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Portfolio Strategy

Activity Ratios: Alpha Drivers in Long/Short Funds

Long/short funds are typically described in terms of their long, short and net exposures expressed as a percent of invested assets. The net beta value is also sometimes provided as an indication of the fund's probable response to broad market movements. However, the long and short side can include both generic (non-alpha) investments as well as truly active positions. Therefore, the standard exposure and beta measures may shed little light on the fund's alpha potential, tracking error, or information ratio (IR).

One key to alpha potential will be found in the fund's "activity level" — the aggregate weight of all meaningfully-sized active long and short positions. For a given fund structure, the activity level determines the fund's basic alpha characteristics.

It turns out that the IR depends largely on the "Activity Ratio" (AR) — the short activity divided by the long activity. With a given AR, the expected alpha and tracking error both increase (or contract) proportionally with the long Activity Level acting as a scaling factor. Thus, funds with the same AR can be viewed as simply rescaled versions of one another with respect to their intrinsic alpha-producing potential.

Many long/short funds — even those that consider themselves "beta-agnostic" — have investment styles that circle around some average beta value. A modest degree of beta variability does not preclude such funds from being "beta-stretched" to fit specified target levels.

By moving from active to generic positions or vice versa, a fund can adjust its activity levels to achieve a given AR and activity scale. With beta and AR flexibility, some long/short funds can be reshaped to serve as more generalized versions of a 130/30 or 150/50 active extension.

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Activity Ratios: Alpha Drivers in Long/Short Funds

Summary

The majority of long/short portfolio analysis studies focus on the gross weights of the portfolio. The exposures are usually quoted in gross terms, whether they are a long/short (L/S) hedge fund (e.g., 130% long/70% short), a market neutral (MN) fund (e.g., 100% long/100% short) or an active extension (AE) (e.g., 130% long/30% short). However, these gross exposures can be comprised of varying proportions of truly active positions and generic (non-alpha) investments.

The sensitivity to broad market movements is always a paramount consideration, and in this regard, the beta value is a critical parameter. However, for those funds where some average beta can be identified, the analysis naturally next turns to the issues of alpha generation, tracking error (TE) and the associated information ratio (IR). Here, the most important variable becomes the "Activity Level", i.e., the aggregate weights of significant active positions on the long and the short sides. In fact, for a given fund, it can be shown that the IR is determined in large part by the Activity Ratio (AR) — the short Activity divided by the long Activity level.

The different Activity Levels employed by L/S, MN and AE portfolios can be compared by viewing them in a common activity space. This issue has been raised in various ways in several recent studies [1,2]. As shown in our earlier Note [3], funds with different structures can be extended or contracted to fit into the same activity space.

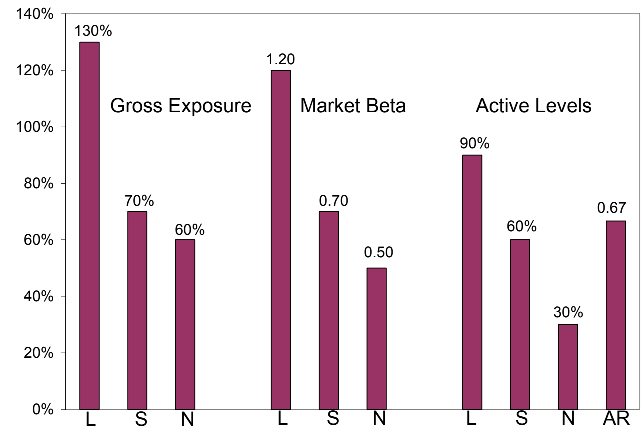
The key to bringing different long/short combinations within a given set of beta constraints is the ability to specify some average beta target and a reasonable degree of beta volatility. Many L/S managers have "beta agnostic" investment styles, but their betas tend to circle around some average value. An L/S fund with an average beta of 0.6 may have a beta volatility of ±0.1 or ±0.2. It turns out that such levels of beta volatility will not have an overriding impact on either the fund's benchmark tracking error or its total volatility. Thus, a modest change in activity structure, accompanied by a shift from the average beta value, can be used to transform an L/S fund so it falls within a specified set of constraints.

Gross, Market, and Active Exposures

Exhibit 1 shows how a typical long/short fund — Fund A — could be described in terms of three different types of yardsticks. The first set of columns is the gross weights of the portfolio, 130% long, 70% short and 60% net. The second set represents the beta exposures of the fund, which may not always correspond with the gross exposures. In this example, the long portfolio has a beta of 1.20, i.e., somewhat lower than the 130% gross long exposure. In contrast, the short portfolio beta of 0.70 is a direct outcome of the 70% gross exposure. The net beta is thus 0.5, somewhat lower than the net portfolio exposure of 60%.

