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#01

1st issue 2018

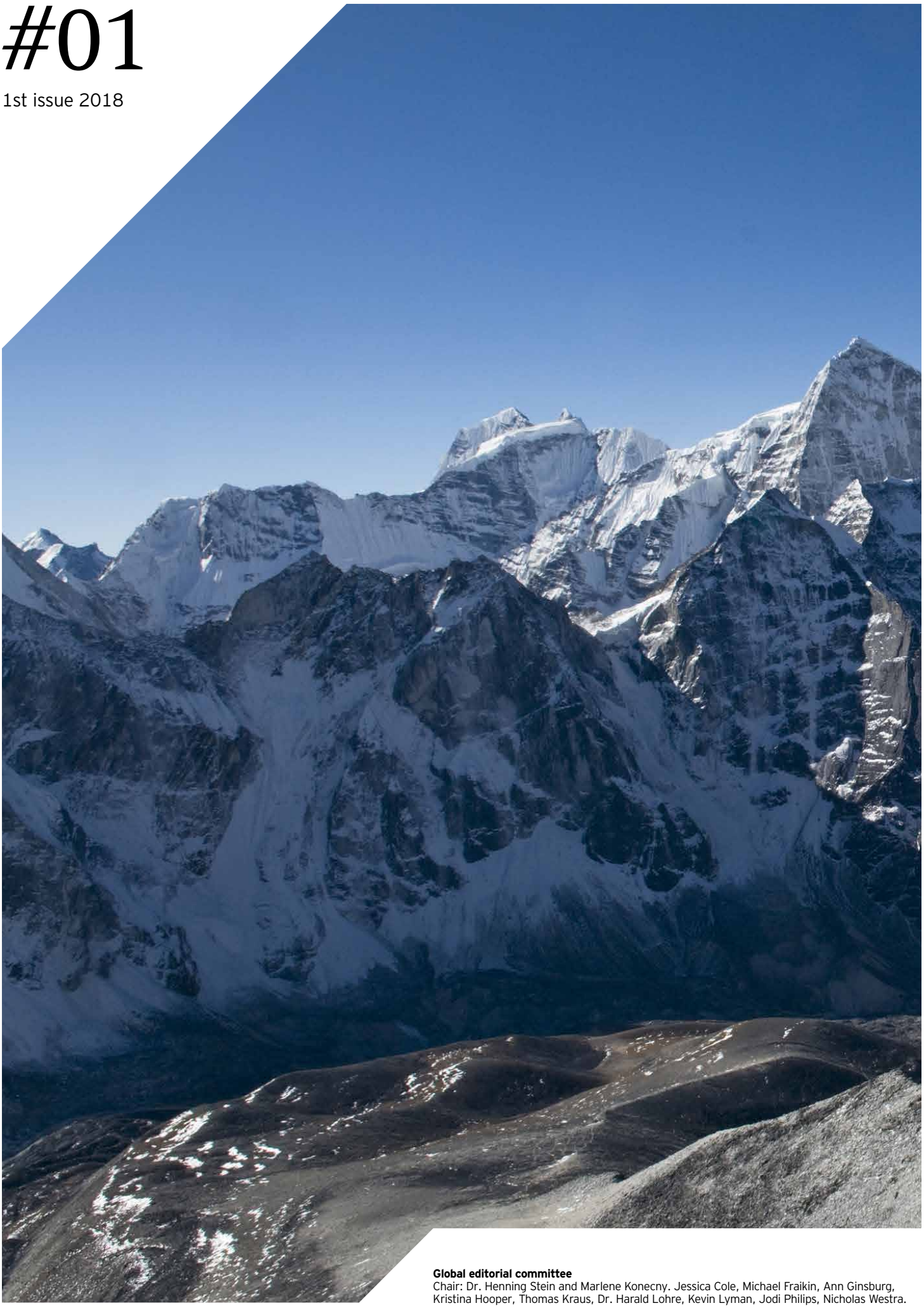
The latest frenzy: rise of the token

Risk & Reward

Research and investment strategies

#01

1st issue 2018



Not long ago, bitcoins were reserved for a small number of computer experts creating their own currency using an arcane technology called "blockchain". Even though many observers foresee blockchain ushering in a new digital revolution, there are clearly risks involved, and the details of the new technology remain fairly obscure. This is why we've devoted our feature article to exploring this technology and the cryptotokens it enables.

