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Idiosyncratic Robustness Penalty for Portfolio Optimization

Many portfolio managers rely heavily on optimizers when constructing or rebalancing their portfolios. When the mean-variance optimization framework is used, optimized portfolios suffer from a well known risk underestimation – the realized risk is typically significantly higher than predicted by the optimizer. We propose a technique that uses an Idiosyncratic Robust Penalty (IRP) to reduce this misalignment. The IRP is constructed to capture potential unobserved systematic factors in factor risk models. Using evidence from ex-post performance of optimized portfolios, we show that IRP significantly realigns forecast tracking error volatility (TEV) to its ex-post historical realization. Furthermore, the optimization solution obtained using the IRP achieves lower realized TEV in the index replication optimization, signaling a more robust optimization solution.

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Introduction

At the heart of modern portfolio theory is the trade-off between return and risk. For example, many applications involve a portfolio optimization exercise that chooses the asset weights that minimize a portfolio's risk for a given level of expected return. Among these theories, Markowitz's seminal mean-variance optimization approach provides an integrated framework unifying risk and expected return models - a framework that laid the foundation of the optimizer in POINT, Barclays' multi-asset portfolio management tool. Yet this framework has a well-known problem: the risk of the portfolios constructed in this context is underestimated, leading to a mismatch between the ex-ante and ex-post risk of optimal portfolios.

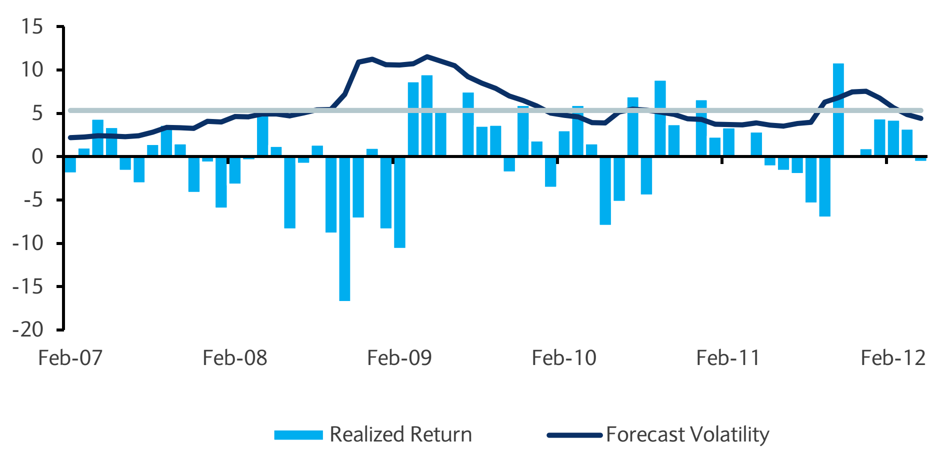
In one sense, the optimization process magnifies the errors in a risk model: the inherent incompleteness of a risk model to capture all risk sources may be inoffensive for typical portfolios. However, when used in an optimization framework, the limitations of the risk model may be significantly highlighted.[1]

To illustrate this we investigate the ex-post performance of the POINT factor risk model on two portfolios: the S&P 500 index and its own replicating portfolio. We get the latter through an optimization exercise that seeks to construct a portfolio with 30 securities that best tracks the S&P 500 index by using POINT's risk model to minimize its risk versus the index.

We begin the analysis with the ex-post performance of POINT's risk model for the S&P 500 index over the past five years. Figure 1 shows the (ex-ante) forecast volatility, the (ex-post) realized returns as well as the realized volatility for the S&P 500 index. One can see that the realized volatility is in line with the forecast one. Specifically, the standard deviation of the realized returns is 5.34% while the average TEV forecast is at 5.53%. Another common statistic used when testing volatility models is the volatility of the standardized returns. To construct the returns, one divides the actual return every month by the forecast volatility at the beginning of that month. A good forecasting model should present a volatility of these returns at about 1 – meaning that on average, the level of volatility forecast is close to the one observed. In our example, the standard deviation of the standardized returns is 0.97, suggesting that POINT's risk model has an excellent performance throughout the period.