Exhibit 1

Gross, Market and Active Exposures for L/S Fund A



Source: Morgan Stanley Research

Activity Levels and Activity Ratios

The third set of columns represents the Activity Levels. To appreciate the significance of the Activity Level concept, first consider a long-only equity portfolio. The gross (and net) exposure of 100% might translate into an effective active weight of 60% (or less). Typically, these effective active weights are concentrated on the overweight side, with the funding underweights being so widely fragmented and dispersed as to contribute negligibly to portfolio alpha and tracking error. However, since the beta effects are additive, these underweights will accumulate in beta terms and affect the portfolio's market risk.

For L/S funds, the long Activity level may also fall well below the gross long exposure. For Fund A depicted in Exhibit 1, this situation is evident in having a long Activity level of 90% compared with a gross level of 130%.

Turning to the 70% shorts in Exhibit 1, these investments can also be separated into the active and non-active categories. However, in practice, the "non-active" component is more likely to consist of generic investments (or derivatives) that help control the beta and factor risks, but are not primarily intended to be alpha-seeking. In Exhibit 1, of the fund's 70% shorts, 60% are allocated to active positions and 10% to generics.

Thus, the fund's Activity Level consists of 90% longs and 60% shorts, which is quite distinct from its respective gross exposures of 130% and 70%. It should be emphasized that the Activity Levels are also quite different from the beta values that affect the fund's response to broad market movements. In contrast, these Activity Levels are strictly related to the fund's active alpha expectations and the associated TE.

These long and short Activity Levels can be usefully compressed into a single value, such as the net Activity Level of 30% shown in Exhibit 1. However, for reasons that will be clear later in the discussion, it turns out that a more useful measure is the "Activity Ratio" (AR) comprised of the short Activity Level divided by the long Activity Level.

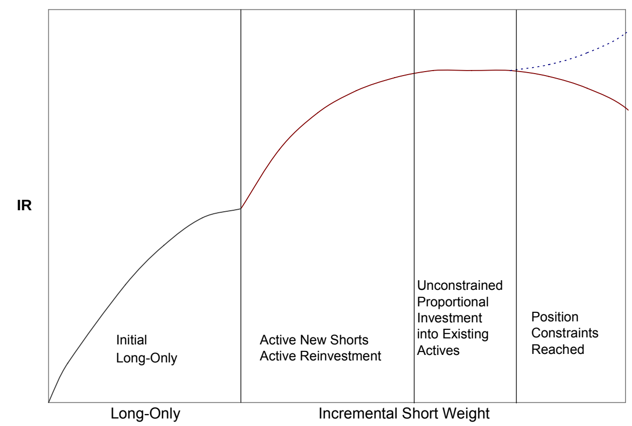
Evolution of the IR

Exhibit 2 is a schematic of the IR improvement in an Active 130/30 Extension as the gross exposure expands due to an increasing level of shorting together with the reinvestment of the short proceeds back into the long portfolio. As shown in our previous Note [4], to achieve significant IR improvement when moving from a long-only portfolio, shorts must be found that can serve both as positive alpha sources and as offsets to any unproductive correlations within the long portfolio. This combination of new alpha-generating positions and offsets accounts for the rise in the IR from the initial phase of shorting.

In the next phase, the opportunity for new active positions has been exhausted and any incremental funds are just deployed in the existing long and short active positions. This proportional amplification of the pre-existing actives leads to a flat IR since it is tantamount to simple alpha leverage. In the last phase, the expansion encounters constraints such as size limits on the active positions. In this phase, the portfolio alpha may continue to grow while the IR departs from its flat path. In general, the constraints will force the IR to turn down, but there are circumstances where the offset effect becomes more powerful and the IR actually rises [4].

Exhibit 2

IR Evolution as the Activity Level Expands

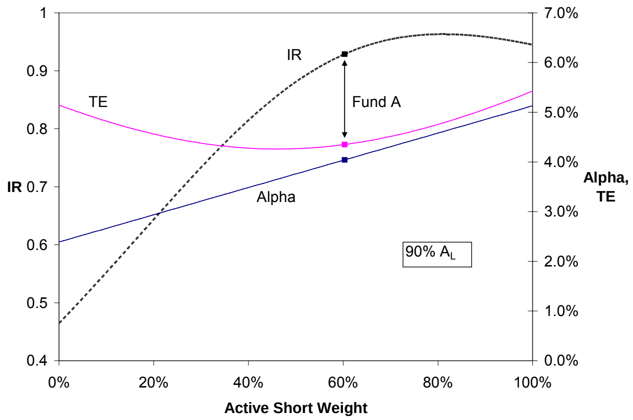


Source: Morgan Stanley Research

Exhibit 3 now focuses specifically on Exhibit 1's Fund A with its fixed 90% long Activity Level. Using the basic model described in the Appendix, Exhibit 3 depicts the alpha, TE and IR as the activity level of the short side is varied from 0% to 100%. With increasing alpha-generating shorts, the portfolio alpha rises linearly from its long-only value. In contrast, the TE at first begins to decrease from the offset effect, but then rises as the growing short weight becomes overriding. The IR curve displays roughly the same ascending and saturation shape as depicted in Exhibit 2.

