exhibit 9 shows the ex ante portfolio volatilities of the optimal strategy and the static strategy as a benchmark at the end of each year (for January in the next year) from 2006 through 2017. The constraint that the optimal strategy should have lower or equal portfolio volatility compared with the benchmark strategy is not binding for the entire backtesting period. Exhibit 10 shows the equity beta constraint is also very slack for most of the period. Again, the third ex ante risk constraint on the tracking error of the currency exposures is always binding, so we do not show it here.

Exhibit 9: USD ex ante portfolio volatilities



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

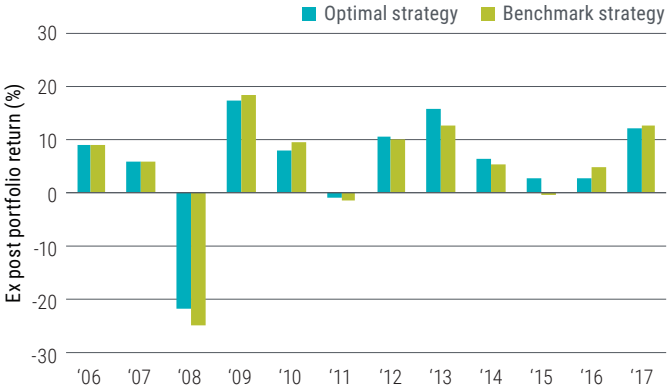
Exhibit 10: USD ex ante equity beta of net currency exposures



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

Exhibit 11 shows the realized portfolio returns for each year under the two different strategies. The annualized cumulative portfolio return between 2006 and 2018 under the optimal strategy is 55 bps higher than that under the benchmark strategy. This is achieved under the constraint that the optimal currency exposure strategy does not add extra risk to the portfolio ex ante, compared with the benchmark strategy.

Exhibit 11: USD realized annual portfolio returns



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

We extend the above analyses for AUD and USD to JPY and EUR, and show the main results, in the Appendix. The out-of-sample backtests for the optimal currency exposure strategy result in an annualized cumulative hypothetical performance improvement of 47 bps for Japanese-based investors and an improvement of 115 bps for European-based investors over the period from 2006 to 2018.

5.3 Summary

In summary, we seek to highlight the importance of including valuations in a model of ex ante estimates of expected currency returns and of adopting a more holistic approach to the currency exposure decision. Exhibit 12 presents more detailed ex post performance statistics for each of three strategies (static hedging, an optimal exposure strategy with carry-only signals, and an optimal exposure strategy with carry and valuation signals) relative to the 100% hedged 60/40 portfolios in the backtests. We present the results for AUD, USD, JPY and EUR. The results indicate that, taking into account both carry and valuations, the optimal exposure strategy consistently outperformed the static hedging strategy and the optimal exposure strategy based only on carry in terms of both absolute and risk-adjusted performance for this sample period.

Exhibit 12: Alphas, tracking errors (TE) and information ratios (IR) of three strategies in backtests

Alpha vs. 100% hedged 60/40 portfolio		AUD	USD	JPY	EUR
Strategy	Static hedging	-0.65%	-0.05%	0.14%	0.09%
	Optimal exposure based on carry only	0.71%	-0.22%	-0.08%	0.97%
	Optimal exposure based on carry and valuation	0.99%	0.50%	0.61%	1.24%
TE vs. 100% hedged 60/40 portfolio		**AUD**	**USD**	**JPY**	**EUR**
Strategy	Static hedging	2.25%	1.46%	2.80%	2.28%
	Optimal exposure based on carry only	2.19%	1.53%	3.21%	2.56%
	Optimal exposure based on carry and valuation	2.21%	1.61%	2.78%	2.63%
IR vs. 100% hedged 60/40 portfolio		**AUD**	**USD**	**JPY**	**EUR**
Strategy	Static hedging	-0.29	-0.03	0.05	0.04
	Optimal exposure based on carry only	0.32	-0.14	-0.03	0.38
	Optimal exposure based on carry and valuation	0.45	0.31	0.22	0.47

Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product. Model performance figures do not reflect the deduction of investment advisory fees and would be lower if applied.