In this edition of Risk & Reward, three of my colleagues from Invesco Private Capital have explored in great detail virtually all aspects of the crypto trend – from the nature of cryptotokens, to their risks and future potential, to regulatory and technical issues. Find out how bitcoins and other so-called "tokens" are created, what features make the blockchain technology so interesting and why a wide variety of industries are so fascinated by the long-term potential of cryptotokens.

In two of the other articles, we continue our examination of factor investing. Those transitioning from a traditional asset allocation into a more modern factor approach can benefit from thoughtful guidance. Our experts have developed a roadmap to help portfolio managers along the way. We also demonstrate how factor investing can be applied to currencies, how currency risks can be mitigated and currency returns enhanced, by using foreign-exchange style factors.

Finally, responsible investing (RI) has attracted a growing following in recent years. But most RI strategies remain confined to developed market equities. Our researchers have explored a wholly different approach to RI, focusing on emerging market bonds. Read on to discover the compelling truth about the future of responsible investing.

We hope you will enjoy the latest issue of Risk & Reward.

Best regards,

Marty Flanagan
President and CEO of Invesco Ltd.

Contents

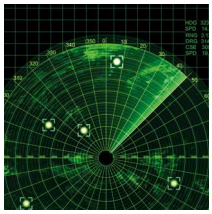
Feature

In focus

Factor investing cuts through the traditional way of organizing an investor's asset allocation. But not every investor can go directly for the magic bullet solution – especially if an allocation to traditional asset classes is already in place. So, how do multi-asset factors work in such a context?

Can an ESG-focused fundamental analysis improve the assessment of investment risk? What is the impact of ESG investment objectives on returns? Is RI likely to have a positive impact on the world? We believe that emerging market bonds offer some compelling insights into these questions.

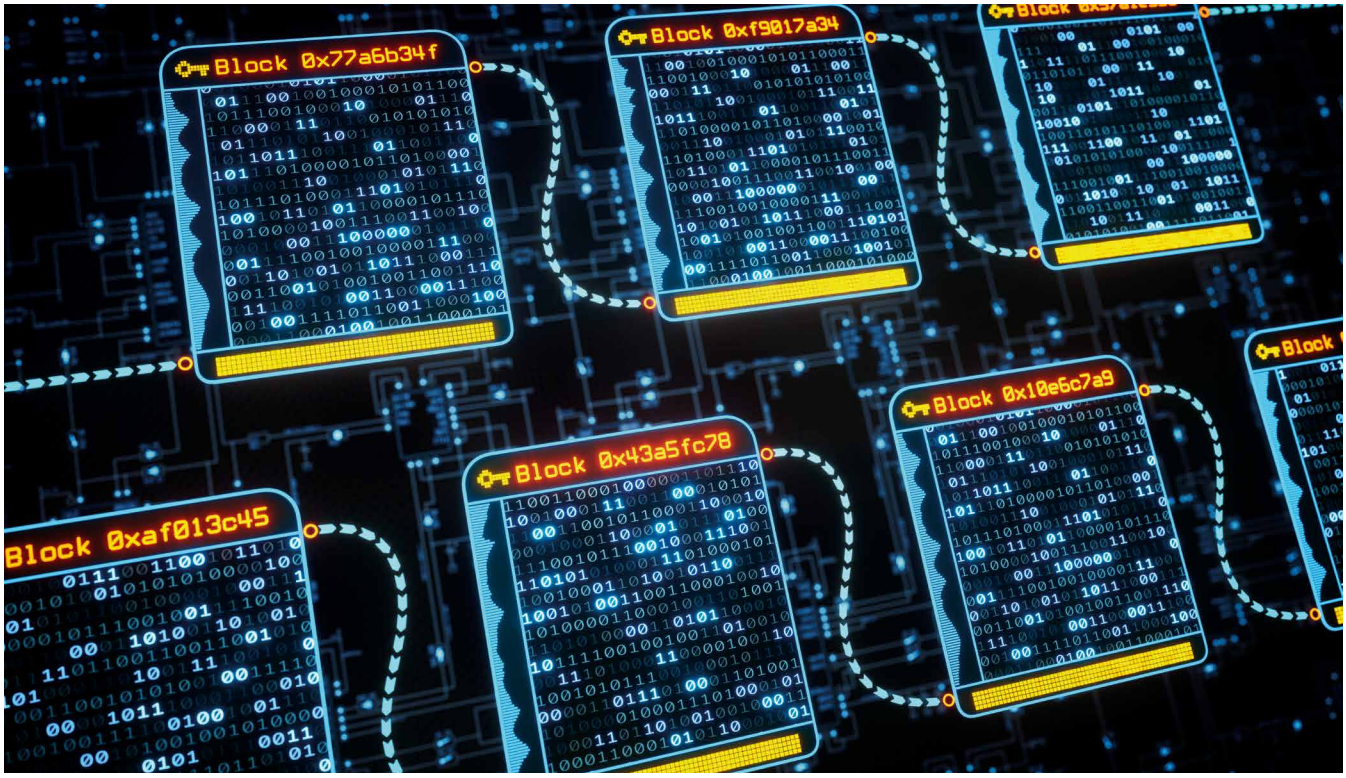
There are good reasons to believe that the optimal currency hedge lies between the two extremes of a full hedge and no hedge at all. It may pay off to look more closely at currency style factors for determining a beneficial currency allocation.