FIGURE 1

Forecast Volatility versus Realized Volatility – S&P 500 index



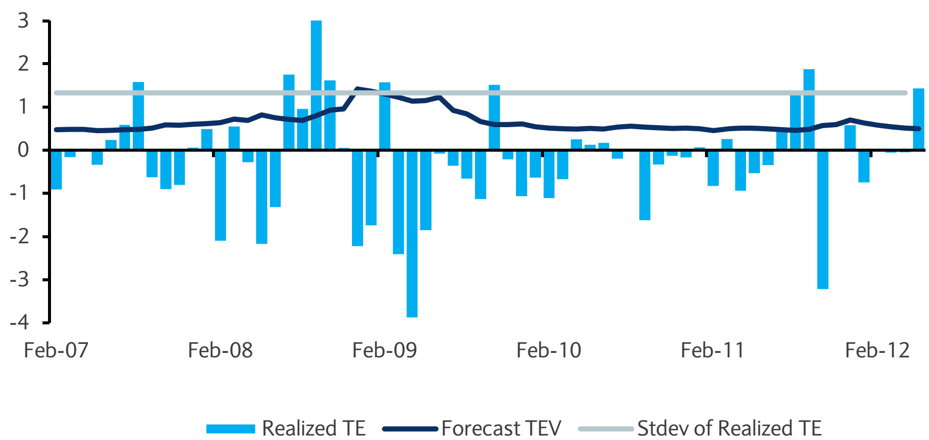
Source: Barclays Research.

[1] Li and Silva (2012), Jagannathan and Ma (2003) and Tibshirani (1996) have suggested various methodologies to remedy this problem.

We next inspect the ex-post performance of the same risk model on a classical optimization exercise – a benchmark replicating portfolio - using POINT's optimizer. Each month, we select 30 stocks out of the S&P 500 index by minimizing the total risk of the portfolio with respect to the index. The portfolio's risk is measured by the Tracking Error Volatility (TEV), that is, the standard deviation of the portfolio's return net of benchmark (the tracking error (TE)). The results from this exercise are displayed in Figure 2. It shows that the optimized portfolio of 30 stocks has a forecast TEV significantly lower (average at 0.65%) than the realized one (1.33%). Accordingly, the standard deviation of the standardized TE is now at 1.88, indicating significant ex-post risk underestimation for this optimal portfolio. This example exemplifies the general problem under analysis: good factor risk models can be explored by the optimizer in ways that lead to misleading results.

FIGURE 2

Forecast TEV vs Realized TEV – 30 stocks from the S&P 500 index replication optimization



Source: Barclays Research.

The magnifying effect of the risk underestimation comes from the optimization process. Intuitively, in a risk-minimizing optimization, the optimizer selects the least risky securities with respect to the benchmark. In many cases, these are securities with the most risk underestimation, explaining the poor performance out of sample.

This paper examines the origin of this risk underestimation and proposes a solution – augmenting the risk model with an idiosyncratic robustness penalty (IRP). The IRP component is added into the objective function in the optimization, with the penalty weight as a user preference. Designed to capture the amplified risk underestimation in an optimal portfolio, the IRP realigns the risk estimation in the optimized portfolio and further improves the robustness of the optimal solution.

The paper is organized as follows. The next section identifies the source of the risk underestimation in the factor risk model. After that, we describe the proposed technique, IRP and its implementation in POINT. Then we present empirical evidence on the effects of IRP by analyzing the ex-post performance of the optimal portfolios. We present our conclusions in the final section.

Identify the risk underestimation

To understand the risk underestimation, we start by introducing the risk model in POINT[2]. It can be described in general as a linear factor risk model. In particular, the total return of a

[2] For detailed description of linear factor model, please refer to Lazanas, Silva, Gabudean and Staal (2011)

security is broken down into a systematic and an idiosyncratic component. The systematic return is the part of the total return attributable to movements in common risk factors, defined ex-ante, such as interest rates, sector spreads or equity industries. The idiosyncratic return, on the other hand, can be described as the residual or security specific component that cannot be explained by the systematic factors. In POINT, these models are estimated every period using a large cross section. Returns are regressed into factor loadings, resulting in systematic factor realizations for that period. The residual is interpreted as the idiosyncratic return, and is by construction independent of the systematic factor loadings. It is also assumed generally to be uncorrelated across issues. This assumption is validated through a judicious choice of systematic factors. This model design implies that correlations between securities are driven by their exposures to the systematic risk factors and the correlations between these factors. The latter are driven by a factor covariance estimation based on the estimated factors referred to above.

