How to Combine Investment Signals in Long/Short Strategies

Insights from Simulations and Empirical Analyses

We analyse the relative advocacy of competing approaches for the combination of investment signals in long/short portfolios. Specifically we study if it is preferable to (1) calculate weights for individual signals and then combine those weights (Mixed); or (2) combine signals and then calculate weights (Integrated). In our analysis we contrast insights obtained through a conceptual theoretical angle in simulations with a concrete application of Mixed and Integrated using empirical data to gain a broader perspective on the results. In both frameworks we find no meaningful performance differences between the methodologies. Transaction costs for the portfolio containing the combined signal are not significantly different between the two methodologies as long as trades are netted.

1. Introduction

Much has been written about the Mixed and Integrated approaches for the combination of signals[1]. The literature has concentrated on the combination of multiple investment signals in a long-only context. The point of this article is to evaluate the benefits and challenges to Mixed and Integrated in a long/short context which has received little attention by academics and practitioners previously. For this purpose a range of analyses based on simulations and empirical data are conducted.

It should be self-evident that for a general enough portfolio construction methodology and in the absence of constraints one should not find substantial differences between Mixed and Integrated. The introduction of constraints can lead to the loss of information when translating signals to weights which leads to more substantial differences in the performance of the two methodologies. In the Smart Beta world the portfolio construction is constrained to a long-only context which may lead to an Integrated approach potentially outperforming a Mixed approach as the latter may lose information due to the non-shorting constraint. In the long/short space this constraint does not hold and therefore cannot introduce any differences. However, other constraints do exist in a long/short setting and may lead to systematic differences between Mixed and Integrated. In particular, investors may be constrained in terms of concentration, liquidity, and leverage.

[1] The debate around the combination of the information in multiple signals evolves around two methodologies: (1) combine **weights after** the portfolio construction process is applied to signals (Mixed) or (2) combine **signals before** the portfolio construction process is applied (Integrated).

Mixing introduces an additional transformation of the signals before they are combined. This may lead to Mixed filtering out noise which is captured by signals, enhancing robustness of the portfolios. In particular when one of the signals has a particularly large magnitude combining information using Mixed might allow for a more balanced combination of signals. On the other side in the Mixed approach the portfolio construction step before the signal combination may have a similar effect to an investment constraint and may remove information from the signals which is related to future returns. The final effect may also depend on the portfolio construction methodology used to determine the signal portfolios which are to be Mixed. Ex ante it is not clear which effect prevails and will be part of our analyses. Furthermore, we will study the effect of Winsorization in the context of an Integrated approach to see how this approach of signal normalization may relate to a Mixed approach.

Next to such performance driven considerations this analysis discusses a range of practical implications of Mixed and Integrated. Benefits of a Mixed approach are that it allows for easier style attribution or modularisation of investment strategies enhancing transparency for investors. The Integrated approach can reduce turnover in certain scenarios or be more effective when weights are constrained.

This article combines a simulation analysis with an empirical analysis to tackle the subject matter from different angles. Simulations are a means to compare Mixed and Integrated in a controlled experimental framework absent of noise from uncontrolled effects. Furthermore, simulations are a more generic approach that illustrates the results independent of a concrete context rendering the results relevant for a broad range of applications. For example, as long as assumptions about signal distributions and their link to expected returns are reasonable, the results on comparing Mixed versus Integrated are as valid for the combination of signals based on satellite image information and credit card transaction as they are for signals based on equity value and momentum. The empirical analysis using Carry, Value and Momentum in Equities, Foreign Exchange, Fixed Income and Commodities, however, moves from the conceptual angle of a parametric simulation to a concrete empirical example that does not suffer from the simplifications a simulation makes about the reality. Hence, simulations sharpen our understanding of the features of Mixed and Integrated from a conceptual theoretical angle while the empirical analysis complements our understanding through a specific application relevant in practice.

In our simulation approach we start with the assumption of two distinct, uncorrelated and normally distributed signals. Asset returns are then modelled as a function of those signals plus a noise term, where the latter drives the predominant portion of asset returns. We apply a portfolio construction which ranks assets using a specific signal from best to worst and then uses a linear weighting on the ranks going long the highest ranked and short the lowest ranked asset. Applying this methodology on a signal which represents the average of multiple individual signals is an implementation of the **Integrated** approach. Implementing this portfolio construction methodology on individual signals and then averaging the resultant weights leads to a **Mixed** portfolio. We then compare various statistics for the resulting portfolio returns.

The results are consistent with our expectations by showing no economically meaningful difference in risk-adjusted performance between Mixed and Integrated for unconstrained long/short portfolios although statistical significance is in favour of Integrated. The transfer coefficient (i.e., the rank correlation between a signal and the weights in a portfolio using such signal) is marginally but statistically significantly higher for the Mixed approach which shows that this approach delivers a cleaner signal capture. These results still hold true even if we add variations to this basic setup through correlations between the signals, correlations between the assets or noise. We also find that the results are robust to alternative methodologies of portfolio construction such as equal weighting which allows the evaluation of different degrees of portfolio concentration. Changing the distributional assumptions for the signal can lead to Integrated delivering stronger results if asymmetric distributions are used, illustrating how the additional signal transformation step in the Mixed approach can remove performance-relevant information from signals.

We complement these simulation-driven analyses using an empirical analysis implementing style portfolios based on carry, value, and momentum. Those style portfolios are implemented in fixed income, foreign exchange, commodities, and equities. We then combine those styles within an asset class using Mixed and Integrated. Results are roughly in line with the simulation analysis in showing no major differences between the methodologies although risk-adjusted returns now generally favour Mixed. Transfer coefficients remain in favour of the Mixed approach, delivering a higher factor capture in the overall portfolio.

We contribute to the literature in three ways. First, this article contributes to the growing literature on signal combination. Bender and Wang (2016) as well as Fitzgibbons et al. (2016) show superior risk-adjusted returns for the integration approach in a long-only investment space. Clarke et al. (2016) confirm these results by illustrating the Sharpe ratio decay a portfolio in the long-only space suffers when following a Mixed approach. In contrast, Ghayur et al. (2018) find in a long-only setting that Mixed generates generally higher information ratios as long as low-to-moderate levels of equity factor exposures are targeted. This finding is largely driven by the interaction effects between equity value, momentum, quality, and low risk. Leippold and Rueegg (2016) arrive at similar conclusions by finding no strong evidence to favour the Integrated or Mixed approach. They do point out that the Integrated approach exhibits a higher sensitivity to the low risk factor. Jivraj et al. (2016) find similar results attributing the outperformance of the Integrated approach in their long-only analysis to a persistent bias to the low risk factor. In contrast to these analyses, we focus on long/short portfolios. In this long/short context we cannot find significant differences when using Mixed or Integrated in a linear ranking based portfolio construction setting using simulations and empirical results. These results are related to Clarke et al. (2016) who argue in a smart beta context that the Sharpe ratio decay of Mixed is largely driven by the long-only constraint.

Second, this article contrasts two approaches to portfolio construction. The base case uses a linear weighting scheme based on the ranking of the assets in question with respect to the signal. A similar methodology has been applied by Bender and Wang (2015, 2016). We contrast this approach by another portfolio construction methodology which forms percentile portfolios with equal weighting (compare, e.g., Fama and French, 1992, 1993, or Jegadeesh and Titman, 1993). In this percentile-based portfolio construction analysis the Sharpe ratio is the highest for Mixed as well as Integrated when going long the top 30% and short the bottom 30% of assets using an equal weighting. Such an implementation of percentiles where long, neutral and short positions have roughly the same number of members is comparable to a linear portfolio construction approach. In general, the results comparing Mixed and Integrated are insensitive to the portfolio construction methodology.

Third, we further our understanding of style portfolios across asset classes. In single equities the market (compare, e.g., Sharpe, 1964, Lintner 1965, or Mossin, 1966), value (compare, e.g., Fama and French, 1992, 1993), size (compare, e.g., Banz, 1981), momentum (compare, e.g., Jegadeesh and Titman, 1993) and carry style portfolios (compare, e.g., Cochrane, 2011, and Ilmanen, 2011) are broadly researched. Work by Asness et al. (2013) on momentum and value style portfolios or Koijen et al. (2016) on carry style portfolios extends this research across further asset classes[2]. Our analysis contributes by providing additional evidence for the existence of value, carry, and momentum (compare Baz et al., 2015) in asset class specific portfolios across equity country indices, fixed income, foreign exchange, and commodities. While these themes work on average across asset classes, we find weak performance for momentum in foreign exchange and equities as well as value in commodities, fixed income and equities.

[2] A particular focus of the literature has been the carry factor in foreign exchange (compare Brunnermeier et al., 2008, Christiansen et al., 2011, and Menkhoff et al., 2012).

In the following we will provide further evidence on the advantages and challenges when comparing Mixed and Integrated using simulations and empirical analyses. In Section 2 we show results contrasting the usage of Mixed versus Integrated signal combinations in our simulation framework. An empirical analysis of the effect of signal combination methodologies on multi-signal portfolios is conducted for various asset classes in Section 3. The following Section 4 adds a discussion of practical implications of choosing one methodology versus the other. We conclude in Section 5.

2. Comparing Mixed Versus Integrated Using Simulations

2.1 Simulation Framework

We simulate 10,000 monthly return periods for $n = 100$ assets. We assume that returns follow a normal distribution which is driven by signals and an unexplained component. We start by assuming that there exist two signals – s_1 and s_2 – with a distribution of:

$$s_1 \sim N(0, 0.0051^2),$$

$$s_2 \sim N(0, 0.0051^2).$$

Furthermore, a noise term is used to simulate the unexplained component of returns

$$\varepsilon \sim N(0, 0.05^2).$$

Using these components the monthly returns of an asset i at time t can be simulated as

$$r_{i,t} = s_1^{i,t} + s_2^{i,t} + \varepsilon^{i,t}.$$

The given parametrisation leads to assets obtaining an annualised volatility of 17.5%. In terms of variance, this leads to 98% of the variance being driven by a noise term and 1% of the variance being driven by signals 1 and 2, respectively. This leads to an IC of 0.1 for each signal, which is respectable for a monthly forecasting horizon. **Please note that we assume the risk free rate in this simulation to be 0%. Thus, returns are equal to excess returns and the return-risk ratio is equal to the Sharpe ratio.** All statistics will be given for monthly returns without annualisation.

To balance our data set and reduce the sensitivities to spurious biases in the simulation we extend it by adding another set of random numbers which is equal to the first 10,000 simulated numbers multiplied by -1. This brings the total number of simulated numbers to 20,000.

In the base case the signals and assets are not correlated.

2.2 Portfolio Construction

Having described how returns are simulated, we turn to a description of how portfolios are constructed using the information in the simulated signals. The portfolio construction uses a linear ranking approach:

a. Take the signal value $s_d^{i,t}$ across all assets i at time t for signal type d

b. Rank assets for a specific date t based on these signal values from highest to lowest generating scores of $R_1 \dots R_n$ where the highest signal is associated with the highest rank using ranking function $R_{d,t}(\, s_d^{i,t})$.

c. Weights for asset i at time t for signal d are determined as:

$$w_d^{i,t} = \frac{2R_{d,t}(\, s_d^{i,t}) - 2}{n - 1} - 1$$

In the Mixed case the weights of an investor with access to both methodologies is now determined as:

$$w_M^{i,t} = \frac{w_1^{i,t} + w_2^{i,t}}{2}$$

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially.
Source: GSAM.

In the case of the Integrated approach the weights are determined as:

$$s_I^{i,t} = \frac{s_1^{i,t} + s_2^{i,t}}{2}$$

with

$$w_I^{i,t} = \frac{2R_{I,t}\left(s_I^{i,t}\right) - 2}{n-1} - 1$$

The return of the different strategies is now simulated by multiplying the asset returns of period t with the weights assigned to period t.

These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially.

2.3 Comparison of Mixed versus Integrated in Long-Only Context

Some of the discussions around the comparison of Mixed and Integrated have concentrated on the long-only space, particularly smart beta strategies (compare, e.g., Bender and Wang, 2016, and Fitzgibbons et al., 2016). We run a variation of the framework introduced in the previous section using a long-only portfolio to test if our approach delivers results consistent with the previous literature.

We calculate the ranked linear portfolio weights for our portfolio and floor all weights at 0. This has the effect that the portfolio invests in the top 50 assets in our simulation and has no position in the bottom 50 assets. To model a cash-based portfolio without leverage we re-normalise the weights to sum to 100%. We compare performance and transfer coefficients[3] for this long-only portfolio construction. Results are summarized in Table 1.

Table 1: Performance Statistics for Long-Only Portfolio Construction. The table below shows the performance statistics of portfolios combining two signals in a long-only investment context using the introduced simulation methodology. Performance statistics are calculated on simulated monthly excess returns. Avg and Std reference average and standard deviation of simulated excess returns, respectively. Sharpe ratios are calculated as the ratio between Avg and Std.

Type	Signal 1	Signal 2	Integrated	Mixed
Avg	0.6%	0.6%	0.8%	0.6%
Std	0.8%	0.8%	0.8%	0.7%
Sharpe	0.71	0.70	1.00	0.85
Min	-2.5%	-3.1%	-2.8%	-2.1%
Max	4.2%	4.0%	4.1%	3.3%
Skewness	-0.02	0.04	-0.01	0.00
Excess Kurtosis	0.00	-0.03	0.02	0.00

Source: GSAM.

