Learning From a Decade of Managed Volatility

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Executive Summary

- Dynamic risk mitigation strategies seek to provide a capital-efficient way to generate both higher risk-adjusted returns and reduced drawdowns without the cost normally associated with left tail protection.
- Nearly a decade after it came to prominence, managed volatility continues to be a viable solution for many and performs comparably with other algorithms, such as option replication, trend-following and a blended approach.
- In our view, investors should not evaluate these strategies solely on the post-2010 period, which was marked by a strong equity bull market without significant downturns until recently.
- There is no one-size-fits-all solution, and results vary across different countries. We analyze the trade-offs, leaving it to investors to pick the strategy that best suits their needs.

Since 2010, managed volatility strategies, which systematically vary portfolio equity exposure to target a more stable level of portfolio volatility, have created a multibillion-dollar industry.[1] In this paper, we highlight the lessons we have learned from a decade of developing and managing these strategies, and consider possible enhancements to the approach.

Managed volatility came to prominence following the financial crisis to help reduce portfolio drawdowns during equity bear markets. Its efficacy was due to the short-run persistence of volatility and the negative correlation between volatility and prices. As volatility spiked and markets sold off, managed volatility strategies sought to de-risk and reduce further losses without giving up much return. As a secondary benefit, the strategy was also used to assist in meeting the hedging needs of insurance companies that sold variable annuities, by helping to reduce the range of realized volatility outcomes and thus implied or actual hedging costs. Though it is not the only purpose of the strategy, the ability to systematically vary exposures to risk has become a key area of interest for investors.

As the adoption of managed volatility strategies has broadened over the past decade, equity markets have undergone some gyrations but until the most recent COVID-19 crisis did not experienced a deep, recessionary bear market – at least, not in the U.S. Although the strategies typically de-risk by design during

1 Morningstar as of April 2020

falling markets, subsequent rapid rebounds have generally erased any performance benefit. As such, market sentiment about the performance of managed volatility has generally become more negative, leading some to question whether the approach still makes sense.

Our own experience with managed volatility portfolios has been mostly favorable. This may reflect design choices, including the parameters used, implementation techniques and appropriate benchmarking. Nonetheless, after nearly 10 years it is prudent to reevaluate the approach and seek any potential improvements.

In the spirit of learning from the past, we analyze managed volatility using a long historical sample of the S&P 500 (U.S.), FTSE-All Share (U.K.), TOPIX (Japan) and DAX (Germany) indexes. Over the long horizon, we find managed volatility had higher Sharpe and Calmar ratios, and kept volatility in a tighter range than a static portfolio. Post-2010, we find the strategy continued to outperform on a risk-adjusted basis in the U.S., but the strategy underperformed relative to the indexes in other countries .

Next, we focus on the risk mitigation properties of managed volatility. More specifically, we compare it with three additional strategies that seek to reduce downside losses without consideration for a stable volatility profile. We label these strategies option replication, trend-following and a blend strategy. Option replication dynamically adjusts exposure to a risk asset as a function of the drawdown of the strategy, reducing exposure as the portfolio begins taking losses. Trend-following relies on a simple time-series momentum signal to follow the market and de-risk as asset prices fall. The blend strategy aims to diversify one's diversifiers; it uses an equal-weighted blend of the signals from managed volatility, option replication and trend-following.

In the full historical sample, all the strategies broadly generated higher Sharpe and Calmar ratios. However, Post-2010, the strategies lagged the static index with the only exception being managed volatility in the U.S. We also found the performance of the dynamic strategies was better in the U.S. than abroad.

The strategies outperformed the static index during downturns and kept up when markets rallied. During recessions, all the dynamic strategies offered improved performance against large drawdowns (greater than 25% in the index). Although the outperformance was less reliable during smaller drawdowns, we find managed volatility still outperformed the index, on average, during mild recessions in the U.K., Japan and Germany post-2010. The lack of large drawdowns post-2010 until recently contributed to the underperformance of the strategies, but this cannot fully explain why the strategies worked better in the U.S. than internationally.

Turning to recent events, we find that the drawdown due to the coronavirus had large effects on the performance of the dynamic risk mitigation strategies. While results vary slightly across strategies and countries, the inclusion of this one significant bear event meaningfully improved information ratios: The most significant improvement was seen for managed volatility in the U.S. In addition, the dynamic approaches broadly outperformed put options while offering similar drawdown characteristics. Furthermore, these strategies can be implemented in capital-efficient ways for those seeking the potential for additional gains; our results are a lower bound on potential performance.

Looking to the future, we find risk mitigation strategies to have potentially large benefits for investors. No single approach dominates; each strategy trades off return, stability of volatility, degree of downside risk mitigation and trading volume.

Our paper relates closely to the existing literature on volatility management. Our findings are consistent with Moreira and Muir (2017), which argues managed volatility in equities generates returns in excess of the index that cannot be explained by existing risk factors. However, we extend the backtest to a longer historical sample and include multiple strategies. Our paper also relates to Harvey et al. (2018), which argues the managed volatility strategy works across asset classes. In our paper, we focus on the degree of downside risk mitigation in equities, as stocks are the primary source of risk in investor portfolios. Finally, we note our calibration method is not subject to the criticism in Liu et al. (2019). While we acknowledge that the strategies' performance is sensitive to the choice of parameters, our method is designed for direct comparability with a static or constant allocation to equities, not for maximizing the absolute returns of each strategy.

MANAGED VOLATILITY IN THE U.S.

We begin our analysis by focusing on a canonical managed volatility portfolio using the S&P 500 index and cash. The U.S. serves as a good starting point because we have daily equity return data going back to 1928. We define the strategy as setting a weight in the equity index equal to the quotient between a constant volatility target and the portfolio volatility.

We measure the portfolio volatility using the annualized one-month rolling realized volatility of index returns. Though one can use implied measures for volatility, such as the CBOE Volatility Index (VIX), option-based measures have a short history, going back only to 1990. We constrain the equities' weight to between 20% and 120%. We find these leverage constraints reasonable for most investors; some managed volatility indexes allow much higher allocations, up to 200% in some cases, leading to excessive basis risk versus a static exposure. To ensure the portfolio is realistic, we also constrain trading; we trade only if the current estimated exposure volatility exceeds a 2% band around the target or if the leverage constraints are breached. We also include a 1 basis point (bp) trading cost as a fraction of the net asset value traded. We calibrate the volatility target so that the time-series average weight of the portfolio in the index is 1 and thus directly comparable to a static allocation in the index (see appendix for more details).

Exhibit 1: The hypothetical managed volatility portfolio outperformed the S&P 500 over the full sample and post-2010

Period	Strategy	Mean return	SD return	Sharpe	Information ratio	Calmar
Full sample	Index	8.99%	18.84%	0.26	0.00	0.10
(Post-1929)	MV	9.37%	14.92%	0.35	0.04	0.16
Post-2010	Index	12.02%	13.77%	0.80	0.00	0.61
	MV	11.69%	12.20%	0.88	-0.06	0.73

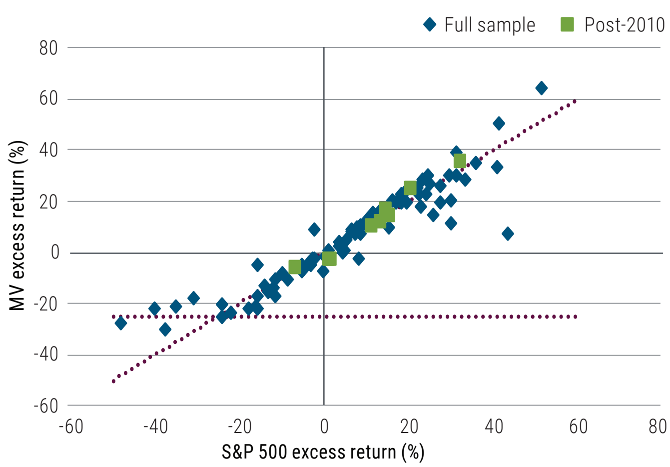
Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. S&P 500 and managed volatility are abbreviated as Index and MV, respectively. Values are computed using monthly returns. Geometric means are used, and all values are annualized. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

In Exhibit 1, we compute return statistics for the above detailed hypothetical managed volatility portfolio for both the full available history of equity data and the post-2010 period.