In general, a simple factor model can then be represented as:

$$R_t = L_t F_t + v_t \quad (1)$$

R_t , with dimension Nx1, is the return of the portfolio with respect to the benchmark. L_t , with dimension NxK, denotes the factor loading matrix, and F_t , Kx1, are the factors in the risk model. The linear factor model decomposes the security return into two components: a systematic return component denoted by $L_t F_{Lt}$ and an idiosyncratic return component denoted by v_t . With this formulation, the volatility of a portfolio can then be written as

$$Var(h' R_t) = h'[L_t \Sigma_F ' L_t' + \Omega]h \quad (2)$$

In the equation above, Σ_F represents the covariance matrix of systematic factor returns; Ω is the covariance matrix of idiosyncratic security returns and h represents the vector of security allocations in the portfolio.

The problem of omitted variables is common to statistical models, such as the linear factor model. In practice, there is always a set of marginal factors that we may decide to include or exclude, based on statistical evidence and common sense but also on the set of applications planned for the factor model. Purely unknown (or unidentified) risk factors also cannot be included in the model. Both unknown and excluded factors lead to problems with omitted variables. First, they may create biased estimates if correlated with other independent variables. Second, even if uncorrelated with identified factors, they may lead to underestimation of security correlations – as they will be associated with idiosyncratic risk and therefore assumed uncorrelated.

To better understand this point, let's consider that the true model contains instead an omitted factor ε_t :

$$R_t = L_t F_t + \varepsilon_t + u_t \quad (3)$$

ε_t , with dimension *Nx1*, is the unobserved omitted variable vector in the model and u_t is the classic idiosyncratic error term. ε_t can be interpreted more generally as the source of return that is controlled by unobserved systematic factors. It is correlated across securities through the unobserved factors and loadings. Note that here we assume that $\varepsilon_t \perp L_t$, $u_t \perp L_t$

When estimating the model using (1), we are left with a residual that is not the assumed i.i.d. v_t, but instead $\varepsilon_t + u_t$. Because ε_t is correlated across securities, treating it as i.i.d. in the cross section is problematic. We can, however, use a property of these regression residuals: the fact that ε_t resides now on a space that is orthogonal to L_t. Specifically, note that:

$$\varepsilon_t = \left(1 - L_t(L_t' L_t)^{-1} L_t'\right)\varepsilon_t \quad (4)$$

This representation will be useful in what follows, as we impose assumptions on this unknown term.

And the portfolio's variance is given by:

$$Var(h' R_t) = h'[L_t \Sigma_F ' L_t' + \Omega + \varepsilon\varepsilon']h \quad (5)$$

So we have now an augmented risk model, with a an extra volatility term, $\varepsilon_t \varepsilon_t'$. Recall that this term is unknown, so in what follows we formulate a strategy to approximate it.

This expression also provides another way of understanding the exaggerated effect of risk underestimation in an optimization. A proper risk model that captures sufficient relevant risk factors should have a trivial omitted risk on a regular portfolio. The optimization process, however, creates a wedge between the model forecast and the realized risk: In a basic mean-variance framework, where the objective is simply to minimize the portfolio risk, equation (2) is used as the minimizing objective function whereas the true risk is determined by equation (5). Consequently, the optimal portfolio loads on the omitted risk factors freely (in terms of the objective function). This leads to potential large exposures – and risk – that go unnoticed by the risk model and by the optimization procedure. It is this missing penalty on the omitted risk component that makes the optimized portfolio tilt toward securities more subject to risk underestimation, as measured by the omitted variables.

Idiosyncratic robust penalty

With the risk underestimation in the optimal portfolio identified, we now propose an idiosyncratic robust penalty that realigns the risk estimation process for optimization purposes. The ultimate challenge lies in proxying the unobserved return covariance $\varepsilon_t \varepsilon_t'$. Specifically, there are two major issues to be resolved. First, one needs to identify how this term varies in the cross section (relative exposure of the different assets to the missing factor and their correlations); second, we need a particular penalty when adding this term to the objective function (price of the omitted risk).