6 CONCLUSION

In this research, we sought to rethink common industry practices around currency hedging and currency exposure for multi-asset portfolios, with the view of improving portfolio construction and efficiency. The current common industry practice for currency hedging results in currency exposures that are a by-product of static, "rule of thumb" hedging rules. These rules constrain potential currency exposure as a result of arbitrary tilts like the regional market capitalization of underlying asset classes. This fails to exploit the potential return and risk diversification benefits of currencies. We considered this an opportunity to improve portfolio efficiency by seeking to treat currency as its own asset class in the broader portfolio construction problem.

Using our proprietary currency valuation model to estimate ex ante currency return expectations, we were able to increase return over our sample period while controlling for overall portfolio risk, equity beta and currency exposure tolerance, compared with traditional hedging practices. The out-of-sample backtests for the optimal currency exposure strategy resulted in an annualized cumulative hypothetical performance improvement of 164 bps for Australian-based investors, 55 bps for U.S.-based investors, 47 bps for Japanese-based investors and 115 bps for European-based investors for the period from 2006 to 2018. These performance gains could be meaningful in their own right but have the potential to be particularly significant in today's low yield environment.

We therefore consider our findings worthy of further consideration and development. Although optimization results tend to be more sensitive to estimated return expectations, one possible extension of this research would be to adopt a more dynamic volatility model, as the current paper does not consider forward-looking covariance assumptions.

7 APPENDIX

7.1 Efficient frontiers

We categorize the four approaches for determining currency exposure into two categories: currency hedging strategies and optimal currency exposure with constraints.

I. Currency hedging strategies (uniform, asset-specific and currency-specific)

We construct mean-variance efficient frontiers by solving the following optimization problem at different levels of target portfolio volatility $\bar{\sigma}$:

$$\max_{h=\{h_i\}_{i=1}^{N}} \quad E[R_U] + E[R_H(h)]$$

subject to

$$\sigma_P(h) \leq \bar{\sigma}$$

$$0 \leq h_i \leq 1, i = 1, 2, \ldots, N$$

where R_U is the return on the unhedged portfolio and $R_U(h)$ is the return on the currency hedging overlay, which is a function of the hedging ratios. Moreover, h_i is the proportion of currency i exposure the investor actually hedges. If $h_i = 1$ for all currencies, then all the currency exposures are hedged. For the hedging strategies considered in this paper, we impose the constraint $0 \leq h_i \leq 1$ – i.e., no overhedging or doubling up on currency risk is permitted.

We consider three types of hedging strategies:

1 Uniform hedging: $h_i = h_A$ "for all " i where the universal hedging proportion h_A is chosen optimally.

2 Asset-specific hedging: $h_i = h_B w_i(B) + h_E w_i(E)$ where a fraction h_B of all overseas bond holdings is hedged and a fraction h_E of all overseas equity holdings is hedged. The hedging proportions h_B and h_E are optimally chosen.

3 Currency-specific hedging: h_i's are unrestricted, other than the constraint that $0 \leq h_i \leq 1$.

II. Optimal currency exposure strategy with constraints

Instead of solving for the optimal hedge ratio(s) to apply to the unhedged portfolio, this strategy focuses on the optimal net currency exposures $\{(1 - h_i)w_i\}$ for the portfolio. This effectively allows the hedge ratio to go beyond the $[0, 1]$ range.

