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Risk & Reward

Research and investment strategies

This magazine is not intended for members of the public or retail investors. Full audience information is available inside the front cover.

Invesco has more than 40 years' experience in factor investing. Regular readers of Risk & Reward recognize that factor investing is one of our specialties. Invesco teams from all over the world are committed to this investment style, which – though its theoretical foundations were laid out in the 1950s – has only fairly recently gained broad popularity. Needless to say, we believe factor investing is here to stay. Given its clear rationale and effectiveness, we're convinced that its appeal will continue to grow.

In the current edition, one of my colleagues from the Asia-Pacific region systematically compares factor investing to both active and passive approaches. His conclusion: although each of these three capabilities has advantages, none of them is inherently superior. Rather, finding the right approach depends on the investor's goals and circumstances. Personally, I believe this result confirms Invesco's strategic decision to offer all three approaches in our efforts to meet the wide variety of clients' needs.

In another article, we discuss risk mitigation strategies. Portfolio insurance, once a niche concept, has now become mainstream. But many common approaches fail to adequately account for investors' risk preferences. My colleagues demonstrate how skilfully modifying traditional dynamic proportion portfolio insurance – or DPPI – can potentially lead to better outcomes.

Finally, we deal extensively with emerging market investments. Read more in this Risk & Reward about the possible attractions of investing in India, and learn how emerging market currencies can be integrated within a currency carry portfolio.

We hope you enjoy this latest issue of Risk & Reward.

Best regards,

Marty Flanagan
President and CEO of Invesco Ltd.

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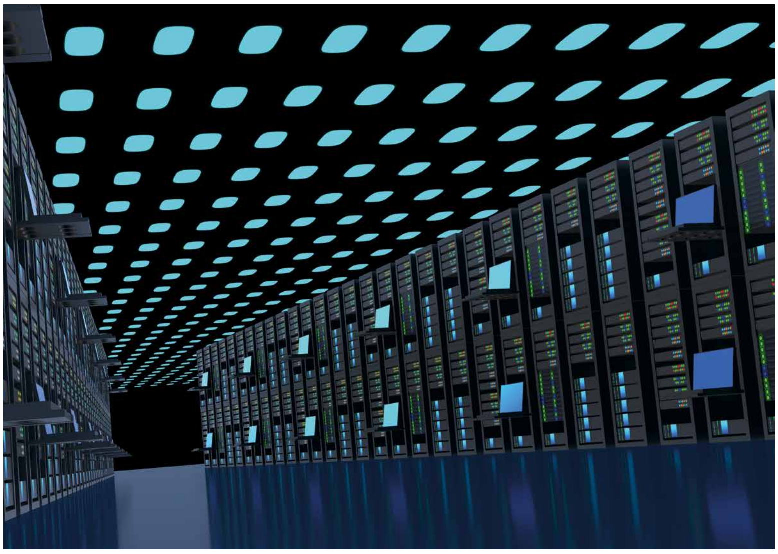
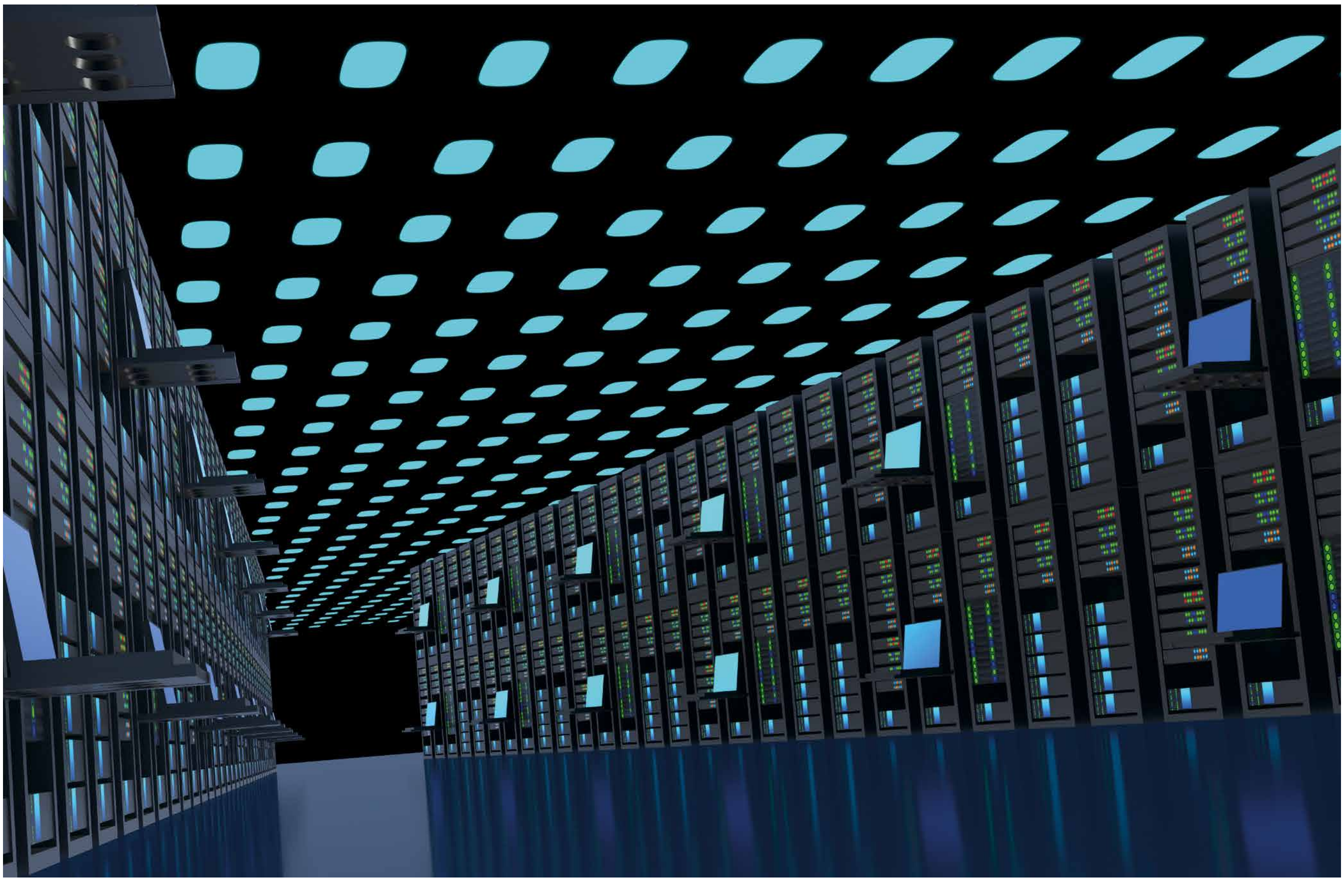


In focus

Factor investing: the third pillar of investing alongside active and passive

By Stephen Quance



In brief
This article examines what it means to be active or passive in today's complex investment landscape. As factor strategies increasingly become mainstream, investors face more choices than ever. Adding to the confusion is terminology that is commonly misused when trying to distinguish between strategies. We propose an inclusive framework to help comprehend terms like active, passive and factor investing in a way that aids decision making.

Factor investing is emerging as a third pillar of investing alongside traditional alpha strategies and market cap-weighted indexing. By focusing on the components of portfolio returns that can be controlled, we can distinguish between the three investment options with clarity and purpose. The point is not to dictate which one is best, but instead to aid in understanding of how they differ so that investors can make more informed decisions.

As indexing and factor investing increase in popularity, there has been confusion about what these terms actually mean and whether the strategies are active or passive. A natural first question might be: why does this matter? It matters because factor investing is emerging as a third pillar of investing alongside traditional alpha sources and market cap-weighted indexing. At its core, factor investing represents a breakthrough in fundamental elements of investing, like price discovery and risk and return – and could mark a permanent shift in asset management.

At its core, factor investing represents a breakthrough in fundamental elements of investing, like price discovery and risk and return – and could mark a permanent shift in asset management.

How we think about and then apply these pillars should fundamentally change our perceptions. But they are often misunderstood, leading some investors to incorrectly dismiss them or solely focus on one over the other. Such misconceptions limit investors' flexibility and capacity to improve their overall investment experience.

The point is not to dictate which option is best, but to provide information that enables investors to choose what's right for them. Each of the three pillars of investing – market cap-weighted indexing, factor investing and alpha strategies – offer distinct advantages and disadvantages (table 1). Each plays a valuable role in the investment ecosystem, and each can therefore be an attractive option given the right set of circumstances. Equipped with this framework to focus on what is possible to control and a proper perspective on what it means to be active and passive, investors can make better decisions and improve their overall investment outcomes.

Components of portfolio returns as criteria for comparison

We can simplify the discussion by dissecting portfolio returns into four components: (1) market returns (2) asset allocation returns (3) return from active management (or alpha) and (4) drag from fees. From these four components, we must also identify what can be controlled and understand what cannot. Individual investors cannot control market returns. No matter how badly we want to, we can't force German bunds up or down tomorrow. This simple fact frees us to think about market returns only in the context of what might happen and how our portfolio will react. On the other hand, we do have control over asset allocation, active management and fees. Thus, much of our decision making should focus on these areas.

As Brinson, Hood and Beebower (1986) first documented, asset allocation explains quite a lot of long-term performance variation. Luckily, there is valuable and publicly available information we can use to help decide on an allocation – the market portfolio.

The market portfolio is a theoretical collection of all listed assets, weighted according to size. It is completely diversified and only vulnerable to systematic risk, whereby new developments affect different segments differently. In liquid, publicly traded markets, the current price is the clearing price between all buyers and sellers, reflecting the aggregate assessment of every investor.

If a preponderance of investors think US stock markets are overpriced compared to others, for example, they will tend to sell in the US and purchase

Table 1
The three pillars of investing

		Active or passive		Control points	
		vs. market	vs. benchmark	Active performance drivers	Costs
Market cap-weighted indexing		Passive	Passive	Market (none)	Lowest
Factor investing	– Indexing (Smart Beta)	Active	Passive	Factor allocation	Low
	– Managed/Customized Factor Strategy	Active	Active	Factor allocation and/or implementation	Moderate
Alpha seeking strategy		Active	Active	Active allocations and/or active management	High

Source: Invesco. For illustrative purposes only.

somewhere else, thus putting downward pressure on US equity prices. So even though there is much more to the story, the market portfolio is an informed starting point.

Passive investing
We now have the start of a robust definition of a passive investment. In passive investing, key decisions are made not by individuals, but by aggregate market participants using, and benefitting from, competitive buying and selling forces. Most passive investors have decided, whether implicitly or explicitly, that the market portfolio is good enough. Perhaps market returns suffice to help them meet their investment goals, or maybe the investors don't have the appetite to risk underperforming the market. So, they opt to accept what the market dictates.

Allowing the market to set asset allocation
Referring back to the three components within our control – asset allocation, active management and fees – passive investors allow the market to set their allocation for them and employ no active management. What's left? Fees. For passive investors, fees are the only thing left within their control. This is why fee levels are such a particular focus for them. Warren Buffet famously advised his wife to invest in low-cost passive funds in the event of his death. So why would one of the world's most accomplished active investors would say this? Even after committing the vast majority of his multi-billion US dollar fortune to charity, Buffet's wife is at no risk of running out of money unless she makes foolish decisions. Market returns seem good enough, with any deviation simply adding risk.

But, for everyone who has less than an extreme overabundance of resources, making the decision to invest passively might not be so straightforward. A little extra gain over time could make the difference between a pension fulfilling its promises or telling workers that it cannot hold up its end of the bargain. Due to the power of compounding, seemingly small differences add up over time. Consider, a 1% difference in return (from 5% to 6%) over an investment lifetime of 25 years ultimately leads to 33% more wealth. Of course, this cuts both ways, so fees matter and risk control is critical as well. For most investors, the stakes are high.

From the above discussion we understand the passive investor's focus on fees. But low fees alone do not define passive investing. Under this definition, holding a single stock in a portfolio would be passive. It ignores the asset allocation component, which we know has a major impact on return variation, and ignores risk.

How then do we further define passive investing in a way that can be helpful?

Is passive only against the index?
When it comes to passive investing, we must have context. Remember, the market portfolio is the asset allocation of aggregate investors, rather than just a random group of securities. This means that, if a portfolio deviates from the market portfolio, it has an active component, whether intentional or not.

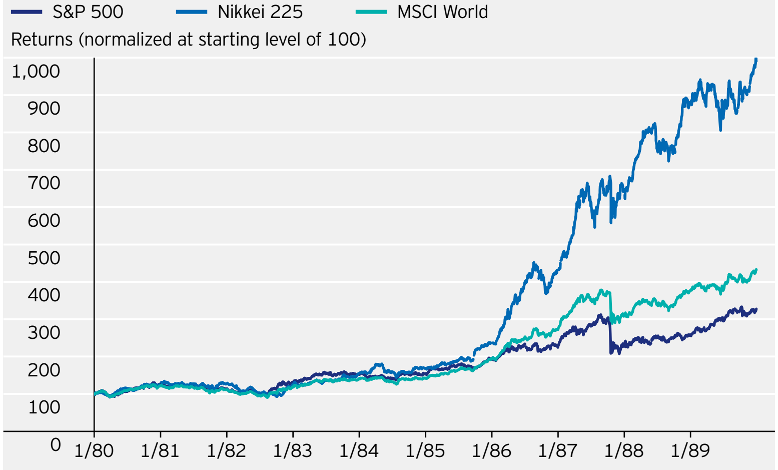
For instance, a fund with the objective of tracking the S&P 500 Index is passive only with respect to

Box
Historic example: Comparing passive strategies by asset allocation
Allocation has a major impact on returns, which gets magnified over time. From 1990 to 2017, the S&P 500 Index returned an annualized 9.8%, for a cumulative return of 1,270%. If you instead invested in the MSCI World Index, opting for global exposure, your total return would be significantly less – an annualized 6.8% or 529% cumulatively.*

Let's suppose you had opted to invest in the Nikkei 225 Index. It is easy with hindsight to caution against such an investment, but by the end of 1989 the Nikkei had dominated both US and global returns for many years, much the way the US has dominated more recently. In the 10 years ending 1989, the Nikkei was up 891%, dwarfing the returns of the MSCI World Index (333%) and the S&P 500 Index (407%) (figure A). The passive investor tracking the Nikkei 225 from that point onward would be sorely disappointed, however, as the index dropped 25% in price and delivered a total return of just 1% over an almost 30-year period (figure B).

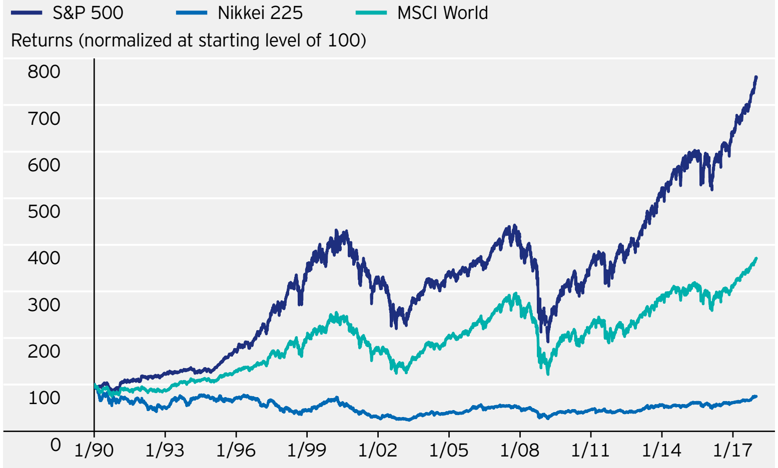
Many core investment principles are at work in these examples. First, asset allocation really does matter a lot. An S&P 500 index fund may be passive with respect to the index but is active when considering the full opportunity set. We are also reminded that past performance may not be predictive of future performance, and, as seen in the case of Japan, even long-term trends can change.

Figure A
Comparing index returns (1980-1989)



Source: Bloomberg, Invesco. Data from 1 January 1980 to 31 December 1989.

Figure B
Comparing index returns (1990-2017)



Source: Bloomberg, Invesco. Data from 1 January 1990 to 31 December 2017.

* Source: Bloomberg. Indexes cannot be invested in directly; all returns in USD and excluding any fees.

that specific benchmark. The index is essentially the 500 largest stocks in the US, weighted by market cap. There is no active management component. Instead, index returns drive the fund's return and the asset allocation tracks any constituent or weighting changes in the S&P. But the same investment could not be considered passive when compared to a global opportunity set. In that scenario, it is in fact very active. US stocks were 52% of the MSCI ACWI IMI Index, for instance, so the S&P fund ignores half of a global equity opportunity set.[1]

> An investment designed to track an index is passive only against that index, but the index itself may be very active in certain respects.

A helpful understanding is emerging from our discussion. The first point is to focus on elements of an investment that can be controlled: asset allocation, active/passive decisions and fees. The second point is recognition that what is active and what is passive requires some context. An investment designed to track an index is passive only against that index, but the index itself may be very active in certain respects. Only by understanding the ways in which an investment is active can we identify the applicable risk and return opportunities. Crucially for investors, this unlocks new insights into what could potentially go right, or wrong, with an investment.

Active investing
Moving on from the asset allocation discussion, we now address the next item within our control: active management. Active management is the opposite of passive. Rather than passively accepting market returns or a market-dictated asset allocation, investors can actively pursue their own unique strategies. Historically, this is what was expected from professional money managers: to use skill, experience, knowledge, or some sort of advantage to produce a better outcome.