There have been various suggestions to solve this problem. For instance, Bender, Lee and Stefek (2009) suggest using an expected return covariance matrix as a proxy for the first step. Saxena and Stubbs (2010) instead propose an approach with dynamic features, assuming that ε_t is endogenously dependent on the realization of the optimization solution h. Note that both approaches deal only with the first step described above. When integrating this term into the objective function, they both rely on relatively ad-hoc parameters. Unfortunately that is hard to calibrate when the portfolio is relatively heterogeneous, such as multi-asset class portfolio (see last example in the paper). Our suggested approach addresses both problems simultaneously in an intuitive fashion.

The unobserved return ε_t can be interpreted as the product of the unobserved loadings multiplying by unobserved factors. For the unobserved loadings, as ε_t spans into the orthogonal space of the systematic factor space (equation (4)), the orthogonal loadings are a sensible assumption. These also drive the correlation between the unknown factors. Furthermore, we suggest to proxy the magnitude of the unobserved factor by that of the idiosyncratic return. Therefore, the idiosyncratic robust penalty (IRP) term we propose is formulated as:

$$IRP = P_{\perp} \times \Omega \times P'_{\perp} \quad (6)$$

where $P_{\perp} = \left(1 - L_t (L_t ' L_t)^{-1} L_t '\right)$. Being a diagonal matrix, the idiosyncratic variance matrix Ω serves as the weight on the omitted factor loadings across securities. On the security level, a high idiosyncratic risk signifies a potentially high volatility on the omitted factors. This aspect is particular important for portfolios with very diverse holdings, such as multi-asset class portfolios. The correlation of the unobserved factor return is described by the orthogonal factor loading matrix, which is non-diagonal. Evidence of the advantage of exploiting the idiosyncratic matrix as a source for the IRP will be shown in the empirical studies in the next section.

The implementation of the augmented risk model using (6) is straightforward: We just add the robust penalty term - $P_{\perp} \times \Omega \times P'_{\perp}$ - to the optimization objective function. The weight used to add this term may be fine-tuned, but we find that setting it to 1 typically ensures good results (see empirical analysis below). The penalty seems sensible only when either the total TEV or the idiosyncratic TEV is selected as the objective in the optimizer at the same time.

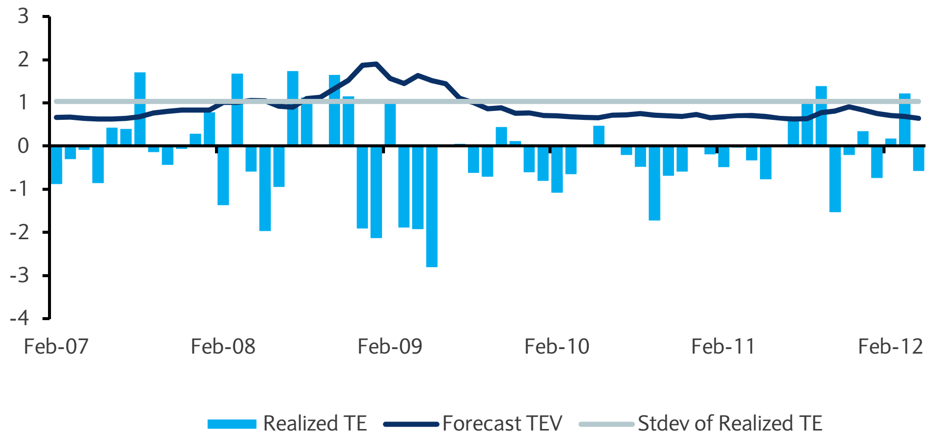
Empirical study

One of the most popular applications of an optimizer is to produce index-replicating portfolios. A passive asset manager’s goal is to peg the portfolio performance to a benchmark index while limiting the number of transactions and positions. This is achieved by constructing index-replicating portfolios seeking to minimize the TEV relative to the index, subject to turnover constraints. In this section, we illustrate the impact of IRP on such an exercise, using POINT’s optimizer. Our illustration spans three sample portfolios: one in equities, one in fixed income and one multi-asset. For all examples and techniques, the IRP term is added to the objective function with a weight of one. One can argue that better results could be achieved with a more judicious choice for the price of the penalty.