Over a long history, the managed volatility portfolio generated a higher return and a higher Sharpe ratio. The portfolio better protected against large left tail events, as seen in the higher Calmar ratio. We also demonstrate this mechanism using the scatter plot in Exhibit 2. For each calendar year, we plot the excess return of the managed volatility portfolio against the excess return of the index. The graph is reminiscent of a protective put position, in which the portfolio pares losses. We highlight in green the annual data since 2010.

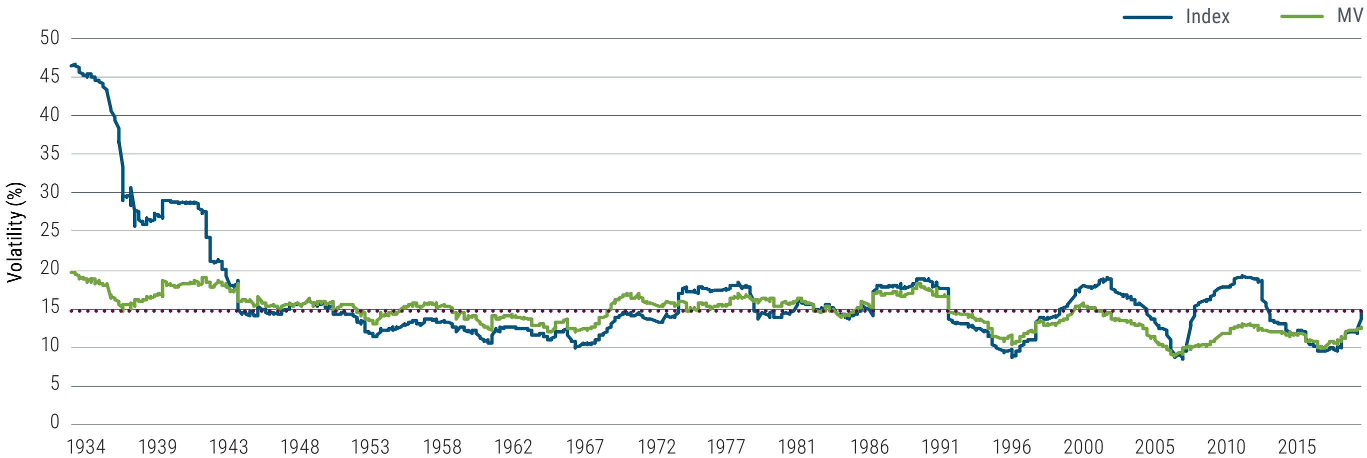
Next, we plot the five-year rolling volatility of the equity index and the managed volatility portfolio, as shown in Exhibit 3. We find that, as designed, the managed volatility portfolio kept the realized volatility of returns within a much tighter band than a static allocation did. We find the volatility of rolling volatility for the managed volatility portfolio was 2.2% and stayed much closer to the calibrated volatility target of 15%, shown as the dotted red line.

Exhibit 2: The hypothetical managed volatility portfolio pared left tail events in the S&P 500 index



Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Managed volatility is abbreviated MV. Each point represents one year. The y=x line and a horizontal line at -25% are shown for reference. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Exhibit 3: The hypothetical managed volatility portfolio had a more stable volatility profile than the S&P 500

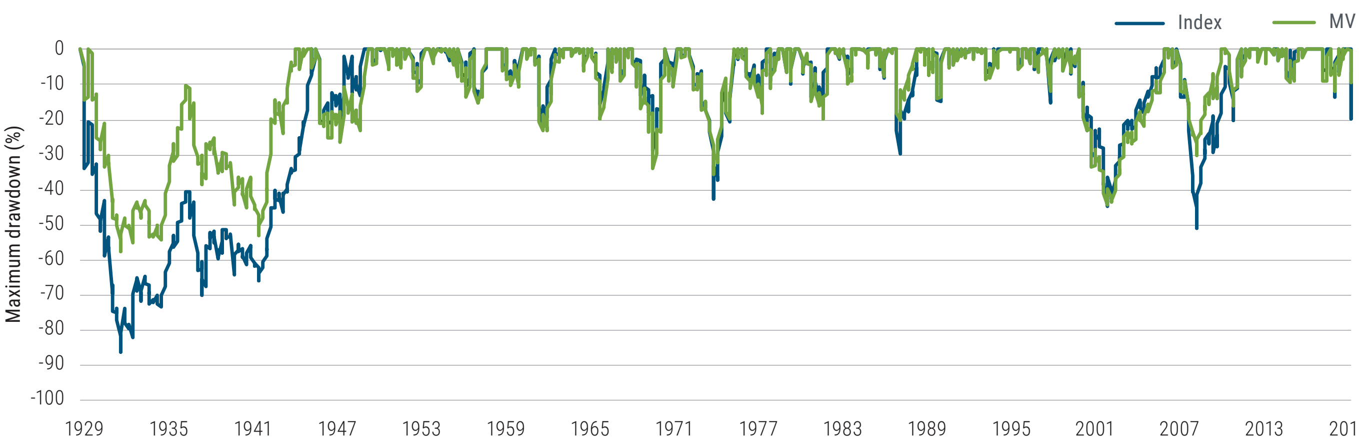


Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. S&P 500 and managed volatility are abbreviated as Index and MV, respectively. Rolling five-year volatilities are computed using monthly in percentages returns. The calibrated volatility target of 15% for MV is shown as the dotted red line. The volatility of rolling volatility for MV is 2.2%. Values are annualized and shown in percentages. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

In Exhibit 4, we plot peak-to-trough drawdowns of the S&P 500 and the managed volatility portfolio. Most notably, the portfolio significantly reduced drawdowns during the Great Depression and the 2008 financial crisis. In more moderate drawdowns, however, the strategy did not materially improve outcomes.

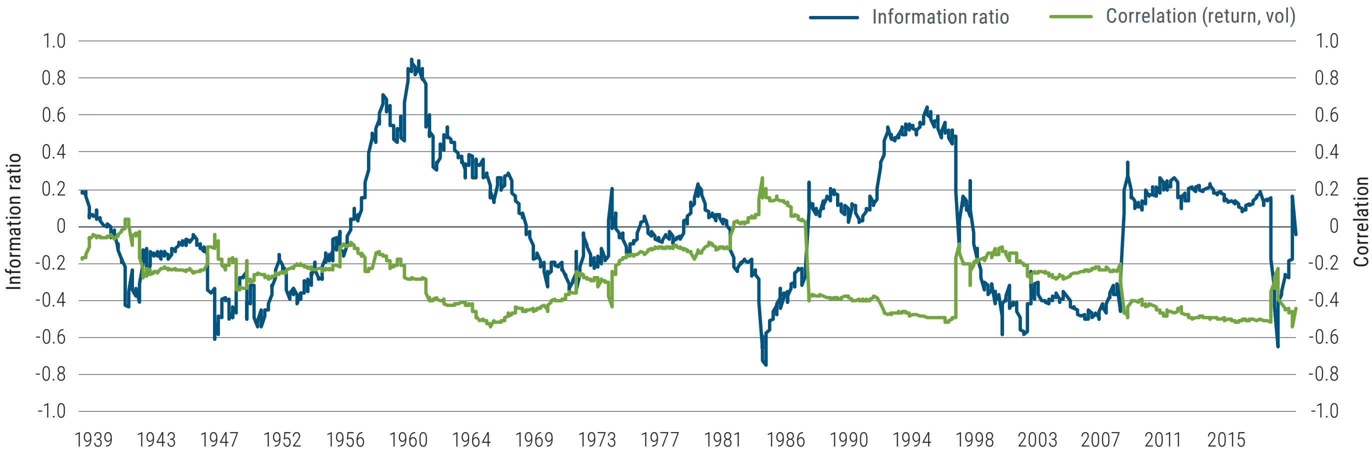
To quantify the performance of the managed volatility portfolio over time, Exhibit 5 plots the 10-year rolling information ratio alongside a 10-year rolling measure of the correlation between index return and index volatility.