A zero-sum game
The term alpha is used to describe excess return generated versus a benchmark. It simply refers to the positive performance not explained by the other three elements of returns: market returns, asset allocation and fees. Alpha could come in the form of higher returns, lower risk or some combination of the two.[2]

A key reality of alpha-seeking active managers is that, if there are winners, there must also be losers. If one manager produces a return stream that demonstrates positive alpha, someone else must have inferior returns, because the market incorporates all investors. This is what is meant when people say active management is a zero-sum game. All above benchmark returns must, by definition, be balanced by below benchmark returns somewhere else. And this is before accounting for any fees. With that in mind, it should not be surprising to anyone that capturing alpha is difficult – though that has not stopped investors from trying. In the United States alone, active management accounts for more than three-quarters (or USD 11.3 trillion) of open-ended funds, excluding money market and fund of funds.[3]

Seeking to exploit an advantage
Understanding the role of active management helps investors select and evaluate potential managers. What investors should want from alpha-seeking managers is for them to actively exploit advantages for their benefit. What they should not want is unnecessary barriers that reduce the manager's ability to do so. For instance, if there is a manager that can add alpha in Korean equities, investors should not want that manager to invest outside this area of expertise, e.g. to suddenly consider the entire global equity market.

Put another way, think about firefighters. If you have a group of highly trained, highly skilled firefighters, you do not want them doing other jobs, even if that means spending a lot of time waiting around between fires. Instead, we want them to focus on what they are good at, and we evaluate them in this light.

An understanding of the sources of alpha also improves one's ability to monitor and evaluate the manager. Scalability of the alpha, for example, can be estimated. If the manager captures alpha by dynamically changing the asset allocation across markets, this strategy will have a much different capacity than a manager who invests in small companies of a single country, or illiquid high-yield bonds. While reviewing investment performance, managers should relate the outcome drivers to the process – elements which they control – rather than elements completely out of their control. In short, the manager owes a candid explanation identifying the active elements of the strategy and the impact the active management had on performance.

Always assess in context
Similar to passive investing, it is often helpful to add context to active management. Take the example of the Korean equity manager. We would naturally benchmark the achieved performance to a Korean equity index. Why? Because the allocation decision to focus on Korean equities was not made by the manager, it was made beforehand when the decision to hire a Korean equity expert was made. If Korean markets outperform other markets, the Korean manager doesn't get credit – much as he should not be blamed if the Korean won declines against other currencies. Therefore, the alpha generated is most appropriately evaluated in the context of Korean equities generally.

In this situation, we are clear as to whether we have an active or passive asset allocation to Korean equities and whether or not active management within Korean equities is doing what we hoped. We control both the asset allocation and the active/passive decision.

Factor investing
We are now ready to address factor investing. A brief definition is warranted to ensure a common understanding. Factor investing is a systematic, evidence-based approach that targets certain

characteristics of an asset, called factors, which tell us something useful about the security's expected return or risk.

We can specifically structure a portfolio around an investment factor. Some of the most common investment factors are value, momentum, quality and size. Meanwhile, macroeconomic factors, like unemployment and inflation, enable investors to assess how exposed their portfolios are to different stages of the economic cycle, similar to a doctor collecting information to diagnose a patient's condition (figure 1).

> Factor investing unlocks an improved understanding of markets and asset allocation, and might thus be considered a third pillar of investing.

Factor investing unlocks an improved understanding of markets and asset allocation, and might thus be considered a third pillar of investing. Previously, we looked primarily at asset classes – like stocks, bonds, cash – and also at sectors and other characteristics to understand the expected risk and return sources of the portfolio. Rigorous academic research has pushed the understanding further, illustrating how factor exposures help explain more of historically observed security returns. Factors, at least the ones that we have confidence are worth monitoring and pursuing in a portfolio, also have a solid economic rationale. Because factor investing is based on improved understanding, its increasing adoption throughout the world likely marks a permanent change in how assets are managed.

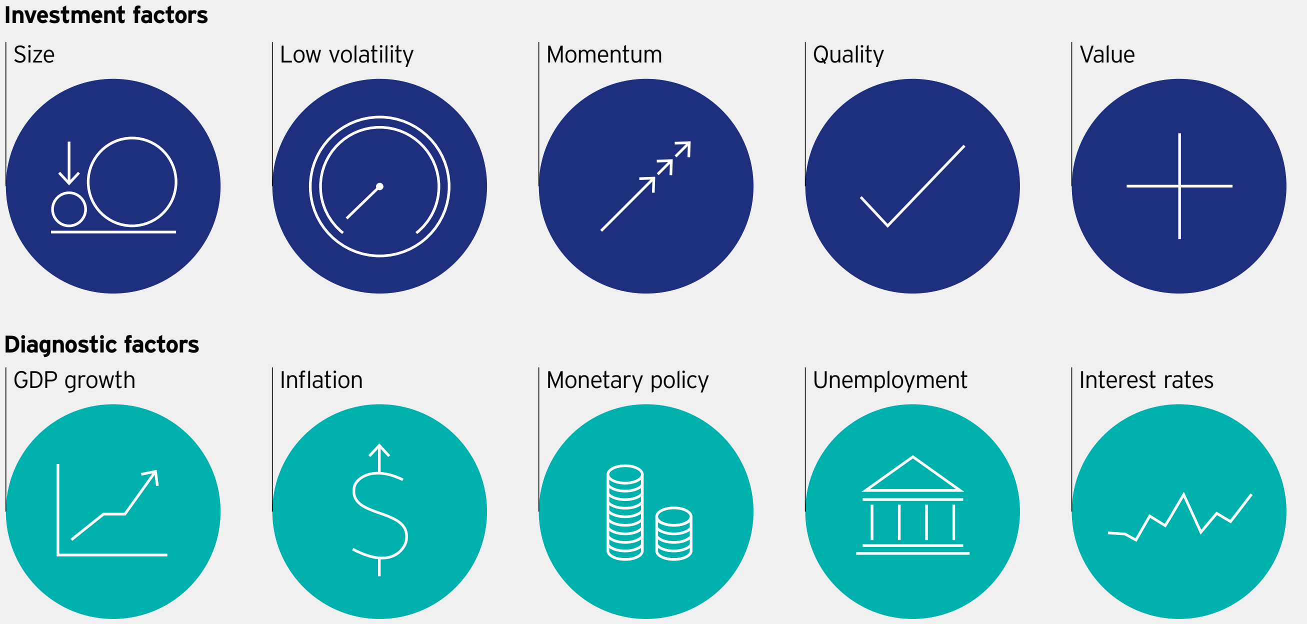
Utilizing active asset allocations

How do we fit factor investing into our active/passive framework? To a degree, factor performance is like market performance. Just as nobody can control whether European stocks go up or down today, there is no way to say for sure whether a premium on value or size will persist. Banz (1981) documented that small-cap stocks historically generated higher risk-adjusted returns, for example, and while the research tells us we should expect the size premium to be material and positive in the long run, it is less predictable in the short term. Factor returns are therefore out of our control in the same way that market returns are out of our control.

But we still have control over asset allocation, active management and fees. Since investment factors help us improve our risk and return expectations, our allocation to them is important. Most investors still don't monitor the factor exposures of their portfolio, nor do they deploy factor-specific strategies. This is changing quickly, however.[4] Someday it may be as common for investors to monitor their investment factor exposures as it is currently for them to monitor their equity, bond and cash allocations.

The market portfolio has an allocation to factors in much the same way that it has an allocation to different countries. We can use our understanding of the risk and return opportunities of factor investing to adjust our allocation, increasing or decreasing the exposure to one or more investment factors. This is an active asset allocation decision, just as it is an active decision when we reweight country exposures.

Figure 1
Common investment and diagnostic factors



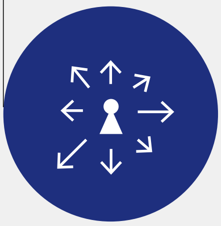
Source: Invesco. For illustrative purposes only.

Figure 2
Three groups of factor rationales

Risk premiums

For bearing additional risk over the broader market e.g. an undesirable return pattern

Behavioral rationales



Markets are inefficient due to behavioral biases of participants

Market structure

Markets may be distorted because of restrictions and limitations

Source: Invesco. For illustrative purposes only.

Accommodating unique objectives without winners or losers
However, it is different than alpha-seeking strategies. Unlike active investing, factor investing is not necessarily a zero-sum game. The reason is simple: whereas in tradtional active investing, everybody pursues the same goal of beating the index, factor investing can cater for different investors' needs and preferences. Factor strategies can be easily customized to an investor's individual goals and risk tolerance.

There are three groups of factor rationales: risk, behavioural and market structure (figure 2). If a factor premium exists because of some element of risk, then an investor's desire to bear or avoid this particular risk is a matter of choice. Investors who achieve higher returns for bearing this risk do not do so at the expense of other investors who may well be happy with lower returns because it was their choice to follow a less risky approach. We have riskier and more conservative portfolios. Similarly, if a factor premium is believed to be available due to a market structure impediment, investors who are not subject to the impediment can benefit. In these ways, among others, factor investing is distinct from traditional active management, and certainly distinct from passive.

Providing advantages through flexibility
With these distinctions, we can make informed choices: to be active or passive in asset allocation and/or portfolio management, and at what cost. Once we decide whether to actively or passively allocate across factors, we can decide whether to actively or passively manage the allocation. Most smart beta strategies are passive exchange traded fund (ETF) applications relating to a single or multi-factor index. Remember, the index construction is making active factor bets that should be understood, as these bets are likely to be a driver of performance. These ETF applications might be attractive because of transparency. The index construction methodology is usually available and straightforward. A more active application allows for unique factors, differentiated definitions of factors, ongoing trade-offs between factor exposures and/or evolution of the process as new techniques are developed. We know the world is constantly changing, so there might be real advantages to having flexibility available to achieve active implementations.

Last, but certainly not least, are fees. There is no question that fees directly impact performance in a negative way. But, do not be fooled into thinking cheaper is always better. Nor should we accept that higher cost always means better outcomes. All we can do is consider both the costs and the benefits of any investment. True alpha is a relatively scarce resource and, as mentioned above, requires some sort of advantage. We should not expect this valuable benefit to be given away. There should be a balance between alpha and the cost to capture it. Factor strategies can potentially add returns and/or control risk in ways pure indexing cannot. Therefore, the optimum should be somewhere between pure alpha and indexing. Traditional passive indexing involves no added value, so it is mostly about low cost.

Conclusion
Whether we classify a strategy as passive or active requires context. There is an active element in any strategy that materially differs from a market portfolio, because the market portfolio is determined largely by competitive buying and selling of all market participants, particularly in equities. Asset allocation explains a lot about risk and return, so it should be determined deliberately.

Taking an active or passive approach to asset allocation is likely to make a big impact on results in the long term. Active management can be used in an attempt to supplement returns or as the basis of alpha-seeking strategies. Finally, fees are important and should be judged in relation to the benefits offered by a particular approach. Skill is very valuable and should be priced appropriately. Market exposure should be relatively inexpensive. Factor investing, is a third distinct approach with its own advantages and disadvantages. Depending on the application and complexity of approach, it usually lies somewhere between the other two options in both expected value-add and cost.

References

- Banz, R. W. (1981): The relationship between return and market value of common stocks.
- Brinson, G., Hood, R., Beebower, G. (1986,): Determinants of Portfolio Performance.

About the author

Stephen Quance
Director of Factor Investing
Stephen Quance promotes the global factor initiative by supporting clients, aiding research, setting strategy, refining operations and increasing education both internally and externally, primarily in the Asia Pacific region.

Notes
1 As at 29 December 2017. Source: MSCI. MSCI ACWI IMI Index is designed to cover approximately 99% of the global equity investment opportunity set.
2 These examples are intended to be illustrative and are not an exhaustive list of objectives.
3 Source: Morningstar data as of 15 December 2017.
4 Invesco's Global Factor Investing Study 2017 examined the change in factor allocations globally. In 2017, institutional investors increased allocations in North America (16% AUM to 19%), Europe (17% to 19%) and Asia Pacific (7% to 10%).

About risk

The value of investments and any income will fluctuate (this may partly be the result of exchange rate fluctuations) and investors may not get back the full amount invested.

"It's time to take a step back and clarify where and how factor investing fits into the investment landscape."

Interview with Stephen Quance, Director of Factor Investing

Stephen Quance
Director of Factor Investing

Invesco's Stephen Quance shares insights from his daily contact with investors trying to make up their minds and decide between active, passive and factor investing.

Risk & Reward
Why is there a need for a framework to distinguish between active, passive and factor strategies?

Stephen Quance
Active, passive and factor strategies are three distinct investment approaches, each having advantages and disadvantages depending on what the investor is trying to achieve. I now see volumes of information hitting the market about factor investing, a topic still new to a lot of investors. This is good news, as factor investing unlocks productive new capabilities. Many seem unclear about the core principles of these strategies, however, causing them to incorrectly dismiss potential options, or worse, use them in an unintended way.

Even sophisticated institutional investors can fall into this trap. A large institution recently sought to implement a non-market-cap-weighted mandate, for example, deciding to hire asset managers to track a newly created customized index. The asset managers went through a formal due diligence process with nearly every aspect of their approach analyzed by the institution. The index construction methodology, however, was not subject to the same scrutiny. This is illogical, as most of the active choices, and with them long-term performance, are driven by the stock selection and weighting of the index.

I think it is time to take a step back and clarify where and how factor investing fits into the overall investment landscape. Hopefully, this can enable investors to distinguish between investment options with more clarity and purpose.

Risk & Reward
In your paper, you mention that terminology is often confusing and leads to misunderstanding when discussing the three strategies. How does your framework address that?

Stephen Quance
We have new terms being used that do not have universal definitions, like "style factors", "alternative risk premiums" and "factor investing" more generally. These terms may be useful in certain contexts, but they are sources of confusion as well. The framework is intended to move the conversation beyond inconsistently used terms and jargon, and instead focus on a couple key considerations. As a starting point, there must be a focus on the elements of an investment that can be controlled: asset allocation,

active/passive decisions and fees. Once we clarify the control points, we can concentrate our efforts on making the best decisions. There must also be recognition that understanding what is active and what is passive requires some context. An investment designed to track an index is passive against that index, for example, but the index itself may be very active in a larger context.

Risk & Reward
On the topic of terminology, there is some confusion within factor investing whether or not it is synonymous with "smart beta". Are there any distinctions between the two?

Stephen Quance
Smart beta is another often used term without a universal definition. Generically, it refers to a systematic weighting of securities based on criteria other than market-cap. In practice, it most often refers to an exchange traded fund (ETF) tracking an index that screens and weights its constituents through one or more factors, like high dividend or low volatility, for instance. With this understanding, smart beta can be considered a subset of factor investing.

Risk & Reward
When we talk about factor investing, how would you say it differs from other quantitative strategies?

Stephen Quance
All factor investing is quantitative – but not all quantitative investing is factor-based. The traditional quantitative approach is focused on gaining alpha and trying to create an absolute return or beat the market by targeting proprietary information or exploiting a skill. High-frequency trading, for example, uses complex, closely-guarded algorithms and computational power to take advantage of a supposed information advantage over an infinitesimal timeframe. When it works, the return stream is idiosyncratic.

Factor investing, on the other hand, is about identifying characteristics of groups of securities that we expect to behave in a certain way. Its basis comes from empirical academic research. The first widely adopted use of a factor is beta from the capital asset pricing model (CAPM). This is a single-factor model. Over the years, additional factors have better described observed security returns. This makes factor investing, once understood, more transparent. We can explain to investors which factors we plan to pursue and how we are going to do it. We can also pursue excess return, and do it in a very scalable way, because we are targeting groups of securities. It's clearly quantitative, but fundamentally distinct from other forms of quantitative investing.

Risk & Reward
You say that factor investing has emerged as the "third pillar" of investing. How widely is it being utilized by investors?

Stephen Quance
To the extent that factor exposures help explain security returns, all investors already have exposure to a series of factors. This is one of the most compelling realizations in recent years, and the reason why portfolio analysis through a factor lens is increasingly popular. Unless they employ an explicit factor-based approach, however, their portfolios might demonstrate a very different risk and return profile from what was intended. Implementing a dedicated factor strategy, on the other hand, enables direct control over factor exposures. It is a rigorous process, and the benefits are most likely to accrue to those who take the time to understand what they are getting into.

Adoption of factor investing as a mainstream approach is still in the early stages. It is currently used more widely in North America and Europe than in Asia. But further growth is anticipated in all regions. For instance, the Invesco Global Factor Investing Study 2017 indicated that institutional investors globally are increasing their factor allocations.

Risk & Reward
Does it ever make sense for an investor to consider all of them: active, passive and factor strategies? Or should they just focus on one or perhaps two?

Stephen Quance
Each of the three pillars of investing: market-cap-weighted indexing, factor investing and alpha strategies – offers distinct advantages and disadvantages. Each plays a valuable role in the investment ecosystem, and therefore each can be an attractive option given the right set of circumstances.

In reality, the three approaches are not discrete. Many strategies combine different elements together. This is why I wanted to provide a framework that could disentangle the investment options and cut through marketing terms in order to get at the heart of what drives performance. As an investment professional, it helps me, and I hope it can help others as well.

Risk & Reward
Thank you.