[3] The transfer coefficient is defined as the rank correlation coefficient between a signal and the weights determined based on the signal information.

The results of this analysis show how Integrated leads to a higher overall volatility of 0.8% compared to 0.7% for the Mixed approach. Returns in the Integrated approach outpace the Mixed approach for signal combination (0.8% versus 0.6%). Both effects lead to a risk-adjusted outperformance of the Integrated (Sharpe ratio of 0.99) approach when compared to Mixed (Sharpe ratio of 0.85).

The average transfer coefficient is marginally higher for the Mixed approach (0.62 for both signals) than for the Integrated approach (0.61 for both signals).

These results correspond to the empirical work by Ghayur et al. (2018) who find that Integrated delivers stronger risk-adjusted returns for high levels of factor exposures for equity smart beta strategies. However, for lower and moderate levels of factor exposures the authors find that the balance tips in favour of the Mixed approach in their equity smart beta context.

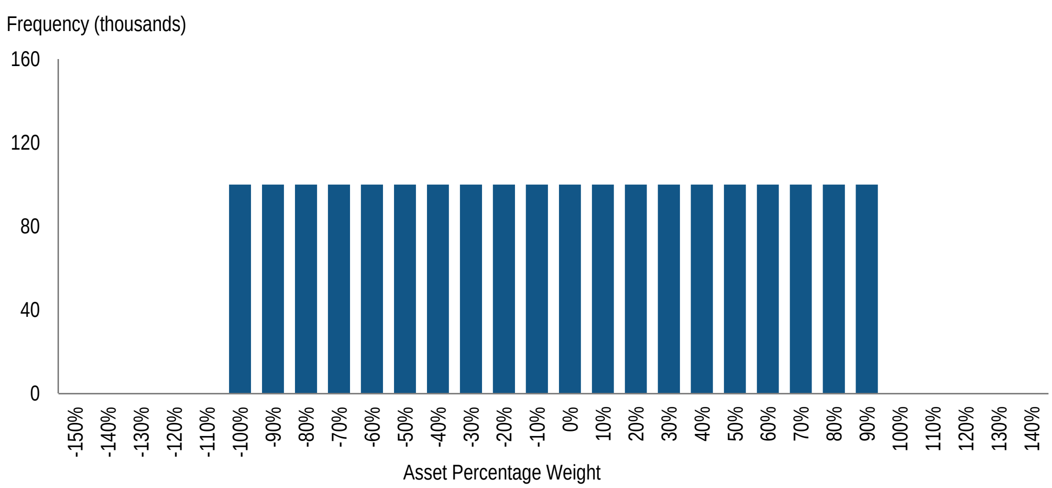
The literature and our results confirm the intuition that due to long-only portfolios having only a limited ability to underweight assets (effectively weights cannot be smaller than zero), integrating signals may be better able to trade off positive and negative signals than the mixing approach when large active exposures are sought. In a long/short context we no longer need to be concerned with a limited ability to underweight. The following sections will discuss the impact the removal of the long-only constraint has on simulated and empirical portfolios constructed from multiple signals using Mixed and Integrated.

2.4 Basic Statistics of Standard Long/Short Portfolio Construction

In the remainder of Section 2 we are using the methodology outlined in Sections 2.1 and 2.2. We rescale the weights of the Mixed approach to have the same average gross exposure across time as the Integrated approach. In addition we divide the weights by a factor of 10 to scale returns and volatility to levels that are more comparable with the figures observed for actual portfolios.

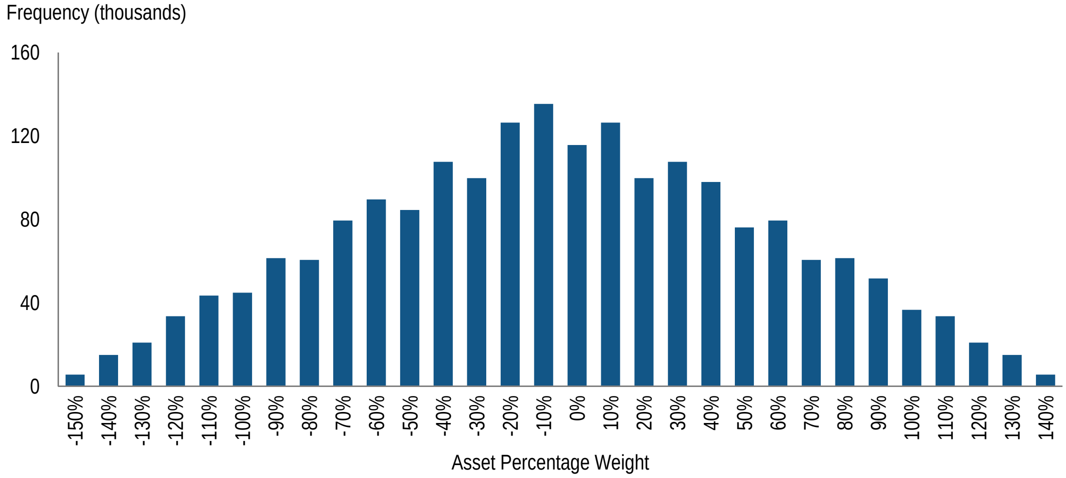
Figure 1: Weight Histograms Using Integration or Mixed Approach for Combining Signals 1 and 2. Figure shows the histogram of the portfolio weights determined using the Mixed and Integrated approach on the simulated signals. Histograms pool information across the 20,000 simulated repetitions for the 100 simulated assets leading to 2,000,000 observations.

Panel A: Integrated



These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially.
Source: GSAM.

Panel B: Mixed



We start the analysis by comparing the weight histograms of Mixed and Integrated in Figure 1. The graphs give for each methodology the weight histogram across assets and time. It illustrates how the Integrated approach has a univariate distribution where the probability of a very large positive or negative weight is as large as a weight close to zero. This is the exactly same signal distribution we would obtain if we were to use one signal only. This is a result of the linear ranking based approach which we apply to construct the portfolio on the combined signal. On the other hand the histogram for the Mixed approach has more mass around the mean than in the tails. This is a result of the netting that can take place if at a given point in time we obtain for an asset a long position for one signal and a short position for another. As a result, the histogram will converge to a normal distribution for a sufficiently large number of assets per the central limit theorem. This netting effect in Mixed can lead to time varying leverage as the degree of netting between Signals 1 and 2 changes over time. The histogram shows that for the Mixed case situations in which an asset receives large signals in the same direction can lead to particularly sizable allocations.

Table 2: Performance Statistics. The table below shows the performance statistics of portfolios combining two signals in a long/short investment context using the introduced simulation methodology. Performance statistics are calculated on simulated monthly excess returns. Avg and Std reference average and standard deviation of simulated excess returns, respectively. Sharpe ratios are calculated as the ratio between Avg and Std.

Type	Returns Signal 1	Returns Signal 2	Integrated	Mixed
Avg	2.9%	2.9%	4.1%	4.4%
Std	2.9%	3.0%	2.9%	3.1%
Sharpe	1.00	0.98	1.42	1.40
Min	-7.6%	-9.4%	-7.1%	-6.9%
Max	15.3%	14.0%	14.1%	16.6%
Skewness	0.03	0.01	-0.04	0.04
Excess Kurtosis	0.00	0.02	0.02	0.07

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially.
Source: GSAM.

After discussing the weight histogram we turn to comparing the performance of portfolios that combine the information in the two signals by using Mixed or Integrated. As Table 2 illustrates there is no economically significant difference between the two methodologies to combine signals in terms of risk-adjusted returns. For the Mixed approach we obtain a Sharpe ratio of 1.40 which is in line with the Integrated Sharpe ratio of 1.42. This result illustrates that the economically noticeable differences in the Sharpe ratio observed for Mixed versus Integrated signal combination in the long-only case do NOT carry over into the long/short space. Mixed achieves higher expected returns and volatility than Integrated while showing the same average gross leverage over the course of the simulation. Thus, it leads to a more capital efficient way to achieve a return objective. It is important to note that return differences between Signal 1 and 2 are driven by the noise in the simulation.

Table 3: Testing for Significance in Selected Performance Statistics. The table shows the differences of average, standard deviation and Sharpe ratios of returns for Mixed and Integrated obtained when using the introduced simulation methodology. The significance of the differences is evaluated using the Boot-IID methodology by Ledoit and Wolf (2008). Significance at the 10% / 5% / 1% / level is indicated by * / ** / ***.

Type	Integrated	Mixed	Difference Mixed Minus Integrated	Significance of Difference
Avg	4.1%	4.4%	0.2%	***
Std	2.9%	3.1%	0.2%	***
Sharpe	1.42	1.40	-0.02	***

Next we assess the significance of the simulated performance metrics using the methodology by Ledoit and Wolf (2008). The results of this analysis are shown for selected statistics in Table 3. For the Sharpe ratio we obtain a difference of 0.02 in favour of Integrated which is economically negligible but statistically significant at the 1% level.[4] The higher expected returns (+0.2 percentage points) and volatility (+0.2 percentage points) achieved when using Mixed compared to Integrated are also significant at the 1% level. Here, again, we obtain results which are significant statistically but not economically.

Table 4: Transfer Coefficients. The table shows the transfer coefficients between the signals and the corresponding portfolio weights. The transfer coefficient is the rank correlation coefficient between a signal and the corresponding portfolio weights.

Weight Methodology	Transfer Coefficient to Signal	Mean	Std	Min	Max
Mixed	1	0.70	0.04	0.54	0.82
	2	0.70	0.04	0.54	0.82
Integrated	1	0.68	0.06	0.41	0.87
	2	0.68	0.06	0.44	0.85

[4] It can be shown in simulations and analytically that the differences in Sharpe ratios between Mixed and Integrated remain economically negligible as long as the magnitude of the signal volatility remains low relative to the volatility of the noise.

We next turn to study the transfer coefficient which is defined as the rank correlation coefficient between a signal and the weights determined based on the signal information. The transfer coefficients of signal 1 and 2 are higher for Mixed (mean transfer coefficient of 0.70) than for Integrated (mean transfer coefficient of 0.68) as can be seen in Table 4. Those differences are found to be statistically significantly higher for Mixed at the 1% significance level. The minimum transfer coefficient for Integrated can drop to as far as 0.41 while the lowest number we see for the transfer coefficient for Mixed is 0.54. The analysis also finds larger variation of transfer coefficients found for Integrated (0.06) than for Mixed (0.04). These results illustrate that the Mixed approach is allowing for a better signal capture when combining the information of various signals.

Using the transfer coefficients on the respective signal on a standalone basis, we get to values of 1 (not reported). This is not surprising given that our linear ranking does not change the order of the signal ranking and is a mathematical feature of this portfolio construction approach that is worth highlighting.

2.5. Portfolio Construction

Having analysed a portfolio construction based on linearised rankings, we are now moving to an analysis where we use percentiles. Long and short sides of the portfolio are constructed by equally weighting assets whose rank is in the top x-th percentile or in the bottom x-th percentile, respectively.

We start with a comparison of performance using a percentile of 30% for the Mixed and Integrated approach to signal combination. Results are summarized in Table 5.

Table 5: Performance Statistics Using a Percentile Cut-off at 30%. The table below shows the performance statistics of portfolios using the two simulated signals independently and combining them using Mixed and Integrated. The portfolio construction methodology weights the simulated assets equally using a 30% cut-off level on the long and the short side. Performance statistics are calculated on simulated monthly excess returns. Avg and Std reference average and standard deviation of simulated excess returns, respectively. Sharpe ratios are calculated as the ratio between Avg and Std.

Type	Signal 1	Signal 2	Integrated	Mixed
Avg	3.0%	3.0%	4.3%	4.3%
Std	3.3%	3.3%	3.3%	3.3%
Sharpe	0.92	0.91	1.30	1.29
Min	-8.8%	-10.1%	-8.1%	-9.1%
Max	16.0%	14.9%	16.7%	16.7%
Skewness	0.02	0.03	-0.04	0.05
Excess Kurtosis	0.00	-0.04	-0.04	0.12

Compared to the linear ranking approach Sharpe ratios decay for all scenarios. However, there is no economically significant difference in risk-adjusted returns between Integrated and Mixed. Consistent with the linear ranking approach, the skewness of the Mixed approach is higher than the Integrated one.

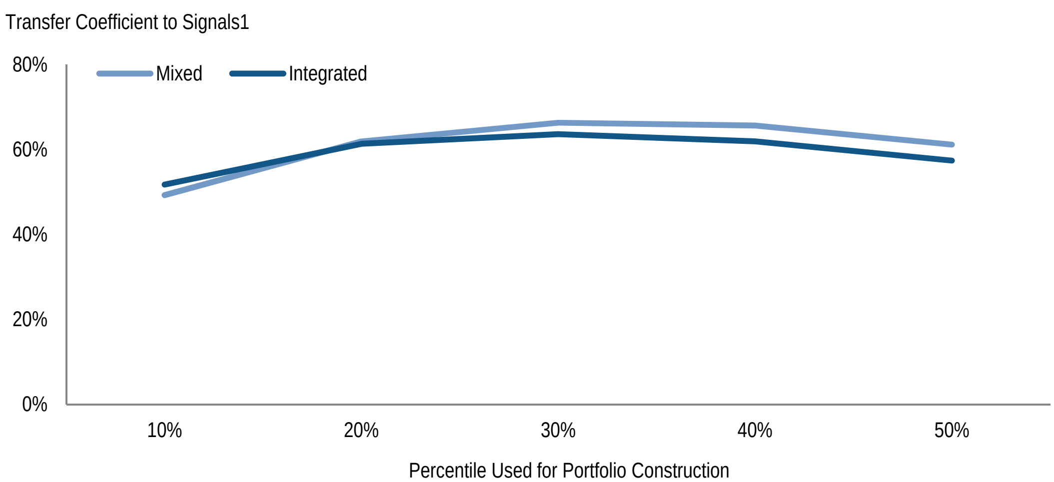
These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially.
Source: GSAM.