In general, there will be some point where a maximum IR is reached and sustained. As noted earlier, a flat IR does not necessarily reflect the optimal design point. Even when the IR is constant, the portfolio continues to gain alpha with proportional increases in TE. If the fund has unused capacity for higher TE's, then there may be good reason for pressing for the higher alphas even in the face of a flat IR.

Exhibit 3
Alpha, TE and IR at Varying Short Active Weights



Source: Morgan Stanley Research

Exhibit 4 introduces a second L/S fund, Fund B, which has the same active position structure, but differs from Fund A along several dimensions. In particular, Fund B has active longs of 120% versus Fund A's 90%. Consequently, Fund B has a higher alpha and higher TE than Fund A.

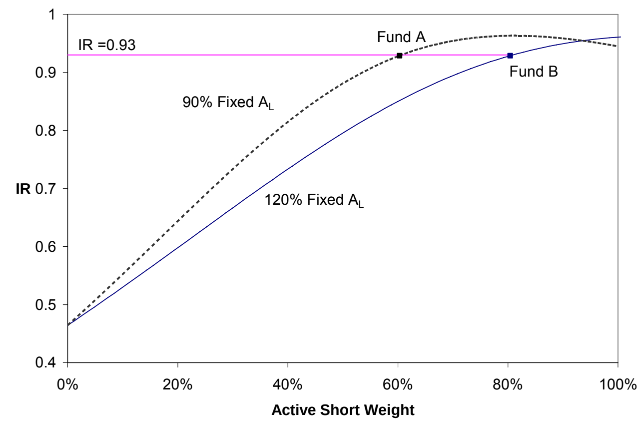
Exhibit 4
IR Determined by Activity Ratio

	L/S A	L/S B
Gross Exposure		
Long	130%	160%
Short	70%	110%
Net	60%	50%
Long	1.2	1.3
Short	0.7	0.7
Net Beta	0.5	0.6
Activity Levels		
Long (A_L)	90%	120%
Short	60%	80%
Net	30%	40%
AR	0.67	0.67
Alpha	4.04	5.39
TE	4.35	5.80
IR	0.93	0.93

Source: Morgan Stanley Research

Exhibit 5 plots the IR curves for various active short weights for funds with fixed long activity weights of 90% and 120%. One can see that Fund A and Fund B both generate the same 0.93 IR.

Exhibit 5
Fund A and Fund B: IR vs. Active Short Weights

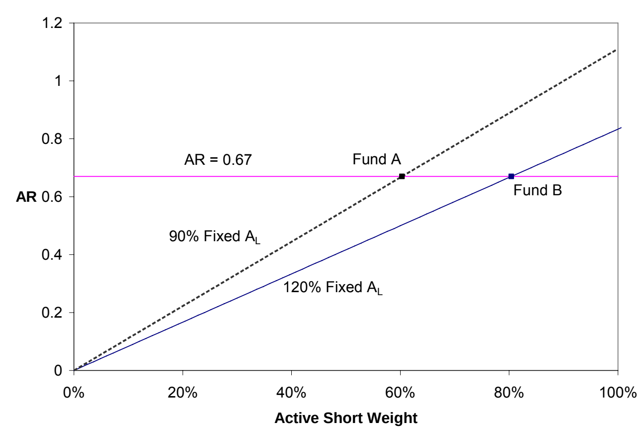


Source: Morgan Stanley Research

Moving to the Activity Ratio

The preceding graphs followed the more standard procedure of using the active short weights as the horizontal axis. An alternative approach is to make use of the Activity Ratio to reflect the shorts as a percentage of the total longs. Exhibit 6 shows how the varying active short weights translate into Activity Ratios. It can be seen that Funds A and B share the same AR value of 0.67.

Exhibit 6
AR as Function of Active Short Weight



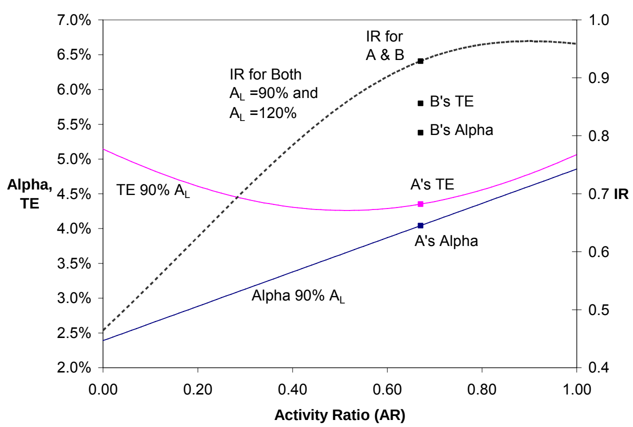
Source: Morgan Stanley Research

The benefit in using the AR becomes evident in Exhibit 7, which like Exhibit 3, plots alpha, TE and IR for a fixed 90% long weight, under varying short weights, but now with the AR as the horizontal axis. Fund A with its 60/90 ratio and Fund B with its 80/120 ratio both have the same AR ratio. The specified values for Fund A all fall on the designated points on their respective curves. The corresponding values for Fund B are also plotted and can be seen to all lie on the same vertical line, although Fund B's alpha and TE are positioned above Fund A's values. However, the IR point for Fund B coincides exactly with Fund B's IR. If we were to trace the corresponding curves for fund B, we would find that while the alpha and TE curves were quite distinct, the two IR curves would be identical.