In our series, we have presented many different time series models and the user often can't see the forest for the trees. For even if a model passes all the tests, the "true" model can be quite a different story. Bayesian Model Sampling helps solve this problem – it also marks the end of our series.

The latest frenzy: rise of the token

By Evan Jaysane-Darr, Jessica Mulvihill and Mariam Waheed



In brief
In this article, we discuss various aspects of Bitcoin and other cryptocurrencies, as well as the underlying blockchain technology. We offer a detailed description of the technical aspects of blockchain, its applications in the world of finance, fundraising mechanisms for new crypto projects, cryptocurrencies as an asset class, risks, regulatory aspects and the future potential of the new technology. We end on an optimistic note, arguing that the advent of blockchain has the potential to be the beginning of a new technological revolution.

Bitcoin and other cryptotokens (hereafter used interchangeably with cryptoassets) have captivated a large segment of the retail investment world in ways not seen since the dotcom bubble of 1998-2000. Despite a recent correction Bitcoin has appreciated ~23x since the start of 2016. Other cryptoassets have followed similar trajectories. In spite of (or perhaps because of) the volatility present in these assets, speculators of all stripes have been attracted to the emerging asset class by the echo of ever increasing prices. It is undoubtedly a speculative bubble. Yet most speculative bubbles have something real and potentially transformative underpinning them, and crypto is no exception.

Economist Carlota Pérez writes about bubbles and techno-economic paradigms in her seminal book *Technological Revolutions and Financial Capital*.[1] According to Pérez, technological revolutions follow similar patterns, which she classifies into techno-economic surges. She identifies five such paradigms:

1. The Industrial Revolution
2. Age of Steam and Railways
3. Age of Steel, Electricity and Engineering
4. Age of Oil, Automobiles and Mass Production
5. Age of Information and Telecommunications