Exhibit 4: The hypothetical managed volatility portfolio had smaller drawdowns than the S&P 500



Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. S&P 500 and managed volatility are abbreviated as Index and MV, respectively. Peak-to-trough drawdowns are computed using monthly returns and are shown in percentages. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Exhibit 5: The hypothetical managed volatility portfolio performed well when index returns and volatility were negatively correlated



Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Information ratios are computed over 10-year rolling periods with monthly returns using a geometric mean and are annualized. Correlation is computed between monthly volatilities and monthly returns over a rolling 10-year window. Monthly volatilities are computed using the standard deviation of daily returns for each month. All values are shown as decimals. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Exhibit 5 demonstrates two interesting findings. First, the rolling information ratio and rolling correlation between index returns and index volatility are very tightly and negatively linked. This result is intuitive, as the strategy relies on prices falling when volatility rises. Second, there are periods when the rolling correlation changed dramatically. This correlation risk causes the strategy to be vulnerable when there is a non-negative relationship between returns and volatility in the index.

Post-2010, the managed volatility portfolio continued to outperform a static position in the index, with a higher Sharpe ratio but a slightly negative information ratio. Our results suggest managed volatility can work as designed: It reduced large drawdowns and kept volatility within a tight range.

MANAGED VOLATILITY IN THE WORLD

To test the robustness of our results, we expand our dataset to include the FTSE-All Share (U.K.), TOPIX (Japan) and DAX (Germany) indexes. We repeat the exercise for each country, using the same construction for the managed volatility portfolio, again calibrating the volatility target to have a time-series average weight of 1 in the equity index (see appendix for more details). In Exhibit 6, we show returns and performance.

Exhibit 6: Across countries, the hypothetical managed volatility portfolio outperformed the indexes over the full sample but underperformed post-2010 outside the U.S.

Country	Period	Strategy	Mean return	SD return	Sharpe	Information ratio	Calmar
U.S.	Full sample	Index	8.99%	18.84%	0.26	0.00	0.10
	(Post-1929)	MV	9.37%	14.92%	0.35	0.04	0.16
	Post-2010	Index	12.02%	13.77%	0.80	0.00	0.61
		MV	11.69%	12.20%	0.88	-0.06	0.73
U.K.	Full sample	Index	11.13%	18.83%	0.19	0.00	0.17
	(Post-1966)	MV	10.73%	15.94%	0.21	-0.05	0.20
	Post-2010	Index	5.36%	12.49%	0.37	0.00	0.21
		MV	3.21%	11.82%	0.22	-0.53	0.17
Japan	Full sample	Index	7.61%	18.02%	0.19	0.00	0.11
	(Post-1950)	MV	7.75%	17.26%	0.21	0.02	0.10
	Post-2010	Index	7.06%	16.90%	0.41	0.00	0.30
		MV	5.15%	15.66%	0.32	-0.36	0.20
Germany	Full sample	Index	5.21%	19.14%	0.04	0.00	0.08
	(Post-1960)	MV	5.00%	17.41%	0.03	-0.03	0.09
	Post-2010	Index	5.98%	17.23%	0.36	0.00	0.22
		MV	4.30%	15.38%	0.29	-0.31	0.18

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Managed volatility is abbreviated MV. Values are computed using monthly returns. Geometric means are used, and all values are annualized. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

With few exceptions, the managed volatility portfolio had higher Sharpe and Calmar ratios for the full sample across countries. In the post-2010 period, we find systematic underperformance outside the U.S. Exhibit 7 shows the percentile of the information ratio post-2010 relative to 10-year rolling historical values.

Interestingly, the underperformance in recent times is quite severe internationally. The information ratios represent values in the bottom decile values relative to historical distributions. We find, however, that managed volatility is currently pursued mainly in the U.S., where the information ratio is close to its median value..

Exhibit 7: Post-2010, the hypothetical managed volatility portfolio performed worse abroad than in the U.S.

Country	Full sample			Post-2010	
	Min	Median	Max	Information ratio	Percentile
U.S.	-0.75	-0.04	0.90	-0.06	47.79%
U.K.	-1.14	-0.09	0.87	-0.53	3.21%
Japan	-0.67	0.03	0.63	-0.36	7.81%
Germany	-0.74	-0.09	0.43	-0.31	17.37%

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Exhibit shows rolling 10-year information ratios and the empirical percentile of post-2010 performance relative to the historical distribution. Values are computed with monthly returns using geometric means. Information ratios are annualized. The managed volatility portfolio is shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

RISK MITIGATION STRATEGIES AROUND THE WORLD

While the full-sample historical data showed the potential benefits of managed volatility, there are other strategies that more explicitly seek to maximize returns while reducing drawdowns rather than prioritizing a stable volatility. Each of the three additional strategies we consider are designed to generate a return profile consistent with Exhibit 2, reducing drawdown while keeping up with index returns in good times. To achieve this, the strategies dynamically and pro-cyclically vary exposure to the underlying equity index without resorting to options. Intuitively, we would expect such strategies to come at an average cost to returns. However, certain strategies, such as trend-following, are well-known anomalies that have the potential to generate both higher returns and smaller drawdowns (see Moskowitz et al. 2012). With this context in mind, we introduce the additional strategies to serve as comparisons for the risk mitigation properties of managed volatility (see appendix for more details).

Option replication

We define the option replication strategy as one that synthetically replicates a protective put position. Rather than buying puts outright, which can be expensive when volatility is high and the market sells off, we replicate the put option by dynamically adjusting the equity exposure. To determine the weight in equities, we compute the delta of a put option using the strategy's net asset value as the current price. The strike is set at a constant fraction of the maximum of a three-month rolling average of the strategy's net asset value over the past year. We set the option to expire one year from the date of this maximum. We set the "risk-free rate" as the market risk-free rate[2] and the volatility as the one-month rolling realized volatility in index returns. Given the delta, we set the weight in equities to be equal to 1 plus the delta of the option plus a reference level to ensure maximum leverage when the delta of the option is near zero. We calibrate the fraction of the maximum that determines the strike such that the time-series average weight in equities over the full historical sample is 1, consistent with our managed volatility construction. We also constrain the equity weight to be between 20% and 120%, and trade only if the optimal weight varies from the current weight by more than 2% or if the leverage constraints are breached. We incorporate a 1 bp trading cost as a fraction of the net asset value traded.

2 Additional details on the data are included in appendix

Trend-following

We construct a trend-following signal using a rolling year-over-year return of the equity index. We compute the quantile of this return relative to a normal distribution with a mean equal to the long-run mean of equity returns over the full historical sample. We then subtract 0.5 to recenter the value and scale by a constant factor. We set the equity weight as the new rescaled value plus 1. We calibrate this scaling factor such that the time-series average weight in equities over the full historical sample is 1, consistent with our other strategies. We again constrain the weight to between 20% and 120%, and trade only if the optimal weight differs from the current weight by more than 2% or if the leverage constraints are breached. As before, we incorporate a 1 bp trading cost as a fraction of the net asset value traded.

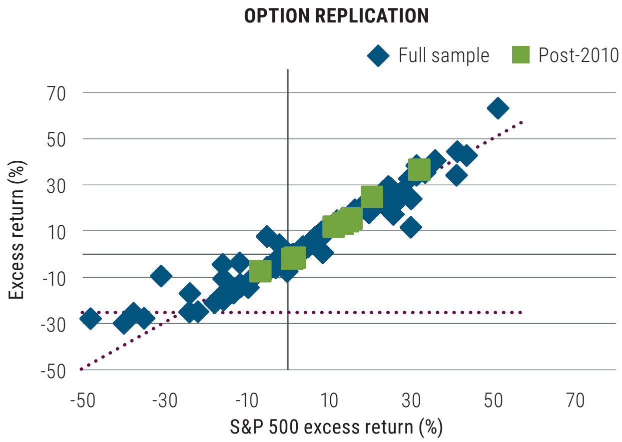
Blend

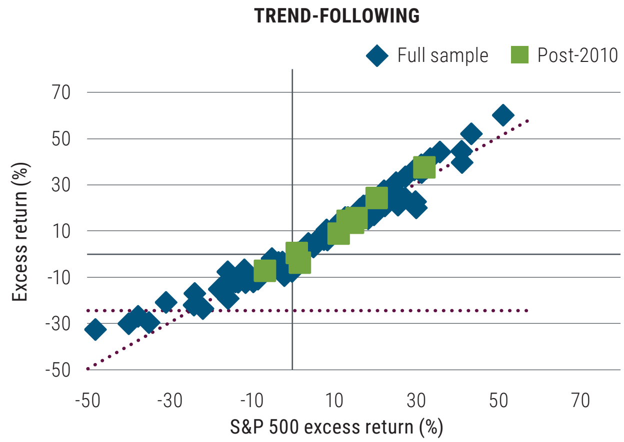
We compute the blend signal by first computing the managed volatility, option replication and trend-following signals. We use the blend strategy's net asset value when constructing the option replication signal. We then apply the leverage constraints such that the recommended weight from each signal is between 20% and 120%, and set the weight in equities to be the equal-weighted average of the resulting signals. By the nature of averaging, the weight will always lie between 20% and 120%. We again constrain trading to happen only if the optimal weight differs from the current weight by more than 2% or if the leverage constraints are breached. Consistent with the other strategies, we incorporate a 1 bp trading cost as a fraction of the net asset value traded.