Table 6: Performance Statistics for Different Percentile Cut-offs. The table below shows the performance statistics of portfolios using Mixed and Integrated to combine the two simulated signals. The portfolio construction methodology weights the simulated assets equally using cut-off levels on the long and the short side ranging from 10% to 50%. Performance statistics are calculated on simulated monthly excess returns. Sharpe ratios are calculated as the ratio between average and standard deviation of monthly excess returns.

Percentile		10%	20%	30%	40%	50%
Mixed	Sharpe	1.13	1.27	1.29	1.23	1.14
	Skewness	0.035	0.016	0.049	0.058	0.041
	Excess Kurtosis	-0.048	0.041	0.124	0.034	-0.049
Integrated	Sharpe	1.11	1.28	1.30	1.25	1.16
	Skewness	0.013	0.014	-0.044	-0.064	-0.084
	Excess Kurtosis	-0.016	0.041	-0.042	-0.048	0.014

Table 6 summarizes performance characteristics using a range of percentile cut-offs. Risk-adjusted performance is marginally better for the Mixed approach when looking at a percentile cut-off of 10% but then tips in favour of the Integrated approach for the more balanced percentiles. Skewness is consistently in favour of the Mixed approach, showing how the portfolios constructed using Mixed tend to be more balanced.

Figure 2: Transfer Coefficient for Different Percentile Cut-offs. The figure shows the transfer coefficients for the simulated signals for the Mixed and Integrated portfolios. The portfolio construction methodology weights the simulated assets equally using cut-off levels on the long and the short side ranging from 10% to 50%. The transfer coefficient is the rank correlation coefficient between a signal and the corresponding portfolio weights.



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Source: GSAM.

The transfer coefficients for Mixed as well as Integrated follow a concave shape as we increase the percentiles used for the portfolio construction from 10% to 50% (compare Figure 2 for Signal 1; results for Signal 2 are visually indistinguishable and not reported here for brevity). The highest transfer coefficient is achieved for a percentile of 30%. This result is not surprising as essentially we categorise assets in a percentile context in three buckets – long, neutral, short. The more similar these buckets are in terms of their size, the higher the transfer coefficient. Mixed delivers the highest transfer coefficient in the mid and high ranges of the percentiles (e.g., percentile of 30%) while Integrated fares better in the very small percentiles of 10%.

2.6. Additional Stability Tests

We run a range of additional stability tests.

Our first stability test concentrates on the validity of our results in an environment with a higher number of signals (compare Appendix A1 for details). In this analysis we run Integrated and Mixed on portfolios which are driven by 2 to 20 signals and compare the resultant Sharpe ratios. To ensure comparability we keep the signal-to-noise ratios constant in this analysis by driving in all cases 2% of total variance in returns by signals. The analysis illustrates that our results in comparing Mixed and Integrated are consistent and independent from the number of signals.

We study the impact different levels of correlations between signals have on our conclusions (compare Appendix A2 for details). The corresponding analyses illustrate how the differences between the Sharpe ratios of Mixed and Integrated remain negligible even when signals are negatively or positively correlated. Transfer coefficient are the higher the more correlated the signals are which applies equally to Mixed and Integrated. An increased correlation between signals is found to lead to higher Sharpe ratios of the overall portfolio for the Integrated and Mixed case. Thus, our general conclusions concerning the comparison of the Mixed and Integrated approach are not altered by this variation.

Another question one might ask is if the results are different in portfolios where we introduce correlations between the noise terms of the returns. We show in Appendix A3 that an increase in such correlations of the noise component leads to higher Sharpe ratios generally which is not surprising given that a higher correlation means that more risk will be netted out in our long/short portfolio construction. There is little difference in the Sharpe ratios between the Integrated and Mixed methodology for different levels of correlations. Although for very large correlations of 0.8 and more between assets there is a marginal benefit for the Integrated approach.

In Appendix A4 the stability test evolves around the impact of using different distributional assumptions for the signals. In particular, normal, uniform, student t, and centered lognormal distributions are being used. A larger Excess Kurtosis in signals as represented, for example, by the uniform and the student t distributions has no economically significant impact on the relative attractiveness of Mixed and Integrated. For a non-symmetric distribution of signals, such as the one modelled through a centred lognormal distribution we do get better results for the Integrated approach (Sharpe ratio of 1.10) when compared to the Mixed approach (Sharpe ratio of 0.99). However, the transfer coefficient in the centred lognormal case is higher for the Mixed approach. Overall our results appear to be rather robust to changes in the distributional assumptions of the signals.

Finally, we add a noise term to the signal itself and interact it with the magnitude of the signal (compare Appendix A5 for details). This allows a simulation of scenarios in which larger signals tend to also contain more noise. While an increased noise level in the signal deteriorates the performance of the simulated strategies as we would expect, there is no economically relevant difference between Mixed and Integrated in their robustness to signal noise from a performance angle.

We conclude after this series of stability tests that our methodology and the corresponding results are robust.

3. Mixed Versus Integrated Using Common Factor Strategies in Various Asset Classes

3.1. Data and Methodology[5]

While the previous section concentrated on a simulation analysis allowing us to study certain aspects of the Mixed and Integrated approach for signal combination in a controlled environment, this section analyses the benefits of Mixed versus Integrated for a range of financial markets using their actual historical data. In our analysis we focus on the major asset classes (equities, fixed income, foreign exchange, and commodities). In each one of those asset classes we implement commonly used style portfolios based on value, carry, and momentum.

In equities the investment universe consists of 13 equity index futures: Amsterdam Exchange, South Africa Top40, S&P 500, CAC 40, DAX, FTSE 100, Hang Seng, TOPIX, Kospi, IBEX 35, SGX S&P CNX Nifty, MSCI Taiwan Stock, and S&P/TSX 60. The carry score is calculated as the future basis. The value score is computed as Book-to-Price of the respective index.

In fixed income we implement the strategy in a set of six liquid futures markets (Canada, Germany, United Kingdom, Japan, United States, and Australia) where we invest in the corresponding 10 year futures. Our carry signal is based on the carry and roll down that is achievable in the respective bond market. The value metric is based on the long run mean reversal of government bond rates to their 5 year average.

Foreign exchange strategies are implemented in 23 liquid currency markets: AUD, BRL, CAD, CHF, CLP, EUR, GBP, HUF, IDR, ILS, INR, JPY, KRW, MXN, NOK, NZD, PHP, PLN, RUB, SEK, TRY, TWD, and ZAR. We only trade the USD crosses of the above currency markets using 1 month currency forwards. The carry score is defined as the log of spot exchange over forward price.[6] The value score is based on the percentage deviation of a currencies fair value, as determined through the Goldman Sachs Behavioural Equilibrium Exchange Rate value model, from the corresponding current spot price.[7] The value signal exploits expected mean reversal of spot to the fair value.

In commodities we trade 19 liquid futures contracts: Corn, Crude Oil (WTI), Cotton, Gold, Copper (COMEX), Heating Oil, Aluminum, Lead, Nickel, Zinc, Coffee ,Crude Oil (Brent), Gasoil, Natural Gas, RBOB Gasoline, Soybeans, Sugar, Silver, and Wheat (Chicago). The carry score in this universe is the slope between the two front contracts relating to a commodity which is calculated as the difference between future price of the expiring contract and the future price of the contract further out and normalizing this metric by the future price of the expiring contract. Value in commodities is driven by a mean reversion argument. The value score is defined as the log of the ratio the future price of the expiring contract over the future price 5 years ago.

The momentum score is defined uniformly for all markets as the cumulative return of the rolling future or FX forward system over the past 12 months skipping the most recent month, i.e. the signal uses 11 months of returns lagged by one month.

5 Note that the strategies and signals discussed in this section may or may not be related to the strategies actually implemented by the Goldman Sachs Asset Management Alternative Investment Strategies group.

6 For non-deliverable forwards we use a spot proxy.

7 Compare Goldman Sachs (2005) for more details.

Table 7: Performance Summary of Styles across Asset Classes. The table below shows the performance statistics of style portfolios (Carry, Momentum, and Value) across different asset classes (Fixed Income, Foreign Exchange, Commodities, and Equities). All statistics are computed using monthly data. The investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

Asset Class	Style	Annualized Avg ER	Annualized Std	Sharpe	Skewness	Excess Kurtosis
Fixed Income	Carry	3.7%	5.4%	0.68	0.1	1.4
	Momentum	1.9%	6.5%	0.30	-0.2	1.4
	Value	0.3%	6.3%	0.04	-0.2	1.7
Foreign Exchange	Carry	6.8%	8.9%	0.77	-0.3	0.7
	Momentum	1.2%	7.9%	0.16	-0.1	0.3
	Value	3.3%	6.3%	0.53	0.3	0.7
Commodities	Carry	8.0%	10.1%	0.79	0.4	1.2
	Momentum	2.4%	11.1%	0.22	0.4	1.5
	Value	-0.4%	12.9%	-0.03	-0.3	0.7
Equities	Carry	5.7%	9.3%	0.61	0.2	-0.2
	Momentum	-1.2%	10.8%	-0.11	-0.3	1.6
	Value	-0.7%	9.6%	-0.07	-0.2	0.7

The signals are determined by normalizing all scores in the cross section by subtracting the mean and dividing by the cross sectional standard deviation for a given date. The portfolio is constructed using a linear ranking methodology where we first rank all the assets in the given asset class according to the signal in question for a specific date. We then apply a linear portfolio construction methodology where we assign a weight of +100% to the asset with the highest rank (i.e., the most attractive asset) and -100% to the asset with the lowest rank (i.e., the least attractive asset). For the remaining assets there is a linear trade-off between rank and weight. Those weights are then multiplied by a static asset class specific factor to adjust for the different investment universe sizes.[8]

We rebalance all portfolios on a monthly basis. Our base case assumes no transaction costs.

[8] We apply static leverage multipliers of 1.00, 0.20, 0.11, and 0.33 for fixed income, foreign exchange, commodities and equities, respectively.

Table 8: Signals and Weights for Momentum and Value in Foreign Exchange. The below table shows the signals and weights for each currency (vs USD) for Momentum and Value in Foreign Exchange. Data is as of July 2017. Weights for Mixed are normalized to have the same gross leverage as Integrated.

	Signals		Weights	
Currency (vs. USD)	Momentum	Value	Integrated	Mixed
TRY	-1.78	1.90	0.27	-0.08
JPY	-1.55	0.27	-0.82	-0.41
PHP	-0.82	-0.07	-0.55	-0.74
SEK	-0.81	1.25	0.55	0.00
GBP	-0.70	0.05	-0.27	-0.41
CAD	-0.59	-0.27	-0.36	-0.58
CHF	-0.53	-1.30	-1.00	-1.32
EUR	-0.43	0.07	-0.18	-0.08
NOK	-0.38	2.41	0.91	0.66
KRW	-0.23	-1.01	-0.73	-0.90
CLP	-0.21	0.04	-0.09	0.00
NZD	-0.20	-1.20	-0.91	-0.82
AUD	-0.14	-0.73	-0.45	-0.33
HUF	-0.09	0.15	0.18	0.49
IDR	-0.06	-0.82	-0.64	-0.33
TWD	0.28	-0.30	0.00	0.16
MXN	0.57	0.37	0.64	0.90
PLN	0.57	0.56	0.73	1.07
INR	0.66	-0.68	0.09	0.25
ILS	0.83	-0.67	0.36	0.41
BRL	1.03	-0.86	0.45	0.08
ZAR	2.28	1.62	1.00	1.56
RUB	2.32	-0.81	0.82	0.41

Our analysis evaluates the effect over an investment period from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

In Table 7 the performance of the styles are summarized across asset classes. The strongest performance comes from the carry style which achieves a Sharpe ratio between 0.61 (Equities) and 0.79 (Commodities). The strategies which returns a negative Sharpe ratio are the Commodities Value (-0.03), Equity Momentum (-0.11), and Equity Value (-0.07). The skewness we calculate for the strategies is between -0.3 and 0.4. The Excess Kurtosis is between -0.2 and 1.7. Both moments indicate that the risk of extreme events is comparably limited and that the strategies do not suffer from any outsized tail risks.

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We repeat this analysis taking transaction costs into account. The results are consistent with the ones discussed in this section and are reported in Appendix A6.[9] After deducting estimated transaction costs the Sharpe ratios come out between -0.15 (Equity Momentum) and 0.74 (Commodity Carry). This equates to a reduction of Sharpe ratios between 0.03 and 0.14 because of transaction costs. Our results indicate that in the liquid markets where we implement the styles the impact of transaction costs on the results is limited. An efficient trading and implementation framework can help to reduce these costs to make them even less impactful. Thus, we continue to focus on the analysis of results before transaction costs.