$$\max_{h=\{h_i\}_{i=1}^{N}} \quad E[R_U] + E[R_H(h)]$$

subject to

$$\sigma_P(h) \leq \bar{\sigma}$$

$$-0.2 \leq (1 - h_i)w_i \leq 0.2, i = 1, 2, \ldots, N$$

$$\sigma_{FX}(h) \leq \bar{\sigma}_{FX}$$

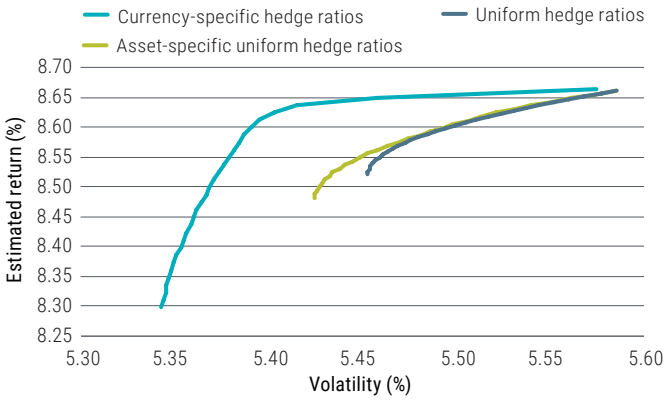
$$\beta_{FX}(h) \leq \bar{\beta}_{FX}$$

where $\sigma_{FX}(h)$ and $\beta_{FX}(h)$ are the tracking error and the global equity beta of the net currency exposures under strategy h. For the efficient frontier of this strategy, we set $\bar{\sigma}_{FX}$ and $\bar{\beta}_{FX}$ to be equal to those of the benchmark strategy for the base currency case. In the backtest, we further set $\bar{\sigma}$ to be that of the benchmark strategy, to ensure the optimal currency exposure strategy does not take any extra risk – measured by portfolio volatility, tracking error from currency exposures or equity beta – than the benchmark strategy ex ante.

AUD efficient frontiers for illustration

First, we model the efficient frontiers for the three hedging methods described previously. In Exhibit 13, the green line represents the efficient frontier given a uniform hedge ratio across all currencies at the portfolio level; it is the most restrictive option. The yellow line represents the frontier under asset-specific uniform hedging constraints. The blue line represents the frontier under currency-specific constraints. At any given level of risk, the optimized portfolio return under currency-specific hedging constraints is higher than that under uniform hedging constraints (at either the portfolio level or the asset level). This is expected because the opportunity set for the former contains that for the latter.

Exhibit 13: AUD efficient frontiers for uniform and currency-specific hedge ratios



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product. Model performance figures do not reflect the deduction of investment advisory fees and would be lower if applied.

However, we think looking at currency through a hedging lens rather than an exposure lens introduces significant opportunity costs. Therefore, we introduce the fourth frontier, which will represent the optimal currency exposure strategy with the constraints outlined previously. Given that the currency-specific approach to hedging will always dominate the uniform hedging strategies, we will focus on comparing the frontiers of the currency-specific hedging strategy and the optimal exposure strategy with constraints only.

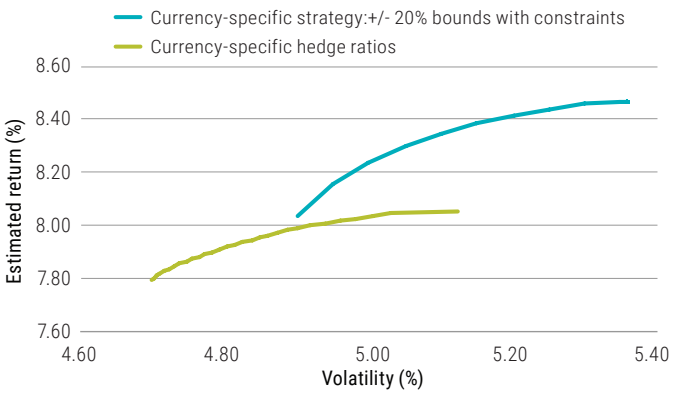
Exhibit 14 shows estimates of expected currency returns for June 2015. Despite the carry contribution being negative across all currencies, expected returns were positive due to the dominant positive valuation component. In general, the valuation contribution tends to dominate the carry contribution, further highlighting the need to incorporate value when determining expected returns.

Exhibit 14: Estimated returns

Currency	Carry contribution	Valuation contribution	Estimated return
USD	-0.9%	2.0%	1.2%
EUR	-1.1%	3.0%	1.9%
JPY	-1.3%	6.0%	4.8%
GBP	-0.5%	1.5%	1.0%
CAD	-0.8%	0.9%	0.1%
CHF	-0.7%	0.9%	0.2%

Source: PIMCO as of June 2015. **Hypothetical example for illustrative purposes only.**

Exhibit 15: AUD efficient frontiers



Source: PIMCO. **Hypothetical example for illustrative purposes only.** Exhibits provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product. Model performance figures do not reflect the deduction of investment advisory fees and would be lower if applied.

Exhibit 15 plots the two frontiers as of June 2015. The yellow line represents the currency-specific hedging strategy, and the blue line represents the optimal exposure strategy with constraints.