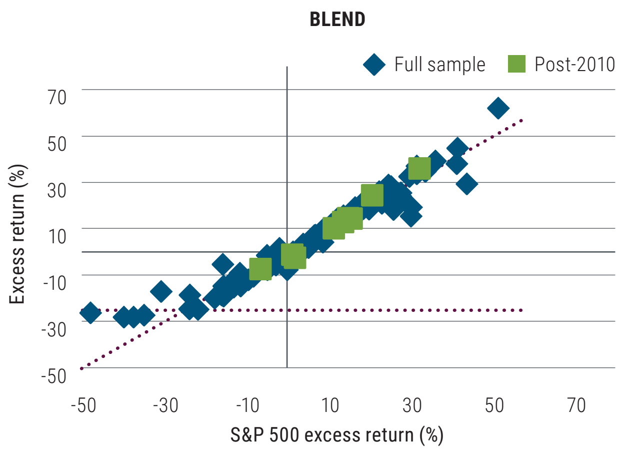
Strategy performance

We reproduce Exhibit 2 to show the performance of option replication, trend-following and a blend for the S&P 500. As expected, each of these hypothetical portfolios generates the same shape as the analogous plot for the managed volatility portfolio shown previously. We omit the cross-country results because they are very similar to those for the U.S. For each portfolio, Exhibit 8 shows that drawdowns were reduced without sacrificing upside when the index returns were positive.

Exhibit 8: The hypothetical option replication, trend-following and blend portfolios also pared left tail events in the S&P 500







Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Each point represents one year. The y=x line and a horizontal line at -25% are shown as reference. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

We compute the return moments, including all portfolios for both the full sample and the post-2010 sample, in Exhibit 9. Option replication, trend-following and the blend all generated higher Sharpe and Calmar ratios than the static portfolio over the long historical sample. However, we find that all of the portfolios, except managed volatility in the U.S., underperformed the index on a risk-adjusted basis post-2010 and the underperformance was more severe internationally than in the U.S. Consistent with our previous findings, the portfolios' year-over-year returns for the recent period highlighted green in Exhibit 8 did not deviate significantly from historically observed values, suggesting the recent underperformance does not seem to be an outlier relative to history.

Exhibit 9: Across countries, the hypothetical dynamic risk mitigation portfolios outperformed the index over the full sample but underperformed post-2010

Country	Period	Strategy	Mean return	SD return	Sharpe	Information ratio	Calmar
U.S.	Full sample (Post-1929)	Index	8.99%	18.84%	0.26	0.00	0.10
		MV	9.37%	14.92%	0.35	0.04	0.16
		OR	10.43%	15.79%	0.40	0.18	0.18
		TF	9.82%	17.36%	0.33	0.17	0.13
		BL	9.94%	15.62%	0.37	0.14	0.16
	Post-2010	Index	12.02%	13.77%	0.80	0.00	0.61
		MV	11.69%	12.20%	0.88	-0.06	0.73
		OR	11.79%	14.04%	0.77	-0.12	0.63
		TF	10.53%	14.19%	0.67	-0.64	0.49
		BL	11.53%	13.28%	0.80	-0.18	0.67
U.K.	Full sample (Post-1966)	Index	11.13%	18.83%	0.19	0.00	0.17
		MV	10.73%	15.94%	0.21	-0.05	0.20
		OR	13.17%	17.80%	0.31	0.41	0.37
		TF	11.86%	17.38%	0.25	0.16	0.24
		BL	11.77%	16.39%	0.26	0.11	0.26
	Post-2010	Index	5.36%	12.49%	0.37	0.00	0.21
		MV	3.21%	11.82%	0.22	-0.53	0.17
		OR	3.66%	12.50%	0.24	-0.65	0.17
		TF	4.72%	11.91%	0.34	-0.30	0.22
		BL	3.95%	12.02%	0.27	-0.56	0.19
Japan	Full sample (Post-1950)	Index	7.61%	18.02%	0.19	0.00	0.11
		MV	7.75%	17.26%	0.21	0.02	0.10
		OR	9.89%	17.89%	0.32	0.37	0.18
		TF	9.12%	18.02%	0.27	0.43	0.15
		BL	8.76%	17.39%	0.26	0.27	0.13
	Post-2010	Index	7.06%	16.90%	0.41	0.00	0.30
		MV	5.15%	15.66%	0.32	-0.36	0.20
		OR	5.64%	17.06%	0.33	-0.24	0.19
		TF	6.74%	17.25%	0.39	-0.11	0.26
		BL	6.14%	16.78%	0.36	-0.34	0.24
Germany	Full sample (Post-1960)	Index	5.21%	19.14%	0.04	0.00	0.08
		MV	5.00%	17.41%	0.03	-0.03	0.09
		OR	5.78%	18.13%	0.07	0.09	0.12
		TF	6.29%	18.69%	0.10	0.30	0.11
		BL	5.85%	17.75%	0.08	0.13	0.11
	Post-2010	Index	5.98%	17.23%	0.36	0.00	0.22
		MV	4.30%	15.38%	0.29	-0.31	0.18
		OR	4.23%	17.02%	0.26	-0.50	0.15
		TF	4.99%	17.46%	0.30	-0.40	0.18
		BL	4.72%	16.51%	0.30	-0.40	0.19

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to the equity index (Index), managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Values are computed using monthly returns. Geometric means are used, and all values are annualized. The portfolios are shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

To ensure our results are robust, we include two additional checks in the appendix. First, we compute the strategies' performance post-1990 and show that the results are consistent with our findings in the full historical sample. Second, we repeat our backtest using implied volatility rather than historical volatility. Because implied measures are forward looking, they may react faster to changes in the market than retrospective ones. Due to data availability, we compare results for the post-2010 period. While the choice of volatility measure has some impact on performance, our findings remain mostly unchanged.

Exhibit 10 shows the percentile of the information ratio post-2010 relative to 10-year rolling historical values for the various strategies across countries. Managed volatility, option replication and the blend portfolios had higher-percentile information ratios in the U.S. than abroad, while trend-following had a higher-percentile information ratio internationally. We also find that post-2010 managed volatility generally had higher percentile information ratios than the other strategies.

Dissecting strategy performance

To better understand the performance, we first analyze how these strategies behave in both good and bad times. In Exhibit 11, we compute upside capture, downside capture and capture ratios for the various portfolios over the full historical sample across countries. We show the pooled country averages because results are largely similar across countries.

Exhibit 10: Across strategies, the hypothetical managed volatility portfolio underperformed the least post-2010

Country	Strategy	Full-sample			Post-2010	
		Min	Median	Max	Information ratio	Percentile
U.S.	MV	-0.75	-0.04	0.90	-0.06	47.79
	OR	-0.71	0.17	1.01	-0.12	7.09
	TF	-0.85	0.16	1.05	-0.64	0.41
	BL	-0.74	0.12	1.11	-0.18	7.19
U.K.	MV	-1.14	-0.09	0.87	-0.53	3.21
	OR	-1.01	0.20	1.24	-0.65	2.83
	TF	-0.81	0.10	0.65	-0.30	6.98
	BL	-1.17	0.12	0.83	-0.56	3.21
Japan	MV	-0.67	0.03	0.63	-0.36	7.81
	OR	-0.28	0.40	0.92	-0.24	1.12
	TF	-0.24	0.39	1.07	-0.11	1.81
	BL	-0.63	0.30	1.19	-0.34	1.81
Germany	MV	-0.74	-0.09	0.43	-0.31	17.37
	OR	-0.79	0.03	0.59	-0.50	3.71
	TF	-0.58	0.36	0.77	-0.40	1.18
	BL	-0.78	0.14	0.66	-0.40	2.70

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to the equity index (Index), managed volatility (MV), option replication (OR), trend-following (TF), and blend (BL). Exhibit shows rolling 10-year information ratios and the empirical percentile of post-2010 performance relative to the historical distribution. Values are computed with monthly returns using geometric means. Information ratios are annualized and shown as decimal. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Exhibit 11: The hypothetical dynamic risk mitigation portfolios reduced the downside without large sacrifices to the upside

Strategy	Upside	Downside	Capture ratio
MV	0.94	0.92	1.02
OR	0.98	0.89	1.09
TF	0.99	0.94	1.05
BL	0.97	0.92	1.06

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Values are computed first using monthly returns for each country, then averaged across countries. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

The portfolios outperformed the index by reducing downside capture without sacrificing too large a fraction of the upside. As a result, all the portfolios had a capture ratio greater than 1.