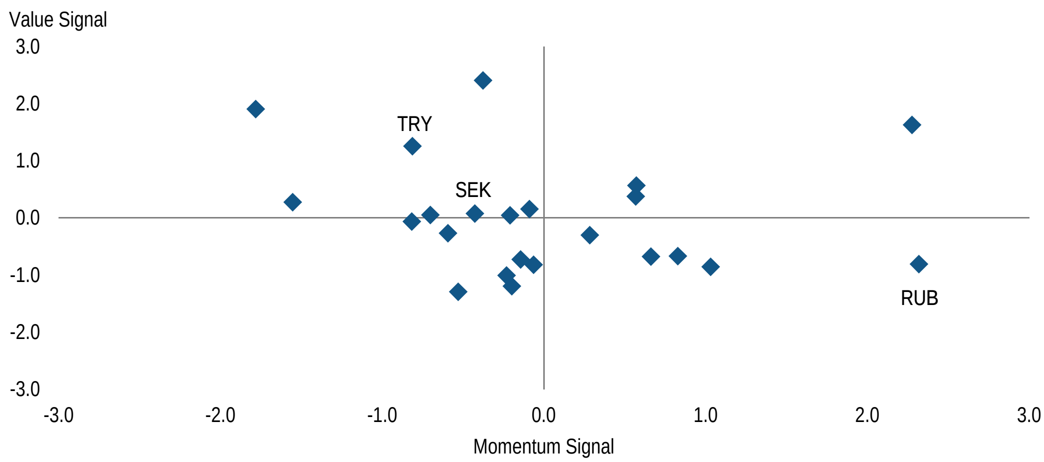
3.2. An Example Using FX Value and Momentum

Next we set out to combine the different style portfolios within an asset class. We start the analysis using a specific example to illustrate the interaction between empirical signal values and the resulting Mixed and Integrated portfolios based on these signals. In this example we will use a combination of Momentum and Value for FX at a specific date.

We show signals and weights as of July 2017 in Table 8 as well as a graphical representation of this information in Figures 3 and 4. One interesting case is TRY which has a strong negative momentum signal (-1.78) and a strong positive value signal (+1.90). They offset each other and resulting signals for both the Integrated and Mixed approaches are small (0.27 and -0.08). On the other side, RUB has a strong momentum signal (2.32) but a moderately negative Value signal (-0.81). The negative Value signal partially offsets the Momentum signal leading to moderately long positions in RUB for Integrated and Mixed (0.82 and 0.41, respectively). More generally, the data illustrates how Momentum and Value signals are negatively correlated (-18%).

Figure 3: Momentum and Value signals for Foreign Exchange. Figure shows the signals for each currency (vs USD) for Momentum and Value in Foreign Exchange. Data is as of July 2017.

Signals

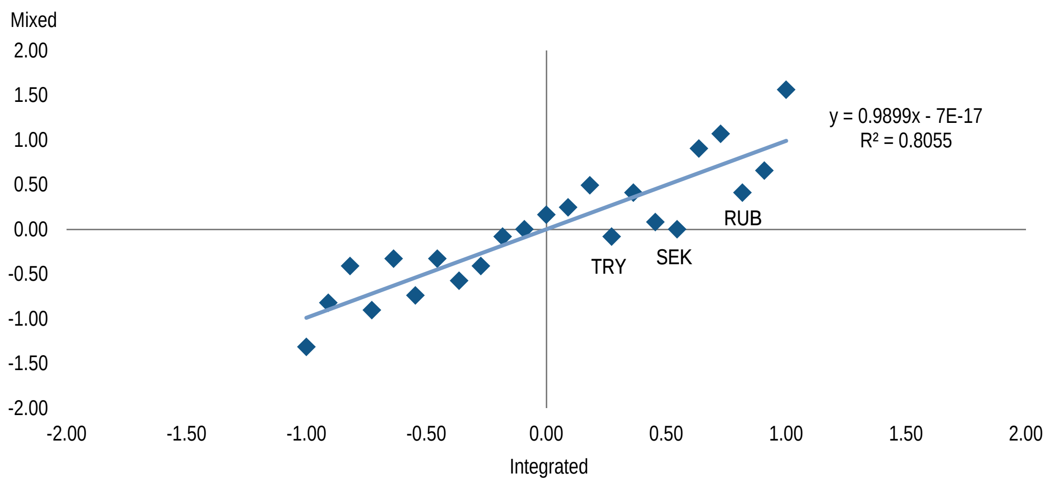


Weights for the Integrated and Mixed combinations of Momentum and Value are shown in Figure 4. The weights of portfolios constructed using Mixed and Integrated are rather similar as can be illustrated with the high correlation (90%) between the corresponding weights. Furthermore, the slope of regressing Mixed on Integrated weights comes out close to 1 which provides additional evidence for the similarity between the resulting weights.

[9] We give additional details on the modelling of the transaction costs in Appendix A6.

Figure 4: Mixed and Integrated Weights for Momentum and Value Signals in Foreign Exchange. Figure shows the weights for each currency (vs USD) for Momentum and Value in Foreign Exchange. Data is as of July 2017. Weights for Mixed are normalized to have the same gross leverage as Integrated.

Weights



3.3. Comparing the Mixed and Integrated Methodologies Across Style Combinations in an Asset Class

This section combines two out of three possible styles which results in three possible combinations: Carry-Momentum, Carry-Value, and Value-Momentum. We use the Integrated as well as the Mixed approaches. In Table 9 we give the Sharpe ratios associated with those combinations. We also report 90% confidence intervals for the Sharpe ratio differences using the Boot-IID approach by Ledoit and Wolf (2008).

On average the Mixed approach delivers a higher Sharpe ratio than the Integrated approach. For the Carry-Value combinations within an asset class the Sharpe ratios are on average 0.61 across asset classes when using Integrated and 0.66 when using Mixed, which is the smallest difference of 0.05 in favour of Mixing across the strategy space. The largest difference between the two approaches for signal combination is for Value-Momentum and Carry-Momentum which comes out with a lead of 0.08 in the average Sharpe ratio for Mixed.

When combining all three strategies – Value, Carry, and Momentum – the average Sharpe ratio is with 0.68 in favour of the Mixed versus the Integrated approach (at a Sharpe ratio of 0.59). In the case of combining all three styles, we find in each one of our asset classes an advantage for Mixed.

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Table 9: Sharpe Ratios Achieved when Aggregating Styles within Asset Classes. The table below shows Sharpe ratios of portfolios combining different styles using Integrated and Mixed across different asset classes. Sharpe ratios are computed based on monthly data. The confidence intervals labelled "90% Confidence Interval (Mixed - Integrated)" are computed using the Boot-IID approach by Ledoit and Wolf (2008). The investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

		Fixed Income	Foreign Exchange	Commodities	Equities	Mean
Carry-Momentum	Integrated	0.62	0.53	0.47	0.13	0.44
	Mixed	0.56	0.62	0.58	0.33	0.52
	90% Confidence Interval (Mixed - Integrated)	(-0.20;0.07)	(-0.02;0.19)	(-0.003;0.20)	(0.01;0.35)	
Carry-Value	Integrated	0.52	0.95	0.53	0.42	0.61
	Mixed	0.58	1.00	0.68	0.37	0.66
	90% Confidence Interval (Mixed - Integrated)	(-0.17;0.26)	(-0.09;0.18)	(-0.08;0.34)	(-0.22;0.10)	
Value-Momentum	Integrated	0.53	0.51	0.11	-0.15	0.25
	Mixed	0.48	0.66	0.27	-0.09	0.33
	90% Confidence Interval (Mixed - Integrated)	(-0.30;0.21)	(-0.06;0.32)	(-0.03;0.31)	(-0.16;0.25)	
Value-Carry-Momentum	Integrated	0.72	0.79	0.60	0.25	0.59
	Mixed	0.74	0.95	0.74	0.29	0.68
	90% Confidence Interval (Mixed - Integrated)	(-0.18;0.21)	(0.01;0.28)	(-0.06;0.30)	(-0.16;0.20)	
Mean		0.59	0.75	0.50	0.19	0.51

While Mixed has in general the higher Sharpe ratio, the difference in the Sharpe ratios is not statistically significant at the 95% confidence level. At 90% confidence[10] Mixed has a statistically higher Sharpe ratio than Integrated only for 2 cases: Value-Carry-Momentum for foreign exchange and Carry-Momentum for equities (in bold in Table 9). It is consistent with our simulations that Mixed and Integrated have similar performance.

In the Appendix A7 we show additional statistics for the different signal combinations.

[10] All other confidence intervals contain zero i.e. the difference in the Sharpe ratios is not statistically significant.

Table 10: Transfer Coefficients Achieved when Aggregating All Styles within Asset Classes. The table shows the transfer coefficients between the signals and the corresponding portfolio weights. The rows labeled Difference (Mixed vs Integrated) show the difference in correlations between Transfer Coefficients for Mixed and Integrated. The statistical significance of the difference at the 10% / 5% / 1% level is indicated by * / ** / *** using the the Boot-IID approach by Ledoit and Wolf (2008). The transfer coefficient is the rank correlation coefficient between a signal and the corresponding portfolio weights. The investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

		Carry	Momentum	Value
Fixed Income	Integrated	84%	45%	14%
	Mixed	86%	48%	18%
	Difference (Mixed vs Integrated)	2%***	3%**	5%***
Foreign Exchange	Integrated	62%	48%	36%
	Mixed	70%	54%	35%
	Difference (Mixed vs Integrated)	7%***	6%***	-1%*
Commodities	Integrated	57%	59%	15%
	Mixed	71%	65%	8%
	Difference (Mixed vs Integrated)	14%***	6%***	-7%***
Equities	Integrated	59%	46%	45%
	Mixed	66%	49%	46%
	Difference (Mixed vs Integrated)	7%***	3%***	1%

In Table 10 we aggregate an overview of the transfer coefficients which corresponds to a portfolio combining all the styles within an asset class (carry, value, momentum). What we find generally is that the transfer coefficients tend to be higher for the Mixed than for the Integrated case. The differences between the transfer coefficients for Mixed and Integrated are statistically significant for most of the cases (amongst the twelve cases shown in Table 10 ten are in favour of Mixed). Another interesting observation is that the transfer coefficient tends to be the highest for carry and the lowest for value investing. One driver of this result is a negative correlation of value with carry and momentum: the average pairwise correlation for value is -33%, while it is -9% for momentum and +9% for carry.

Further statistics on transfer coefficients are given in Table A8 in the Appendix.

3.4. Winsorizing Signals to Reduce Impact of Outliers

One of the challenges which we face combining empirical signals is that they have different distributions. The Mixed approach is not as sensitive to the signal distribution as each signal is ranked independently. However, the Integrated approach can be more sensitive and would essentially require all signal distributions to be the same if the objective is to achieve a comparable contribution of each signal to the portfolio risk in the long term (assuming there are no structural biases in the signals). For example, if one signal were to have a larger cross sectional standard deviation than another, this signal would tend to dominate the Integrated score, $s_I^{i,t}$. To improve the comparability of signals the chosen methodology

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used in this analysis does a cross sectional normalization of each signal (i.e., demean signals and divide the demeaned signal by the cross sectional standard deviation) which ensures that all signals have the same cross sectional standard deviation. This methodology might still leave the Integrated score sensitive to fatter tails which are causing outliers in the signals. Ex ante it is not clear if such outliers are actually value enhancing in empirical portfolios. To test the impact of outliers, we Winsorized signals for each investment style for a given date and evaluate the resulting portfolios. More precisely the signals are Winsorized to be within the below interval using the Median Absolute Deviation (MAD):

$$\left[\underset{i}{\mathrm{median}}\, s_d^{i,t} - 3 \cdot \underset{i}{\mathrm{MAD}}\, s_d^{i,t}\, ; \underset{i}{\mathrm{median}}\, s_d^{i,t} + 3 \cdot \underset{i}{\mathrm{MAD}}\, s_d^{i,t}\right]$$

The impact of Winsorization on the performance of combined investment styles is shown in Table 11. For each style combination and each asset class we report results for Integrated without Winsorization, Integrated with Winsorization, and Mixed approaches. We test the impact of Winsorization using two measures: Sharpe Ratio and correlation between Integrated and Mixed.