Any combination of long and short activity levels that results in the same AR value will lead to the same IR. More generally, any funds having the same structure — regardless of their long activity level — will have the same IR curve.

Exhibit 7

Coincidence of IR Curves



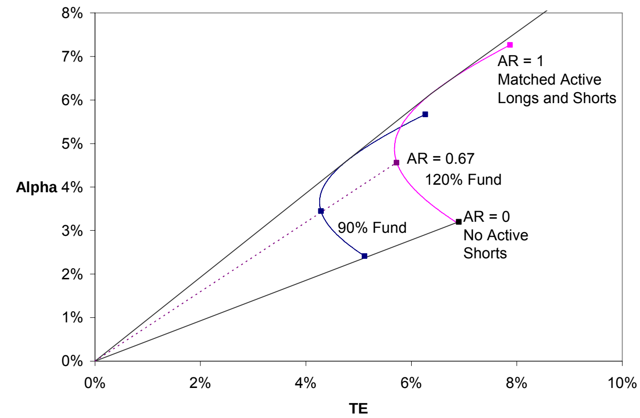
Source: Morgan Stanley Research

AR-Based Efficient Frontiers

Exhibit 8 places the curves for the two funds in alpha vs. TE space. For each fund, the curve here represents the alpha and TE values as the AR moves from 0 to 1.0. All points falling on a straight line from the origin will have the same IR and the same AR. Thus, even though these funds have very different alphas and TE's, they have the same IR. As a result, the increase in the active long weight from 90% to 120% can be seen to be a scaling effect as higher alphas are accompanied by higher TE's.

Exhibit 8

Alpha vs. TE for 90% and 120% Active Long Funds

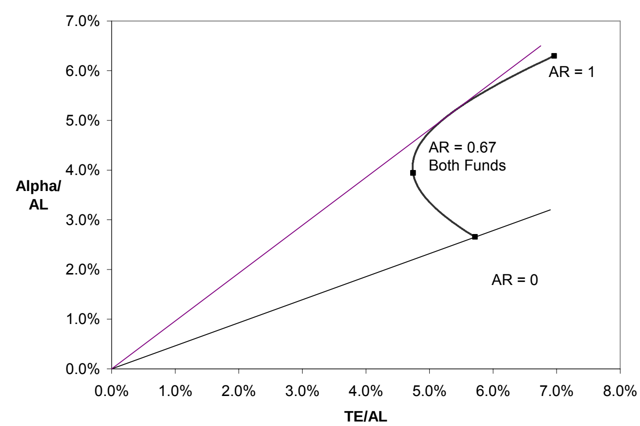


Source: Morgan Stanley Research

The results from Exhibit 8 can be "normalized" by dividing both the alpha and TE by their active long weights. This leads to a single curve for both the 90% and 120% case as shown in Exhibit 9. Basically, all L/S funds having the same structure are described by this single curve in normalized alpha versus normalized TE space.

Exhibit 9

Normalized Alpha vs. TE Curves



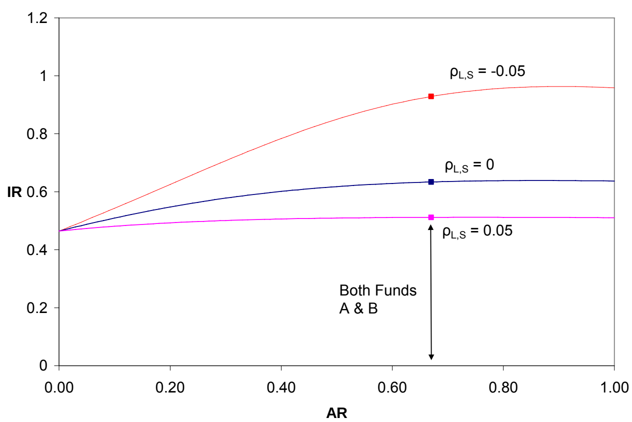
Source: Morgan Stanley Research

Correlation, Position Count and Alpha Ranking Effects

To this point, the funds have been assumed to have a common structure in terms of the number of active long and short positions, the correlations within and between the long and short portfolios, as well as the alpha ranking functions. Basically, the different activity levels have served to determine the magnitude of the average weight for the long and the short active positions. In this section, we begin to explore how changes in the fund structure affect the IR curves.

Exhibit 10 shows the effect of different correlation assumptions between the long and short positions. The base case used in the preceding discussion assumed a negative -0.05 correlation between the longs and shorts. This offset correlation played an important role in raising the IR to 0.93. With zero correlation, the IR at the 0.67 AR declines to 0.63, while with a positive correlation (reinforcing common factor risks), the IR drops to 0.51.