Next, we analyze the strategies' performance during recessions. We define a recession in each country using NBER and OECD country-specific recession indicators, allowing the stock market to precede the indicators by up to six months. We then compute the largest drawdown of the equity index during this period and calculate the drawdown of the strategy for the same time window. Exhibit 12 shows the recessions with the three largest index drawdowns, the average across all recessions for each country and the average across post-2010 recessions, pooling countries.

Exhibit 12: The hypothetical dynamic risk mitigation portfolios significantly reduced losses during recessions

Country	Recession dates		Drawdown				
	Start	End	Index	MV	OR	TF	BL
U.S.	1929-09-30	1933-03-31	86.03%	56.53%	58.60%	76.61%	63.55%
	2008-01-31	2009-06-30	50.91%	29.96%	34.21%	39.76%	35.00%
	1937-06-30	1938-06-30	49.68%	31.60%	34.41%	41.93%	36.51%
	Full-sample avg		25.81%	21.27%	19.81%	21.70%	21.02%
U.K.	1973-04-30	1975-08-29	66.59%	52.30%	35.07%	48.84%	44.56%
	2008-01-31	2009-06-30	41.09%	26.31%	29.34%	31.12%	29.67%
	1968-08-30	1970-02-27	26.14%	26.80%	23.35%	25.40%	24.94%
	Full-sample avg		20.93%	19.23%	17.08%	18.31%	18.26%
Japan	1990-08-31	1994-09-30	52.48%	51.01%	38.54%	42.91%	43.93%
	2008-02-29	2009-03-31	52.30%	29.02%	26.99%	41.27%	32.20%
	1973-04-27	1975-01-31	35.31%	43.01%	30.10%	32.93%	34.84%
	Full-sample avg		23.92%	23.04%	20.79%	21.87%	21.76%
Germany	2001-05-31	2005-02-28	64.33%	48.41%	40.54%	52.46%	46.58%
	2008-03-31	2009-06-30	52.35%	38.92%	38.04%	45.73%	40.70%
	1961-01-31	1963-02-28	38.93%	44.00%	32.28%	33.05%	34.60%
	Full-sample avg		27.68%	25.07%	24.41%	24.96%	24.50%
Pooled	Post-2010 avg		17.82%	15.75%	18.94%	18.69%	17.53%

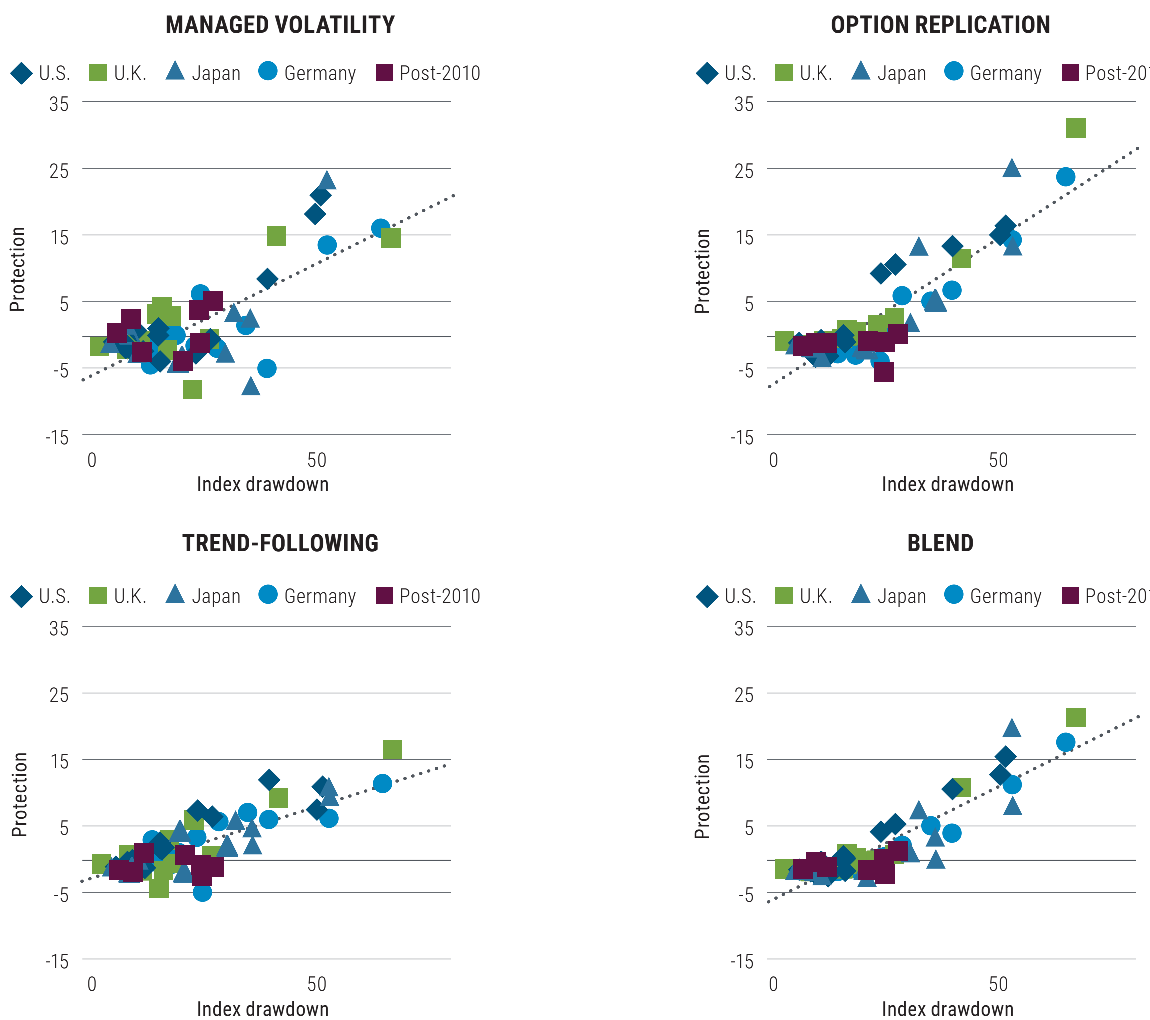
Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to the equity index (Index), managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). For each recession in each country, we allow the market to lead country recession indicators by up to 6 months. Within this window, we then compute the dates that have the maximum index drawdown. We show the drawdown of the index and strategies on this same time window. The exhibit shows the three recessions with the largest index drawdowns and the average recession for each country. We also show the average post-2010 recession, pooling countries. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Note that each portfolio outperformed the index for the average recession in the full sample and performed remarkably well during large recessions. For major bear events, managed volatility, option replication, trend-following and the blend portfolios each significantly reduced drawdowns compared with the static portfolio. Furthermore, the managed volatility portfolio continued to slightly outperform the index, on average, during the milder post-2010 recessions in the U.K., Japan and Germany, while option replication, trend-following and the blend did not.

Quantifying protection against losses

Now we leverage the large number of country-recession observations to quantify each strategy's degree of risk mitigation. Using the methodology described in the previous section, we compute the drawdown of the index and the strategies for each country-recession pair. We define drawdown protection as the difference in drawdown between the strategy and the index. Exhibit 13 shows drawdown protection plotted against index drawdown for each recession. We highlight in purple the OECD recessions that have occurred since 2010 in the U.K., Japan and Germany.