Four years on: Modi lays down building blocks for growth in India

By Stuart Parks and Paula Niall

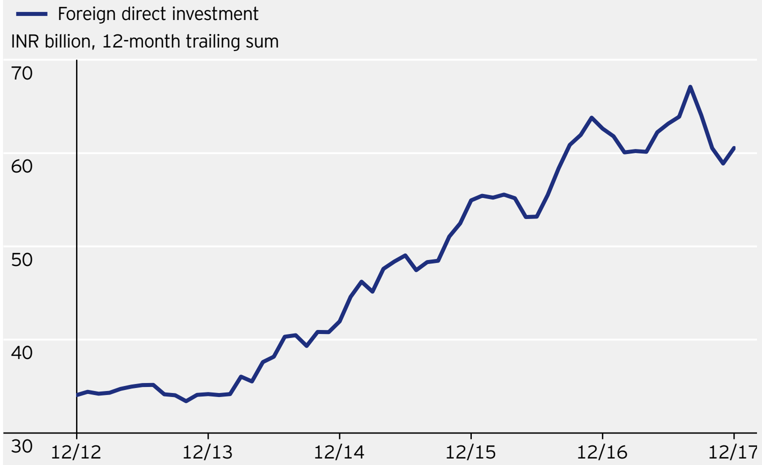
In brief
An important theme within Asia is the progress of reform in India. Under Prime Minister Narendra Modi, India has the best reform momentum amongst the Asian countries we invest in. Several structural reforms have already been undertaken: the implementation of the Goods & Services Tax (GST) is progressing well, the high-value currency demonetization is shrinking the black market, the approval of the Insolvency & Bankruptcy Code has been a significant step towards cleaning up bank's balance sheets, the state-owned banks' recapitalization should enable the stronger banks to grow their loan books more aggressively, the affordable housing buildout is likely to help revive growth and, finally, the digital transformation is reducing costs and increasing efficiency. Ultimately, investors have remained confident that Modi's reforms will increase the economy's potential growth rate and therefore support higher corporate earnings in the longer term. We concur with this view. But if these reforms do not actually produce improved growth in 2018, then investors may start to question whether the valuation premium attached to Indian companies is deserved.

Four years after Narendra Modi became Prime Minister of India, there are good reasons to be optimistic about his reform programme and the impact it may have on economic growth in the medium term. We have identified six key areas of significant positive change.

International investors like India's Prime Minister Narendra Modi and his economic reforms.

International investors like India's Prime Minister Narendra Modi and his economic reforms. Since he assumed office in May 2014, investor sentiment towards the subcontinent has taken a turn for the better. This is true for financial investors as well as foreign companies trying to get a foothold in Asia. In any case, assuming foreign direct investment is the appropriate indicator, there are clear signs that Modi's international credibility is high (figure 1).

Figure 1
Foreign direct investment in India has increased by 60% in the last three years



Source: Department of Industrial Policy & Promotion (DIPP), Centre for the study of Education in an International Context (CEIC), Morgan Stanley Research. Data as at 31 December 2017.

The Goods and Services Tax (GST) is arguably one of the most ambitious reforms ever attempted in India.

Roll-out of GST should lend support to economic growth over the medium-term

The Goods and Services Tax (GST) is arguably one of the most ambitious reforms ever attempted in India. It was implemented in July 2017 with six different tax rates on goods or services across the country, though the long-term plan is to reduce the number to two. The rationale for the GST is very clear: Firstly, India's pre-GST indirect tax structure had layers of government and individual state taxes, which made state border-checks necessary. To reduce their tax bill, many companies' distribution centres were subscale. Under the new regime, supply chains will be based on economic criteria, leading to lower costs and better delivery timelines. Secondly, the GST will help reduce the number of tax evaders. Since this tax is built on a matching invoice and tax-credit concept, where supporting documents are required for the GST input credit to be claimed, large companies will not do business with tax evaders. Finally, the GST will also help to reduce the excessive level of bureaucracy in the economy. The logistic sector is an obvious beneficiary of the GST, but all companies transporting goods across many different states will benefit.

Demonetization is reducing corruption and boosting tax revenues

The Indian government unexpectedly announced in November 2016 that INR 1,000 and INR 500 notes were no longer legal tender and that new security banknotes in denominations of INR 2,000 and INR 500 would be issued. This action was aimed at clamping down on corruption and tax evasion. When demonetization was implemented, it reduced the availability of cash and black money in the system, at least temporarily, and as a consequence increased the percentage of deals / deal value with a greater component of "white money". What is important is that demonetization generated a lot of fear, as individuals and businesses were forced to deposit large amounts of cash in bank accounts, increasing the potential for scrutiny by tax officials. This encouraged tax returns to be filed and more businesses to shift to legitimate channels. This should have a positive impact on India's fiscal deficit over the medium term (3.5% of GDP for FY18).

Insolvency & Bankruptcy Code is critical in reducing bad debts and accelerating loan growth

A key obstacle to growth in India has been the high level of bad debt on banks' balance sheets. The banks account for nearly 80% of financing in the economy, and their stressed loan ratio is approximately 12%.[1] The inability to wind up loss-making companies has stopped banks from financing new projects and hindered any potential upturn in the investment cycle to date. Hence, there is a macro imperative to address the level of non-performing loans (NPLs) if loan growth is to match the Indian economy's need for it.

A notable step in this direction took place in December 2015, when the Reserve Bank of India (RBI) asked banks to fully provide for all bad loans by March 2017. To help, an Insolvency & Bankruptcy Code (IBC) was introduced. Under this framework, all banks must work towards resolving defaults, and failure to put in place a plan within six months would result in a referral to the IBC for insolvency proceedings. With 'encouragement' from the RBI, banks referred 12 major cases – approximately one-quarter of total stressed assets – to the National Company Law Tribunal (NCLT)[2] in June 2017. The outcome of these cases and a second list of 28 cases (results due later in 2018) should establish new price marks and hopefully lead to a widespread restructuring process. While we expect this to

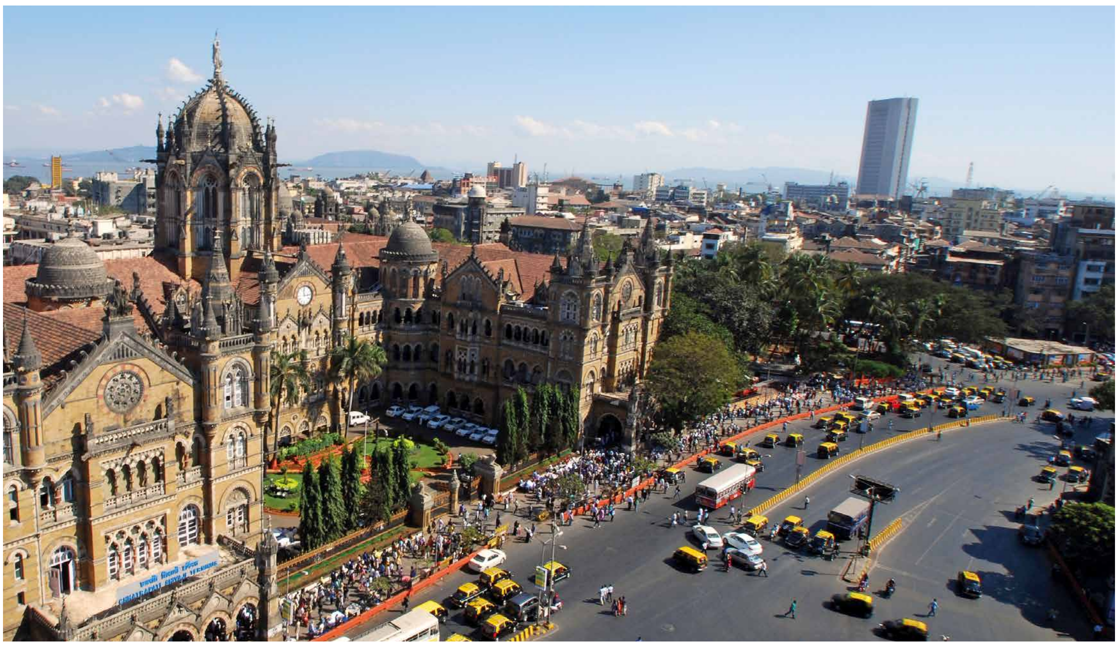
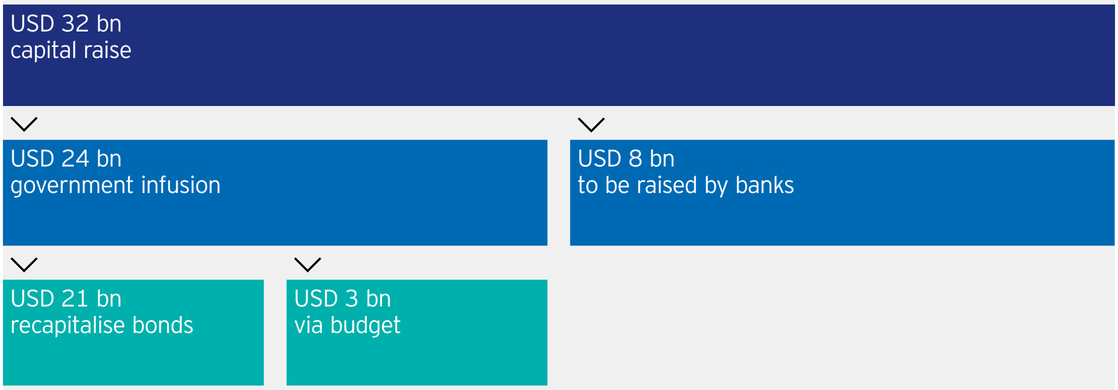


Figure 2
Recapitalisation of India's state-owned banks



Source: CLSA, February 2018.

increase near-term pain for the banks, particularly as we could see more skeletons tumbling out of banks' loan books, this is what is needed to improve their long-term health.

Government's bold plan to recapitalize state-owned banks is a medium-term positive for growth
A critical step in Modi's reform agenda is recapitalization of the state-owned banks, which are still the largest corporate lenders with a more than 70% share of the corporate lending market.[3] Some of these state-owned banks are only just meeting their capital adequacy ratios, and are not able to handle large write-offs. In October 2017, the government announced a recapitalization plan totalling INR 2.11 trillion (USD 32 billion) to be provided over the next two years (figure 2). Overall, this capital infusion is equivalent to approximately 35% of the market cap of the state-owned banks. We believe this recapitalization should help to speed up NPL resolution as the banks would be able to accept larger haircuts.

A push for affordable housing may act as a structural driver of economic growth
One way the government can both revive growth and generate jobs is through the mass buildout of affordable housing. Under its "Housing For All" plan, the government aims to build an additional 20 million homes for lower-income households by 2022 (atop existing stock of around 100 million urban homes). Although India's housing stock has grown enormously over the past decade, there is a glut of large, expensive homes and too few smaller, cheaper ones. To address the housing issue, all constituents of the housing chain – developers, home-loan borrowers and lenders – are now being incentivised by the government. Affordable housing projects are given "infrastructure status", which warrants a reduced tax rate and cheaper financing, while buyers are offered interest subsidies for home loans subject to annual income levels and house size limits. Also, these incentives need to be seen in the context of reforms such as the introduction of the Real Estate Regulation Act (RERA) in May 2017. For years, buyers had to bear the costs when their new homes were not delivered on time – frequently because builders diverted buyers' payments into alternative projects. The RERA rectifies this problem by requiring developers to deposit 70% of the money raised from buyers on any given project into an escrow account.

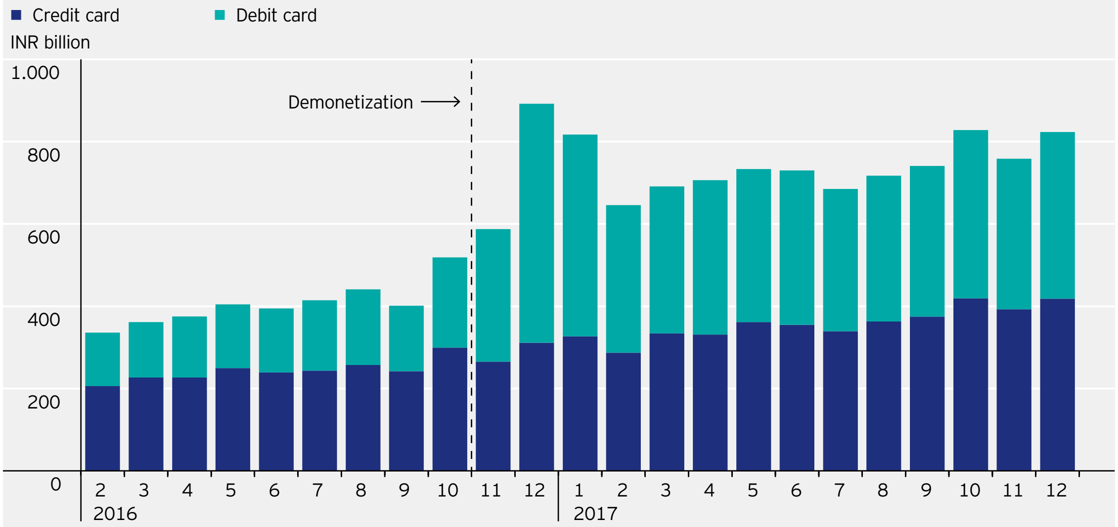
The real estate sector's linkages to the broader economy involve some large sectors that could benefit from a housing boom, such as cement, steel, paints, electrical goods/appliances and building materials. Since construction is a low tech intensity sector, which is relatively immune to automation, it is one of the key sectors for absorbing India's declining labour requirement in agriculture.

A digital transformation benefits government finances, governance & consumer demand
"Digital India" is a campaign launched by Modi's government in July 2015 to address technological shortcomings, save money and reduce corruption. As part of this campaign, the government is focused on ensuring that high-speed internet is available to all, government services are distributed online, financial transactions above a certain threshold are electronic and ownership of bank accounts becomes widespread. This digital initiative is only possible due to the existence of the unique identification project, Aadhaar (introduced in 2009). This provides a cradle to grave digital identity (UID) for each resident, based on their biometric data, which is used to access government and financial services. Currently, Aadhaar enrolment is within the range of 70% to 100% across most states.[4]

One of the most notable benefits of Aadhaar has been the increase in banking penetration (previously below 60%),[5] as the UID by itself is sufficient for opening a bank account. This has brought hundreds of millions of households into the banking system. It is also worth noting that the government used the opportunity provided by demonetization to promote a switch from cash to electronic transactions as the primary means of payment (figure 3).

The greater ownership of accounts has facilitated the government's direct benefits transfer (DBT) scheme. The aim of this scheme is to transfer a range of subsidies (e.g. cooking fuel, food, fertilisers and guaranteed rural wages) directly into citizens' bank accounts using the UID system (table 1). This is aimed at reducing corruption.

Figure 3
Demonetization resulted in an increase in e-payments



Source: RBI. Data as at December 2017.

Turning to internet connectivity, the number of internet users increased at a CAGR of roughly 31% from 2000 to 2017 (figure 4). The use of mobile phones has driven this growth, particularly among economic segments of the population who cannot afford computers.

The use of mobile phones has driven this growth, particularly among economic segments of the population who cannot afford computers.

Currently, India's internet economy, though not as developed as China's, is booming in some segments. Although the retail segment, for example, has only about 3% of total market share coming from online business, segments such as mobile phones now see more than half of their sales done via online channels.[6]

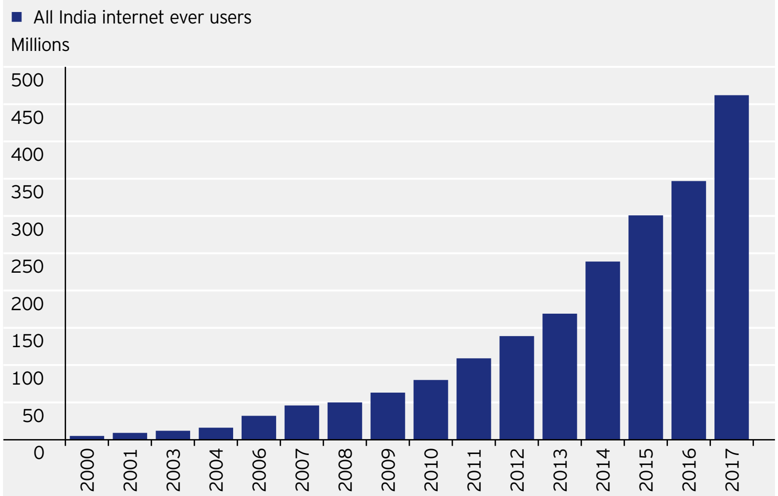
Conclusion: What next?
We expect the combination of these reforms to have a marked effect on the Indian economy. The twin balance sheet problems of highly overleveraged corporates and banks saddled with high levels of debt has been a key growth constraint reflected in the low level of capex as a % of GDP (figure 5). However, we are confident that the necessary steps to address these problems have now been taken, coupled with a plan to revive the housing market. As a result, loan growth has already picked up to 10% year-on-year, from a low of 6% in 2017.[7] Consequently, we are optimistic for India's growth momentum, which is crucial for the country's long-term success.

Table 1
DBT programme – estimated annual savings
Key subsidies and DBT implementation

Subsidy	**Potential savings (USD bn)**
Cooking fuel	0.9
Rural employment	0.9
Kerosene (cooking fuel)	0.2
Food	3.0
Fertilisers	1.6
Total	**6.6**

Source: CLSA, January 2017.