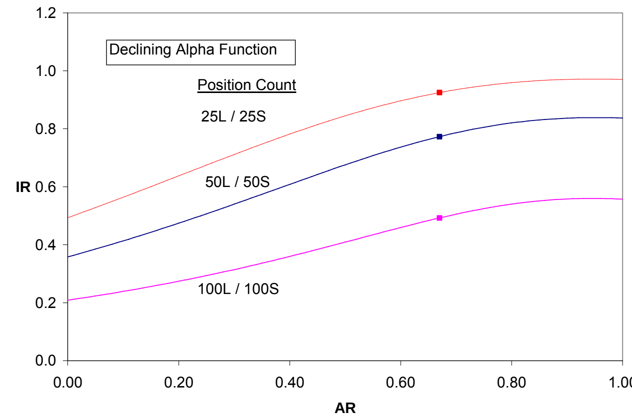
Exhibit 10
IR with Different Correlations



Source: Morgan Stanley Research

The previous examples assumed active structures comprised of 30 long positions and 20 short positions. Exhibit 11 displays the IR's for three different position structures, each with equal position counts on both the long and short side. Since the same declining alpha function is applied, greater diversification lowers the portfolio alpha to a greater extent than it reduces the TE. This effect is evident in the IR for the 100L/100S portfolio falling significantly below the IR for the more concentrated 25L/ 25S portfolios.

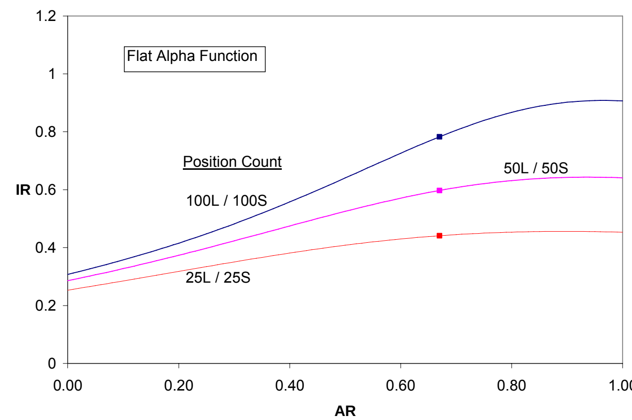
Exhibit 11
IR with Different Position Counts



Source: Morgan Stanley Research

The results from Exhibit 11 should not be too surprising given the nature of the declining alpha ranking curve used. In these examples, the highest expected alpha is 5%, which then declines to 0.4% by the 50^{th} position. With a flat alpha ranking curve (here assumed to be at a constant 1.5%), the results are quite different, as shown in Exhibit 12. The more diversified portfolio of 100L/100S provides a higher IR than in the 25L/25S case.

Exhibit 12
IR with Flat Alpha Rankings

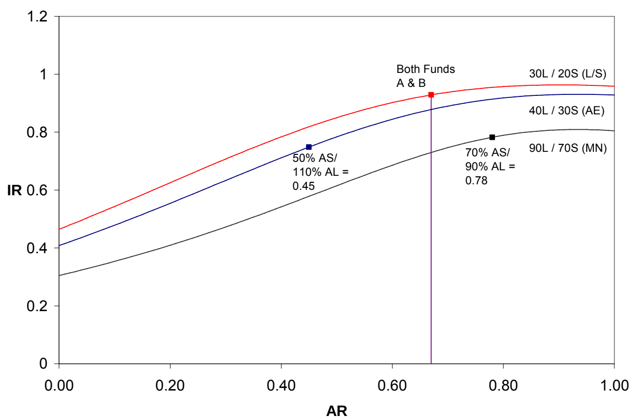


Source: Morgan Stanley Research

IR Curves for Different Fund Types

We can also compare fund strategies that have different combinations of position structures and assumed alpha functions. Exhibit 13 displays the IR curves for long/short strategies having the same structure as Funds A and B, as well as for representative examples of active extension (AE) and market neutral (MN) strategies. The AE strategy tends to be more diversified than an L/S fund, so the structure assumed here consists of 40 long positions and 30 short positions. With its quantitative investment approach, the market neutral portfolio becomes even more diversified with 90 longs and 70 shorts. Both the L/S and AE portfolios use the declining alpha ranking function, while the MN assumes flat alpha ranking.

Exhibit 13
IR for L/S, AE and MN

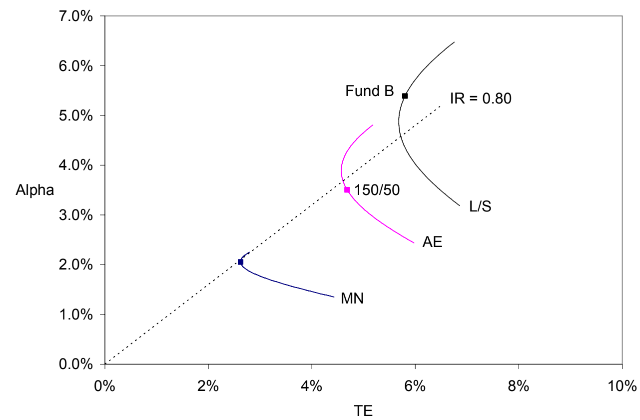


Source: Morgan Stanley Research

The active extension portfolio depicted represents gross levels of 150/50, but 110/50 in Activity terms.