Table 11: Performance and Correlation Statistics for Style Combinations for Winsorized Signals. The table below shows Sharpe ratios and correlations (vs Mixed) of portfolios combining different styles using Integrated without Winsorization, Integrated with Winsorization, and Mixed approaches across different asset classes. Sharpe ratios and correlations are computed based on monthly data. The difference row in the correlation part of the table shows the difference in correlations between Integrated With Winsorization vs Integrated W/O Winsorization. The statistical significance of the difference at the 10% / 5% / 1% level is indicated by * / ** / *** using the the Boot-IID approach by Ledoit and Wolf (2008). The investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

		Fixed Income	Foreign Exchange	Commodities	Equities	Mean
Sharpe Ratio						
Carry-Momentum	Integrated W/O Winsorization	0.62	0.53	0.47	0.13	0.44
	Integrated With Winsorization	0.59	0.56	0.53	0.16	0.46
	Mixed	0.56	0.62	0.58	0.33	0.52
Carry-Value	Integrated W/O Winsorization	0.52	0.95	0.53	0.42	0.61
	Integrated With Winsorization	0.49	0.96	0.70	0.37	0.63
	Mixed	0.58	1.00	0.68	0.37	0.66
Value-Momentum	Integrated W/O Winsorization	0.53	0.51	0.11	-0.15	0.25
	Integrated With Winsorization	0.51	0.48	0.21	-0.21	0.25
	Mixed	0.48	0.66	0.27	-0.09	0.33
Value-Carry-Momentum	Integrated W/O Winsorization	0.72	0.79	0.60	0.25	0.59
	Integrated With Winsorization	0.78	0.81	0.76	0.13	0.62
	Mixed	0.74	0.95	0.74	0.29	0.68
Correlation vs Mixed						
Carry-Momentum	Integrated W/O Winsorization	94.9%	96.7%	96.8%	92.4%	95.2%
	Integrated With Winsorization	94.9%	98.2%	98.1%	95.2%	96.6%
	Difference (Integrated With Winsorization vs Integrated W/O Winsorization)	0.0%	1.5%**	1.3%***	2.8%***	
Carry-Value	Integrated W/O Winsorization	87.2%	95.0%	86.7%	93.1%	90.5%

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	Integrated With Winsorization	87.5%	96.6%	92.3%	94.8%	92.8%
	Difference (Integrated With Winsorization vs Integrated W/O Winsorization)	0.3%	1.6%***	5.6%***	1.7%**	
Value-Momentum	Integrated W/O Winsorization	76.9%	90.5%	91.4%	89.4%	87.1%
	Integrated With Winsorization	80.4%	93.8%	93.2%	93.1%	90.1%
	Difference (Integrated With Winsorization vs Integrated W/O Winsorization)	3.5%**	3.3%***	1.8%**	3.7%***	
Value-Carry-Momentum	Integrated W/O Winsorization	85.4%	95.3%	91.8%	91.1%	90.9%
	Integrated With Winsorization	86.2%	96.9%	94.2%	93.4%	92.7%
	Difference (Integrated With Winsorization vs Integrated W/O Winsorization)	0.8%	1.6%**	2.4%**	2.3%**	

Winsorization improves the Sharpe ratio of the Integrated methodology for most of the style combinations and asset classes. The average Sharpe ratio increase is 0.02 across styles and asset classes. This increase in Sharpe ratio also indicates that – on average – extreme scores in one signal may overpower the information content in another signal leading to a reduced signal breadth deteriorating the Sharpe ratio. It is important to highlight here that unreported analyses showed that Winsorizing had little effect if performed on portfolios constructed using individual signals only, underlining that the improvement of Sharpe ratios we measure here is really driven by the positive effect the Winsorization has on the signal combination aspect. In other words, the improved Sharpe ratios observed when using Integrated with Winsorization appear to be less related to reducing an increased level of noise in extreme signals but rather related to a more balanced approach to combine signals.

For the 16 cases displayed in Table 11 we take the Sharpe ratio improvements obtained when introducing Winsorizing to the Integrated approach and regress them on the average Skewness and Excess Kurtosis,[11] respectively, of the underlying signals:

$$SR_i^{Integrated\ With\ Winsorization} - SR_i^{Integrated\ W\ /\ O\ Winsorization} = \alpha^S + \beta^S \cdot Avg\ Skewness_i + \varepsilon_i^S,$$

$$SR_i^{Integrated\ With\ Winsorization} - SR_i^{Integrated\ W/\ O\ Winsorization} = \alpha^K + \beta^K \cdot Avg\ Excess\ Kurtosis_i + \varepsilon_i^K,$$

where $i = 1 \dots 16$ is one of combinations (Asset Class and Style Combinations) in Table 11. $SR_i^{Integrated\ With\ Winsorization}$ and $SR_i^{Integrated\ W/\ O\ Winsorization}$ are the Sharpe ratios for the relevant combination i. $Avg\ Skewness_i$ and $Avg\ Excess\ Kurtosis_i$ are average skewness and excess kurtosis of signals in styles in the combination i.

[11] Please note that all numbers are cited in terms of Excess Kurtosis. The Skewness of the used signals ranges between -0.3 for Equity Carry and 1.2 for Foreign Exchange Carry. The Excess Kurtosis ranges between -0.7 for Fixed Income Momentum and 3.9 for Commodity Carry.

There is a stronger link between the Sharpe ratio improvement from adding Winsorizing to an Integrated portfolio and the underlying average signal Excess Kurtosis (R2 of 0.33). The beta estimate linking Sharpe ratio improvement from adding Winsorization and the average signal Excess Kurtosis (β^K) is at 0.06 (t-stat is 2.6). The economic relevance of this result can be illustrated using an example: assume we are integrating one signal with a cross sectional Excess Kurtosis of 0 with another one with a cross sectional Excess Kurtosis of 2. The average Excess Kurtosis of these two signals is 1, which leads to an expected improvement of the Integrated Sharpe ratio of 1 * 0.06 = 0.06 when adding the Winsorizing of the signals. These empirical results highlight how fat tails in signals may lead to a suboptimal signal combination if we do not impose a normalization step before the signal combination as we would do in Mixed or when using Integrated with Winsorizing. The R2 of the regression using the Skewness as explanatory variable is 0.00 indicating that this metric has little explanatory power for the changes in the Sharpe ratio observed when introducing Winsorizing to Integrated. We have to caveat these results though as the 16 observations we use are too few for robust statistical inference. However, this appears to be an interesting avenue for future research.

Winsorization increases correlations between Integrated and Mixed strategies for all tested combinations and the average increase is 2.2%. In most cases the increase is statistically significant at the 5% level. It brings the average correlation between Integrated and Mixed to as high as 93.0%. This consistent improvement of the correlations illustrates how there are similarities in the normalization introduced by the linear ranking based portfolio construction applied to the signals in the Mixed case and the introduction of signal caps and floors through the Winsorizing in the Integrated case.

All the above shows that the Integrated and Mixed approaches are similar and Winsorizing signals makes them even closer.

4. Discussion of Practical Aspects

This section compares the respective conceptual advantages for the Mixed and the Integrated approach.

A range of empirical and conceptual advantages can be listed for to the Mixed approach (compare Table 12). Firstly, mixed may be more robust when combining extreme values in just one signal with other moderate signal values. By imposing the portfolio construction on each signal before combining the information in the signals, the Mixed approach imposes a normalization step which dampens the extreme readings of an individual signal, leading to a more balanced way to combine the information across the various signals. To illustrate this point, let us assume two scenarios:

(1) In one scenario Signal 1 is particularly large exceeding the value for this signal for all other assets while Signal 2 is just above average for a specific asset. Let us further assume that the average of the two signals remains particularly large leading to this asset getting the largest portfolio weight in the Integrated approach but only a limited positive weight in the Mixed case as we combine the maximum weight achieved for Signal 1 with a neutral weight derived using Signal 2.

(2) In another scenario Signal 1 and Signal 2 are particularly large exceeding the respective values for all other assets. In this case we get the largest portfolio allocation for the respective asset using Mixed and Integrated.

In scenario (1) the Mixed approach would be more robust to the increased noise level often times observed in the context of the forecasting power of extreme signals while there are no significant differences in the methodologies in scenario (2). These considerations are consistent with the results obtained in the previous section where the return correlations between Mixed and Integrated increase when Winsorizing is introduced. While this holds for the portfolio construction methodologies applied on the signals in this article, it may not hold for alternative methodologies.

Secondly, the return attribution using Mixed is easier as the total returns of a portfolio can be decomposed into how the Mixed strategies contribute. Thirdly, Mixed allows for a modularization where asset managers can mix and weight strategies specifically towards client requests and then allocate the total assets under management to the individual strategies which are managed independently. Finally, the analyses in the previous sections showed that the Mixed portfolio consistently delivers a higher transfer coefficient. This indicates that Mixed delivers a higher signal capture in the overall portfolio which shows that it is more aligned with economic intent of the investor.

Table 12: Conceptual Advantages of Mixed and Integrated. Table summarizes conceptual advantages of the Mixed and Integrated approaches for signal combination.

Mixed	Integrated
■ More robust to increased noise in extreme signals ■ Return attribution easier as style factor returns are known ■ Modularisation of strategies allows easier customisation to client needs ■ Higher signal capture in the final portfolio	■ Information in the distribution of the scores is preserved until the integration step ■ Reduced turnover and transaction costs compared to mixing approach without netting ■ For long-only factors preserve information for assets in the underweight part of the portfolio ■ May be easier to implement in illiquid markets

There are also practical reasons which could prompt an asset manager to use Integrated. Firstly, the Integrated approach preserves the information inherent in signals until the final portfolio construction while Mixed already translates signals into weights for the individual signals before constructing the actual investment portfolio. Secondly, some implementation of the Mixed approach may lead to higher

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transaction costs as the underlying strategy portfolios are managed on an individual basis and trades in the same assets but with opposing directions are not netted across individual strategies. While this is an advantage of the Integrated approach where the netting happens implicitly on the signal level, many asset managers do have an efficient implementation of the Mixed approach where trades are netted across strategies held by an individual client before being brought to the market. Thirdly, Integrated can deliver higher performance in the long-only context for large tracking errors. Empirical results show though that for low to medium levels of tracking error – which is the predominant situation investors face – this effect disappears (compare Ghayur et al., 2018). Finally, the Integrated approach shows less extreme weights (compare Figure 1). While this does not lead to portfolios showing improved tail characteristics as measured by Skewness and Excess Kurtosis, there may be an advantage to implement Integrated in illiquid markets where larger allocation may be more difficult to implement.

In summary, there is a range of practical aspects investors need to consider when deciding between Mixed and Integrated which may tilt the preferences in one direction or the other. When executing efficiently and investing in a long/short investment paradigm, the balance of these considerations tips in our view in favour of Mixed.

5. Conclusion

The point of this analysis is to study the advantages and disadvantages of the Mixed and Integrated approach towards signal combination in a long/short context.

Using simulations, our results are in line with the literature by finding a benefit to the Integrated approach for signal combination in the long-only context for portfolios with large active risk. We discuss these results against the backdrop of Ghayur et al. (2018) who illustrate that for small to medium levels of active risk the Mixed approach outperforms. We contribute by extending this analysis to the context of long/short portfolios conducting simulations and empirical analyses. While simulations sharpen our understanding of the Mixed and Integrated approaches from a conceptual theoretical angle the empirical analysis complements our understanding through a specific application relevant in practice. Using such simulations and empirical data we find no economically meaningful performance differences between Mixed and Integrated. We can show in our analyses though that Mixed leads to a higher signal capture in the final portfolio as evidenced by the transfer coefficient.

Conceptually we find that Mixed is able to better express the additional information we obtain when an asset ranks highly in two signal dimensions at the same time rather than only having a high overall attractiveness score based on a combined signal. To the extent this feature adds value, Mixed can lead to advantages. Furthermore, Mixed allows an easier modularization of strategies and cleaner performance attribution which helps to efficiently manage multi-signal portfolios. Integrated can lead to lower turnover if the individual signal portfolios in the Mixed case are implemented separately without netting the corresponding trades. A further advantage of Integrated is a better preservation of signal information in portfolio implementations with constrained weights, such as in the long-only portfolio case.

While we have now illustrated that there are no substantial performance differences between the Mixed and Integrated approach in most empirical and simulated settings in a long/short context, there remain open questions. One set of questions evolves around the stability of the results in comparing Mixed and Integrated under different assumptions about the link between signals and future returns. Ideally the portfolio construction and signal combination methodology captures the full information content in signals to maximize the expected future returns of the portfolio. However, the precise empirical nature of how signals are linked to future returns is not fully researched yet but may have an impact on the preference between the Mixed and Integrated methodology to combine signals. Particular emphasis needs to be put on the functional form linking signals with future returns. Furthermore, the interaction between signal noise and signal magnitude is going to be relevant for comparing the different methodologies to combine signals. Such questions can be tackled with simulations as well as empirical analyses. A deeper understanding of such questions will allow investors to evaluate the pros and cons of Mixed and Integrated even better. In this context the generality of the findings in this article could be evaluated for more advanced portfolio construction techniques as well.

References

Asness, Clifford S., Tobias J. Moskowitz, and Lasse Heje Pedersen (2013): “Value and Momentum Everywhere,” Journal of Finance, 68 (3), pp. 929-985.

Baz, Jamil, Nick Granger, Campbell Harvey, Nicolas Le Roux, and Sandy Rattray (2015): “Dissecting Investment Strategies in the Cross Section and Time Series,” Working Paper, pp. 1-31.

Bender, Jennifer and Taie Wang (2015): “Tilted and Anti-Tilted Portfolios: A Coherent Framework for Advanced Beta Portfolio Construction,” Working Paper, pp. 1-28.

Bender, Jennifer and Taie Wang (2016): “Can the Whole Be More Than the Sum of the Parts? Bottom-Up versus Top-Down Multifactor Portfolio Construction,” Journal of Portfolio Management, Special Issue 2016, pp. 1-12.

Brunnermeier, Markus K., Stefan Nagel, and Lasse H Pedersen (2008): “Carry Trades and Currency Crashes,” Ed. Kenneth Rogoff, Michael Woodford, & Daron Acemoglu. NBER Macroeconomics Annual 2008, pp. 313-347.

Carhart, Mark M. (1997). ”On Persistence in Mutual Fund Performance,” Journal of Finance. 52 (1), pp. 57–82.

Christiansen, Charlotte, Angelo Ranaldo, and Paul Soederlind (2011): “The Time-Varying Systematic Risk of Carry Trade Strategies,” Journal of Financial And Quantitative Analysis, 46 (4), pp. 1107–1125.

Clarke, Roger, Harindra de Silva, and Steven Thorley (2016): “Fundamentals of Efficient Factor Investing,” Financial Analysts Journal, 72 (6), pp. 9–26.