Figure 4
Internet users CAGR of approx. 31% in India from 2000 to 2017

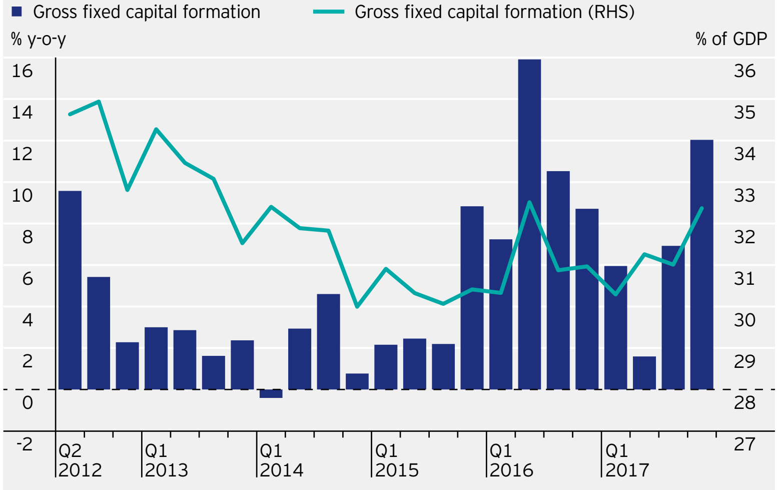


Source: Euromonitor, Telecom Regulatory Authority of India (TRAI), February 2018.

Finally, a word about valuations: the MSCI India Index is currently trading at a 12-month forward price/earnings ratio of around 21x, just above its historical average over the last decade (figure 6). The consensus expects earnings growth of 19% and 17% for FY18 and FY19 respectively. Corporate earnings and valuations should be supported as economic growth ticks up. Four years after Modi came into power, prospects are good not only for the Indian economy, but also for the Indian stock market.

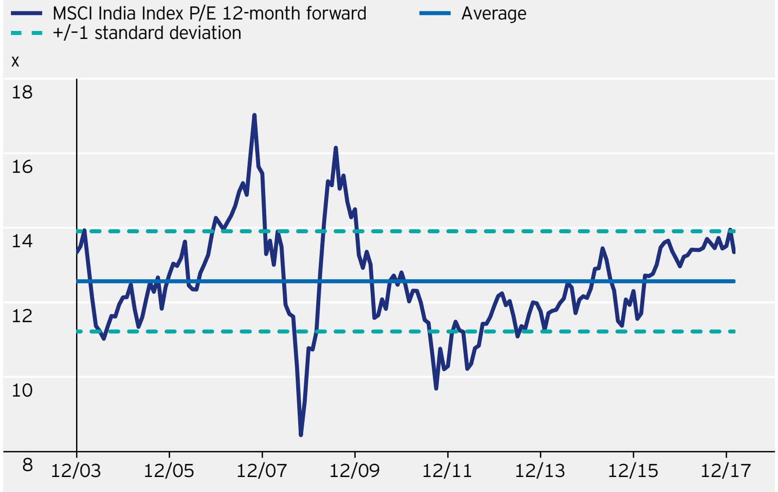
Overall, we are impressed with the progress made in addressing some of the key issues in the economy. A lot of problems which are being addressed have needed to be tackled for 20-30 years, and it is only this government that has been able to find solutions. Although valuations in many areas of the Indian equity market remain stretched, we believe there are companies which are well placed to benefit from higher growth and offer attractively valued opportunities for active bottom-up stock pickers. India can have a leap in growth, if Modi continues to do the 'the right thing'.

Figure 5
Gross fixed capital formation



Source: Gavekal Research, March 2018. Data as at Q4/2017.

Figure 6
MSCI India Index P/E 12-month forward



Source: Bloomberg. Data as at 28 February 2018.

Box
What type of companies can potentially benefit from incremental economic growth?
Our preferred way to play higher economic growth is through the financial sector. In particular, a large private bank has suffered from asset quality problems which have put downward pressure on its market valuation. However, we now believe that we have passed the peak of these problems and the bank's profitability should gradually normalize. Another bank on higher valuation multiples, which is likely to be a beneficiary of a recovery in housing, is a sizable mortgage financier. With an average loan ticket size of INR 2.5 million, this bank is well positioned to capture any growth in the affordable segment (house price < INR 5 million, approx. USD 40,000), and we expect continued strong loan growth going forward. Elsewhere, we believe a satellite TV and broadcasting company is well-positioned to benefit from an economic revival. Companies will spend more on advertising while consumers with higher disposable income will increase their subscriptions to this company's TV channels.

About the authors

Stuart Parks
Head of Asian Equities,
Invesco Perpetual
Stuart Parks is Head of Asian Equities at Invesco Perpetual and is one of the most experienced fund managers covering the region.

Paula Niall
Product Manager,
Invesco Perpetual
Paula Niall is a Product Manager with the Asian and Japanese equity teams.

Notes

1 Source: Gavekal Research, 'Escaping The Indian Funk', November 2017. Stressed loans include both non-performing loans (NPLs) and restructured loans. Non-performing loans are loans on which a bank has not received payments up to 90 days past due. Some of these loans are restructured.
2 National Company Law Tribunal is a quasi-judicial body in India that adjudicates issues relating to Indian companies.
3 Gavekal Research, 'India: Poised For A Pickup', August 2017.
4 CLSA, Reform'nation, November 2016.
5 Ibid.
6 CLSA, March 2018.
7 Source, 'India Banks: SBI raises retial term deposit rates', Nomura, 28 February 2018.

About risk

The value of investments and any income will fluctuate (this may partly be the result of exchange-rate fluctuations) and investors may not get back the full amount invested. When investing in emerging and developing markets, there is potential for a decrease in market liquidity, which may mean that it is not easy to buy or sell securities. There may also be difficulties in dealing and settlement, and custody problems could arise.

Currency carry strategies: unconventional weightings may improve performance and diversification

By James Ong

In brief

Currency carry portfolios have a history of generating attractive returns, but they can be highly correlated to other risky assets, such as stocks. Knowing that currency carry portfolio diversification can be improved through the addition of emerging market currencies, we examine how performance might be improved by strategically re-weighting emerging market and developed market currencies. Our objective is to build a currency carry portfolio that complements traditional asset allocations and improves risk-adjusted portfolio returns. We find that an unconventional weighting of emerging and developed market currencies within carry strategies can improve the attractiveness of currency carry portfolios.

As the popularity of factor investing increases, more investors have focused on the currency carry factor as a means of generating returns. Developed market carry portfolios are often diversified using emerging market currencies. But how can this fairly simple approach be optimized to improve risk-adjusted returns?

> A currency carry portfolio seeks to generate return by buying higher yielding currencies and selling lower yielding currencies.

A currency carry portfolio seeks to generate return by buying higher yielding currencies and selling lower yielding currencies. The "carry" on a currency pair is determined by the difference between the short-dated interest rates of the two currencies. Since a carry investor typically buys and sells currencies against the US dollar, one of the two currencies is always the US dollar and the currency carry portfolio has no US dollar exposure.

Currency carry strategies are generally viewed as risk-seeking strategies. The academic literature has

pointed to their long-term positive expected return. Carry strategies also tend to be especially sensitive to growth risk – they tend to perform well when growth performs well and poorly when growth performs poorly. This growth sensitivity can mean that carry strategies end up correlated to other risky assets, such as equities, which are also growth-sensitive.

The most typical carry strategies include developed market currencies, while a smaller subset have included emerging market currencies. We seek to determine the effects of adding emerging market currencies to help reduce the correlation of currency carry strategies to risky assets and render them more complementary within portfolios.[1]

A comparison of three currency carry portfolios
To investigate the potential diversifying effects of adding emerging market currencies to a currency carry portfolio, we constructed three portfolios: a pure developed market portfolio, a pure emerging market portfolio and a combination of the two.

The pure developed market portfolio consists of a traditional G10 currency carry strategy with nine currency pairs (i.e each of the other nine currencies vs. the US dollar), where the portfolio is long the top three currency pairs, in terms of carry, and short the bottom three.[2]

The emerging market portfolio is based on a universe of 16 emerging market currencies vs. the US dollar, i.e. 16 currency pairs, where the strategy is long the top five currency pairs in terms of carry and short the bottom five.[3]

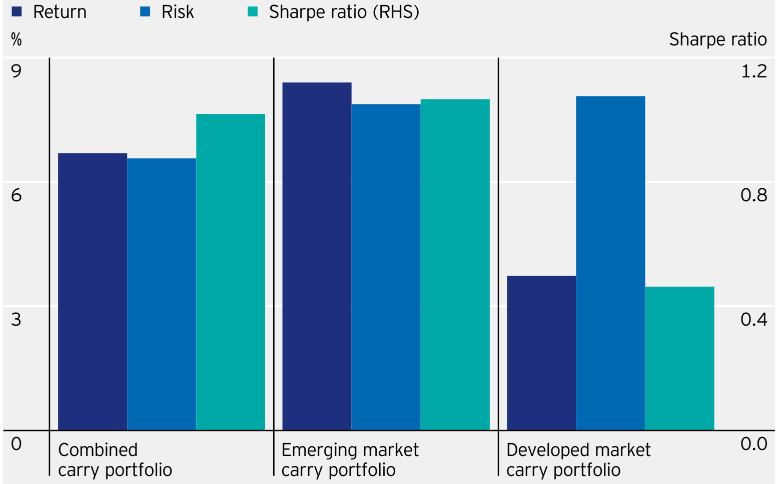
The third portfolio constructs a similar carry strategy from the combined universe of currencies, consisting of all 9+16=25 currencies vs. the US dollar. The combined portfolio is similarly long the top third of currency pairs from the combined universe, in terms of carry, and short the bottom third.

Figure 1 shows the performance of the three portfolios.

The pure developed and emerging market carry portfolios each generated positive excess returns over our selected timeframe. As expected, both portfolios had a high volatility. However, the Sharpe ratio of the emerging market carry portfolio was significantly higher compared to the developed market portfolio, signifying that the emerging market portfolio's return compensation was stronger for each unit of risk.

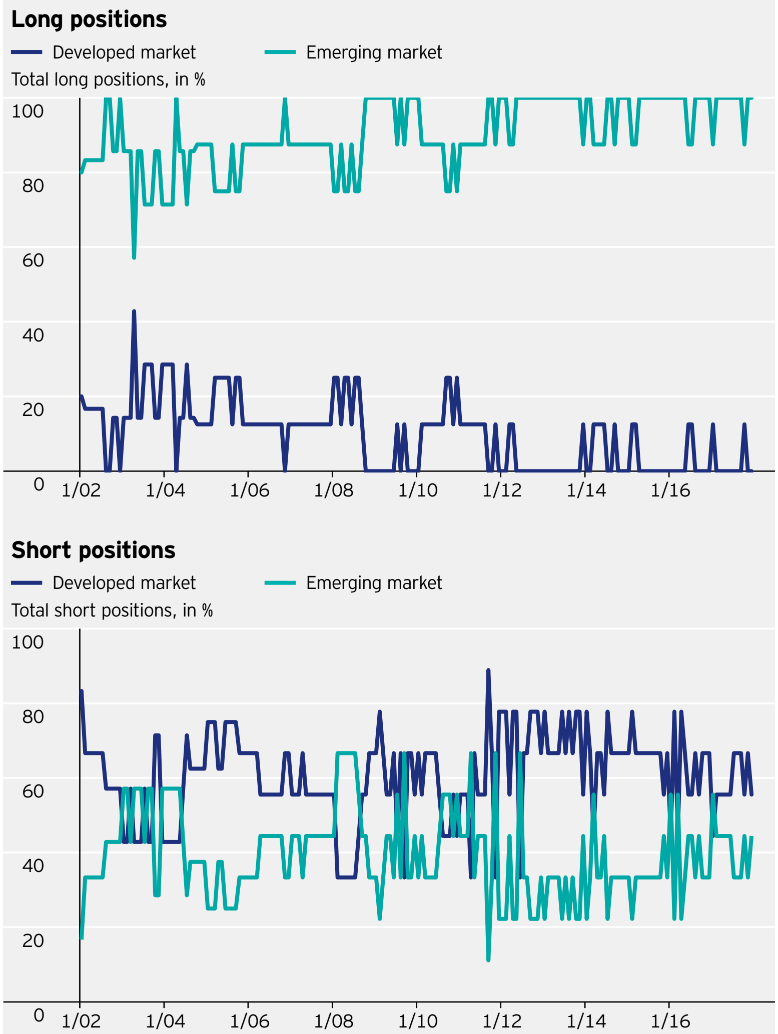
The combined portfolio also yielded positive excess returns over the period. However, its Sharpe ratio was slightly lower compared to the emerging market portfolio. This suggests that combining both currency universes did not produce an increase in risk-adjusted return, despite increased diversification. This may have to do with the fact that, in contrast to the pure emerging market portfolio, the combined portfolio was long emerging market currencies and short mostly developed market currencies (figure 2). This mismatch may have produced unexpected risk exposures, which had been neutralized through offsetting long and short positions in the pure portfolios.

Figure 1
Risk and return across currency carry strategies



Source: Invesco. Data period: 1 January 2002 to 1 December 2017. Monthly rebalancing, equal weighting of the currency pairs with the highest and lowest carry, no transaction costs, base currency USD, annualized. Risk is defined as standard deviation of returns.
Past performance is not a guide to future returns.

Figure 2
Combined portfolio long and short positions



Source: Invesco. Data period: 1 January 2002 to 31 December 2017.

Role of the "growth factor" in combined portfolio performance

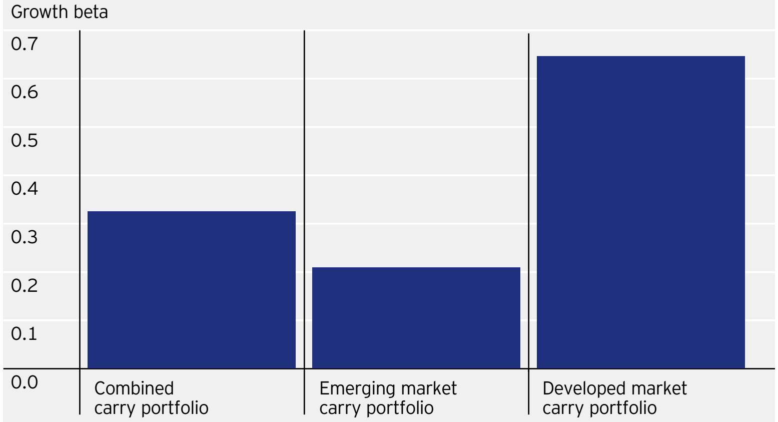
We now examine how the long and short legs of the combined portfolio behaved differently relative to the most important of our macro risk factors, the "growth factor". We chose the growth factor because we believe it is the most important driver of risky asset performance.

Our research shows that growth drives around 35% of risky asset class performance, including our carry strategies, which tend to perform best when growth exceeds expectations and worst when growth disappoints.

Interestingly, the emerging market carry portfolio was less sensitive to global GDP growth than the developed market carry portfolio (figure 3). This is surprising since volatile assets like emerging market currencies typically exhibit higher growth sensitivity. The unexpected result may be due to generally higher risk premia in emerging markets or the fact that emerging market growth has traditionally had lower correlation to growth in the rest of the world. In any case, emerging market carry's lower sensitivity to this factor has led to its better performance during periods of global growth stress.

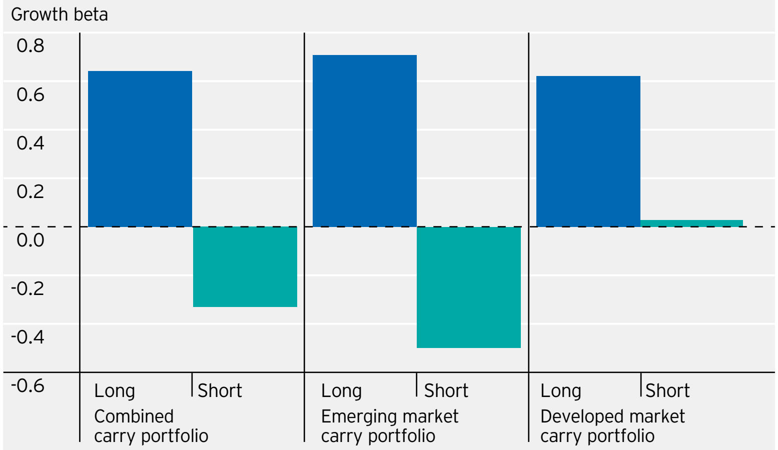
To make further sense of these results, we examined the growth sensitivity of the long and short legs of the pure emerging market and developed market portfolios (figure 4). We found that the growth risk of the emerging market long and short legs was broadly balanced, meaning that the performance of each leg was similarly affected by growth conditions. However, the growth risk of the pure developed market strategy was concentrated in the long leg of the portfolio. The short leg was much less sensitive to growth. This is important because this imbalance caused the developed market carry portfolio to demonstrate higher volatility and a lower Sharpe ratio than the emerging market portfolio – a somewhat surprising result since the developed market portfolio comprised less volatile assets.