Exhibit 13: The hypothetical dynamic risk mitigation portfolios provided the most protection during large market downturns



Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Each point represents a recession period. Index drawdown is computed as the maximum drawdown within each NBER/OECD recession period, allowing the market to lead recession indicators by up to 6 months. Protection is defined as the difference in drawdown between the strategy and the index on the same time window. The line of best fit pooling all countries for each strategy is shown as the dotted line. Recessions post 2010 are highlighted in purple. All values are reported in percent. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

The plot shows three interesting results. First, the strategies work as designed: The hypothetical managed volatility, option replication, trend-following and blend portfolios all reduced drawdowns; the line of best fit for each strategy has a distinct upward slope. Second, the protection was more reliable in drawdowns exceeding 25%. We find higher variation in drawdown protection in smaller downturns than in the more significant bear market events. Third, the performance of the strategies during recent smaller drawdowns in the U.K., Japan and Germany (highlighted purple) does not seem to represent a significant outlier relative to the portfolios' previous performance; the points remain clustered in line with the historical distribution.

In Exhibit 14, we list regression coefficients corresponding to the line of best fit for each of the plots above. The slope represents the fraction of drawdown the portfolio protects against. For example, the hypothetical managed volatility portfolio protected against 33% of the drawdown in the index, on average.

Exhibit 14: The degree and reliability of downside protection varies across strategies

Strategy	Slope	R-squared	Fraction outperform
MV	0.33	0.57	0.49
OR	0.43	0.82	0.51
TF	0.22	0.65	0.64
BL	0.33	0.84	0.55

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Slope coefficients, R-squared, and the fraction of recessions for which the strategy outperformed the index are shown. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Note that although option replication had the highest slope, representing the largest average degree of drawdown protection, the strategy outperformed the index in only about half of the recessions studied. Trend-following had the smallest slope, representing the smallest average degree of drawdown protection, but it outperformed the index in the largest fraction of recessions.

Distribution of drawdowns

Because the portfolios outperformed the index primarily during large market downturns, we compute the distribution of drawdowns for the full historical sample rather than post-2010. For each day in the sample, we compute the maximum drawdown for a rolling one-year window preceding the day. We then compute the fraction of days that have a drawdown exceeding various thresholds for the full sample and post-2010 for each country in Exhibit 15.

Exhibit 15: There have been few large downturns in equity markets post-2010

Country	Drawdown threshold	Fraction of days	
		Full	Post-2010
U.S.	5%	0.95	0.93
	10%	0.57	0.51
	20%	0.21	0.01
	30%	0.10	0.01
U.K.	5%	0.95	0.96
	10%	0.61	0.58
	20%	0.22	0.02
	30%	0.09	0.01
Japan	5%	0.96	1.00
	10%	0.73	0.91
	20%	0.32	0.32
	30%	0.08	0.00
Germany	5%	1.00	0.99
	10%	0.80	0.75
	20%	0.31	0.31
	30%	0.15	0.11

Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Values show the fraction of days in which the maximum drawdown in the equity index over a rolling one-year window exceeded various thresholds.

The fraction of days with a drawdown greater than 30% decreases for all countries; because these portfolios outperformed primarily during market downturns, the lack of day with large drawdowns since 2010 may have contributed to their underperformance. However, we also find evidence that the strategies work better domestically than internationally. Post-2010, the U.K., Japan and Germany have had more days with drawdowns exceeding various thresholds than the U.S. has, but information ratios have been more negative abroad.

The COVID-19 Drawdown

The recent pullback in markets was the largest dislocation in the post-2010 period. In Exhibit 23, we show the year-to-date maximum drawdown in 2020 of the indexes and strategies across countries.

Exhibit 16: Dynamic risk mitigation strategies meaningfully reduced drawdowns in 2020

	2020 YTD Max Drawdown				
	Index	MV	OR	TF	BL
U.S.	33.79%	17.11%	31.85%	32.87%	27.30%
U.K.	35.32%	22.66%	29.89%	29.24%	27.38%
Japan	29.08%	22.75%	26.87%	26.36%	25.35%
Germany	38.78%	24.85%	34.83%	36.41%	32.18%

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to the equity index (Index), managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Exhibit shows maximum year-to-date drawdown for 2020 for the index and the strategies across countries. Values are computed with daily returns using geometric means. Portfolios are shown before the effect of fees, and results would be lower if fees were applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

During this downturn, all the strategies meaningfully pared losses compared to a static position in the index, with managed volatility having the largest reduction in drawdown. Managed volatility uses a one-month realized volatility to de-risk in contrast to option replication and trend-following, which use longer-term signals. Since the sell-off occurred remarkably quickly, managed volatility adapted faster to the sudden drop in markets, leading to the most protection against losses.

To see how even one event can affect the performance of the strategies, we show the information ratios of the strategies across countries, both with and without the first four months of 2020, in the sample in Exhibit 17.

Broadly across strategies and countries, the information ratios are significantly improved by adding even one meaningful drawdown to the sample. We find a large improvement with managed volatility in the U.S. in just four months. An exception to this improvement is trend-following in the U.S. and Germany

Exhibit 17: Even one significant bear event can have large effects on strategy performance

Country	Information ratio		
	Strategy	2010 -2019	2010 -YTD 2020
U.S.	S&P 500 Index	0.00	0.00
	MV	-0.18	-0.06
	OR	-0.11	-0.12
	TF	-0.46	-0.64
	BL	-0.22	-0.18
U.K.	FTSE 100 Index	0.00	0.00
	MV	-0.85	-0.53
	OR	-0.95	-0.65
	TF	-0.59	-0.30
	BL	-1.01	-0.56
Japan	TOPIX Index	0.00	0.00
	MV	-0.35	-0.36
	OR	-0.23	-0.24
	TF	-0.11	-0.11
	BL	-0.33	-0.34
Germany	DAX Index	0.00	0.00
	MV	-0.45	-0.31
	OR	-0.58	-0.50
	TF	-0.37	-0.40
	BL	-0.51	-0.40

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to the equity index (Index), managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Values are computed using monthly returns. Geometric means are used, and all values are annualized. The portfoliosare shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

where we find a slightly worse information ratio when including the additional returns from 2020. We attribute this to the one-year signal used by the trend-following strategy and the choice of parameters. In addition we also find minimal to no change in the information ratios in Japan. We do, however, find that all the dynamic strategies across countries had reduced drawdowns during 2020 when compared to the index.

Option buying and capital efficiency

There are two additional points to consider when evaluating these strategies. First, the hypothetical dynamic portfolios performed remarkably well given their risk mitigation properties. Even post-2010, we find that across countries most of the portfolios had higher alpha than simple option buying. Thus, the dynamic risk mitigation approaches provided similar levels of left side protection, with potentially higher returns in the full sample and a smaller cost post-2010.

Second, the strategies' equity exposure can be implemented in capital-efficient ways. Rather than buying shares of the underlying equity indexes, which are fully collateralized, the strategies can be implemented using futures, which require only a small margin. Then the remaining collateral can be invested in other assets to earn additional returns. If we assume asset managers can outperform cash, our results are a lower bound on the potential performance.

WHERE DO WE GO FROM HERE?

Diversifying your diversifiers

Though all the hypothetical portfolios reduced drawdowns, there are differences among the algorithms and potential benefits from blending approaches. Exhibit 18 shows the correlations among the alphas of the portfolios relative to the index, pooling countries.

Exhibit 18: The hypothetical blend portfolio offered diversification across strategies

	MV	OR	TF
MV	1.00	0.64	0.57
OR	0.64	1.00	0.76
TF	0.57	0.76	1.00

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to managed volatility (MV), option replication (OR), and trend-following (TF). Exhibit shows correlations between monthly alphas, pooling countries. Portfolios are shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

When it comes to outperformance, the hypothetical managed volatility, option replication and trend-following portfolios were not perfectly correlated, leaving room for potential diversification benefits. Interestingly, we find these benefits allow the hypothetical blend portfolio to have the highest R-squared for the regression of drawdown protection. Because the portfolio only adjusts the equity allocation significantly when all three signals are in accord, we interpret our finding to mean the portfolio more reliably protects on the downside, as it has the smallest unexplained variation in the regression. However, the diversification does not seem to improve overall information ratios for the blend in the post-2010 period.

Which strategy do we prefer?

With few exceptions, all of the portfolios had higher risk-adjusted returns compared with a static portfolio over the full sample. We broadly find the strategies trade off return, volatility of volatility, degree of drawdown protection and trading volume. Averaging the computed value for each portfolio across the four countries studied, we present an aggregated comparison of performance in Exhibit 19.