7.2 JPY results

JPY is considered a risk-off currency, so, in general, foreign currency exposure will add risk for a JPY-based investor. The benchmark portfolio is shown in Exhibit 16. JPY investors are assumed to apply a 100% hedge to their international bond exposure but leave equities unhedged.

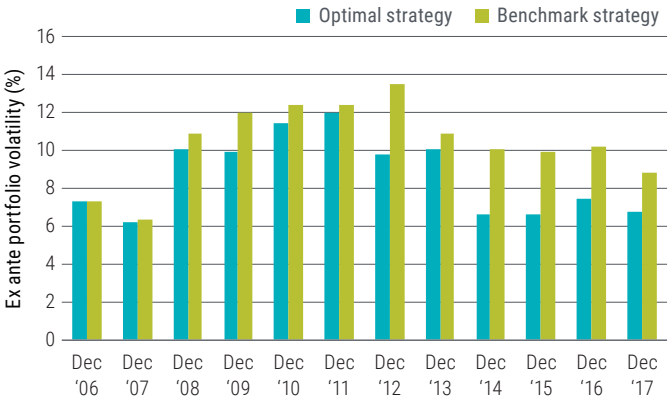
Exhibit 16: JPY benchmark portfolio

Asset	Proxy	60/40 portfolio	USD	EUR	AUD	GBP	CAD	CHF
Global equities	MSCI World	30%	65%	14%	3%	7%	4%	3%
Global bonds	Bloomberg Barclays Global Agg	20%	52%	31%	2%	6%	3%	1%
Domestic equities	MSCI Japan Index	30%						
Domestic bonds	FTSE Japan Gov Bond Index	20%						
Total benchmark exposure			20%	4%	1%	2%	1%	1%

Currency exposures in the benchmark portfolio are calculated as currency exposures in global equities × portfolio weight in global equities × (1-hedge ratio for global equities) + currency exposures in global bonds × portfolio weight in global bonds × (1-hedge ratio for global bonds).

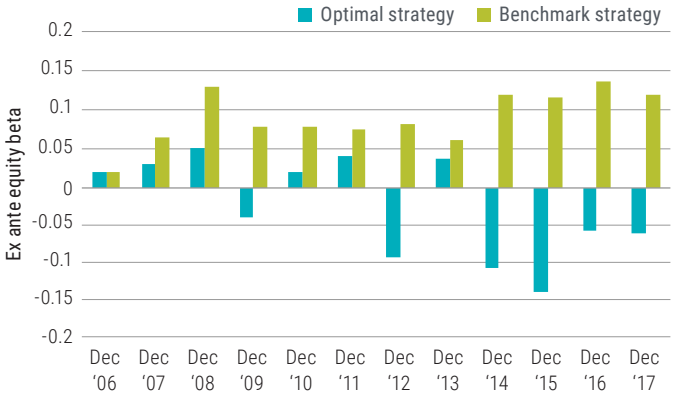
Source: Bloomberg

Exhibit 17: JPY ex ante portfolio volatilities



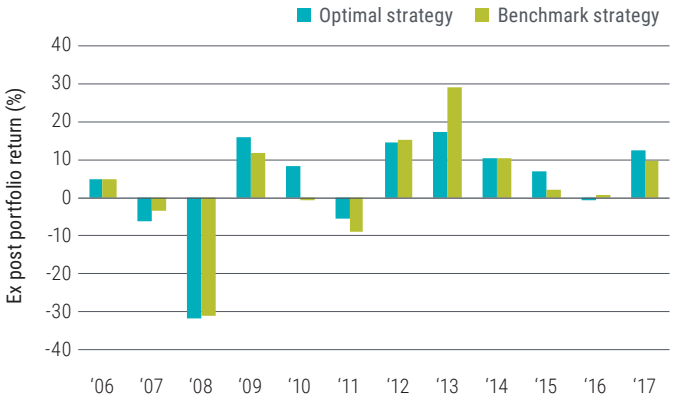
Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

Exhibit 18: JPY ex ante equity beta of net currency exposures



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

Exhibit 19: JPY realized annual portfolio returns



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product. Model performance figures do not reflect the deduction of investment advisory fees and would be lower if applied.