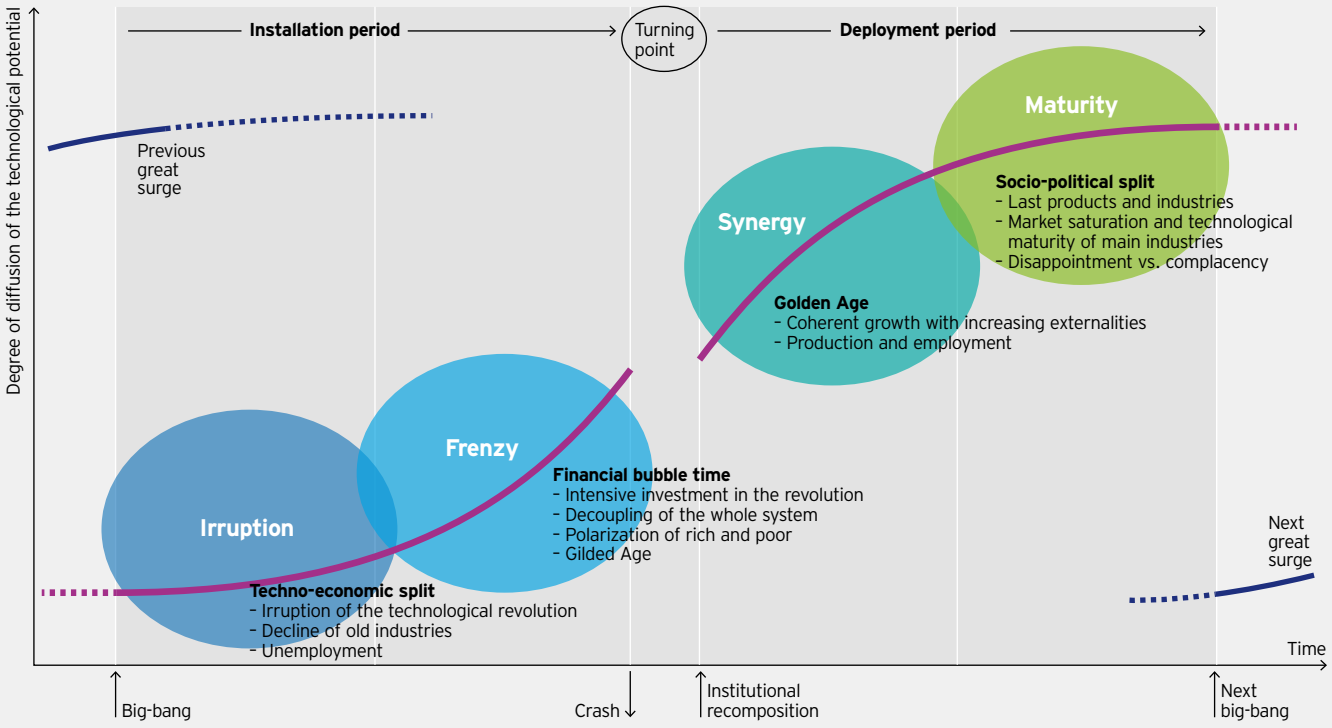
As shown in figure 1 below, all of these paradigms align along the following sequence: installation phase, bubble and subsequent crash, followed by an extended deployment phase as the technology is diffused across society.

During the installation period, investment ramps up as speculators are drawn to the new opportunity and promise of outsized returns. This speculative behavior peaks with in the frenzy phase, deemed "irrational exuberance" in 1996 by Alan Greenspan. Some contend this is where we sit today within the crypto space.

If we are nearing the end of the current IT paradigm then it begs the question of what will precipitate it.

A few notable venture capital firms subscribe to versions of Pérez's theory (such as Union Square Ventures and Andreessen Horowitz), which suggests the coming completion of the current technological paradigm, marked by the beginning of the next. If we are nearing the end of the current IT paradigm then it begs the question of what will precipitate it. Each new wave has been epitomized by a corresponding innovation in distributing commerce and innovation throughout society (e.g. canals were the internet of the Industrial Revolution). Blockchain has the potential to enable a disintermediated, frictionless marketplace. As a result, some venture capitalists regard crypto as the next paradigm, a new decentralized internet. Indeed, to date the price of the largest and best

Figure 1
Technological surge cycle: Recurring phases of each great surge in the core countries