Let us first come back to the earlier example with S&P 500 index. Specifically, we add the IRP to be objective function of the index-replicating optimization exercise. The ex-post performance is shown in Figure 3. The forecast TEV, with average at 0.88 (vs. 65 without the IRP), tracks much closer the realized TEV (1.03). Figure 4 summarizes the key performance metrics across different back tests. The standard deviation of the standardized TE reduces significantly from 1.88 to 1.1, confirming a remarkable improvement of the risk forecast on the optimal portfolio. In particular, the realized TEV reduces from 1.33 to 1.03 with the IRP – suggesting a more robust ex-post performance of the optimization solution.

FIGURE 3

Forecast TEV vs Realized TEV – 30 stocks from the S&P 500 index replication optimization with IRP



Source: Barclays Research.

With IRP added to the risk minimizing objective function, not only is the forecast TEV better aligned to the realized level, but a more robust index replication solution is achieved.

FIGURE 4

Forecast versus Realized – S&P 500

	S&P 500 index	Optimal Portfolio	Optimal Portfolio with IRP
Average TEV	5.53	0.65	0.88
STD of realized TE	5.34	1.33	1.03
STD (realized TE/TEV)	0.97	1.88	1.10

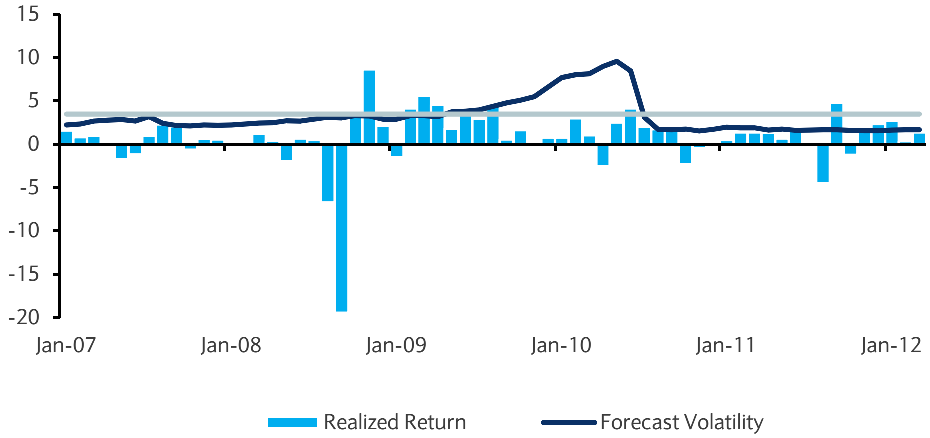
Source: Barclays Research.

Passing on to the fixed income side, we perform similar test using the USD Barclays Emerging Market index. Each month, 30 bonds are selected by POINT's optimizer by minimizing the TEV with respect to the index. We observe results qualitatively similar to the equity ones. For completeness, Figure 5 shows the performance of the GRM for the EM index. We can see that, generally, the forecasts are in line with realized volatility.

Figure 6 displays the performance of the replicating portfolio using no IRP. Figure 7 shows the performance with the IRP. Comparing the numbers (Figure 8), the standard deviation of the standardized TE falls from 1.71 to 1.38, indicating a more accurate risk forecast on the optimal portfolio. This number is 1.23 for the index, suggesting some underestimation of risk during the financial crisis. Moreover, the realized TEV improves slightly, from 0.38% to 0.31%. We once again verified the robustness enhancement from the IRP with the index in the fixed income sector.

FIGURE 5

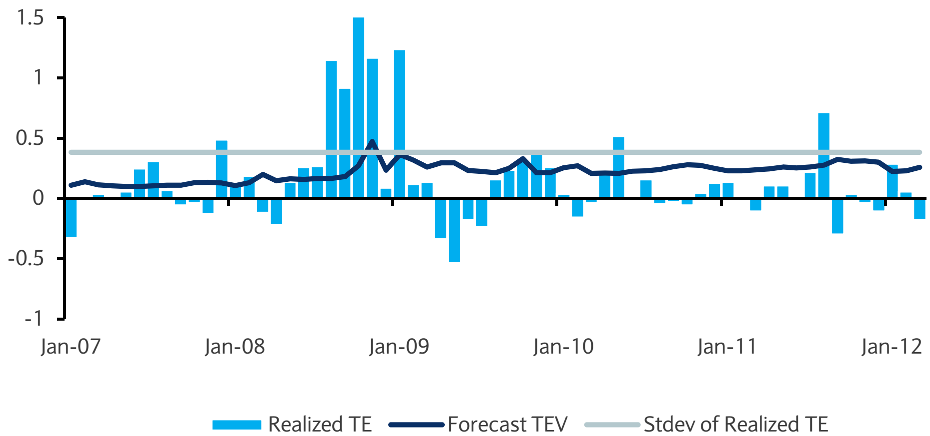
Forecast TEV versus Realized TEV – Emerging Market index



Source: Barclays Research.