Cochrane, John H. (2011): “Discount rates,” Journal of Finance, 66 (4), pp. 1047–1108.

Fama, Eugene F. and Kenneth R. French (1992): “The Cross-Section of Expected Stock Returns,” Journal of Finance, 47 (2), pp. 427–466.

Fama, Eugene F. and Kenneth R. French (1993): "Common risk factors in the returns on stocks and bonds," Journal of Financial Economics, 33 (1), pp. 3-56.

Fitzgibbons, Shaun, Jacques Friedman, Lukasz Pomorski, and Lauren Serban (2016): “Long-Only Style Investing: Don't Just Mix, Integrate,” Working Paper, pp. 1-18.

Ilmanen, Antti (2011): “Expected Returns,” John Wiley, United Kingdom.

Jegadeesh, Narasimhan and Sheridan Titman (1993): “Returns to Buying Winners and Selling Losers: Implications for Stock Market Efficiency,” Journal of Finance, 48 (1), pp. 65-91.

Jivraj, Farouk, David Haefliger, Zein Khan, and Benedict Redmond (2016): “Equity Multi-Factor Approaches: Sum Of Factors Vs. Multi-Factor Ranking,” QIS Insights, Barclays, pp. 1-22.

Ghayur, Khalid (Kal), Ronan Heaney, and Stephen Platt (2018): “Constructing Long-Only Multi-Factor Strategies: Portfolio Blending versus Signal Blending,” Financial Analysts Journal, Forthcoming, pp. 1-25.

Goldman Sachs (2005): “Merging GSDEER and GSDEEMER: A Global Approach to Equilibrium Exchange Rate Modelling,” Global Economics Paper, 124, pp. 1-28.

Koijen, Ralph S. J., Tobias Moskowitz, Lasse Pedersen, and Evert Vrugt (2016): “Carry,” Working Paper, pp. 1-56.

Ledoit, Oliver and Michael Wolf (2008): “Robust performance hypothesis testing with the Sharpe ratio,” Journal of Empirical Finance, 15 (5), pp. 850-859.

Leippold, Markus and Roger Rueegg (2016): “The Mixed vs the Integrated Approach to Style Investing: Much Ado About Nothing?,” Working Paper, pp. 1-38.

Lintner, John (1965): “The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets,” Review of Economics and Statistics, 47 (1), pp. 13–37.

Menkhoff, Lukas, Lucio Sarno, Maik Schmeling, and Andreas Schrimpf (2012): “Carry Trades and Global Foreign Exchange Volatility,” Journal of Finance, 67 (2), pp. 681-718.

Mossin, Jan (1966): “Equilibrium in a Capital Asset Market,” Econometrica, 34 (4), pp. 768–783.

Sharpe, William F. (1964): “Capital asset prices: A theory of market equilibrium under conditions of risk,” Journal of Finance, 19 (3), pp. 425–442.

Appendix

A1. Impact of the Number of Signals on the Comparison of Mixed and Integrated

Throughout the simulation component of this analysis the empirical work concentrates on combining the information in two signals. This section tests if the findings relating to performance when comparing Mixed and Integrated with two signals hold up in the context of multiple signals.

The analysis tests portfolios which are constructed with up to 20 signals using our base methodology introduced in Section 2.a. All signals s_i have the same volatility but we keep the signal-to-noise ratio constant by ensuring that 98% of the volatility of the assets is driven by noise in order to keep the results comparable across variations with different numbers of signals. This leads to the following signal distribution:

$$s_j^q \sim N\left(0, 0.0051^2 \cdot \frac{2}{q}\right) \ \forall q \in \{2,3,\ldots,9,10,15,20\}$$

where the subscript j identifies a specific signal and q is the total number of signals chosen for a specific iteration. The returns of an asset i at time t in a simulation with q signals is then

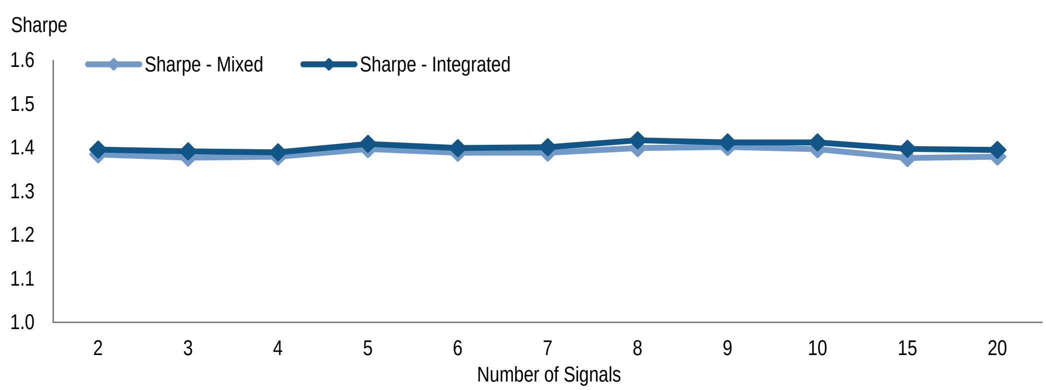
$$r_{i,t,q} = \sum_{j=1}^{q} s_j^{i,t,q} + \varepsilon^{i,t}$$

where $\varepsilon^{i,t}$ is defined as in Section 2.a.

The results of this analysis are summarized in Figure A1 which illustrates Sharpe Ratios (Panel A) and portfolio volatilities (Panel B) for different numbers of signals.

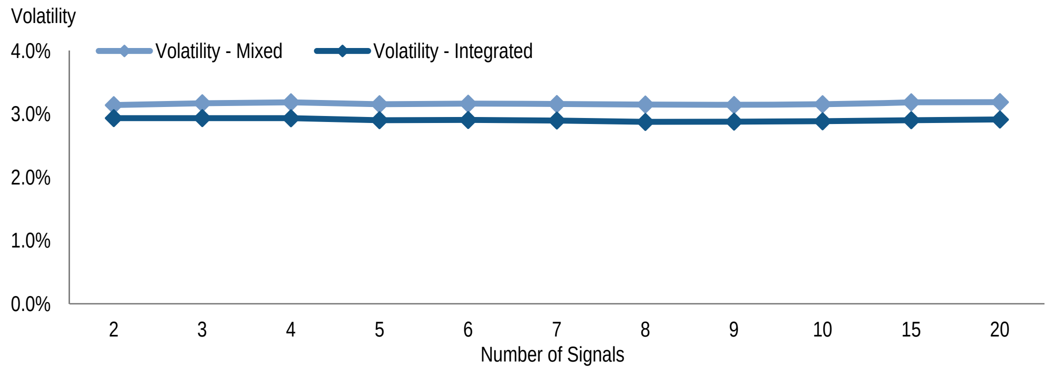
Figure A1: Comparing Mixed and Integrated Key Performance Metrics Conditional on the Number of Signals. Figure illustrates Sharpe ratios and volatility levels for the simulated signals and returns when combining to a portfolio using Mixed and Integrated. The number of simulated signals is varied between 2 and 20.

Panel A: Sharpe Ratio



These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. **Past performance does not guarantee future results, which may vary.** These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

Panel B: Volatility



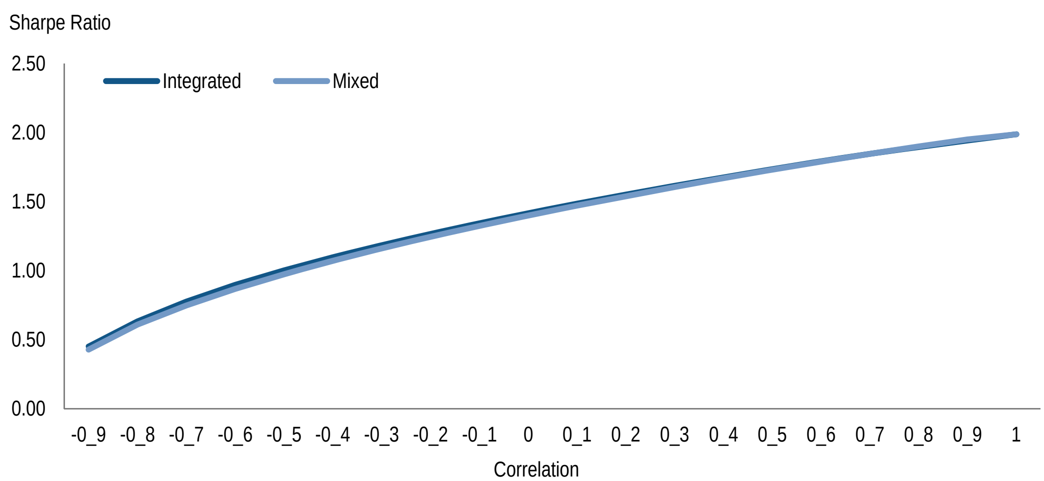
The results of this analysis show that the conclusions we had for our standard case of two signals apply equally for situations with a larger number of signals. Sharpe ratios range in rather close bandwidths (Mixed between 1.39 and 1.42 and Integrated between 1.38 and 1.40) for the studied number of signals and do not deviate economically significantly between the two methodologies for signal combination. A similar result applies for the volatility although Mixed returns consistently a marginally higher volatility.

Our conclusions when comparing Mixed and Integrated remain unchanged as we change the number of signals. This illustrates that our base case with two signals provides a good starting point for analysing more complex specifications for signals as we do in Sections 2.5 to 2.7.

A2. Impact of Signal Correlations

We would like to evaluate the impact of signal correlation between Signals 1 and 2 on our findings from the previous section. To this end we vary the correlation between our simulated signals to be between -0.9 and +1.0. A correlation of -1 leads in our setting to not having a signal (we drop this case in the following) and +1 to the signals being identical. This analysis will allow us to evaluate the effect similarities of signals has on the relative appropriateness of mixing versus integrating.

Figure A2.1: Portfolio Risk / Return Characteristics for Different Correlation Assumptions. Figure shows the Sharpe ratios obtained when modeling varying degrees of correlations amongst the simulated signals. Performance statistics are calculated on simulated excess returns.



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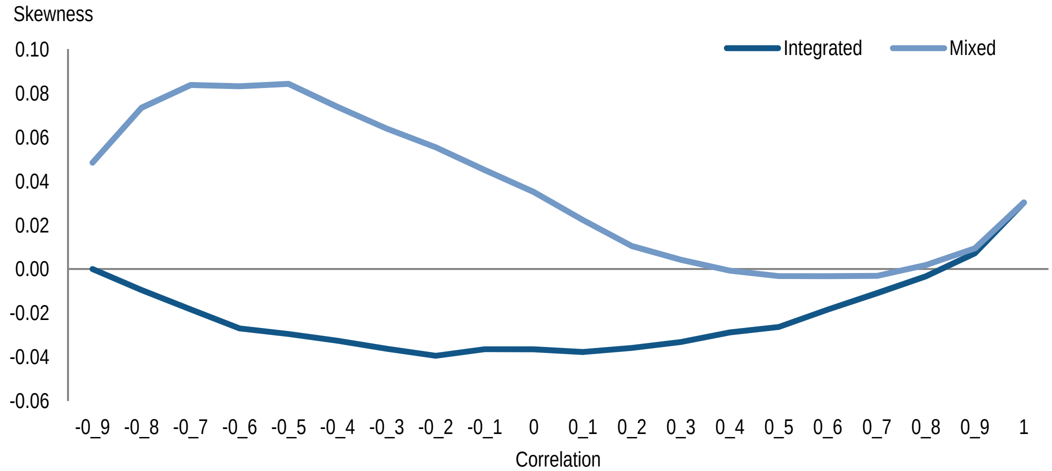
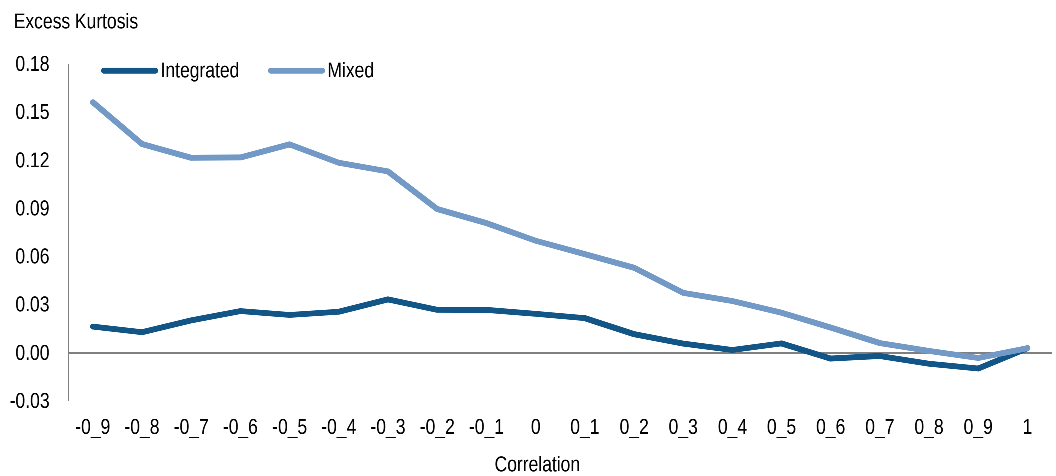
The Sharpe ratio of the portfolio grows monotonously as signal correlation increases, which is driven by the overall signal to noise ratio increasing in the simulation. The results indicate no significant differences between Mixed and Integrated.