Exhibit 19: There is no one-size-fits-all solution to risk mitigation

	Metric			
Strategy	Information ratio	Volatility of volatility	Drawdown protection	Trade volume
Index	0.00	1.00	0.00	0.00
MV	0.00	0.47	0.33	223.52
OR	0.26	0.75	0.43	317.19
TF	0.26	0.86	0.22	157.17
BL	0.16	0.63	0.33	178.46

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Each value represents an arithmetic average across countries. The information ratio and the volatility of volatility are annualized and shown as decimal. The volatility of volatility is computed by taking the standard deviation of one-month volatilities for each strategy. The one-month volatility is computed taking the standard deviation of daily returns over a month. We normalize the volatility of volatility by dividing by the volatility of volatility for the equity index. Degree of drawdown protection is defined as a slope of the regression of drawdown protection on index drawdown. Trading volume is defined as the average annual total trading volume and shown as a percentage of portfolio value. Portfolios are shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

In all respects, no one strategy dominates another. The table highlights the trade-offs, using criteria that potentially matter to investors. Managed volatility had the most stable volatility profile but lower returns. Option replication had the highest drawdown protection but the highest trading volume. Trend-following had the highest return but the least drawdown protection and the highest volatility of volatility. The blend offered diversification but did not excel in any category.

CONCLUSION

Our research suggests managed volatility works as designed. It can be used to help seek to reduce losses during large market downturns and try to keep portfolio volatility within a tighter range. Its ability to reduce drawdowns in significant bear markets was shown during the recent crisis which marked the only meaningful dislocation since 2010, so we should be cautious in evaluating this strategy based only on its return performance over the past decade.

Looking to the future, if the focus shifts toward risk mitigation rather than simply reducing the variability of volatility outcomes, our analysis suggests dynamic strategies such as managed volatility, option replication, trend-following and a blend have the potential to provide meaningful risk mitigation during deep downturns. The approaches often have higher return potential when compared with static option buying and can be implemented in capital-efficient ways to seek additional alpha. We find there is no one-size-fits-all solution to mitigating portfolio losses, and results vary across countries. We highlight the trade-offs of each strategy and leave it to end investors to pick one that suits their needs.

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Appendix

DATA DESCRIPTION

For our analysis, we use daily data on the total return of equity indexes in the U.S., U.K., Japan and Germany. We use daily data on the SPX, TPX and DAX from Bloomberg and daily data on the FTSE All-Share from Global Financial Data (GFD). Exhibit 19 shows the resulting samples.

Exhibit 20: Data availability for countries and equity indexes

Country	Index	Date range
U.S.	SPX	1928-2020
U.K.	FTSE	1965-2020
Japan	TOPIX	1949-2020
Germany	DAX	1959-2020

Source: PIMCO, Bloomberg and Global Financial Data as of April 2020

To construct the risk-free rate, we use data from GFD. When available, we use the three-month interbank lending rate for each country. When the interbank rate is not available, we use the yield on a three-month government bond. For Japan, we use the overnight interbank lending rate before 1960 due to data availability. The historical risk-free rates are only available at a monthly frequency, so we use the most recently available data point for each day in each country.

Because of data availability, we do not add other countries. The recession indicators come from the Federal Reserve Bank of St. Louis's FRED database. The U.S. recessions are based on monthly NBER recession indicators. Recessions in the U.K., Japan and Germany are based on OECD country-specific recession indicators.

For the comparison between historical and implied volatility, we use data from Bloomberg tickers VIX, VFTSE, VNKY and V1X, using a 0.85 haircut on implied volatility measures. We use VNKY as a proxy for the implied volatility on the TPX because direct measures were not readily available. The VFTSE series was discontinued at the end of June 2019, so we restrict our sample to before June 2019 for the U.K. implied volatility results.

PORTFOLIO CONSTRUCTION

Here we detail the exact construction of the signal and weight in the underlying equity indexes for the results shown in the paper.

Managed volatility

Managed volatility sets a weight w_t in the equity index with the following formula:

$$w_t = \frac{\bar{\sigma}}{\sigma_t}$$

σ_t is the rolling one-month historical volatility of the equity index. $\bar{\sigma}$ represents the fixed volatility target of the portfolio. We calibrate $\bar{\sigma}$ for each country such that the time-series average weight in the equity index is 1. We find $\bar{\sigma}$ is 15%, 14%, 15% and 16% for the U.S., U.K., Japan, and Germany, respectively.

Option replication

Let S_t^O denote tthe NAV of the option replication portfolio, and X_t^O denote the three month rolling mean of the NAV. Let $\hat{X}_t^O$ denote the rolling maximum over the past year of X_t^O and τ_t^O the corresponding time of the max.

Let $\Delta(S, K, r, T, \sigma)$ denote the Black-Scholes delta of a put option with underlying price S, strike K, risk-free rate r, and volatility σ with T time to maturity. We then set the weight in equities using the following formula:

$$\hat{w}_t = 1 + \Delta(S_t^O, (1-\hat{\alpha})\hat{X}_t^O, r_t^f, 1-(t-\hat{\tau}_t^O), \sigma_t) + \hat{\gamma}$$

$\hat{\alpha}$ is the target drawdown level, σ_t is the rolling one-month historical volatility of the equity index, and $\hat{\gamma}$ is a constant level adjustment. We fix $\hat{\gamma}$ to be 0.2. We calibrate $\hat{\alpha}$ such that the time-series average weight in the equity index is 1. We find $\hat{\alpha}$ is 12%, 11%, 17% and 16% for the U.S., U.K., Japan, and Germany, respectively.

Trend-following

Let X_t^F denote the rolling one-year return on the equity index. We first construct a score using the normal distribution,

$$Z_t^F = 2(\Phi(X_t^F, \breve{\mu}, \breve{\sigma}) - 0.5)$$

$\Phi(x, \mu, \sigma)$ denotes the cumulative distribution function of a normal distribution, with mean and standard deviation evaluated at x, Given the score, we set a weight in the risky asset using the following formula:

$$\breve{w}_t = \breve{\gamma} Z_t^F + 1$$

$\breve{\mu}$ is set to be the long-run average mean. We fix $\breve{\sigma}$ to be 16% because the variables are eventually rescaled. We calibrate $\breve{\gamma}$ such that the time-series average weight in the equity index is 1 We find $\breve{\gamma}$ is 0.74, 0.70, 0.59 and 0.56 for the U.S., U.K., Japan, and Germany, respectively

Blend

The blend strategy computes the signal from managed volatility, option replication, and trend-following. It uses the blend portfolio's NAV in the option replication construction and uses the previously calibrated parameters for each strategy within each country. The leverage constraints of 20% to 120% are then applied to each signal, and the signals are averaged using an equal one-third weight. The weight in equities is then set to this average. By construction, the time series average weight in equities of the average signal is also 1.

ROBUSTNESS TESTS

Post-1990 return results

For robustness, Exhibit 20 shows the return statistics of the various strategies across countries for the post-1990 period.

Exhibit 21: Post-1990 results resemble full-sample performance

Country	Period	Strategy	Mean return	SD return	Sharpe	Information ratio	Calmar
U.S.	Post-1990	Index	9.48%	14.60%	0.42	0.00	0.19
		MV	9.29%	12.61%	0.47	-0.03	0.21
		OR	10.03%	13.70%	0.49	0.12	0.29
		TF	9.59%	14.07%	0.44	0.03	0.24
		BL	9.74%	13.26%	0.48	0.06	0.26
U.K.	Post-1990	Index	7.13%	14.05%	0.19	0.00	0.17
		MV	6.17%	13.03%	0.13	-0.21	0.14
		OR	7.27%	13.14%	0.21	0.03	0.22
		TF	7.33%	12.87%	0.22	0.07	0.22
		BL	6.91%	12.90%	0.19	-0.06	0.19
Japan	Post-1990	Index	-0.90%	19.17%	-0.10	0.00	-0.01
		MV	-1.56%	16.04%	-0.16	-0.09	-0.02
		OR	1.23%	17.21%	0.01	0.26	0.02
		TF	0.41%	17.56%	-0.04	0.32	0.01
		BL	-0.27%	16.54%	-0.08	0.11	0.00
Germany	Post-1990	Index	6.12%	20.65%	0.16	0.00	0.09
		MV	5.91%	16.88%	0.18	-0.03	0.11
		OR	6.80%	18.75%	0.21	0.09	0.14
		TF	6.82%	20.28%	0.19	0.17	0.11
		BL	6.70%	18.37%	0.21	0.10	0.13

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Values are computed using monthly returns. Geometric means are used, and all values are annualized. Portfolios are shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Broadly consistent with our full-sample results, the hypothetical dynamic portfolios generally resulted in higher Sharpe and Calmar ratios. Interestingly, managed volatility had a slight cost to returns across all countries.