FIGURE 6

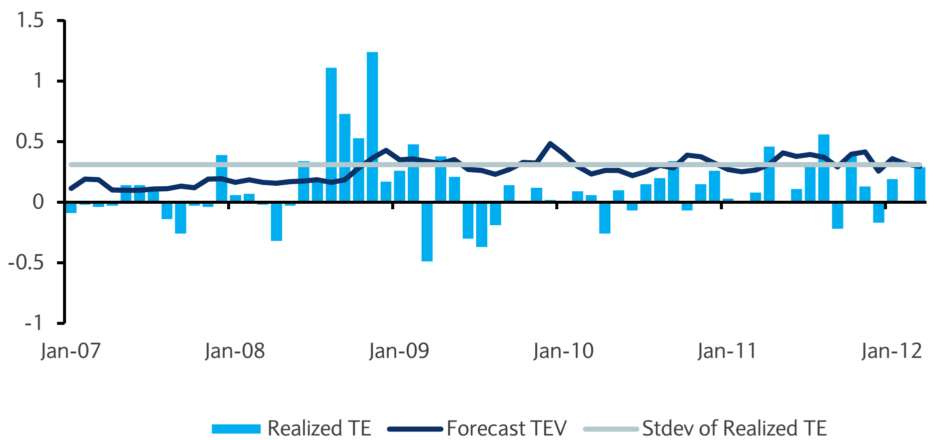
Forecast TEV vs Realized TEV – 30 stocks from the EM index replication optimization – No IRP



Source: Barclays Research.

FIGURE 7

Forecast TEV vs Realized TEV – 30 stocks from the EM index replication optimization with IRP



Source: Barclays Research.

FIGURE 8

Forecast vs Realized – EM Index

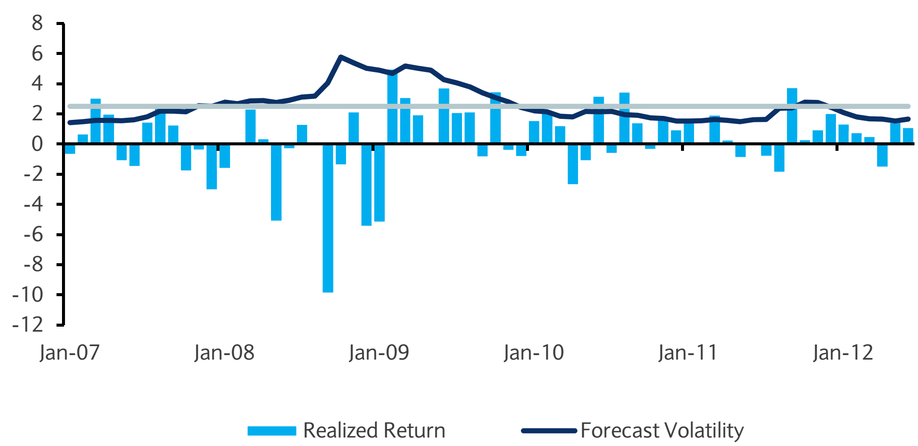
	EM index	Optimal Portfolio	Optimal Portfolio with IRP
Forecast TEV	3.16	0.23	0.28
STD of realized TE	3.48	0.38	0.31
STD (realized TE/TEV)	1.23	1.71	1.38

Source: Barclays Research.

The last example we propose uses a multi-asset index that is comprised by the Barclays US Treasury index and the S&P 500 index. The composite index is volatility weighted, so that each of the sectors contributes equally to the risk of the index. As before, each month 30 securities are selected by the index replication optimization. The final selection contains approximately half Treasury bonds and half stocks, as a result of the volatility-weighted index. One issue we want to delve into is the contribution of the idiosyncratic matrix in the IRP formulation in (6). As we know, Treasuries and stocks have very distinct levels of idiosyncratic risk: the portion of the idiosyncratic risk in the total TEV is above 50% for an average equity stock, while it is less than 10% for a typical US Treasury bond. Moreover, the total volatility of the former is significantly higher than the latter. Consequently, it is intuitive to assign higher IRP to equity securities than to Treasuries. Our implementation handles that directly whereas other solutions may not capture this important nuance.