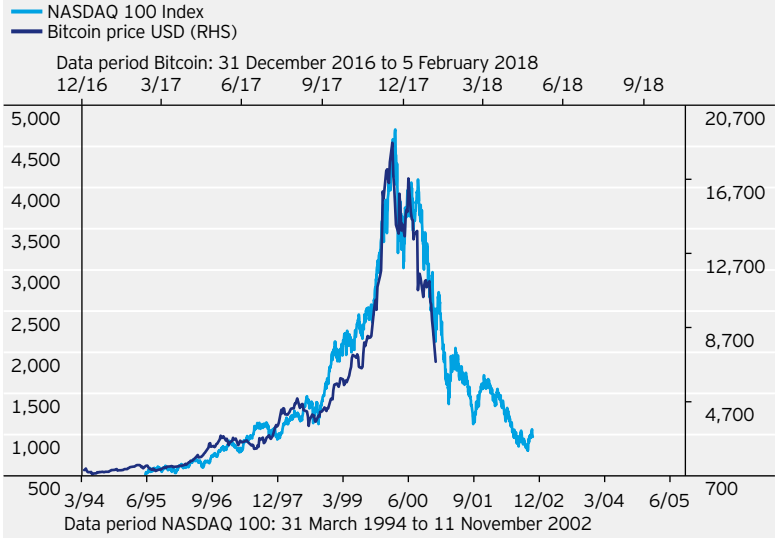
Source: Carlota Pérez. Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages. Edward Elgar Publishing Limited, 2002.

known cryptoasset, Bitcoin, has mimicked that of the NASDAQ bubble with remarkable precision (figure 2).

If the prediction is accurate then there is more short term pain to come for Bitcoin holders. However, the long term guidance could still be immensely positive as the technology gets deployed across society. Ultimately, the price of Bitcoin is less important than the potential found in the underlying technology and token mechanism thereby enabled.

Ultimately, the price of Bitcoin is less important than the potential found in the underlying technology and token mechanism thereby enabled.

Figure 2
Bitcoin versus NASDAQ: Price comparison



Source: Fundstrat.

Bitcoin and the blockchain
Bitcoin is a digital asset initially introduced in 2008 with the publication of Satoshi Nakamoto's landmark paper proposing a decentralized payment system built on an underlying technology now known as a blockchain. Bitcoin started as a peer-to-peer currency and payment system - a financial technology breakthrough. And indeed Bitcoin still offers one of the most well-defined use cases of the crypto movement, a censorship-resistant store of value. However, as potentially disruptive as a new digital currency could be, it alone would not be sufficient to represent a new techno-economic paradigm on par with the steam engine and the internet. Technologists and investors became increasingly enamored with the underlying "blockchain" architecture beneath the currency.

The initial Bitcoin blockchain was designed as a public transaction ledger to track transactions in Bitcoin. Blockchain at its core is an open, distributed ledger, or database. Such a distributed database alone would not be unique. What makes the blockchain innovative is that its ledger is cryptographic, immutable and decentralized, and runs on the concept known as "proof of work." Cryptographic in that transactions are verified using private "hash" keys, to validate that ownership of a party to a transaction's Bitcoin. Immutable or irreversible in the sense that the blockchain is "append only", it cannot be altered, only added to. And finally it is decentralized in that the blockchain is maintained by a global network of miners and developers, rather than by a single, corporate entity. As a result, a blockchain cannot be altered by a single computer and thus doesn't have a single point of failure. Proof of work, meanwhile, is a validation technique. It refers to the fact that in order to add a block to the blockchain (thereby getting compensated in Bitcoin), miners are required to solve a complex mathematical problem, which gets increasingly complicated as more blocks are added to the chain. This is also how the Bitcoin blockchain is secured.

Bitcoin vs. blockchain
Over the past few years, as crypto gained increasing prominence, it became fashionable in the financial and economics worlds to take the position of "blockchain, not Bitcoin." In other words "Bitcoin is not that interesting as it is merely a currency with illicit use cases, but this blockchain technology has potential!" The potential cited is typically represented by the creation of private, or permissioned, blockchains. These leverage distributed databases to improve largely internal efficiencies at incumbent financial institutions, rather than to establish a new decentralized currency or internet. Private blockchains are therefore akin to company intranets, while public, permissionless blockchains are analogous to the internet. Going forward, there will undoubtedly be instances of companies leveraging private blockchain technology to reduce costs and improve efficiency, for example in trade settlement. However private blockchains may represent merely an intermediate step toward a more decentralized system.