Exhibit 14 displays the three portfolio strategies in alpha/TE space. It can be seen that points from Exhibit 13 all lay close to the dotted line representing an IR near 0.80. Given this opportunity for moving to different beta values, an L/S fund may also be able to adjust its long and short exposures to fit within more constrained frameworks. In this sense, an L/S fund could be transformed into a generalized version of an AE fund.

Exhibit 14
Alpha vs. TE for L/S, AE and MN



Source: Morgan Stanley Research

Moving an L/S into a Generalized AE

Many L/S funds — even those that view themselves as beta agnostic — tend to have some average beta value. The beta variability around this average value can often be kept within some reasonable bounds without overly disrupting the basic management style. In an earlier paper [5], it was shown that moderate beta variability may contribute a surprisingly small incremental TE around a specified average beta value. Such funds could then have their effective beta values stretched (or contracted) to satisfy a specified beta constraint.

Exhibit 15 explores how Fund A could be moved into an AE framework. The gross exposures on the long side are increased from 130% to 150% while the gross short exposures are contracted from 70% to 50%. The revised fund would now have a 150/50 structure in terms of gross long/short exposures. Adjustments to the long and short beta (or to the net beta) could bring the fund to the required beta-one status.

Exhibit 15

L/S Contraction into an AE Framework

	Fund A	Contracted A	Standard AE
Gross Exposure			
Long	130%	150%	150%
Short	70%	50%	50%
Net	60%	100%	100%
Long	1.2	1.5	1.5
Short	0.7	0.5	0.5
Net Beta	0.5	1.0	1.0
Activity Levels			
Long (A_L)	90%	90%	110%
Short	60%	40%	50%
Net	30%	50%	60%
AR	0.67	0.45	0.45
Alpha	4.04	3.50	3.50
TE	4.35	4.28	4.68
IR	0.93	0.82	0.75

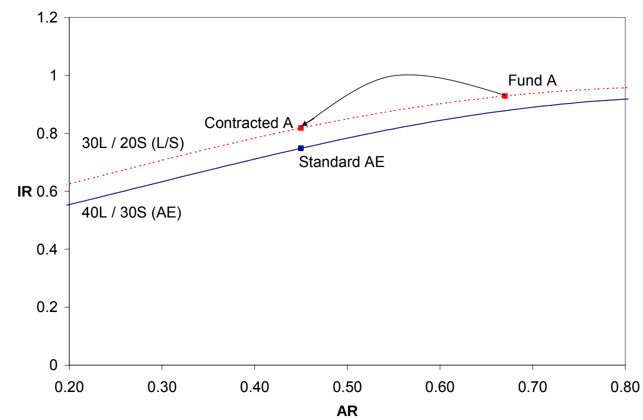
Source: Morgan Stanley Research

In an effort to maintain as much as possible of the basic management style, it might be desirable to minimize the adjustment of the Activity Level. For example, the long Activity Levels could be kept at 90% while the shorts could be reduced from 60% to 40%. The resulting Activity Ratios would then be 0.45, i.e., the same AR as for the illustrative 150/50 AE fund.

In Exhibit 16, the arrow shows the movement along the IR curve from the L/S fund into an AE format. The contraction process lowers Fund A's IR from 0.93 to 0.82, but it still remains higher than the standard AE's 0.75 IR.

Exhibit 16

L/S Contraction along the IR Curve

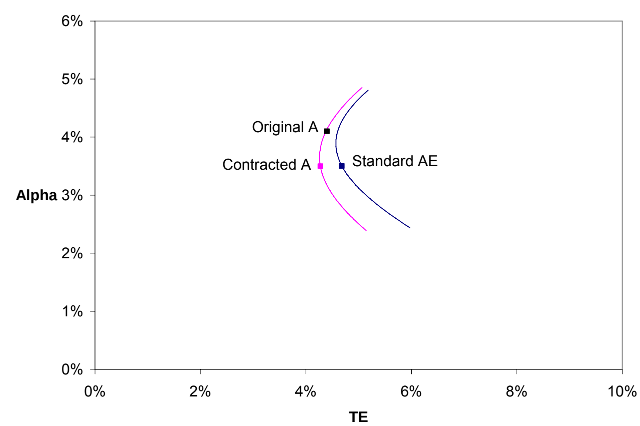


Source: Morgan Stanley Research

The same results can be displayed in alpha vs. TE space. The original L/S Fund A had an alpha of 4.0% with a 4.4% TE, while the contracted L/S A had an alpha of 3.5% and TE of 4.3%. By comparison, the standard AE has an alpha of 3.5% and TE of 4.7%.