Figure 3
Growth factor sensitivity of the three portfolios



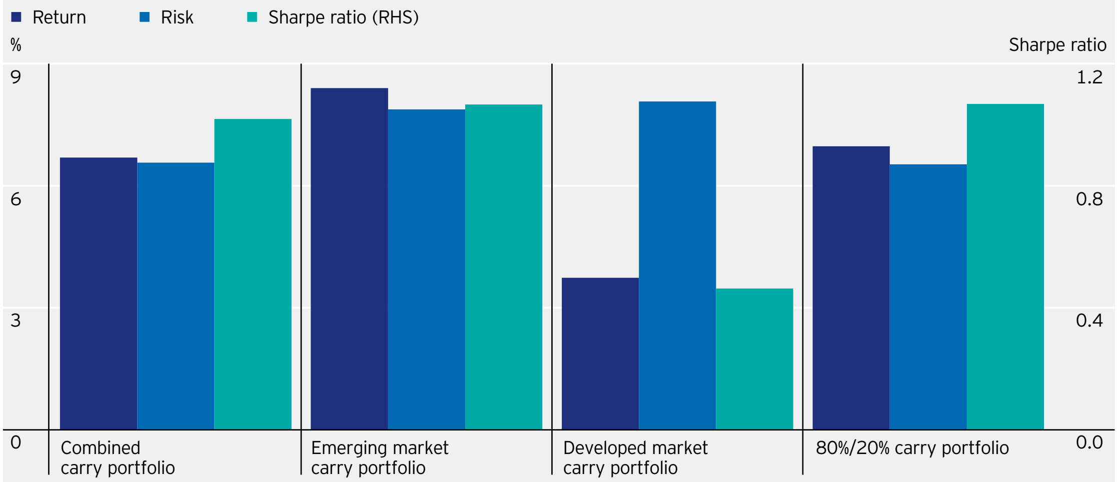
Source: Invesco. Data period: 1 January 2002 to 1 December 2017.

Figure 4
Growth factor sensitivity breakdown



Source: Invesco. Data period: 31 December 2001 to 31 December 2017.

Figure 5
Risk and return across currency carry strategies



Source: Invesco. Data period: 1 January 2002 to 1 December 2017. Monthly rebalancing, equal weighting of the currency pairs with the highest and lowest carry, no transaction costs, base currency USD.annualized. Risk is defined as standard deviation of returns.
Past performance is not a guide to future returns.

On the other hand, the balance of growth risk between the long and short legs of the pure emerging market strategy drove its overall lower sensitivity to growth risk, and therefore, a higher Sharpe ratio. Accordingly, when growth underperforms versus market expectations (negative growth risk), the developed market portfolio would be expected to underperform on a risk-adjusted basis.

Seeking to achieve a better risk-adjusted result
The developed market short leg's low growth sensitivity means that it tends to perform well when other risky assets do poorly. This suggests that a long position in the short leg can be used to diversify the exposure of the overall carry portfolio.

To test this theory, we added a 20% long allocation of the developed market short leg to the emerging market carry strategy, creating a fourth portfolio consisting of an 80% emerging market long leg, a 20% developed market short leg and a 100% emerging market short leg. The fourth portfolio ("80%/20%" portfolio) had a similar risk-return profile compared to the pure emerging market carry portfolio (figure 5). However, its correlation to equities was reduced to nearly zero. We believe this unconventional weighting makes it more attractive than the original combined portfolio as an alternative allocation to a traditional investment portfolio.

Conclusion
We built a series of currency carry portfolios with the aim of improving upon the historical positive performance of the typical currency carry strategy. While standard currency carry strategies typically draw from the developed or emerging market universes of currencies, we proposed combining them to add diversification and create a portfolio with a better risk-return profile. However, while the Sharpe ratio of the combined portfolio was higher compared to the pure developed market portfolio, it was lower compared to the pure emerging market portfolio, despite the larger investment universe.

An analysis of the combined portfolio's performance showed that it was dragged down by exposure to a different risk, namely growth risk, compared to the pure developed or emerging market portfolios, in which this risk was offset. Taking advantage of this differentiation in sensitivity to growth, we found that unconventionally weighting developed and emerging market currencies in a fourth portfolio improved its attractiveness in terms of diversification against growth risk and, therefore, other risky assets. We believe this makes the unconventionally weighted currency carry portfolio a potentially valuable complement to a traditional asset allocation.

We believe this makes the unconventionally weighted currency carry portfolio a potentially valuable complement to a traditional asset allocation.

About the author

James Ong
Senior Macro Strategist and Derivative Portfolio Manager,
Invesco Fixed Income
James Ong contributes economic and market analysis to the macro research platform, in addition to leading the Invesco Fixed Income derivative strategy and overseeing derivatives held in Invesco Fixed Income portfolios.

Notes
1 Developed markets or economies can be defined by many different criteria. In general, however, they tend to be economically advanced with robust capital markets (highly liquid, large market capitalizations and extensive regulatory systems). Often, a developed economy will exhibit a lower growth trend than a developing or emerging economy, and lower prevailing interest rates. Emerging market economies tend to be characterized by lower per capita incomes and active efforts towards industrialization – hence higher growth and higher prevailing interest rates.
2 The G10 currencies are USD, EUR, JPY, GBP, AUD, NZD, CHF, CAD, SEK and NOK.
3 For our analysis, we use the following emerging market currencies: INR, MXN, SGD, ZAR, THB, CLP, TRY, RUB, HUF, PLN, KRW, IDR, ILS, BRL, RON, and MYR.

A scientific approach to avoiding data mining pitfalls

By Joo Hee Lee, PhD, and Julian Keuerleber

In brief
Empirical data analysis by itself cannot provide a true understanding of a dataset. There is always the need for a scientific explanation in order to be sure that the results are repeatable and not just chance. This is where 'data mining' comes in. We illustrate the pitfalls of pure data analysis with an example and lay out the principles of the century-old scientific method as an alternative.

Exponential growth in data and computing power has given rise to a trend that we no longer need to understand the "why" of the data generated. We question this view and argue for a more traditional scientific approach to investment rationale, while fully taking advantage of the benefits of increased data availability and computing power.

Data mining – the practice of examining large databases in order to generate new information – has become embedded in analytical culture as a potentially infinite source of insight, if only the data can be cut and sliced in the most suitable way.[1] In this school of thought, algorithms can learn to translate one language into another without needing to know the meaning of a single word, or decide which film you would like to watch without ever meeting you. Also in investment management, the large-scale analysis of unstructured data and machine learning have become industry trends, aiming to gain insights not available through more traditional research.[2]

While recognizing the wrong shopping patterns in an empirical data driven analysis is undesirable, when it comes to investment management, the financial consequences of a sub-optimal interpretation of data could be severe. The negative impact of incorrect models in investment could lead to dire consequence for individuals' financial security. It is thus critical that we exercise maximum rigour in our analytics.

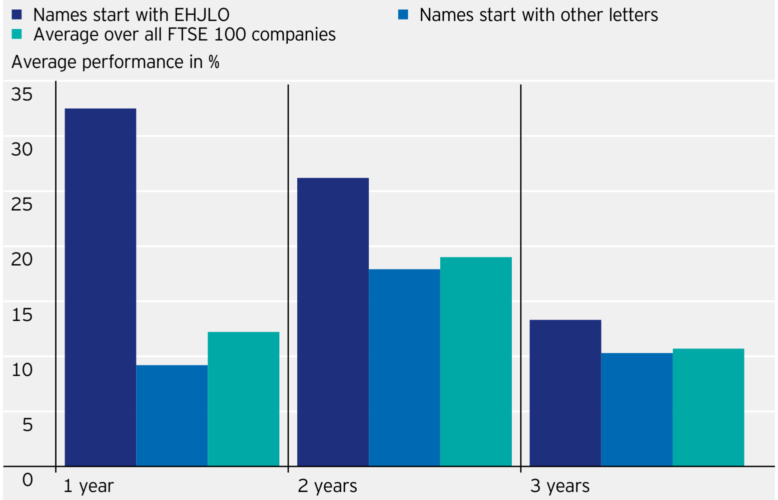
It is often easy to find apparent patterns in a dataset, but these connections do not necessarily always signify genuine underlying truths. Take for instance the performance of FTSE 100 companies over the

past three years: it is possible to show that the average performance of companies having names that start with a letter from one of the authors' names – E, H, J, L and O – performed significantly better than those starting with other letters (figure 1).[3] The average percentage growth across these companies' share prices far exceeded the average growth across all FTSE 100 companies over the three-year period. The pattern in the data is demonstrable, but stock-picking based on the letters in an arbitrary person's name would certainly be a rather strange kind of investment strategy.

While this is a frivolous example, it highlights the importance of analytical rigour as well as market knowledge for those involved in investment analysis, both when using traditional measures and new sources of data, to ensure that results measure up to the highest standard. So, how can financial modellers ensure that newly identified patterns reflect genuine market behaviours, rather than spurious anomalies? Some of these issues, especially when it comes to identifying factors and testing their significance, have been extensively studied by Harvey et al (2016),[4] and their findings have since been widely cited. In this article, we do not introduce any novel tests. But we argue that the "scientific method", an approach that has been used by great thinkers over centuries, could help to ensure the robustness of modelling outcomes.

The scientific method
The scientific method has evolved through history as a way to gain understanding of the world around us. In short, it is empirically grounded theory construction and verification,[5] based on the discovery of facts, rather than reliance on conjecture or opinion. The ultimate goal is to discover truth through thoughtful questioning, conceptualization and collection, then examination, of evidence.

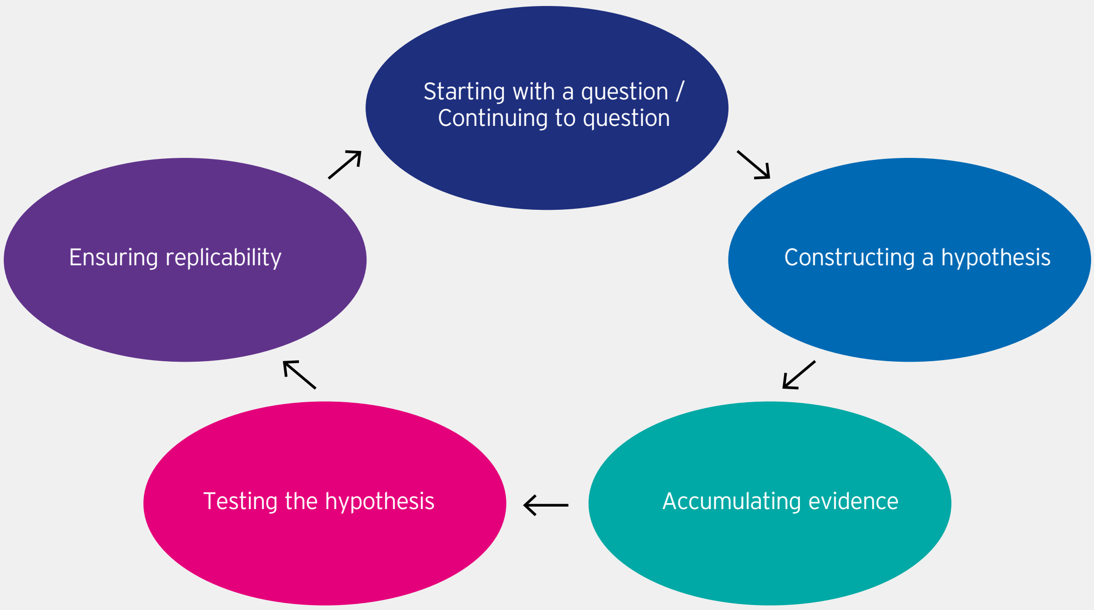
Figure 1
"Alphabet effect" analysis of the FTSE 100
Performance of FTSE 100 companies



Source: Bloomberg. Price returns in GBP. Data as at 31 May 2018.
Past performance is not a guide to future results.

The scientific method always starts with a question – why? – followed by construction of a hypothesis that could answer the question.

Figure 2
The scientific method



Source: Invesco. For illustrative purposes only.

The method values verifiable and replicable results as the basis for knowledge building.

The scientific method always starts with a question – why? – followed by construction of a hypothesis that could answer the question. Experiments are formulated to create empirical evidence, which is then used to test the hypothesis – either adding weight to the idea or disproving it. It can be seen as a circular process, where the results of each experiment are used to refine a hypothesis until it can be developed into a general theory (figure 2).

The advantage of a circular process is that of continual questioning. It means even the most accepted and established theory can be challenged. If additional evidence arises that sheds new light on a hypothesis, then the scientific method demands new questions to establish new and enhanced theories.

Here are the six steps in detail, as applied to modelling and investment management:

Step 1. Starting with a question
By initiating investigations with a question, we minimize the dangers that arise when data and methods alone drive our discoveries.

It is possible to over-rely on data and technique to provide insight, whether you are using traditional or modern methods. Results produced by an established methodology, used as a mainstream approach for many years, are easy to accept without proper questioning. But the tendency in data mining to search data repeatedly until interesting results appear, sometimes in a haphazard way, means a question-led approach is especially beneficial in this methodology. This is particularly the case when past performance is used as a basis for assessing future potential. A robust, questioning approach will reduce the potential for false predictions.

Step 2. Constructing a hypothesis
Even when an initial question has been established, it is important to formulate a hypothesis to answer it, rather than moving straight to data analysis.

An essential part of this process is consideration of the logic behind the hypothesis. A sound rationale – whether economic, investment-based or scientific – helps in the identification of spurious connections and relationships with no basis in reality, as in our name-based investment example.

It can also prevent the over-parameterization of models. The use of a hypothesis encourages the scientific principle of finding the most elegant, simple and parsimonious model to answer the initial question. A complicated model that has many contributory elements or factors may produce a better result on a set of test data, but it is likely to be over-fitted and will rarely contribute to a logical understanding.

Step 3. Accumulating evidence
The collection of robust data to use in hypothesis testing is crucial. Only high-quality data will produce meaningful analytical insights.

More data is available now than at any time in history. But new data sources and methods do not free us from the fundamental checks that have always been critical in analysis. The quality of the data collected is still paramount, whether from a traditional source or an entirely new one. The volume of data, using time series data of sufficient lengths, ensuring the representativeness of data, interval and sample testing are just as important in the modern analytical landscape as they have always been.

The collection of robust data to use in hypothesis testing is crucial.

Step 4. Testing the hypothesis
To assess the validity of a hypothesis, the accumulated evidence must be examined. This usually involves creation of models to discover connections and patterns within data that will support or disprove the concept.

Models should be rigorously validated, with no part of the outcome left unquestioned.

Models should be rigorously validated, with no part of the outcome left unquestioned. For instance, an analysis of residuals should never be taken for granted.

A thorough modelling approach also guards against confirmation bias – the tendency to favour information that confirms our pre-existing beliefs. The more you mine data, the greater the likelihood that you will find a pattern confirming your idea. In the excitement of discovery, it can be all too easy to overlook information that one does not want to see.

Step 5. Ensuring replicability
Replicability in science refers to the ability to repeat an experiment and obtain consistent results. It ensures that results are not one-off aberrations but are based on genuine relationships.

Performing an analysis on alternative datasets provides independent evidence to corroborate model results. In investment analysis, this can be achieved in many ways. Setting up a simulation platform to create many different statistically equivalent sets of data enables performance of a probability analysis or distribution analysis. Bootstrapping may provide an additional way of creating statistically equivalent sets of data. Another approach is Monte Carlo simulation, a parametric method enabling many data analyses to be achieved without being constrained to one dataset.

Back to step 1. Continuing to question
The final element of the scientific method is to keep questioning.

Always continue to look for new evidence to challenge existing models and assumptions.

An approach that has worked in the past is not guaranteed to remain effective in the future. Where models are developed using historical data and applied to real-life return series, conclusions should be considered carefully. The distinction between estimates and forecasts is important and all outcomes should be monitored closely. Always continue to look for new evidence to challenge existing models and assumptions.

Conclusion
In real-world analysis, the scientific method can be summarized as follows:

1. Always start with a question and formulate a hypothesis. Include a market or economic or scientific rationale that supports the concept and consider where to look for evidence.

2. Develop a framework of evidence for the hypothesis using analytical, simulation-based and empirical approaches, or a combination of these. Do not create a theory from an empirical approach alone, but use empirical analysis to support the hypothesis and help establish a theory.

3. Confirm the outcomes with real data. This step should always come last.

Adherence to the scientific method is a principle to which we can all aspire. By being proactive in trying to create rationale-based factors, genuine relationships are more easily found. Whatever answers we find, we must always ask why that should be the case and interpret the outcome. And, we must continually question, recognizing that estimates are not forecasts and ensuring that even the best-proven strategies remain valid over time.

About the authors

Joo Hee Lee, PhD, CFA, CQF
Senior Portfolio Manager,
Invesco Quantitative Strategies
Joo Hee Lee, PhD, is involved in the development of client solutions and the management of quantitative multi-asset multi-factor strategies.

Julian Keuerleber
Head of Global Portfolio Analytics,
Invesco Quantitative Strategies
Julian Keuerleber heads the team responsible for portfolio and performance analysis, investment communication and reporting.

Notes
1 http://www.uvm.edu/pdodds/files/papers/others/2008/anderson2008a.pdf "The end of theory: the data deluge that makes the scientific method obsolete".
2 Alternative ways big data could be used that still have scientific rigour - corroboration from an alternative source: https://www.ft.com/content/f62ee814-f510-11e5-803c-d27c7117d132
3 This is a simplistic adaptation of what has been reported as the "alphabet effect" in Ferson, W.E., Sarkissian, S., and Simin, T., The alpha factor asset pricing model: A parable, Journal of Financial Markets 2 (1999) 49-68.
4 Harvey, C. R., Yan, L., and Zhu, H., (2016), ... and the cross-section of expected returns, Review of Statistics in Medicine 31, 2,782-2,790.
5 Betz, Frederick (2011). Origin of Scientific Method. In Managing Science: Methodology and Organization of Research (pp. 21-41): Springer.