Some of an open blockchain's potential beyond enabling purely a decentralized currency (and store of value) is already being realized with Ethereum. Ethereum was founded by Vitalik Buterin in 2014 as a decentralized computing platform that runs digital smart contracts, with "Ether" as its currency unit. These smart contracts essentially enable (decentralized) applications to be easily programmed to run automatically without any intermediary, or third-party interference. For instance, Augur is a prediction market dApp built on Ethereum's blockchain. The system, which allows users to place monetary bets on any future event, encodes bets made on its platform in Ethereum's underlying smart contract language. When the event in question occurs, the smart contract is triggered and automatically executed, allowing the money to change hands without the use of a central overseeing party. Similar to the Bitcoin blockchain, the code written into these smart contracts is immutable – it cannot be changed. The account is effectively controlled by

this code, rather than by a user. As a result, smart contracts are virtually immune to tampering and fraud once created. While setting up contracted and frictionless execution has utility across most sectors of the economy, including financial services, healthcare, real estate and insurance, it has first manifested itself as a platform for other tokens to be built.

As we are already seeing with Ethereum, limiting one's interest in blockchain to private networks would be missing out on the tremendous potential offered by open blockchains outside the financial sector as well as an innovation of comparable importance to that of the blockchain: the token.

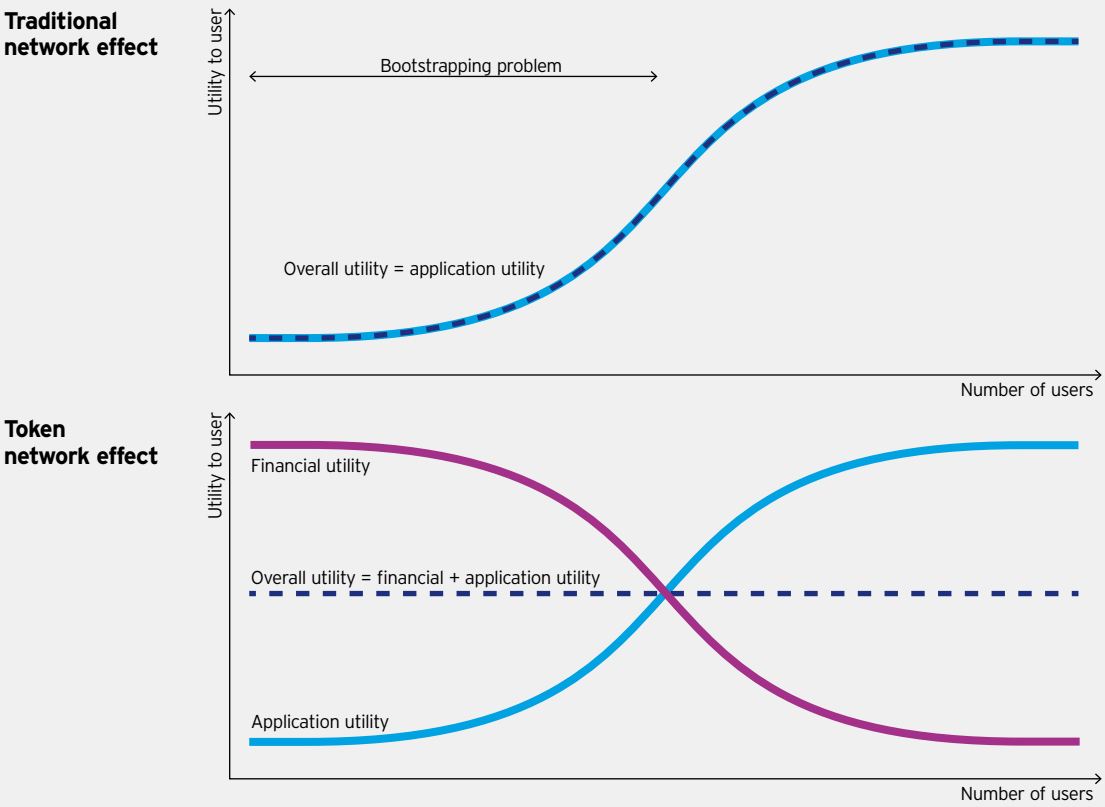
Tokens & the power of decentralization
Over the past few years large web-based, software networks like Google, Netflix and Facebook have amassed ever increasing power because of the network economics inherent in their business models. The more users they have, the more data they amass. The more data they have the better they can train their algorithms and the better the services they offer to consumers (and advertisers). This in turn increases the benefit to being part of their network. Network effects lead to a winner-take-all dynamic as power accrues to the largest network, making it difficult for newer networks (e.g. Snap) to compete with these large incumbents. This is leading to increased centralization of power in our economy. Indeed, these companies are for the first time feeling public pressure and calls for antitrust regulation.