Historical versus implied volatility

We test the effect of using implied instead of historical volatility on the portfolios' performance post-2010, fixing all parameters at their previously calibrated values in Exhibit 21.

Exhibit 22: The hypothetical portfolios performed modestly better using historical rather than implied volatility

Country	Volume measure	Strategy	Mean return	SD return	Sharpe	Information ratio	Calmar
U.S.	Historical	Index	12.02%	13.77%	0.80	0.00	0.61
		MV	11.69%	12.20%	0.88	-0.06	0.73
		OR	11.79%	14.04%	0.77	-0.12	0.63
		BL	11.53%	13.28%	0.80	-0.18	0.67
	Implied	Index	12.02%	13.77%	0.80	0.00	0.61
		MV	10.45%	12.24%	0.78	-0.34	0.69
		OR	10.53%	14.19%	0.67	-0.64	0.49
		BL	10.95%	13.28%	0.75	-0.42	0.65
U.K.	Historical	Index	7.96%	11.24%	0.65	0.00	0.55
		MV	5.07%	11.34%	0.39	-0.85	0.32
		OR	6.84%	11.21%	0.55	-0.62	0.47
		BL	5.96%	11.39%	0.46	-1.02	0.41
	Implied	Index	7.96%	11.24%	0.65	0.00	0.55
		MV	4.80%	10.92%	0.38	-1.06	0.30
		OR	6.84%	11.21%	0.55	-0.62	0.47
		BL	5.94%	11.22%	0.47	-1.15	0.42
Japan	Historical	Index	7.06%	16.90%	0.41	0.00	0.30
		MV	5.15%	15.66%	0.32	-0.36	0.20
		OR	5.64%	17.06%	0.33	-0.24	0.19
		BL	6.14%	16.78%	0.36	-0.34	0.24
	Implied	Index	7.06%	16.90%	0.41	0.00	0.30
		MV	5.16%	13.64%	0.37	-0.40	0.24
		OR	6.74%	17.25%	0.39	-0.11	0.26
		BL	6.16%	16.19%	0.38	-0.37	0.25
Germany	Historical	Index	5.98%	17.23%	0.36	0.00	0.22
		MV	4.30%	15.38%	0.29	-0.31	0.18
		OR	4.23%	17.02%	0.26	-0.50	0.15
		BL	4.72%	16.51%	0.30	-0.40	0.19
	Implied	Index	5.98%	17.23%	0.36	0.00	0.22
		MV	4.27%	15.10%	0.29	-0.33	0.18
		OR	4.99%	17.46%	0.30	-0.40	0.18
		BL	4.78%	16.43%	0.30	-0.39	0.19

Hypothetical example for illustrative purposes only. Source: PIMCO, Bloomberg and Global Financial Data as of April 2020. Abbreviations correspond to managed volatility (MV), option replication (OR), trend-following (TF) and blend (BL). Values are computed using monthly returns. Geometric means are used, and all values are annualized. Portfolios are shown before the effect of fees, and results would be lower if fees applied. The exhibit is provided for illustrative purposes and is not indicative of the past or future performance of any PIMCO product.

Note that using implied instead of historical volatility did not dramatically change the results for the post-2010 period. Within the U.S., the implied measure caused all the strategies to perform slightly worse. Interestingly, the results were different internationally: The implied measure slightly improved or largely left Sharpe ratios unchanged for the strategies in the U.K., Japan, and Germany.

Although fine-tuning of the inputs in the strategies does matter, our main findings are unaffected by the use of implied versus historical measures.

The "risk-free rate" can be considered the return on an investment that, in theory, carries no risk. Therefore, it is implied that any additional risk should be rewarded with additional return. All investments contain risk and may lose value.

The models, scenarios and decisions included here are not based on any particular financial situation, or need, and are not intended to be, and should not be construed as a forecast, research, investment advice or a recommendation for any specific PIMCO or other strategy, product or service. Individuals should consult with their own financial advisors to determine the most appropriate allocations for their financial situation, including their investment objectives, time frame, risk tolerance, savings and other investments.

The analysis contained in this paper is based on hypothetical modeling. HYPOTHETICAL PERFORMANCE RESULTS HAVE MANY INHERENT LIMITATIONS, SOME OF WHICH ARE DESCRIBED BELOW. NO REPRESENTATION IS BEING MADE THAT ANY ACCOUNT WILL OR IS LIKELY TO ACHIEVE PROFITS OR LOSSES SIMILAR TO THOSE SHOWN. IN FACT, THERE ARE FREQUENTLY SHARP DIFFERENCES BETWEEN HYPOTHETICAL PERFORMANCE RESULTS AND THE ACTUAL RESULTS SUBSEQUENTLY ACHIEVED BY ANY PARTICULAR TRADING PROGRAM.

ONE OF THE LIMITATIONS OF HYPOTHETICAL PERFORMANCE RESULTS IS THAT THEY ARE GENERALLY PREPARED WITH THE BENEFIT OF HINDSIGHT. IN ADDITION, HYPOTHETICAL TRADING DOES NOT INVOLVE FINANCIAL RISK, AND NO HYPOTHETICAL TRADING RECORD CAN COMPLETELY ACCOUNT FOR THE IMPACT OF FINANCIAL RISK IN ACTUAL TRADING. FOR EXAMPLE, THE ABILITY TO WITHSTAND LOSSES OR TO ADHERE TO A PARTICULAR TRADING PROGRAM IN SPITE OF TRADING LOSSES ARE MATERIAL POINTS WHICH CAN ALSO ADVERSELY AFFECT ACTUAL TRADING RESULTS. THERE ARE NUMEROUS OTHER FACTORS RELATED TO THE MARKETS IN GENERAL OR TO THE IMPLEMENTATION OF ANY SPECIFIC TRADING PROGRAM WHICH CANNOT BE FULLY ACCOUNTED FOR IN THE PREPARATION OF HYPOTHETICAL PERFORMANCE RESULTS AND ALL OF WHICH CAN ADVERSELY AFFECT ACTUAL TRADING RESULTS.

Return assumptions are for illustrative purposes only and are not a prediction or a projection of return. Return assumption is an estimate of what investments may earn on average over the long term. Actual returns may be higher or lower than those shown and may vary substantially over shorter time periods.

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Investing in the **bond market** is subject to risks, including market, interest rate, issuer, credit, inflation risk, and liquidity risk. The value of most bonds and bond strategies are impacted by changes in interest rates. Bonds and bond strategies with longer durations tend to be more sensitive and volatile than those with shorter durations; bond prices generally fall as interest rates rise, and low interest rate environments increase this risk. Reductions in bond counterparty capacity may contribute to decreased market liquidity and increased price volatility. Bond investments may be worth more or less than the original cost when redeemed. **Equities** may decline in value due to both real and perceived general market, economic and industry conditions.

There is no guarantee that these investment strategies will work under all market conditions or are suitable for all investors and each investor should evaluate their ability to invest long-term, especially during periods of downturn in the market.

The **Calmar ratio** is a comparison of the average annual compounded rate of return and the maximum drawdown risk of commodity trading advisors and hedge funds. The **Sharpe Ratio** measures the risk-adjusted performance. The risk-free rate is subtracted from the rate of return for a portfolio and the result is divided by the standard deviation of the portfolio returns.

The **DAX** is a blue chip stock market index consisting of the 30 major German companies trading on the Frankfurt Stock Exchange. Prices are taken from the Xetra trading venue. The **FTSE All-Share Index** is a capitalisation-weighted index, comprising around 600 of more than 2,000 companies traded on the London Stock Exchange. Since 29 December 2017 the constituents of this index totaled 641 companies. **S&P 500 Index** is an unmanaged market index generally considered representative of the stock market as a whole. The Index focuses on the large-cap segment of the U.S. equities market. The **TOPIX** (Tokyo Stock Price Index) is a capitalization-weighted composite of all stocks trading on the first section of the Tokyo Stock Exchange ("TSE"), supplemented by size groups that classify first section companies as small, medium, and large and by sub-indices for each of the 33 industry groups. It is not possible to invest directly in an unmanaged index.

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