Evaluating risk mitigation strategies

By Dr. Harald Lohre, David Happersberger and Erhard Radatz

In brief
Risk mitigation strategies seek to create an asymmetric risk-return profile. But benchmarking against the underlying investment is not a valid approach given the potentially stark difference in risk profiles. We discuss how to appropriately calibrate and assess portfolio insurance strategies based on the ensuing return distribution to better fit a given client's risk preferences.

In light of the sustained low yield environment, investors have increasingly taken on more risk to meet their return targets. Yet, their ability to cope with higher risk is limited, which is what makes strict risk management and suitable portfolio insurance techniques so important.

In a previous article[1], we discussed a variety of risk mitigation approaches for a given underlying investment strategy. In particular, we investigated portfolio insurance strategies ranging from static stop-loss techniques to option-based strategies and dynamic portfolio insurance techniques. We concluded that an active portfolio insurance strategy based on a dynamic risk forecast is a cost-effective way to limit a portfolio's maximum loss at a high probability.

In this article we go further and explain how to calibrate such a strategy to individual risk preferences. Since portfolio insurance is meant to accommodate conservative clients' need for an asymmetric return profile, adding a risk overlay ultimately boils down to reshaping the portfolio return distribution. Essentially, the aim is to significantly reduce the probability of suffering from severe tail events while sacrificing some of the underlying strategy's upside potential.

The mechanics of dynamic portfolio insurance
Our preferred dynamic portfolio insurance strategy is rooted in the classic CPPI (constant proportion portfolio insurance[2]) strategy. It typically sets the exposure in a given risky underlying in such a way that a chosen floor level is not breached within a specified investment period. Thus, it is essential to

closely monitor the cushion C_t that represents the difference between the invested wealth W_t and the net present value of the floor $NPV(F_T)$:

(1) $C_t = W_t - NPV(F_T)$

To effectively protect the floor,

$C_t \geq W_t * \text{MaxLoss}(W_t)$

must hold true. With the investment exposure e_t and the corresponding risky investment $E_t = e_t * W_t$ the above formula can be restated as

$$(2) \quad C_t \geq e_t * W_t * \text{MaxLoss}(\textit{risky asset})$$

$$\Leftrightarrow E_t \leq \frac{C_t}{\text{MaxLoss}(\textit{risky asset})} = m * C_t$$

This reformulation brings in the notion of the CPPI multiplier m. The multiplier indicates how often the cushion can be invested in the risky underlying without breaching the floor provided the maximum loss assumption holds.

To be on the safe side, one could impose a static multiplier derived from a worst-case risk estimate. But, as we demonstrated in the previous article, such a conservative estimate would severely undermine participation in the underlying. To remedy this issue, we put forward the use of a dynamic forecast of maximum loss. That is, we make use of a dynamic multiplier

$$m_t := \frac{1}{ES_t^{99\%}(\textit{risky asset})}$$

labelling this type of risk mitigation DPPI (dynamic proportion portfolio insurance). In this setting, the risk budget and investment exposure dynamically adjust to changes in the estimated expected shortfall (ES) forecast. In particular, participation in the underlying is higher in calmer risk environments, while a pick-up in risk leads to a reduction of investment exposure. Obviously, it is essential to rely on risk estimates that allow for timely modelling of tail risk within the portfolio return distribution.

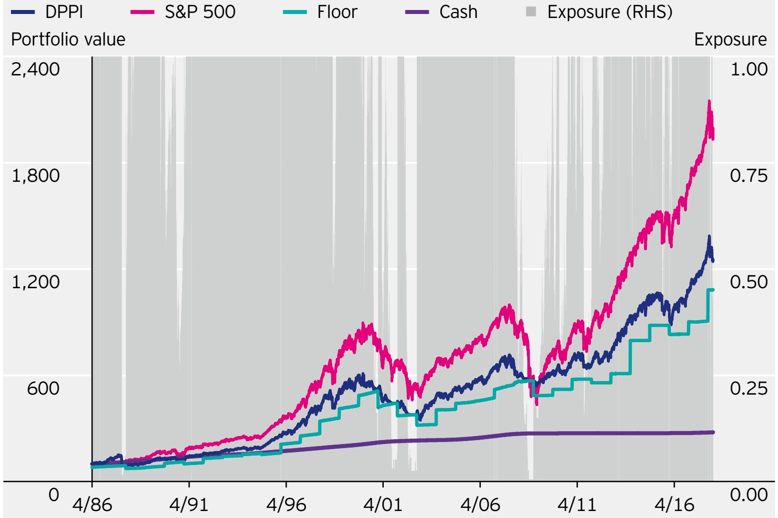
Panel (a) of figure 1 charts the mechanics and evolution of a DPPI strategy applied to an S&P 500 underlying at an 85% floor level.[3] The dynamic adjustment of the time-varying multiplier m_t follows the expected shortfall forecast derived from a GARCH(1,1)-model. Clearly one can appreciate the role and interaction of floor and multiplier: if the underlying investment is far above the floor, the DPPI tends to have a high investment exposure more or less independent of the risk estimate. With less cushion, the DPPI strategy is more sensitive to risk changes, potentially leading to a complete de-investment.

Over the course of the 32-year backtest, we only observe a few periods of de-investment, of which only four ended in a cash-lock position. While one seeks to avoid cash-lock through the adaptive positioning based on the risk forecast, the success of this approach depends on the specific nature of the corresponding market setbacks. For instance, the minimum daily return of the S&P 500 (-28.6% on 19 October 1987) fully consumed a seemingly comfortable cushion of more than 25%, and induced switching from a 100% investment exposure to cash-lock in just one day. However, in other periods of weak S&P 500 performance, market drawdowns evolved more gradually, allowing the DPPI portfolio time to de-invest and re-invest. The last complete de-investment occurred during the global financial crisis. In the aftermath, interest rates have come down, implicitly elevating the floor level. During high volatility episodes in the equity market, we could observe similar de-risking events within the last decade. Yet these only served to reduce portfolio volatility given quick recoveries in the S&P 500.

Examining the whole sample path, we learn that the DPPI strategy was indeed able to mitigate downside risk. Compared to the underlying investment, the maximum drawdown decreases by approximately 15 percentage points, volatility by 5 percentage points and expected shortfall by 1.5 percentage points under the DPPI strategy (cf. panel (b)). Although these reductions come at the cost of some return potential – the DPPI portfolio earns 141bps less than the underlying – , risk-adjusted measures are in favour of the DPPI strategy.

Figure 1
Performance and allocation of the DPPI strategy

Panel (a)



Panel (b)	**S&P 500**	**Money market**	**DPPI**
Return p.a. (%)	9.23	3.20	7.82
Volatility p.a. (%)	19.37	0.22	14.41
Sharpe ratio	0.31	0.00	0.32
Maximum drawdown (%)	-61.17	0.00	-45.80
Expected shortfall 99% (%)	-5.09	0.00	-3.66
Mean exposure (%)	100.00	0.00	86.18

The chart in Panel (a) shows the performance of an equity portfolio (S&P 500) using a DPPI strategy (blue line) in relation to the floor (green line) over time. Exposure is calculated using the cushion (difference between the portfolio value and the floor; here: 85% of the initial annual portfolio value) and the multiplier (based on daily risk forecasting; here: GARCH 99%-ES). For comparison. we have included the performance of the underlying S&P 500 (pink line) and a money market investment (purple line). Panel (b) shows the corresponding performance measures.
Period: 9 April 1986 to 9 April 2018; 9 April 1986 = 100.
Sources: Bloomberg. Invesco. This is simulated past performance and past performance is not a guide to future returns.

Designing DPPI strategies

The preceding example illustrates an important caveat in evaluating a given DPPI strategy, namely, its inherent path dependency. To avoid assessing the strategy based on just one historical path, we rather simulate a large number of alternative price paths and apply the given DPPI-setup. Hence, instead of just one risk and return combination, we obtain a full return distribution.[4] Figure 2 shows portfolio return distributions of yearly returns based on 5,000 simulations, for the portfolio fully invested in the (simulated) underlying S&P 500 as well as for the corresponding DPPI strategy with an 85% floor. The risk estimates required for computation of the dynamic multiplier for the DPPI strategy are based on a simple GARCH(1,1)-model. This model captures the main empirical characteristics of asset returns, such as time-varying volatility, fat tails and volatility clustering.[5]

We observe a left-skewed distribution for the simulated equity underlying. There is tail risk with a non-negligible probability of yearly returns being less than -15%. Applying DPPI results in significantly less tail risk. Yet, one has to note that there is still a small probability of breaching the floor level given that the strategy is adjusted at discrete (daily) intervals.

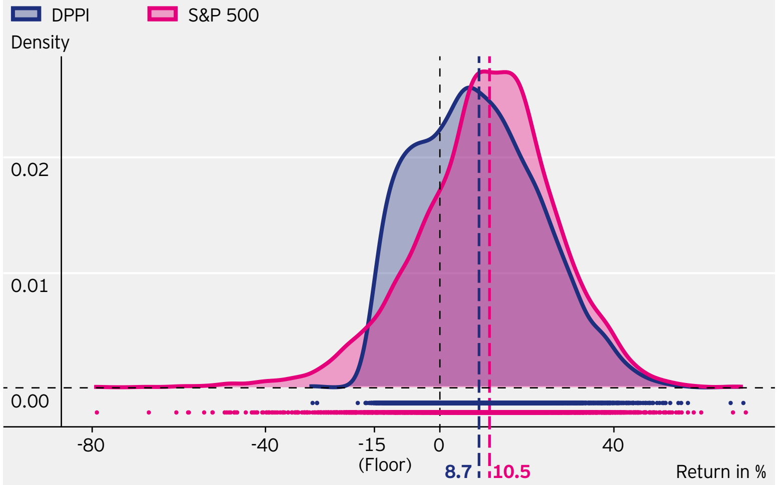
More importantly, however, figure 2 clearly demonstrates that tail risk reduction, on average, comes at the cost of reduced upside potential. While the historical backtest might suggest an outperformance of the DPPI strategy relative to its underlying, the simulated return distributions more readily articulate that portfolio insurance actually comes at an implicit insurance premium.

Judging by the mean yearly return difference of the two distributions, this premium would amount to some 1.8% (10.5% – 8.7% = 1.8%). At this premium, we can expect to avoid severe tail risk events, 29 of which could be worse than -40% (as simulated in our block-bootstrap analysis).

In the same vein, this framework clarifies the consequences of certain design choices (such as underlying and floor level) for the client's expected portfolio return distribution. For instance, a common theme is that floor levels are set too tight relative to the riskiness of the underlying. Put differently, investors often favour riskier underlyings to achieve certain return targets. Yet, absent a higher risk budget, a riskier strategy will frequently be prevented from breathing freely given that the available cushion is easily consumed. This leads to frequent de-investments or even cash-lock situations triggered by the DPPI mechanism.

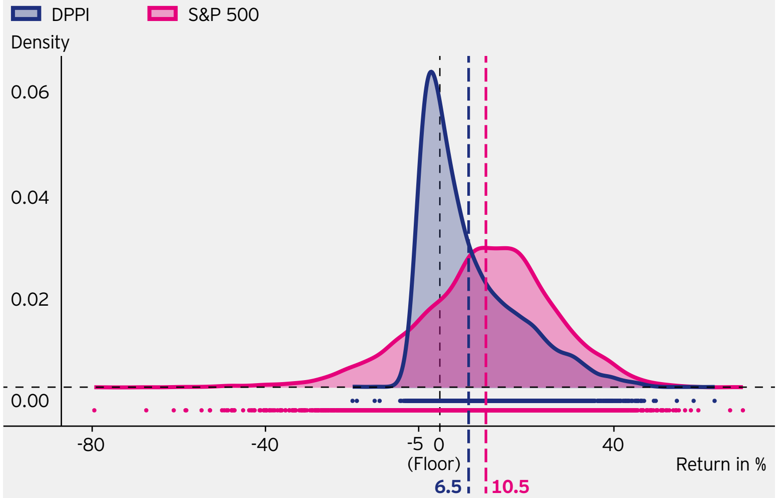
To illustrate this issue, figure 3 shifts the floor level from 85% to 95%. As a result, the DPPI return distribution is massively distorted with a lot of return realizations around -5%, i.e. rather close to the floor level. Obviously, this is reminiscent of the fact that, under a too tight floor level, the DPPI strategy frequently de-invests or ends up in cash-lock, disabling it from participating to a meaningful extent in equity markets. The corresponding statistics in table 1 show that the mean exposure reduces to 61%, leading to a significantly lower mean return (6.5% vs. 8.7%) and lower Sharpe ratio (0.24 vs. 0.35) when we shift the floor level from 85% to 95%.[6]

Figure 2
Comparing return distributions



The chart shows the distribution of block-bootstrapped yearly returns (M = 5,000 simulations) of the DPPI portfolio (blue shade) and the one of a pure buy-and-hold portfolio invested in the corresponding simulated S&P 500 (pink shade). The floor level of the DPPI strategy is 85%. Below the two density plots we have added the corresponding support and the mean levels of the return distributions.
Sources: Bloomberg, Invesco.

Figure 3
Comparing return distributions: tight floor levels



The chart shows the distribution of block-bootstrapped yearly returns of the DPPI portfolio (blue shade) and the one of a pure buy-and-hold portfolio invested in the corresponding simulated S&P 500 (pink shade). The floor level of the DPPI strategy is 95%. Below the two density plots we have added the corresponding support and the mean levels of the return distributions.
Sources: Bloomberg, Invesco.

An alternative benchmark for DPPI strategies

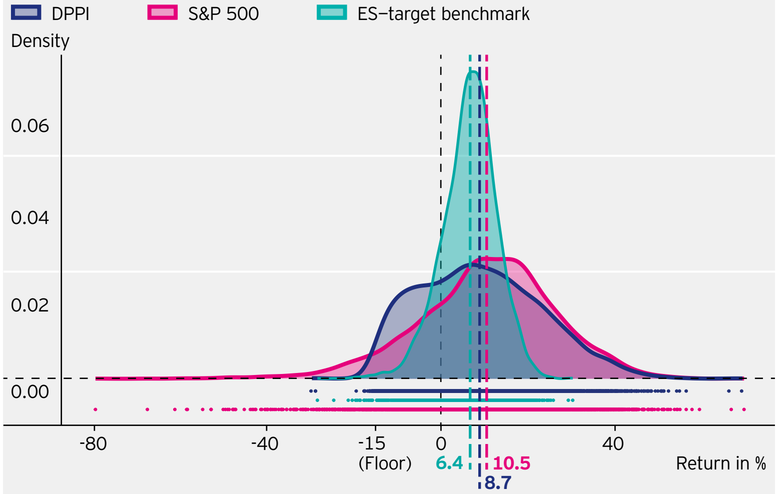
Given the potential for considerable reshaping of the portfolio return distribution through portfolio insurance, it is evident that DPPI should not be benchmarked relative to its underlying. As an alternative, we construct a benchmark with similar risk characteristics. Because we are comparing an asymmetric distribution, a symmetric risk measure like volatility is not viable. Given that risk-averse investors are more concerned about the tails of a distribution, we will base our analysis on the expected shortfall (ES), using a 99% confidence level.

Given the potential for considerable reshaping of the portfolio return distribution through portfolio insurance, it is evident that DPPI should not be benchmarked relative to its underlying.

While there are numerous ways to create a benchmark with a given ES, we opt for an easy and replicable solution. We add cash to the underlying S&P 500 investment to scale down its risk to the pre-defined ES limit of 15%, corresponding to the floor level of the DPPI strategy. We will call this portfolio "ES-target benchmark".[7] As a result, we are comparing two different strategies with similar risk profiles (as defined by their 99%-ES): a portfolio dynamically allocating between cash and the risky underlying (DPPI portfolio) and a static mix of cash and underlying that has an ES similar to the DPPI portfolio (ES-target portfolio).

To achieve an ES of 15% over the sample period, a 39/61 mix of S&P 500 and cash is needed to compute the ES-target benchmark. In figure 4, the ensuing portfolio return distribution is contrasted to that of the underlying S&P 500 and the DPPI strategy with a floor level of 85%. Obviously, the ES-target benchmark return distribution is a compressed version of the underlying S&P 500 return distribution. Most importantly, although its mean return is smaller than the DPPI (6.4% vs. 8.7%), there is still a small probability of significant tail events attached to this strategy (cf. figure 4 and table 1).

Figure 4
Comparing return distributions



The chart shows the distribution of block-bootstrapped yearly returns of the DPPI portfolio (blue shade) and the one of a pure buy-and-hold portfolio invested in the corresponding simulated S&P 500 (pink shade). The floor level of the DPPI strategy is 85%. The third return distribution applies to a partial investment in the underlying that adds cash such that the average risk level (in terms of the 99%-ES) conforms to the floor level of the DPPI strategy (green shade). Below the density plots we have added the corresponding support and the mean levels of the return distributions.
Sources: Bloomberg, Invesco.

Conclusion
Many investors tend to benchmark the performance of their portfolio insurance strategy vis-à-vis the return of the underlying portfolio. Instead, we suggest the ES-target benchmark strategy. This tail risk-adjusted alternative transforms the underlying's return distribution to better fit the client's risk preferences. Of course, investigating the ensuing portfolio return distributions based on block-bootstrap resampling sheds even more light on the effects of a given portfolio insurance application. We seek to apply this methodology in a future article to investigate the merits of different underlyings in a portfolio insurance framework.