Absent new regulation however, there is perhaps only one way to compete with these large centralized networks - decentralization. Decentralized networks have the potential to disrupt large conglomerates, but how do you incentivize innovation without a company of paid employees?

Perhaps an even more significant innovation than being a digital store of value (e.g. in the case of Bitcoin) is that tokens represent a new way to incentivize and design open networks. By rewarding developers and miners directly through the token offering (ICO or initial coin offering) one is effectively "bootstrapping" development of the network and expediting the inherent network effects.

As laid out by venture capitalist Chris Dixon of Andreessen Horowitz, because participants can have direct access to the financial value of a network, one can incentivize investment (rewarding speculation) in the network at a time when application value is low, by giving people partial ownership of that network. Eventually the utility value associated with the actual service should catch up with the speculative value, driving further participation in the network (figure 3). Moreover, as participants contribute directly to the network in exchange for tokens, they are also able to control and monetize their own data. In a world where all data is made freely available, web incumbents can't respond to crypto's free data business model. These large aggregators would thereby be disintermediated. Therein lies blockchain's ultimate

Figure 3
Token help overcome the bootstrap problem by adding financial utility when application utility is low



Source: Chris Dixon, Crypto Tokens: A Breakthrough in Open Network Design, 6/1/17.

potential: an assault on intermediaries, all enabled by the "token", which mechanize blockchains to turn networks into markets.

Tokens

Cryptotokens are blockchain-based digital assets or representations of something else of value. These tokens take many different shapes and sizes. First, they vary by the underlying codebase and blockchain. Bitcoin and Ethereum have their own blockchains, as do newer entrants like Filecoin. Others have forked (analogous to a software upgrade) either the code or blockchain, or both, to create a new network based on some modification of an existing chain. And finally some belong to the rapidly growing segment of tokens built on top of the Ethereum blockchain, using the ERC20 standard. (Ethereum has effectively built a token-as-a-service offering and ERC20 is the set of rules guiding the construction of those tokens.)

Perhaps a more useful guide for investors than characterizing tokens by their architecture is to organize them by their ultimate use case or value proposition. This is complicated by the many different categorizations available. We find the simplest, most relevant denominations to be as follows: (1) Cryptocurrencies, (2) Cryptocommodites, and (3) Decentralized Applications ("dApps"). Cryptocurrencies are those tokens for which the primary use case is as a means of payment or store of value (e.g. Bitcoin, Litecoin or Monero). Cryptocommodities are tokens with more of a utilitarian use case, for instance providing processing power or storage (e.g. Ethereum or Filecoin). Finally, dApps (or appcoins) are those smart-contract applications typically built on top of other cryptocommodity protocols. These dApps don't always require purchasing a token to access the requisite protocols but may simply charge end users a fee. Many of these are still providing raw digital resources, but in the future we suspect user-facing applications will proliferate.

When investing in tokens, one is purchasing access to a network, or a digital service that no centralized party controls, otherwise known as a protocol. Because a token represents network access, the value of tokens is directly dependent on growth in network participation. As Nick Tomaino of venture capital fund *1confirmation* highlights, the value of the token underlying a protocol will persist so long as the digital service is useful, and supported by "a scarce and unique set of resources."[2] It is not necessarily true that tokens with clearly defined use cases will maintain value better than currencies like Bitcoin. Counterintuitively because tokens such as Bitcoin are not tethered to a use case beyond simply "store of value," they could potentially prove more resilient to systematic forces than commodity tokens, which have a more easily derived fundamental value that is subject to fluctuations in the perceived utility of the token as well as the competitive landscape of whatever service they are offering.