Figure A2.2: Portfolio Return Skewness for Different Correlation Assumptions. Figure shows the Skewness for the Mixed and Integrated portfolios using simulated signals and returns for different degrees of correlations amongst the signals.



Concentrating on the higher moments of the portfolio returns the Integrated signal aggregation leads in our example to a marginally negative skewness which is at a minimum of -0.4 for a correlation of -0.2. Mixing signals leads generally to a positive skewness which is usually considered more favourable to investors. The Skewness of Mixed peaks with a value of 0.08 for a correlation of -0.5.

Figure A2.3: Portfolio Return Excess Kurtosis for Different Correlation Assumptions. Figure shows the Excess Kurtosis for the Mixed and Integrated portfolios using simulated signals and returns for different degrees of correlations amongst the signals.

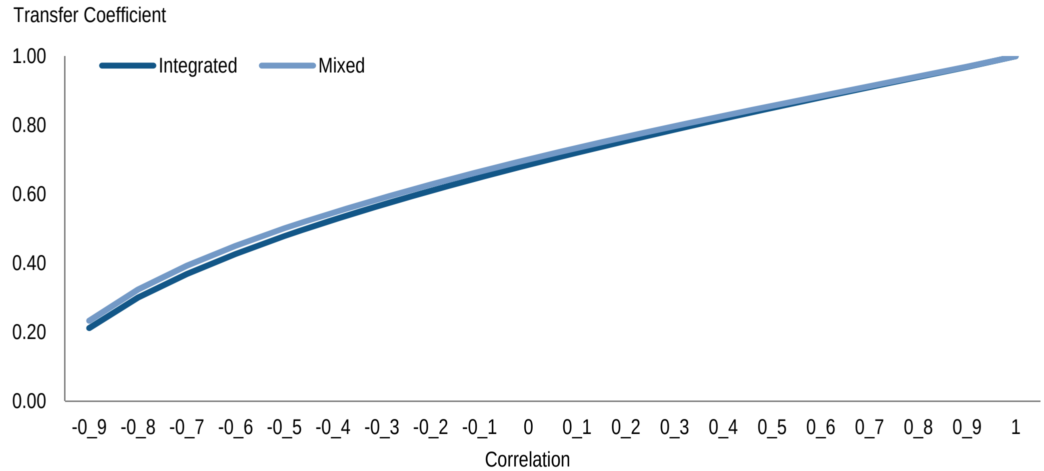


These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. **Past performance does not guarantee future results, which may vary.** These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

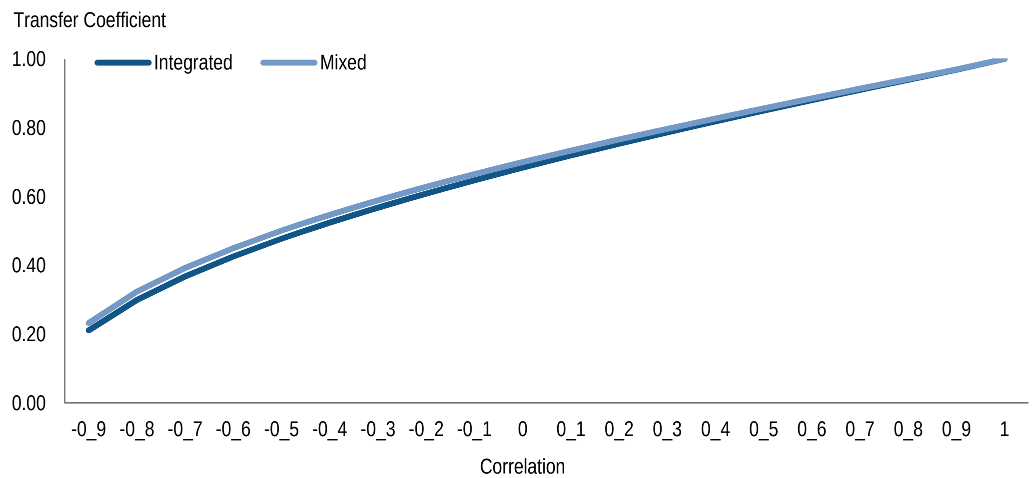
The Excess Kurtosis is higher for Mixed than for Integrated. The maximum Excess Kurtosis is 0.16 for the Mixed case at a signal correlation of -0.9 and 0.03 for the Integrated case at a correlation of -0.3. Neither one of these values has an alarming magnitude, illustrating that the signal correlation has little impact on the tail characteristics of portfolios and our comparison of Mixed versus Integrated.

Figure A2.4: Transfer Coefficient for Different Correlation Assumptions. Figure shows the transfer coefficients between the signals and the corresponding portfolio weights for different degrees of correlation amongst the simulated signals. The transfer coefficient is the rank correlation coefficient between a signal and the corresponding portfolio weights.

Panel A: Transfer Coefficient of Multi Signal Portfolios to Signal 1



Panel B: Transfer Coefficient of Multi Signal Portfolios to Signal 2



We also evaluate the impact of the signal correlation levels on the transfer coefficient. Mixed brings a higher transfer coefficient than Integrated for all correlations < 1. Mixed outperforms Integrated in this aspect by about 1 percentage point on average across the different correlation levels. For a correlation of 1 between the signals the transfer coefficient is 1 in all cases.

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. **Past performance does not guarantee future results, which may vary.** These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

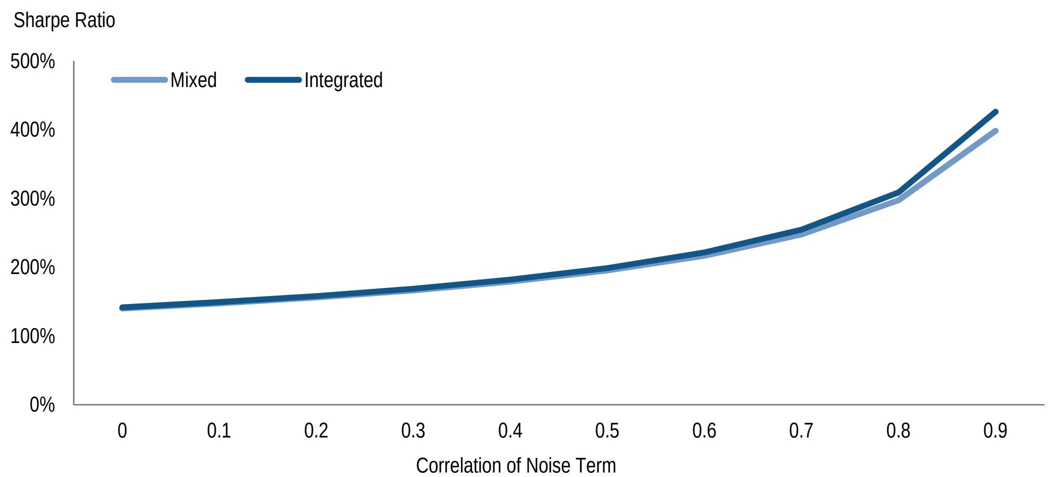
A3. Impact of Correlation in Noise Term on Results

We use a Cholesky matrix decomposition to simulate correlated noise terms. This essentially leads to the asset returns being equally correlated as the noise term dominates the simulated returns.

We would like to better understand if mixing versus integrating works significantly differently if the correlation structure of the underlying assets changes. Correlations between the noise term in the range of 0 (base case) and 0.9 are simulated. Results are summarized in Figure A3 and Table A3.

We find little differences between the Integrated and Mixed approach for combining signals for different correlation assumptions in the noise terms. The more correlated the noise terms are, the higher the risk-adjusted returns.

Figure A3: Sharpe Ratios as Function of Noise Correlation. Figure shows how the Sharpe ratios change when combining simulated signals using Mixed and Integrated under the assumption of different degrees of correlation amongst the simulated asset noise terms.



These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

Table A3: Performance Statistics for Different Noise Correlation Assumptions. The table below shows the performance statistics of portfolios combining two signals in a long/short investment context using the introduced simulation methodology. Different degrees of correlations amongst the noise terms of the asset returns are simulated ranging between 0.0 and 0.9. Performance statistics are calculated on simulated monthly excess returns. Avg and Std reference average and standard deviation of simulated excess returns, respectively. Sharpe ratios are calculated as the ratio between Avg and Std.

	Noise Correlation	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
Integrated	Avg	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%	4.1%
	Std	2.9%	2.8%	2.6%	2.4%	2.3%	2.1%	1.9%	1.6%	1.3%
	Sharpe ratio	1.42	1.49	1.58	1.69	1.82	1.99	2.22	2.55	3.09
	Min	-7.1%	-6.3%	-5.7%	-5.1%	-4.4%	-3.7%	-2.9%	-2.0%	-1.0%
	Max	14.1%	13.5%	13.0%	12.4%	11.8%	11.1%	10.4%	9.5%	8.6%
	Skewness	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
	Excess Kurtosis	0.02	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03
Mixed	Avg	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.4%	4.3%
	Std	3.1%	3.0%	2.8%	2.6%	2.4%	2.2%	2.0%	1.8%	1.5%
	Sharpe ratio	1.40	1.47	1.56	1.66	1.79	1.95	2.17	2.48	2.98
	Min	-6.9%	-6.4%	-5.8%	-5.1%	-4.4%	-3.7%	-2.9%	-1.9%	-0.8%
	Max	16.6%	15.9%	15.3%	14.6%	13.9%	13.1%	12.3%	11.3%	10.2%
	Skewness	0.04	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.07
	Excess Kurtosis	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07
Signal 1	Avg	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%
	Std	2.9%	2.8%	2.6%	2.4%	2.3%	2.1%	1.9%	1.6%	1.3%
	Sharpe ratio	1.00	1.06	1.12	1.20	1.29	1.41	1.56	1.79	2.17
	Min	-7.6%	-7.1%	-6.5%	-5.9%	-5.2%	-4.5%	-3.8%	-2.9%	-1.9%
	Max	15.3%	15.0%	14.3%	13.6%	12.8%	11.9%	11.0%	9.9%	8.6%
	Skewness	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	Excess Kurtosis	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03
Signal 2	Avg	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%	2.9%
	Std	3.0%	2.8%	2.6%	2.5%	2.3%	2.1%	1.9%	1.6%	1.4%
	Sharpe ratio	0.98	1.04	1.10	1.17	1.26	1.38	1.53	1.76	2.13
	Min	-9.4%	-8.3%	-7.8%	-7.1%	-6.4%	-5.6%	-4.7%	-3.7%	-2.6%
	Max	14.0%	13.3%	12.7%	12.1%	11.4%	10.7%	10.0%	9.1%	8.0%
	Skewness	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
	Excess Kurtosis	0.02	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.01

A4. Modify Signal Distribution

In our base case we modelled normally distributed signals. In this section we establish how this distributional assumption relates to our comparison of the Mixed and Integrated way to combine signals.

We apply four alternative distributional assumptions for our signals:

- Normal
- Centred Lognormal

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. **Past performance does not guarantee future results, which may vary.** These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

- Uniform
- Student T

The signals continue to have a mean of zero and a signal volatility of 0.0051 to ensure comparability. In this section we do not extend the sample of 10,000 simulated returns by the inverse (i.e., multiplied by -1) of the returns as this would counter the non-symmetric nature of the Centred Lognormal returns we simulate as part of this analysis.

Results are reported in Tables A4.1 and A4.2.

Table A4.1: Performance Statistics for Different Signal Simulation Distributions. The table below shows the performance statistics of portfolios combining two signals using Mixed and Integrated in a long/short investment context using the introduced simulation methodology. Different distributions are used to simulate the signals: Normal (Base Case), Centered Lognormal, Uniform as well as Student T with degrees of freedom (DF) ranging between 2 and 15. Performance statistics are calculated on simulated monthly excess returns. Avg and Std reference average and standard deviation of simulated excess returns, respectively. Sharpe ratios are calculated as the ratio between Avg and Std. Skew and Kurt reference Skewness and Excess Kurtosis, respectively.

		Normal (Base Case)	Centred Lognormal	Uniform	Student T.DF2	Student T.DF3	Student T.DF4	Student T.DF5	Student T.DF10	Student T.DF15
Integrated	Avg	4.1%	3.3%	4.2%	8.7%	6.3%	5.5%	5.1%	4.5%	4.4%
	Std	2.9%	2.9%	3.0%	3.7%	3.0%	3.0%	3.0%	2.9%	2.9%
	Sharpe	1.42	1.10	1.42	2.37	2.09	1.84	1.73	1.53	1.50
	Min	-7.1%	-7.9%	-6.9%	-4.9%	-5.1%	-6.5%	-5.5%	-7.1%	-5.5%
	Max	14.1%	15.8%	14.8%	73.3%	16.5%	18.0%	16.0%	15.2%	16.3%
	Skew	-0.04	0.04	-0.04	1.54	-0.02	0.01	-0.02	-0.05	0.03
	Kurt	0.02	-0.01	-0.04	17.08	-0.04	0.03	-0.10	-0.11	0.00
Mixed	Avg	4.4%	3.1%	4.5%	8.5%	6.3%	5.6%	5.3%	4.7%	4.6%
	Std	3.1%	3.1%	3.2%	3.7%	3.2%	3.2%	3.2%	3.2%	3.1%
	Sharpe	1.40	0.99	1.43	2.28	1.97	1.77	1.68	1.51	1.48
	Min	-6.9%	-8.5%	-7.4%	-5.0%	-5.3%	-6.9%	-6.0%	-6.5%	-6.3%
	Max	16.6%	15.7%	16.8%	55.0%	18.4%	18.4%	17.8%	16.1%	17.0%
	Skew	0.04	0.08	-0.01	0.75	0.05	0.07	0.03	0.00	0.07
	Kurt	0.07	0.03	0.00	4.86	0.01	0.11	-0.04	-0.05	0.02

The application of a Uniform signal distribution leads to little differences in risk-adjusted returns for Mixed (Sharpe ratio of 1.43) versus Integrated (Sharpe ratio of 1.42), which is consistent with the results using a normal distribution (i.e., the base case). Using a Student T distribution with various degrees of freedoms we see that the Integrated approach tends to have somewhat higher risk-adjusted returns for lower degrees of freedom, but the figures converge as we reach higher degrees of freedom and the student t distribution becomes increasingly similar to a normal distribution. Simulating Centred Lognormal returns results in the Integrated approach outperforming the Mixed approach (compare Sharpe ratios of 1.10 versus 0.99, respectively).