Table 1
Performance of DPPI strategies vis-à-vis the ES-target benchmark

	S&P 500	Money market	DPPI (95% Floor)	DPPI (85% Floor)	ES-Target
Return p.a. (%)	10.49	3.81	6.45	8.71	6.43
Volatility p.a. (%)	15.95	0.96	10.93	14.09	6.30
Sharpe ratio	0.42	0.00	0.24	0.35	0.42
Maximum drawdown (mean, %)	-14.98	0.00	-8.09	-11.77	-3.52
Expected shortfall 99% (%)	-43.83	1.42	-7.85	-16.83	-15.00
Mean exposure (%)	100.00	0.00	61.14	87.28	39.18

The table shows performance measures of a block-bootstrapped DPPI strategy based on an equity portfolio (S&P 500) using different floor levels (85% and 95%). For comparison, we have included the performance measures of an ES-target strategy, targeting the same level of expected shortfall as the DPPI, alongside the underlying S&P 500 and a money market investment. Reported are the mean return, volatility, Sharpe ratio and expected shortfall of the simulated yearly returns, as well as the mean of the maximum drawdowns (which are computed for each simulated path) and mean exposure.
Period: 9 April 1986 to 9 April 2018; 9 April 1986 = 100.
Sources: Bloomberg, Invesco. This is simulated past performance and past performance is not a guide to future returns.

Bibliography

- Andersen, T. G., T. Bollerslev, P. F. Christoffersen, and F. X. Diebold (2013). Financial risk measurement for financial risk management, in Handbook of the Economics of Finance, ed. by G. M. Constantinides, M. Harris, and R. M. Stulz 2(17), 1127–1220.
- Ardia, D., Boudt, K., and Wauters, M. (2016). Smart beta and CPPI performance. Finance, 37(3), 31-65.
- Black, F. and Jones, R. (1987). Simplifying portfolio insurance. Journal of Portfolio Management 14(1), 48–51.
- Black, F. and Jones, R. (1988). Simplifying portfolio insurance for corporate pension plans. Journal of Portfolio Management 14(4), 33–37.
- Happersberger, D., H. Lohre, and I. Nolte (2018). Estimating portfolio risk for tail risk protection strategies. Working paper, Lancaster University Management School.
- Perold, A. F. (1986). Constant proportion portfolio insurance. Working paper, Harvard Business School.
- Perold, A. F. and Sharpe, W. F. (1988). Dynamic strategies for asset allocation. Financial Analysts Journal 44, 16–27.
- Politis, D. N. and Romano, J. P. (1994). The stationary bootstrap. Journal of the American Statistical Association 89(428), 1303–1313.

About the authors

Dr. Harald Lohre
Senior Research Analyst,
Invesco Quantitative Strategies and Visiting Research Fellow EMP/Lancaster University
Dr. Harald Lohre develops quantitative models to forecast risk and return used in the management of multi-asset strategies.

David Happersberger, PhD Candidate
Lancaster University and Invesco Quantitative Strategies
As part of a joint research initiative between Lancaster University and Invesco Quantitative Strategies, David Happersberger is pursuing postgraduate work on practice-oriented issues of financial market econometrics. At the same time, he is actively supporting the transfer of research results into the multi-asset investment process at Invesco Quantitative Strategies.

Erhard Radatz
Portfolio Manager,
Invesco Quantitative Strategies
In his role, Erhard Radatz manages multi-asset portfolios that include the elements factor-based investing, active asset allocation and downside risk management.

Notes

1 See Theory and practice of portfolio insurance, Risk & Reward #2/2017.
2 For more on CPPI strategies, cf. Perold (1986), Black and Jones (1987, 1988), Perold and Sharpe (1988).
3 Throughout the article, and in all figures and tables, we employ the S&P 500 Future as equity investment. For money market investments we use the 3-month US Treasury bill. All asset returns are in local currency. All simulations in this article are provided for illustrative purposes only and are subject to limitations. Unlike actual portfolio outcomes, the model outcomes do not reflect actual trading, liquidity constraints, fees, expenses, taxes or other factors that could impact future returns.
4 In simulating alternative price paths, we use the stationary block-bootstrap of Politis and Romano (1994). We follow Ardia, Boudt and Wauters (2016) in that block lengths are drawn from a geometric distribution with a minimum block length of one day and an average of 15 days.
5 For more on GARCH models, cf. Andersen et al. (2013).
6 As is common in academic literature, the annualized returns, volatilities, and Sharpe ratios shown in Table 1 are based on the 5,000 annual returns from the simulations. So, given the different frequencies, it is not surprising that the historical volatilities shown in Panel (b) of Figure 1 and that are based on historical daily returns, are slightly higher. This effect is exacerbated because, of course, the simulation paths are relatively rare in containing the extreme historical returns realizations, and thus there is a corresponding relativization.
7 See Happersberger, Lohre and Nolte (2018) for an empirical study of ES-target strategies in the context of tail risk protection.

Performance attribution through a factor lens

By Sanne de Boer, PhD, Julian Keuerleber and Carsten Rother

In brief
We propose an adjustment of standard regression-based factor attribution to address a common issue: implementation constraints often mean that investors cannot realize the full potential of a factor strategy, but standard attribution analysis assumes that they can – leaving part of the portfolio return unexplained. Our alternative classifies stocks based on their factor exposures and identifies the segments most responsible for the unexplained portfolio return. The resulting nonlinear factor attribution better reconciles realized performance with the investment process, mitigating both the long-term average and short-term volatility of any residual. While our focus is on equity investing, the proposed methodology for factor attribution also applies to other asset classes.

Over the past decade, factor investing has evolved from an academic concept to a strategic initiative for many market participants.[1] Investors not only want to understand which factors their portfolio is exposed to, but also the resulting contributions to performance and risk. In this article, we address an important technical issue that arises in the performance attribution analysis of factor strategies subject to investment restrictions.

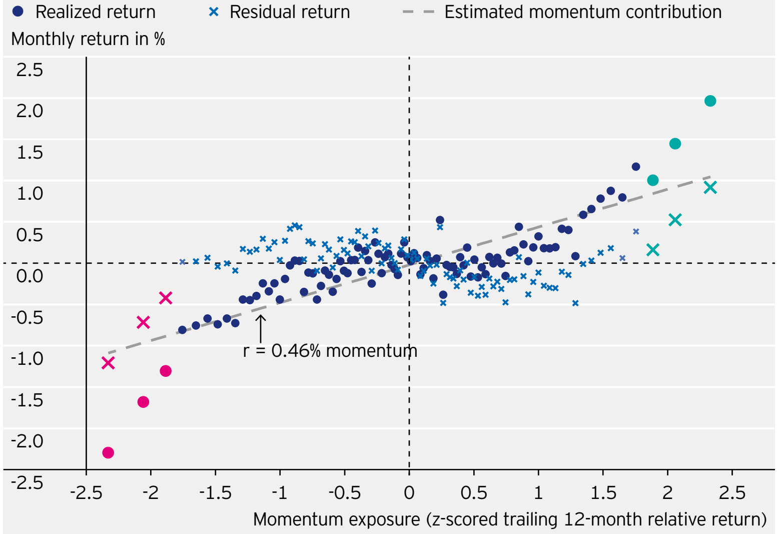
A factor attribution decomposes the portfolio's realized performance into contributions from style factors, as well as geographic and industry exposures. Any residual return left unexplained is commonly attributed to "stock-specific risk" – referring to events with narrow impacts, such as merger announcements or industrial accidents. For quantitative investment managers seeking to understand their performance drivers, finding the residual term dominating attribution is challenging, as meaningful levels of stock-specific return impact are inconsistent with a diversified systematic strategy. In contrast, for fundamental managers, the residual can be interpreted as a measure of stock selection skill.

The traditional linear factor models of stock returns cannot be counted on to capture all possible interactions between the inputs of the investment process.

While some performance impact of stock-specific events is to be expected, the traditional linear factor models of stock returns cannot be counted on to capture all possible interactions between the inputs of the investment process. To illustrate this, suppose the returns from a price momentum factor are particularly strong in its tails. That is, the small group of stocks with the very best trailing returns continue their winning streak, while those few stocks with the very worst past returns continue to underperform sharply. This was the case during the Global Financial Crisis, when defensive industries held up relatively well, but only a handful of counter-cyclical stocks actually managed to rally. Cyclical industries, on the other hand, suffered heavy losses, while already battered financials fell off a cliff after the Lehman Brothers failure.

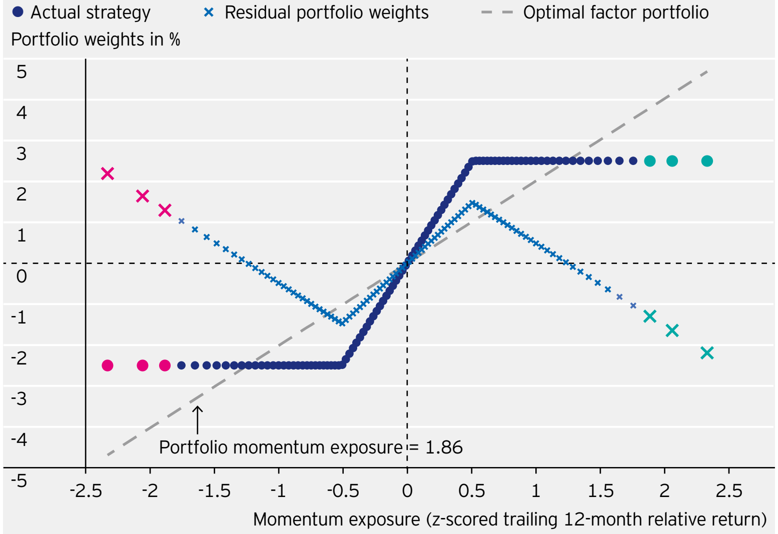
In this example, although the estimated return to momentum might, for attribution purposes, be highly positive, a trend-following long-short investor might not have been able to capitalize on all this return potential. Position limits for diversification and liquidity purposes would shift exposure to more moderate momentum stocks, which might have performed in line with the market. As a result, attribution fails to provide an accurate picture of the performance for this factor investor. The resulting negative residual in attribution reflects nonlinearity in the factor returns to which the strategy was exposed as a result of its investment constraints, rather than stock-specific risk or impact of discretionary security selection. We demonstrate below how this issue can be resolved.

Figure 1
Simulated stock returns by momentum exposure for illustration of attribution



Source: Invesco. Based on simulated data.

Figure 2
Portfolio weights by momentum exposure for illustration of attribution



Source: Invesco.

A closer look at factor attribution
Factor attribution is built on a mathematical foundation. We assume stock returns follow a fundamental linear factor model for which the stocks' exposures are pre-specified – typically based on valuation ratios, price momentum and other characteristics known to explain return dispersion.[2] Realized factor returns are unobservable, and are thus estimated with error, typically by applying a weighted least squares regression of the realized stock returns over the period to the factor exposures. Figure 1 illustrates how this might look for the hypothetical momentum investor above using simulated return and exposure data.[3] The estimated return to momentum from the linear regression is 46bps, which is the slope of the fitted values (dotted line). The regression residuals (crosses) generally reflect moderate stock-specific "noise". However, at the tails (color-coded, larger symbols), they are of greater magnitude due to the assumed nonlinearity of the realized factor return in our example.

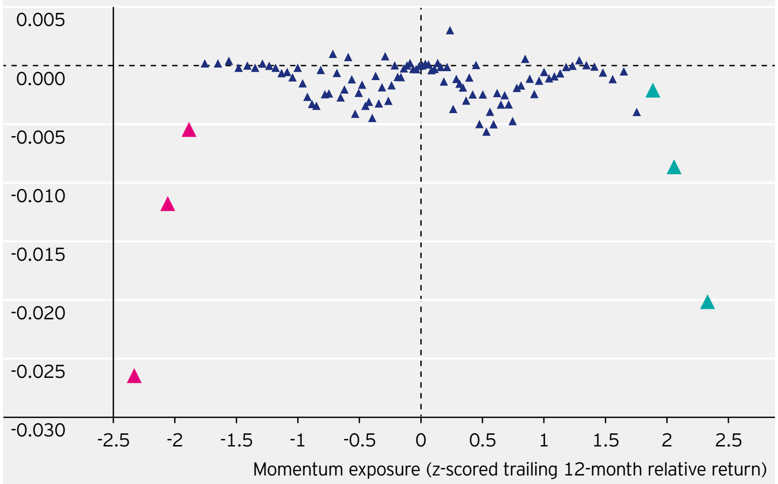
Factor attribution aims to explain a strategy's performance for a given period in the context of the fundamental factor model.[4] A portfolio's realized return is decomposed into the contributions of the individual model factors as measured by factor exposure multiplied by estimated factor return, and a residual. Regression-based estimates of factor returns can be interpreted as the returns to efficient "factor mimicking portfolios": dollar-neutral portfolios with unit exposure to one factor, zero exposure to all others and minimum specific risk.[5] Similarly, the strategy's estimated aggregate factor contributions equal the return to an optimal reference portfolio that emulates its exposures with minimal specific risk. The attribution residual arises partially from constraint-induced deviations to this uninvestable benchmark.

Figure 2 illustrates this portfolio decomposition underlying factor attribution for our systematic long-short investor targeting a high momentum exposure with minimal specific risk but subject to position limits of 2.5%. The unconstrained reference portfolio (dotted line) has the same momentum tilt of 1.86 as the actual strategy (dots), but its weights increase linearly in the factor exposures. We note how the weight differentials (crosses) are positive for those stocks the investor would have liked to short more and negative for those the investor would have preferred to invest in more. The attribution residual in this example thus reflects the return to a "regret portfolio".

The constrained momentum strategy in our example returned 65bps. The final estimate of its factor-driven return component from standard attribution is 85bps: i.e. its momentum exposure of 1.86 (from figure 2) multiplied by the estimated momentum return of 46bps (per figure 1). The attribution residual thus indicates a 20bps shortfall from the strategy's full potential. The contributions of individual stocks to this attribution residual equal their residual return times their residual portfolio weight and are plotted in figure 3. Most positions contributed to the attribution residual being negative, but the "extreme" momentum stocks disproportionately so.

A systematic investor would always like to fully reconcile performance with the investment process.

Figure 3
Residual return contribution by momentum exposure for illustration of attribution



Source: Invesco. Based on simulated data.

Identifying nonlinear factor interactions
A systematic investor would always like to fully reconcile performance with the investment process. Given that the true factor returns are unobservable, we may improve the usefulness of our attribution analysis using thoughtful techniques that reduce the residual component. The result is a more comprehensive, less noisy perspective on realized performance.

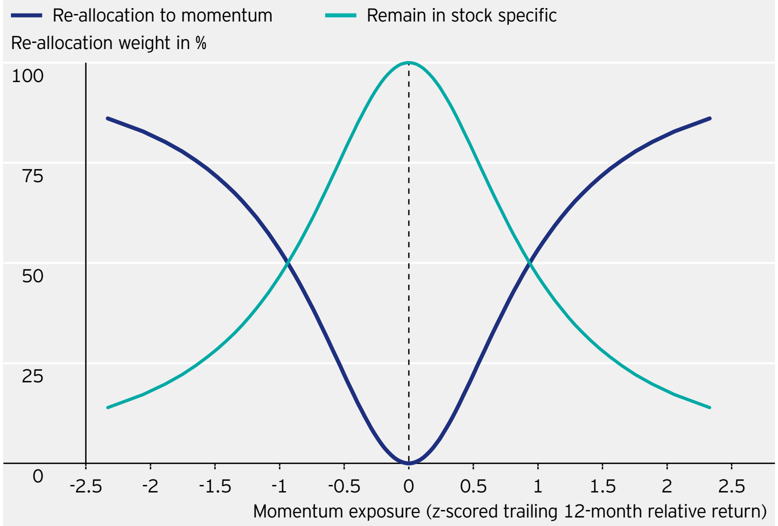
Theorem 1 (least noisy attribution, abbreviated): *We define the "least noisy" estimates of factor returns that fully explain the portfolio's realized return while minimizing aggregated estimation error. The resulting factor attribution re-allocates the residual from standard regression-based attribution in proportion to the portfolio's squared normalized active factor exposures.*[6]

While the above residual redistribution rule is effective in mitigating the impact of estimation noise on the attribution, and fully removes the attribution residual, it is "uninformative" with regard to any model misspecification: the redistribution weights are based on the portfolio's active factor exposures, rather than driven by return data. To address this shortcoming, we can apply the residual re-allocation rule at individual stock level rather than portfolio level, and only then aggregate these back to re-allocate the portfolio's attribution residual. This implicitly assigns each stock's residual to the factors by which it is most characterized, in proportion to its squared standardized factor exposures. The aggregation over all stocks weighted using the residual portfolio weights will then identify, in a nonlinear way, which factors were most responsible for the attribution residual. Intuitively, this takes a portfolio manager's (rather than an econometrician's) point of view: each stock-specific active return contribution is attributed according to the factors that drove the position.

It is also insightful to include an "intercept" among the chosen interaction factors, with unit exposure for all stocks. This implies that the residual return of stocks with relatively moderate factor exposures will remain unexplained. While the resultant factor attribution will no longer fully add up, the magnitude of the residuals will be lower, assuming the interaction effects have been well chosen. From a portfolio manager's perspective, when an active position cannot be explained by factor exposures, its return contribution must inarguably have been stock-specific.[7]

Figure 4 illustrates the classification scheme for our momentum example. The more "extreme" the momentum exposure, the more of a stock's residual return contribution gets re-attributed thereto. The average such weight is 36%. Since stocks with strong positive or negative momentum include the largest contributors to the negative attribution residual, the

Figure 4
Residual re-allocation weight by momentum exposure for illustration of attribution



Source: Invesco. Based on simulated data.

adjustment removes as much as half (10bps) from the estimated momentum contribution – for an adjusted total of 75bps. As mentioned before, this is the estimated impact of nonlinearity in the momentum return to which the strategy was exposed due to its investment constraints. The remainder of the original attribution residual (10bps shortfall) remains classified as "stock-specific", now with better justification.