Exhibit 17

Alpha vs. TE – L/S Contraction into AE



Source: Morgan Stanley Research

Conclusion

The key point is that a fund's long and short weight may cover many different combinations of investments that can be either generic (non-alpha) or actively alpha-generating. Consequently, the standard exposure yardsticks may provide little insight about a fund's alpha potential. The ultimate source of alphas resides in the meaningfully-sized active positions (on both the long and the short side). The cumulative effective weight of these active positions constitutes what we have termed the fund's Activity Level. Together with the position structure, the Activity Levels determine a fund's alpha potential, the associated tracking error, and hence the prospective information ratio.

Moreover, within the context of the basic model described in the Note, the most compact characterization of the fund's alpha potential is given by its Activity Ratio, i.e., the ratio of the short to the long Activity Levels. For funds with similar position structures, it is this Activity Ratio that determines the information ratio. All such funds with the same Activity Ratio will have the same information ratio.

References:

1) Jacobs, Bruce I., and Kenneth N. Levy. "20 Myths about Enhanced Active 120-20 Strategies." Financial Analysts Journal, July/August 2007
2) Johnson, Seanna, Ronald N. Kahn and Dean Petrich. "Optimal Gearing." The Journal of Portfolio Management, Summer 2007
3) Leibowitz, Martin L. and Anthony Bova. "ACTIVE 130/30 CONTRACTIONS: Moving Long/Short Strategies into 130/30 Space." Portfolio Analysis Note, July 9, 2007
4) Leibowitz, Martin L. and Anthony Bova. "Active Return Drivers in130/30 Extensions." Portfolio Analysis Note, August 27, 2007
5) Leibowitz, Martin L. and Anthony Bova. "Beta Targeting: Tapping into the Appeal of 130/30 Active Extensions." Portfolio Analysis Note, April 20, 2007

Appendix

In our basic model, the number of long positions n_L and short positions n_S are both fixed. The uniform weight ω assigned to each position is then determined by the total active weights A_L and A_S assigned for the longs and the shorts,

$$\omega_L = \frac{A_L}{n_L}$$

$$\omega_S = \frac{A_S}{n_S}$$

In the basic model, a fixed residual volatility σ is assigned for all positions, with pairwise correlations ρ_L and ρ_S within the longs and shorts, respectively, and ρ_{LS} between the long and short positions.

The portfolio tracking error (TE) is then approximated by

$$\begin{aligned}
\left(\frac{TE}{\sigma}\right)^2 &= n_L\omega_L^2 + n_S\omega_S^2 + n_L(n_L - 1)\omega_L^2\rho_L + n_S(n_S - 1)\omega_S^2\rho_S + 2n_L\omega_L n_S\omega_S\rho_{LS} \\
&\cong n_L\omega_L^2 + n_S\omega_S^2 + (n_L\omega_L)^2\rho_L + (n_S\omega_S)^2\rho_S + 2(n_L\omega_L)(n_S\omega_S)\rho_{LS} \\
&= \frac{A_L^2}{n_L} + \frac{A_S^2}{n_S} + A_L^2\rho_L + A_S^2\rho_S + 2A_L A_S\rho_{LS} \\
&= A_L^2\left\{\frac{1}{n_L} + \frac{AR^2}{n_S} + \rho_L + AR^2\rho_S + 2AR\rho_{LS}\right\}
\end{aligned}$$

where AR measures the short activity as a fraction of the long activity,

$$AR = \frac{A_S}{A_L}$$

This expression simplifies if $\rho_L = \rho_S = \rho$

$$\left(\frac{TE}{\sigma}\right)^2 = A_L^2\left\{\frac{1}{n_L} + \frac{AR^2}{n_S} + \left(1 + AR^2\right)\rho + 2AR\rho_{LS}\right\}$$

For the two extreme cases of AR =0 (the long-only portfolio) and AR =1 (matched levels of short and long activity), one obtains

$$\left(\frac{TE}{A_L\sigma}\right)^2 = \begin{cases} \dfrac{1}{n_L} + \rho & AR = 0 \\ \dfrac{1}{n_L} + \dfrac{1}{n_S} + 2(\rho + \rho_{LS}) & AR = 1 \end{cases}$$

and for the pure offset case where $\rho_{LS} = -\rho$,

$$\left(\frac{TE}{A_L\sigma}\right)^2 = \begin{cases} \dfrac{1}{n_L} + \rho & AR = 0 \\ \dfrac{1}{n_L} + \dfrac{1}{n_S} & AR = 1 \end{cases}$$

It is interesting to note that the TE may actually be lower for the matched case (AR =1) when $\rho > 1/n_S$

For the portfolio alpha, with average alphas $\overline{\alpha}_L$ and $\overline{\alpha}_S$ for the long and short positions respectively,

$$\alpha_P = \omega_L n_L \overline{\alpha}_L + \omega_S n_S \overline{\alpha}_S$$

And where the alpha $\overline{\alpha}_S$ simply is a constant c lower than $\overline{\alpha}_L$ (usually based on shorting costs)

$\overline{\alpha}_S = \overline{\alpha}_L - c$, then

$$\begin{aligned} \alpha_P &= \omega_L n_L \overline{\alpha}_L + \omega_S n_S \left(\overline{\alpha}_L - c\right) \\ &= \left(A_L + A_S\right)\overline{\alpha}_L - A_S c \\ &= A_L\left\{\left[1 + (AR)\right]\overline{\alpha}_L - (AR)c\right\} \end{aligned}$$

This expression underscores the general form of the alpha-generating structure,

Note that both α_p and TE have A_L as a common factor so that the information ratio (IR) does not depend on A_L. Thus, A_L can be viewed as scaling the level of long activity relative to the original invested amount.