FIGURE 9

Forecast TEV versus Realized TEV – Mixed Index

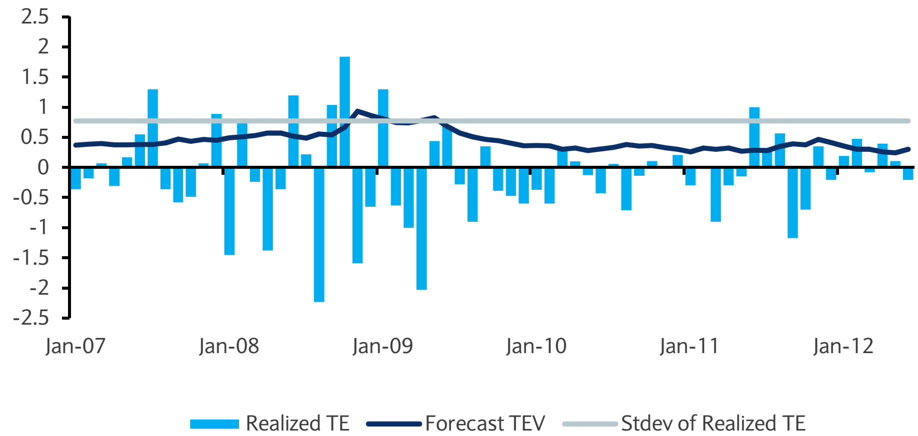


Source: Barclays Research.

Figure 9 shows that the forecast risk is in line with the historical realization at the composite index level. In line with previous evidence, though, we observe a considerable risk underestimation of the optimized portfolio (Figure 10). The standard deviation of the standardized returns is 1.57. The performance of the index-replicating portfolio incorporating our IRP is shown in Figure 11. Here we can see that the forecast TEV is much more in line with the realized level. The above statistic is now at 1.17, implying a significantly smaller estimation bias.

FIGURE 10

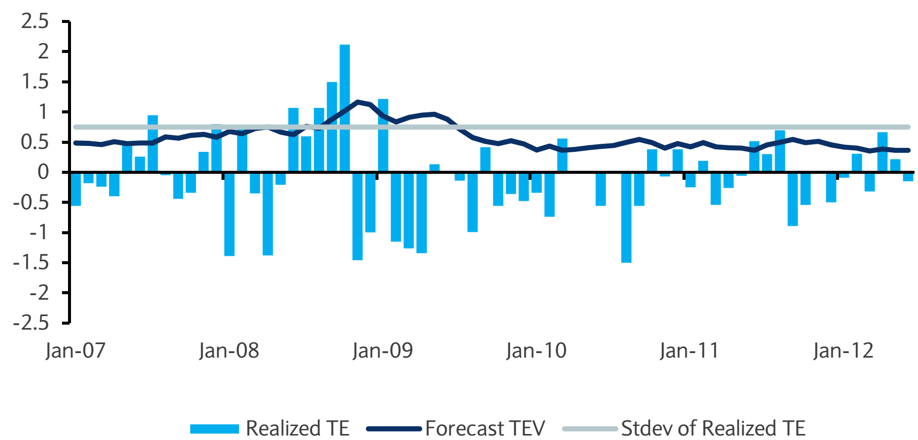
Forecast TEV versus Realized TEV – 30 stocks from the mixed index replication optimization – No IRP



Source: Barclays Research.