7.3 EUR results

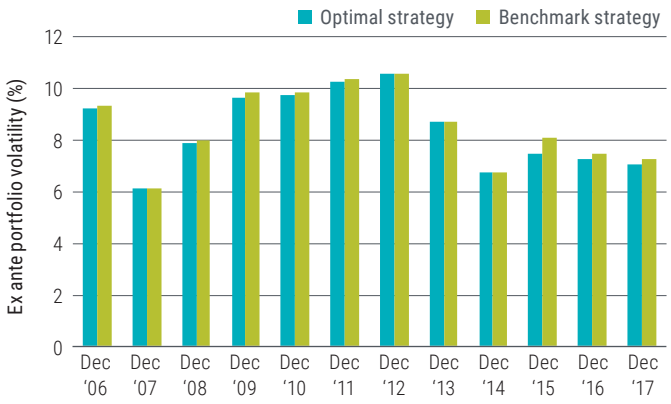
We next analyze the euro, which is considered to lie between JPY and AUD in terms of its "risk-on-off ness." European institutional investors are assumed to leave equities unhedged but apply a full hedge to the international bond currency exposure.

Exhibit 20: EUR benchmark portfolio

Asset	Proxy	60/40 portfolio	USD	JPY	AUD	GBP	CAD	CHF
Global equities	MSCI World	30%	61%	9%	2%	6%	3%	3%
Global bonds	Bloomberg Barclays Global Agg	20%	45%	17%	1%	5%	3%	1%
Domestic equities	MSCI Euro Index	30%						
Domestic bonds	FTSE Euro Broad IG Index	20%						
Total benchmark exposure			18%	3%	1%	2%	1%	1%

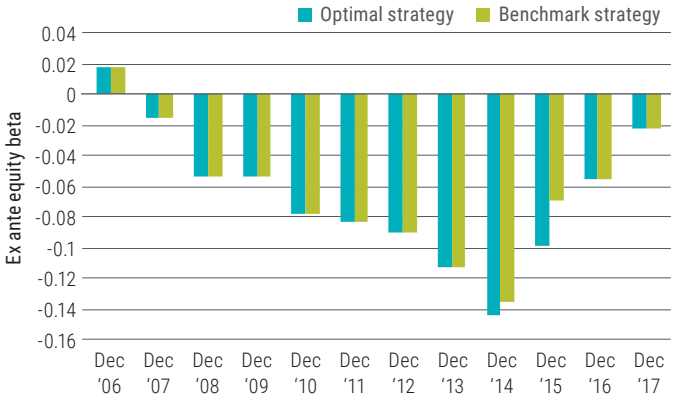
Currency exposures in the benchmark portfolio are calculated as currency exposures in global equities × portfolio weight in global equities × (1-hedge ratio for global equities) + currency exposures in global bonds × portfolio weight in global bonds × (1-hedge ratio for global bonds).
Source: Bloomberg

Exhibit 21: EUR ex ante portfolio volatilities



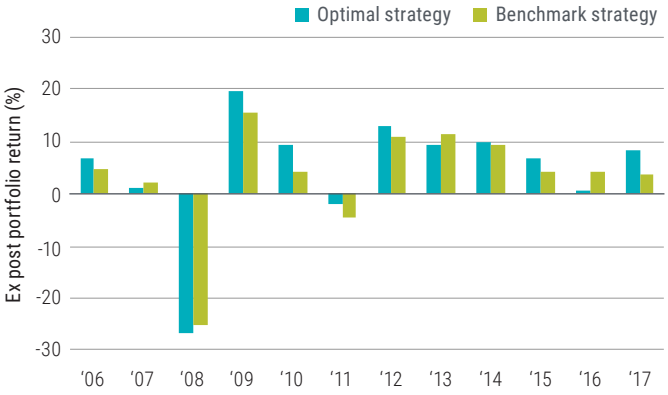
Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

Exhibit 22: EUR ex ante equity beta of net currency exposures



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product.

Exhibit 23: EUR realized annual portfolio returns



Source: PIMCO as of June 2018. **Hypothetical example for illustrative purposes only.** Figure provided for illustrative purposes and are not indicative of the past or future performance of any PIMCO product. Model performance figures do not reflect the deduction of investment advisory fees and would be lower if applied.

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