If the tracking error is then expressed as

$$TE = A_L \sigma(te)$$

where

$$(te)^2 = \frac{1}{n_L} + \frac{AR}{n_S} + \rho_L + AR^2 \rho_S + 2AR\rho_{LS},$$

The portfolio IR then becomes

$$\begin{aligned} IR &= \frac{\alpha_P}{TE} \\ &= \frac{\{[1+(AR)]\overline{\alpha}_L - (AR)c\}}{\sigma(te)} \\ &= \left[\frac{1+(AR)}{(te)}\right] IR_L - \frac{(AR)c}{\sigma(te)} \end{aligned}$$

where

$$IR_L = \left(\frac{\overline{\alpha}_L}{\sigma}\right)$$

When $\frac{c}{\sigma(te)}$ is small, the long/short structure can be viewed as an amplification of IR,

$$IR \cong \left[\frac{1+AR}{(te)}\right] IR_L$$

In the example used in the text, the portfolio alphas are based on an exponential alpha function. Both the longs and the shorts begin with initial α_o for the first-ranked position followed by a decay at a rate μ, with a cost c deducted for each short position,

$$\begin{aligned}
\alpha_p &= \omega_L \sum_{j=1}^{n_L} \alpha_o e^{-\mu(j-1)} + \omega_S \sum_{j=1}^{n_S} \left[\alpha_o e^{-\mu(j-1)} - c\right] \\
&= \omega_L \alpha_o \left[\frac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right] + \omega_S \alpha_o \left[\frac{1-e^{-\mu n_S}}{1-e^{-\mu}}\right] - \omega_S n_S c \\
&= \left(\frac{A_L}{n_L}\right)\alpha_o \left[\frac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right] + \left(\frac{A_S}{n_S}\right)\alpha_o \left[\frac{1-e^{-\mu n_S}}{1-e^{-\mu}}\right] - A_S c \\
&= A_L \left\{ \frac{\alpha_o}{n_L}\left[\frac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right] + \left(\frac{AR}{n_S}\right)\alpha_o \left[\frac{1-e^{-\mu n_S}}{1-e^{-\mu}}\right] - cAR \right\}
\end{aligned}$$

and for the extreme points,

$$\frac{\alpha_p}{A_L} = \begin{cases} \dfrac{\alpha_o}{n_L}\left[\dfrac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right] & AR = 0 \\[2ex] \dfrac{\alpha_o}{n_L}\left[\dfrac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right] + \dfrac{\alpha_o}{n_S}\left[\dfrac{1-e^{-\mu n_S}}{1-e^{-\mu}}\right] - c & AR = 1 \end{cases}$$

For these two extreme points, when $\rho_{LS} = -\rho$,

$$IR = \begin{cases} \dfrac{\left(\dfrac{\alpha_o}{n_L}\right)\left[\dfrac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right]}{\sigma\sqrt{\dfrac{1}{n_L}+\rho}} & AR = 0 \\[4ex] \dfrac{\dfrac{\alpha_o}{n_L}\left[\dfrac{1-e^{-\mu n_L}}{1-e^{-\mu}}\right] + \dfrac{\alpha_o}{n_S}\left[\dfrac{1-e^{-\mu n_S}}{1-e^{-\mu}}\right] - c}{\sigma\sqrt{\dfrac{1}{n_L}+\dfrac{1}{n_S}}} & AR = 1 \end{cases}$$

In our examples where $n_L = n_S = n$,

$$IR = \begin{cases} \dfrac{\dfrac{\alpha_o}{n\sigma}\left[\dfrac{1-e^{-\mu n}}{1-e^{-\mu}}\right]}{\sqrt{\dfrac{1}{n}+\rho}} & AR = 0 \\ \dfrac{\dfrac{\alpha_o}{\sigma}\left(\dfrac{2}{n}\right)\left[\dfrac{1-e^{-\mu n}}{1-e^{-\mu}}\right]-\left(\dfrac{c}{\sigma}\right)}{\sqrt{\dfrac{2}{n}}} & AR = 1 \end{cases}$$

$$= \begin{cases} IR_o \dfrac{\dfrac{1}{\sqrt{n}}\left[\dfrac{1-e^{-\mu n}}{1-e^{-\mu}}\right]}{\sqrt{1+(n\rho)}} & AR = 0 \\ IR_o\sqrt{\dfrac{2}{n}}\left[\dfrac{1-e^{-\mu n}}{1-e^{-\mu}}\right] - \sqrt{\dfrac{n}{2}}\left(\dfrac{c}{\sigma}\right) & AR = 1 \end{cases}$$

where

$$IR_o = \frac{\alpha_o}{\sigma}$$

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