Multi-factor attribution analysis often includes factors that are treated differently than others. There may be factors explicitly pursued as a return source, such as momentum in our example, alongside factors that are controlled strictly for risk purposes or other characteristics such as industry or country exposure, which may also impact returns over a given attribution period. While, theoretically, the residual redistribution rule might include all of these, we can select a subset thereof to obtain a more focused picture. For example, including only the main intended return drivers would result in reducing the estimated contributions from those that failed to deliver. By contrast, including only portfolio construction-related risk control factors might identify which are most responsible for the portfolio's shortfall in factor returns. Lastly, including only industry or country indicators as interaction terms (in lieu of an intercept) identifies the parts of the investable universe where factor performance was differentiated and constraints forced deviation from the ideal implementation. Each of these options might prove insightful in the right situation.

For the sake of completeness, we briefly explore how to implement a similar idea through added regressors in standard attribution. The intent is to approximate any nonlinear interaction factors missing from the return model that have meaningfully impacted performance. We define the set of interaction factors as the decomposition of the residual portfolio weights using the same classification scheme underlying the residual re-allocation rule.

Theorem 2 (nonlinear residual regression):
Regression-based attribution with the added interaction factors always "adds up" exactly to the portfolio's realized active return, and the portfolio's active exposures to these added attribution variables always sum to 1.[8]

Model estimation can be done on a period-by-period basis or on a pooled basis, looking at the average impact on factor pay-offs. We have found the estimation error is such that the resulting attribution residual is generally noisier than under the standard approach over shorter windows, rendering it impractical. However, pooled over time, the regression may provide valuable insights to enhance return predictors. We note that, for a single interaction factor, the estimated coefficient equals the original attribution residual. This allows multi-period and pooled specification tests of our linear factor model of stock returns, under which the residual's short-term volatility should be moderate and its long-term average should approach zero.

Lastly, our proposal may implicitly capture factor return nonlinearities, but does not identify which aspects of portfolio construction caused exposure thereto. An alternative is to capture the impact of investment constraints explicitly in the construction of portfolios that measure factor returns. Vandenbussche (2016) considers including long-only constraints in the construction of "factor-mimicking portfolios" that estimate factor returns. De Boer and Jeet (2016) illustrate how asymmetric and stale factor exposures may result from long-only and turnover constraints. They propose additional attribution variables to account for possible nonlinearity in factor returns related to this. While these approaches may add insight, they do require more calibration.

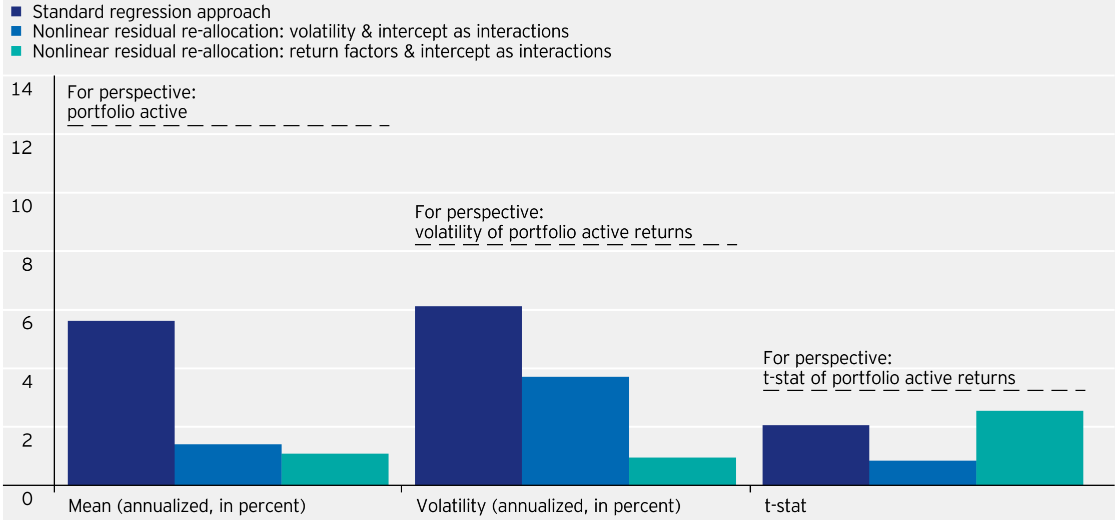
Empirical illustration
We now illustrate the proposed nonlinear attribution method on a more typical example. In particular, we demonstrate how it creates a better understanding of the simulated recent performance of a hypothetical US all-cap market-neutral strategy. The hypothetical long-short portfolio is rebalanced monthly so as to maximize its factor-based return prediction, subject to liquidity considerations and diversification constraints on individual position sizes as well as industry exposures.

The underlying mean-variance optimization limits the hypothetical portfolio's ex-ante annualized volatility based on a custom multi-factor risk model that includes the return factors, other risk control factors and industry indicators. Stocks' return predictions are a balanced proprietary combination of three factor composites that we believe deliver risk-adjusted excess return: momentum (both in earnings and share price), value and quality.[9] Pursuant to Grinold's (1994) rule of thumb, we multiply each stock's score by its estimated stock-specific return volatility to get its final return prediction. This step also allows an insightful application of our attribution toolkit. We have deliberately omitted further implementation details since our sole objective is to illustrate the attribution proposal rather than the merits of any investment strategy.[10]

The average annual simulated gross return of the hypothetical portfolio from January 2013 through December 2017 was 12.41% above the average cash rate for the same period.[11] Its annualized return volatility was 8.22%. We ran standard factor attribution to help understand the drivers, supplemented by the residual re-allocation method using either the three return factors or a volatility factor as nonlinear interaction effects. In both cases we included an intercept in the underlying classification scheme, the residual return of which remains classified as "stock-specific".

Figure 5 compares the distribution of the monthly attribution residuals and shows that the original attribution residual (dark blue bar) comprises nearly half of the hypothetical portfolio's simulated gross return (dotted line). This is unsatisfactory from a reporting standpoint. Its magnitude also causes our specification tests for the return model to fail, both across periods and in aggregate, with p-values of close to zero. This is empirical evidence of nonlinear interactions between factors and the investment process that are not captured by the linear attribution model. In particular, the return factors might offer the best differentiation of performance among the most volatile stocks in the investable universe, which were heavily represented in the portfolio because of the risk scaling. This is corroborated by the fact that adding "volatility" as a nonlinear attribution factor (blue bar) leads to

Figure 5
Distribution of "stock-specific" residual in factor attribution for hypothetical simulated US all-cap market-neutral



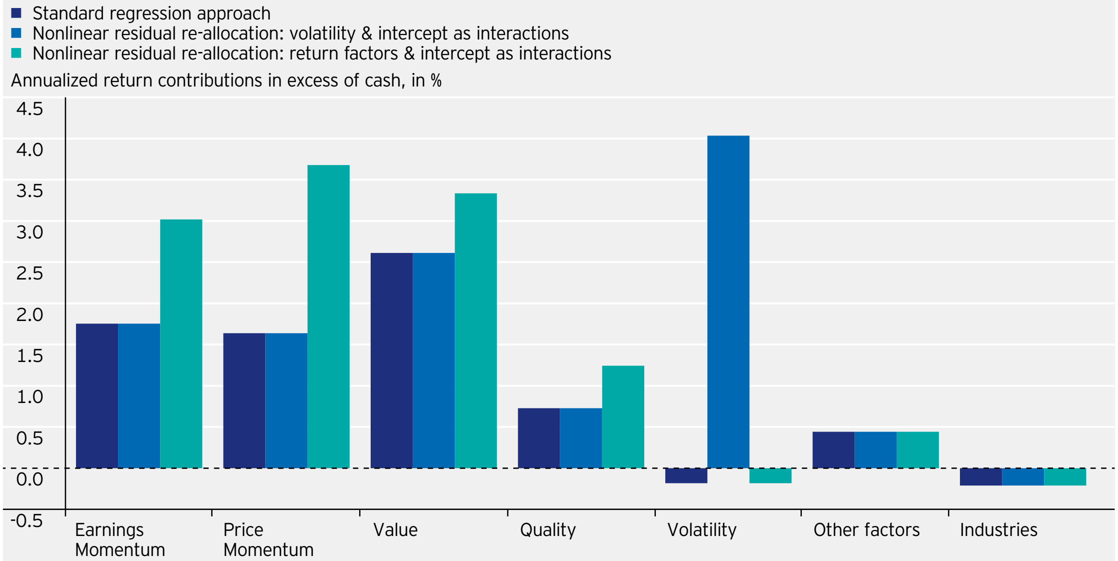
Source: Invesco. Time period: January 2013 – December 2017. Gross of transaction costs and fees.

explaining substantially all of the average simulated gross performance. The resulting reduction in the volatility of the stock-specific attribution residual is smaller, as this inherently reflects the return on stocks with medium specific risk.[12] Lastly, the t-statistic confirms that the average attribution residual is no longer statistically significant, implying that aggregate performance is now fully explained "through a factor lens".

Figure 5 shows that including the return factors as nonlinear interaction terms (green bar) results in a similar reduction in unexplained aggregate performance, and a much stronger reduction in the volatility of the attribution residual. Since most positions of the hypothetical strategy should be driven by the return factors, they can help attribute much of the returns initially left unexplained. However, this approach seemingly fails to pick up on the full realized return-enhancing impact of volatility scaling for stocks with only moderately attractive factor characteristics, resulting in the average attribution residual remaining statistically significant.

Figure 6 compares the actual attributions. Interestingly, the adjusted attribution suggests the return contributions from the return factor exposures was most underestimated for stocks with strong (or poor) momentum. It is possible

Figure 6
Factor attribution for hypothetical simulated US all-cap market-neutral



Source: Invesco. Time period: January 2013 – December 2017. Gross of transaction costs and fees.

that volatility scaling was most effective among this segment of the investable universe, an effect that standard linear attribution would not be able to capture. This example illustrates how attribution based on nonlinear residual re-allocation might allow a more comprehensive and factor-centric understanding of a strategy's performance than the standard linear approach. It also shows that the attribution residual need not always be negative and might reflect aspects of portfolio construction other than investment constraints.

Conclusions

Standard factor attribution assumes a linear relationship between factor exposures and returns, yet investment constraints create a nonlinear relationship between factor exposures and portfolio weights. For systematic investors, this leads to volatile or persistent attribution residuals. We have proposed a nonlinear heuristic that may solve this problem. The resulting attribution more comprehensively links realized performance to the factor-driven investment process by mitigating both the long-term average and volatility of the residual. This approach may facilitate communication with clients, as well as identifying enhancements to the investment process.

References

- Cariño, D. R. (1999) "Combining Attribution Over Time," Journal of Performance Measurement, Summer 4(3): pp. 5–15.
- De Boer, S. (2012) "Factor attribution that adds up," Journal of Asset Management 13: pp. 373–383.
- De Boer, S. and V. Jeet (2016) "Aligning factor attribution with latent exposures," Journal of Asset Management 17: pp. 502–525.
- Greene, W.H. (2003) Econometric Analysis, 5th edition. Englewood Cliffs, NJ: Prentice Hall.
- Grinold, R. (1994). "Alpha Is Volatility Times IC Times Score," Journal of Portfolio Management 20(4): pp. 9-16.
- Grinold, R. and R. Kahn (2000) Active Portfolio Management, 2nd edition. New York: McGraw-Hill.
- Rosenberg, B. and V. Marathe (1975) "Tests of Capital Asset Pricing Hypotheses," Research Program in Finance, Working Paper no. 32.
- Vandenbussche, D. (2016) "Long-only Factor Mimicking Portfolios." Presented at the Fifth Annual Axioma Quant Forum, New York, NY.

Technical appendix

Standard attribution assumes that stock returns follow a linear factor model (e.g. Grinold and Kahn, 2000). Let r denote the vector of all n stock returns over the period of interest:

$$(1) \quad r = Br_b + \varepsilon$$

Here B is an n by m matrix of n stock exposures to m factors, r_b is an m-vector of factor returns and ε is an n-vector of zero-mean "stock-specific" returns with diagonal covariance matrix $\sigma^2\Omega$. The scalar σ^2 reflects the overall level of specific risk.

The regression-based estimates of the factor returns $\breve{r}_b$ follow from the realized stock returns $\breve{r}$:

$$(2) \quad P \triangleq \Omega^{-1}B\left(B'\Omega^{-1}B\right)^{-1}; \; \breve{r}_b = P'\breve{r}$$

See for example Greene (2003).[13] We note that the columns of P are the weights of the efficient factor-mimicking portfolios (e.g. Grinold and Kahn, 2000). The decomposition of the (active) portfolio weights w underlying factor attribution is expressed as:

$$w = Pb + w_{resid}; \; b = B'w \, .$$

The vector b denotes the portfolio's active factor exposures. To formalize our residual re-allocation proposal, define an n by p classification matrix:[14]

$$(3) \quad B_{classif}^{i,k} = \frac{B_{i,k}^2}{\sum_{k=1}^{p} B_{i,k}^2}$$

This matrix has rows summing to one, reflecting the relative importance of each included factor k for each stock i. Furthermore, let $\breve{\varepsilon}$ denote the regression residuals and M denote the residuals-generating matrix such that:

$$(4) \quad M = \left(I - BP'\right); \; \breve{\varepsilon} = M\breve{r}$$

Then the adjustment of the original attribution for all p factors included in the classification scheme equals $\breve{\varepsilon}' B_{classif}$

Lastly, for the regression-based variation on the same idea, we define the added regressors of Theorem 2 as:

$$(5) \quad B_{res\text{-}inter} = M \frac{diag\left(\Omega \breve{w}_{resid}\right)}{w_{resid}' \, \Omega w_{resid}} B_{classif}$$

There is a clear "duality" with the residual re-allocation rule, which classifies (residual) returns for direct attribution rather than (residual) portfolio weights as added regressors. The attribution residual reflects correlation between residual portfolio weights and residual stock returns. Theorem 2 decomposes the residual portfolio weights by interaction factors. This identifies the segments of the investable universe in which active positions contribute most to the residual, and re-attributes accordingly.

About the authors

Sanne de Boer, PhD, CFA
Senior Research Analyst,
Invesco Quantitative Strategies
Sanne de Boer conducts research into quantitative investment management for equities focusing on factor-based return prediction models, portfolio construction as well as performance attribution.

Julian Keuerleber
Head of Global Portfolio Analytics,
Invesco Quantitative Strategies
Julian Keuerleber heads the team responsible for portfolio and performance analysis, investment communication and reporting.

Carsten Rother
Research Analyst,
Invesco Quantitative Strategies
Carsten Rother develops quantitative multi-factor models in equities and across asset classes.

Notes

1 Invesco Global Factor Investing study, 2016.
2 See Rosenberg and Marathe (1975) for an early example.
3 To facilitate our exposition, this is a stylized simulated example of 100 stocks with realized return a cubic function of z-scored "momentum exposures" and only a small homoskedastic Gaussian perturbation as specific risk.
4 For simplicity, we have focused our analysis on arithmetic attribution and linking thereof over time. See Cariño (1999), among others, for proposals on how to geometrically link single-period factor attributions so as to explain multi-period strategy performance.
5 E.g. Grinold and Kahn (2000).
6 The full version of the theorem as well as the proof are included in an expanded version of this report, which is available upon request. We note that the shrinkage estimator by De Boer (2012) as well as the Restricted Least Squares approach by De Boer and Jeet (2016) are similar in intent and outcome but less robust, in rare cases worsening the noisiness of the resulting attribution.
7 In addition, one could argue for pragmatically including the residual return contribution of stocks whose outlying performance indicates some stock-specific event in this category as well.
8 The proof and more detail on this alternative methodology are again left to the expanded write-up.
9 See "Is it a factor and – if so – how many?" in Risk and Reward #4/2017 for more background.
10 The hypothetical strategy's investable universe includes the point-in-time constituents of Russell 3000 index. The custom risk model was created using Axioma's Risk Model Machine on the basis of their US4 equity risk model. The hypothetical portfolio's performance was simulated from 31/12/1993 through 31/12/2017 though only the latest 5 years are included in the attribution, emulating a client's focus on its relatively recent track record. The hypothetical strategy does not represent any actual strategy offered by Invesco. The analysis is presented solely to illustrate different approaches to factor attribution and not as a basis for investment advice or to sollicit business for Invesco.
11 For simplicity, we assume the cash benchmark of the portfolio equals the short rebate rate before stock loan fees, thus netting each other out in the active return calculation. The gross performance presented here makes no accomodation for any investment fees or implementation costs, such as commissions, market impact of trades or the borrowing costs of stocks to be shorted. Had such costs and fees been accounted for, the reported returns would have been meaningfully lower. Hypothetical simulated performance inherently reflects the benefit of hindsight and is not necessarily indicative of future returns.
12 Intuitively, the volatility-scaled return forecast of low-risk stocks does not support large positions in the portfolio, while the residual return contribution of high-risk stocks is re-attributed to the volatility factor.
13 However, consistent with industry practice, we weight by the square root of market capitalizations in our empirical analysis, avoiding the need for a risk model and reducing the impact of less investable stocks in the estimation universe.
14 We assume here that factor exposures have been de-meaned with roughly symmetric positive and negative exposures, excepting segment indicators such as country and industry flags.

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