Table A4.2: Average Transfer Coefficient for Different Signal Simulation Distributions. The table below shows the transfer coefficient of portfolios combining two signals using Mixed and Integrated in a long/short investment context using the introduced simulation methodology. Different distributions are used to simulate the signals: Normal (Base Case), Centered Lognormal, Uniform as well as Student T with degrees of freedom (DF) ranging between 2 and 15. The transfer coefficient is the rank correlation coefficient between a signal and the corresponding portfolio weights.

	Signal	Normal	Centred Lognormal	Uniform	Student T.DF2	Student T.DF3	Student T.DF4	Student T.DF5	Student T.DF10	Student T.DF15
Mixed	1	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	2	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Integrated	1	0.68	0.65	0.69	0.66	0.67	0.67	0.67	0.68	0.68
	2	0.68	0.65	0.69	0.66	0.67	0.67	0.68	0.68	0.68

In terms of the transfer coefficient the results we obtain are in line with the base case, illustrating that the Mixed approach has the higher transfer coefficients. The Student T distribution sequence shows that the difference between Mixed and Integrated transfer coefficients gets smaller the more normal the distributions becomes (i.e., the higher the number of degrees of freedom).

A5. Increase the Noise Level when Signal Magnitude is Large

We are interested in studying the effect the signal to noise ratio has on the comparison of the two signal combination methods. To that end we add a noise term to the signal. The precise formula is:

$$s_s^* = s_s + [ns \cdot |s_s| + 1] \cdot nm \cdot \eta_s \; \forall s = 1{,}2,$$

where η_s is the noise term, ns is the noise slope and nm is the noise multiplier. The noise slope allows us to modulate how fast we arrive at a maximum noise modulation of the signal while the noise multiplier allows us to modulate how large the noise can actually get in relation to the signal. The noise term, η_s, follows the same base distribution as the signal itself, i.e.,

$$\eta_s \sim N(0{,}0.0051^2) \; \forall s = 1{,}2$$

We use s_s^* as input into the weights calculation but continue to base the returns on s_1 and s_2 only. This way we achieve an increase in the noise component of the signal. Results are reported in Table A5.

Table A5: Sharpe Ratio for Mixed and Integrated Signal Combination for Different Extends of Signal Noise. Table summarizes the Sharpe ratios achieved when combining two signals using Mixed and Integrated. Results are given for simulations using varying degrees of noise. Noise Multipliers range between 0.5 and 3.0. Noise Slope ranges between 0.0 and 10.0.

		Integrated (Base = 1.42)				Mixed (Base = 1.40)			
		Noise Slope				Noise Slope			
		0.0	1.0	5.0	10.0	0.0	1.0	5.0	10.0
Noise Multiplier	0.5	1.26	1.26	1.25	1.26	1.25	1.25	1.23	1.25
	1.0	0.98	0.98	1.00	0.96	0.98	0.98	0.99	0.96
	1.5	0.79	0.77	0.77	0.73	0.79	0.77	0.76	0.73
	2.0	0.62	0.62	0.61	0.60	0.62	0.62	0.61	0.59
	2.5	0.52	0.53	0.50	0.50	0.52	0.53	0.50	0.50
	3.0	0.45	0.43	0.45	0.42	0.45	0.44	0.44	0.42

The Sharpe ratio decreases for Mixed and Integrated from about 1.4 without the additional signal noise by about 1.0 to 0.4 for increased amounts of noise modelled through a Noise Slope of 10.0 and a Noise Multiplier of 3.0. Both approaches to combine signals deal with the increase in signal noise equally well.

A6. Detailed Performance Summary of Styles Across Asset Classes After Deducting Estimated Transaction Costs

We subtract transaction and roll costs from all styles and asset classes. Transaction cost vary according to asset but we use averages of 0.01%, 0.03%, 0.03% and 0.01% charged on the traded notional for fixed income, foreign exchange, commodities and equities, respectively. Roll costs are costs of rolling a future when it expires and are set in this analysis equal to the transaction cost.

Table A6: Performance Summary of Styles across Asset Classes After Deducting Estimated Transaction Costs. The table below shows the performance statistics of style portfolios (Carry, Momentum, and Value) across different asset classes (Fixed Income, Foreign Exchange, Commodities, and Equities) deducting estimated transaction costs. All statistics are computed using monthly data. investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

Asset Class	Style	Annualized Avg ER	Annualized Std	Sharpe	Skewness	Excess Kurtosis	Annualized Transaction Cost
Fixed Income	Carry	3.5%	5.4%	0.65	0.1	1.4	0.2%
	Momentum	1.6%	6.5%	0.25	-0.2	1.4	0.3%
	Value	0.0%	6.3%	0.00	-0.2	1.7	0.3%
Foreign Exchange	Carry	6.3%	8.9%	0.70	-0.3	0.7	0.5%
	Momentum	0.2%	7.9%	0.02	-0.1	0.4	1.0%
	Value	2.7%	6.3%	0.43	0.3	0.6	0.6%
Commodities	Carry	7.4%	10.1%	0.74	0.4	1.2	0.6%
	Momentum	2.0%	11.1%	0.18	0.4	1.5	0.4%
	Value	-0.8%	12.9%	-0.06	-0.3	0.7	0.4%
Equities	Carry	5.1%	9.3%	0.55	0.2	-0.2	0.6%
	Momentum	-1.6%	10.8%	-0.15	-0.3	1.6	0.4%
	Value	-1.0%	9.6%	-0.10	-0.2	0.7	0.3%

The impact of the transaction costs on the performance is limited with an average of 0.5% (compare Table A6). The lowest impact is measured for Fixed Income Carry with 0.2% transaction costs per annum while we obtain a more elevated figure of 1.0% per annum in Foreign Exchange momentum.

The transaction costs asset managers with advanced trading systems and dedicated execution teams achieve in the markets tend to be much lower.

A7. Detailed Summary of Performance Metrics Achieved when Aggregating Styles within Asset Classes

The below Table A7 shows the performance metrics realized when aggregating styles within an asset class. We aggregate two styles or three styles at each time. Styles are aggregated using the Integrated and the Mixed Approach.

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

Table A7: Detailed Summary of Performance Metrics Achieved when Aggregating Styles within Asset Classes. The table below shows the performance statistics of portfolios combining different styles using Integrated and Mixed approaches. The statistics are computed based on monthly data. investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

		Performance Stats				
		Annualized Avg ER	Annualized Std	Sharpe	Skewness	Excess Kurtosis
Fixed Income						
Carry-Momentum	Integrated	3.9%	6.2%	0.62	0.1	1.8
	Mixed	2.9%	5.1%	0.56	-0.1	1.2
Value-Carry	Integrated	3.0%	5.9%	0.52	-0.1	1.1
	Mixed	2.1%	3.6%	0.58	-0.7	1.8
Value-Momentum	Integrated	2.7%	5.2%	0.53	0.1	0.5
	Mixed	1.3%	2.6%	0.48	0.2	1.8
Value-Carry-Momentum	Integrated	4.1%	5.7%	0.72	0.7	3.0
	Mixed	2.1%	2.8%	0.74	0.1	0.9
Foreign Exchange						
Carry-Momentum	Integrated	4.3%	8.2%	0.53	-0.4	1.0
	Mixed	4.1%	6.6%	0.62	-0.5	1.7
Value-Carry	Integrated	7.4%	7.7%	0.95	-0.2	0.6
	Mixed	5.2%	5.2%	1	0.1	1.6
Value-Momentum	Integrated	3.3%	6.4%	0.51	-0.3	0.5
	Mixed	2.5%	3.7%	0.66	-0.6	1.0
Value-Carry-Momentum	Integrated	6.2%	7.8%	0.79	-0.6	1.5
	Mixed	4.0%	4.2%	0.95	-0.5	2.4
Commodities						
Carry-Momentum	Integrated	5.03%	10.65%	0.47	0.45	1.53
	Mixed	5.33%	9.19%	0.58	0.64	2.07
Value-Carry	Integrated	5.68%	10.80%	0.53	0.16	-0.16
	Mixed	4.22%	6.25%	0.68	0.19	0.58
Value-Momentum	Integrated	1.19%	10.64%	0.11	0.19	0.09
	Mixed	1.60%	5.88%	0.27	0.2	1.09
Value-Carry-Momentum	Integrated	6.12%	10.15%	0.6	0.49	0.76
	Mixed	3.84%	5.16%	0.74	0.12	0.62
Equities						
Carry-Momentum	Integrated	1.4%	10.6%	0.13	-0.2	1.9
	Mixed	2.5%	7.5%	0.33	0.0	2.3
Value-Carry	Integrated	4.1%	9.7%	0.42	-0.1	0.7
	Mixed	2.7%	7.2%	0.37	0.1	1.2
Value-Momentum	Integrated	-1.5%	9.8%	-0.15	-0.5	1.8
	Mixed	-0.6%	5.8%	-0.09	-0.1	1.2
Value-Carry-Momentum	Integrated	2.5%	9.8%	0.25	-0.1	1.0
	Mixed	1.6%	5.5%	0.29	0.1	0.7

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

A8. Detailed Summary of Transfer Coefficients Achieved when Aggregating Styles within Asset Classes

Table A8 shows the transfer coefficients realized when aggregating styles within an asset class. We aggregate two styles or three styles at each time. Styles are aggregated using the Integrated and the Mixed Approach.

Table A8: Detailed Summary of Transfer Coefficients Achieved when Aggregating Styles within Asset Classes. The table shows the transfer coefficients between the signals and the corresponding portfolio weights. The transfer coefficient is the rank correlation coefficient between a signal and the corresponding portfolio weights. The investment period ranges from February 2001 until August 2017 for all asset classes except equities where we start in October 2002.

		Carry		Momentum		Value	
		Avg	Std	Avg	Std	Avg	Std
Fixed Income							
Carry-Momentum	Integrated	77%	20%	73%	23%		
	Mixed	79%	16%	78%	17%		
Value-Carry	Integrated	63%	23%			61%	28%
	Mixed	68%	19%			67%	21%
Value-Momentum	Integrated			41%	26%	34%	24%
	Mixed			46%	19%	44%	19%
Value-Carry-Momentum	Integrated	84%	16%	45%	33%	14%	40%
	Mixed	86%	13%	48%	35%	18%	42%
Foreign Exchange							
Carry-Momentum	Integrated	71%	17%	77%	12%		
	Mixed	77%	12%	77%	11%		
Value-Carry	Integrated	59%	10%			64%	13%
	Mixed	66%	6%			66%	6%
Value-Momentum	Integrated			51%	12%	55%	13%
	Mixed			58%	8%	57%	9%
Value-Carry-Momentum	Integrated	62%	13%	48%	18%	36%	20%
	Mixed	70%	13%	54%	18%	35%	18%

These results are based on simulated or hypothetical performance results that have certain inherent limitations. Unlike the results shown in an actual performance record, these results do not represent actual trading. Also, because these trades have not actually been executed, these results may have under-or over-compensated for the impact, if any, of certain market factors, such as lack of liquidity. Simulated or hypothetical trading programs in general are also subject to the fact that they are designed with the benefit of hindsight. No representation is being made that any account will or is likely to achieve profits or losses similar to these being shown. Please see additional disclosures. Past correlations are not indicative of future correlations, which may vary. Past performance does not guarantee future results, which may vary. These examples are for illustrative purposes only and are not actual results. If any assumptions used do not prove to be true, results may vary substantially. Source: GSAM.

		Carry		Momentum		Value	
		Avg	Std	Avg	Std	Avg	Std
Commodities							
Carry-Momentum	Integrated	74%	14%	85%	9%		
	Mixed	83%	7%	83%	7%		
Value-Carry	Integrated	32%	22%			63%	17%
	Mixed	55%	10%			54%	11%
Value-Momentum	Integrated			45%	16%	48%	15%
	Mixed			50%	12%	51%	12%
Value-Carry-Momentum	Integrated	57%	18%	59%	16%	15%	23%
	Mixed	71%	14%	65%	15%	8%	23%
Equities							
Carry-Momentum	Integrated	67%	14%	67%	14%		
	Mixed	71%	10%	71%	10%		
Value-Carry	Integrated	61%	14%			71%	14%
	Mixed	70%	9%			69%	9%
Value-Momentum	Integrated			58%	15%	54%	20%
	Mixed			61%	12%	60%	13%
Value-Carry-Momentum	Integrated	59%	18%	46%	23%	45%	20%
	Mixed	66%	14%	49%	22%	46%	18%

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