FIGURE 11

Forecast TEV versus Realized TEV – 30 stocks from the mixed index replication optimization with IRP



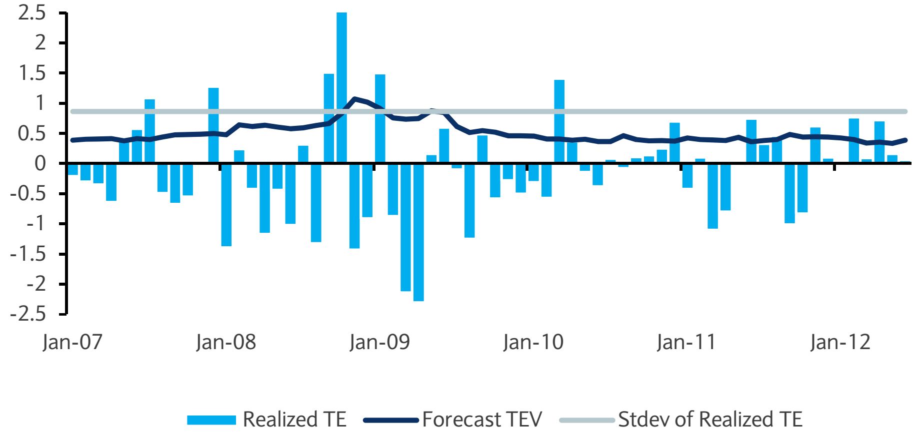
Source: Barclays Research.

For comparison purposes, we also present the performance of the optimal portfolio created with the penalty term formulated instead as $P_{\perp} \times I \times P'_{\perp}$, where *I* is the identity matrix. This formulation assumes an uninformative identity matrix for the unobserved systematic factor covariance and is a popular choice[3]. Figure 12 suggests that the risk realignment is limited compared to the one obtained with IRP.

[3] This approach is used with an iterative choice of the penalty cost. Thus, the results presented here may be unfair to this choice, as better results may be obtained by using a penalty price other than 1. Again, in our case, we directly incorporate a heterogeneous penalty. Our results can be further enhanced with a choice of penalty cost different than 1.

FIGURE 12

Forecast TEV versus Realized TEV – 30 stocks from the mixed index replication optimization with Identity in the penalty term



Source: Barclays Research.

Figure 13 summarizes this information. Note that the realized TEV is also the lowest among optimized portfolio when we use the IRP (0.74), further pointing to the robustness of the enhancement delivered by the IRP.

FIGURE 13

Forecast vs Realized – Mixed Index

	Mixed index	Optimal Portfolio	Optimal Portfolio with IRP	Optimal Portfolio with Identity penalty
Forecast TEV	2.61	0.44	0.58	0.51
STD of realized TE	2.5	0.78	0.74	0.87
STD (realized TE/TEV)	0.89	1.58	1.17	1.54

Source: Barclays Research.

Conclusion

The fact that an excellent risk model exhibits considerable risk bias on an optimized portfolio is a long-time concern for practitioners who use the mean-variance optimization framework to construct or rebalance their portfolios. The risk-minimizing optimization is a selection process that biases in those securities more subject to risk underestimation. Rooting from omitted variables in the risk model, the underestimation term is addressed by adding an Idiosyncratic Robust Penalty (IRP) in the TEV minimizing objective function. To capture the omitted systematic factors in the risk model, the IRP spans into the orthogonal space of the systematic factor loadings and weights them by the idiosyncratic risk of each security.

The ex-post performance of optimized portfolios shows that the IRP significantly reduces risk underestimation, realigning the forecast TEV to the historical realizations. Furthermore, the optimization solution obtained with the IRP typically achieves lower realized TEV in the index replication optimization exercise. Both results suggest significant enhancement on the optimization results when using IRP.

References

Bender, J. Lee, J. and Stefek, D. (2009) Refining Portfolio Construction When Alphas and Risk Factors are Misaligned. *Axioma Research*

Jagannathan, R. and T. Ma. (2003) Risk Reduction in Large Portfolios: Why Imposing the

Wrong Constraints Helps. *Journal of Finance,* 54(4): 1651-1683.

Lazanas, A. Silva, A. Gabudean, R. and Staal, A. (2011) A Portfolio Manager's Guide to Multi-factor Fixed Income Risk Models and Their Applications. Barclays Capital Publication.

Li, C. and Silva, A. (2012) Random Matrix Theory and Risk Factor Models. Barclays Capital Publication

Markowitz, H.M. (1952) Portfolio selection. *Journal of Finance* 7, 77-91.

Saxena, A. and Stubbs, R. (2010) Alpha Alignment Factor: A Solution to the Underestimation of Risk for Optimized Active Portfolios. *MSCI Barra Research*

Tibshirani, R. J. (1996) Regression Shrinkage and Selection via the LASSO. *Journal of the Royal Statistical Society*, Series B, 58, 267-288.

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