Protocol vs. application layer

Part of the excitement around tokens is centered on their ability to incentivize innovation at the protocol level of the technology stack. With the internet, value accrued principally to the application layer, including large conglomerates like Google, Facebook and Amazon, while the underlying protocols were largely commoditized. It was difficult to incentivize development of new protocols because the work was principally being driven by researchers and nonprofits. Relatedly, there was no way for investors to take a position on one protocol (say Transmission Control Protocol/Internet Protocol = TCP/IP) vs. another (e.g. Simple Mail Transfer Protocol = SMTP). However, as Albert Wenger, a partner at Union Square Ventures (USV), points out "with blockchains we now have a way of issuing and redeeming these tokens digitally." Therefore "a for-profit company can now create a new protocol and create value for itself (and its investors) by retaining some of the tokens. If the protocol becomes widely used, the value of the tokens will increase."

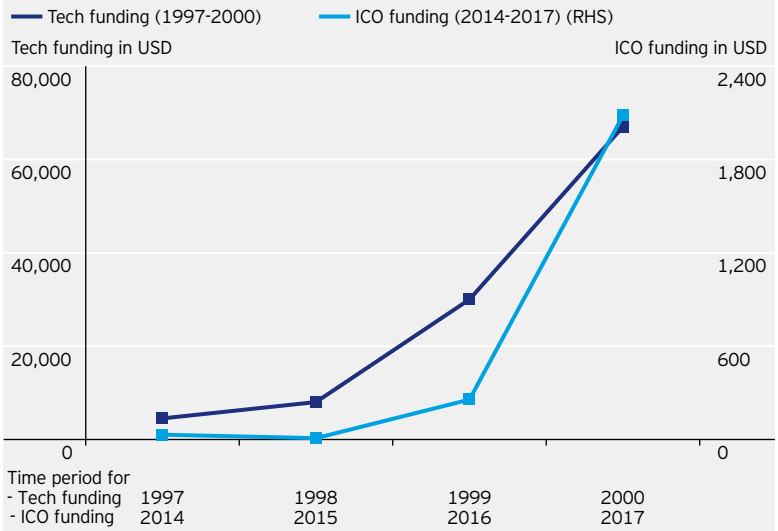
Protocols comprise the first of the three layers of the cryptoasset tech stack, which in order of depth of technology (from most basic to most surface level) are: (1) Infrastructure Protocols, (2) Decentralized Applications ("dApps"), and (3) User Interfaces. Many believe that much of the value is and will continue to be captured at the first two primary levels. This is in direct contrast to the organization of the internet stack, where underlying protocols are commoditized and value is accrued at the user-facing application layer. First astutely laid out in Joel Monegro's piece, "Fat Protocols"[3], unlike with the web where value accrued at the application layer, with blockchain that value will accrue at the protocol (or protocol application) layer. Because crypto-networks function on the premise of free, shared and open data, user applications built on top of the networks can scale easily but have virtually no barriers to entry. The blockchain removes the competitive advantage of having a database, a la Facebook or Google, by capturing this value further down the stack at the protocol layer. As a result, defensibility at the application layer shrinks. Most value accrues instead at the protocol level, where network usage and growth are what in turn could build value in the underlying token. Indeed, the largest use-facing application, Coinbase, was valued at its last round of funding at USD 1.6 billion. As of this writing, Bitcoin's market capitalization is around USD 150 billion and Ethereum's is around USD 84 billion.

Even if it is generally agreed upon that the protocol level has the potential to accrue more value than we saw in the internet age, there are open questions around how that value will be divided – whether we will see a more "maximalist" version with one or two massive protocols, or whether the protocol layer will be split into many smaller sub-protocols. Currently, the market looks more like the former. We've seen enormous growth in the size of individual protocols so far, driven in part by the launch of successful use cases that have helped funnel user growth to just a handful of underlying platforms. For example, Coinbase as an application helped drive user growth and speculation in Bitcoin, just as Ethereum's token crowd sale use case has driven the growth of Ether, rapidly expanding the market cap of both. The inherent network effects will serve as a moat to new entrants. However, as protocols scale, so does the diversity of needs of its user base. An aggregate, generalist protocol may be less efficient at providing more precise types of functionalities – while a specific use case may be more efficiently served with a sub-protocol that has a narrower functionality.

This can be thought of as a push and pull between technical requirements and network effects. Network effects will continue to drive the most momentum to those protocols with the largest user bases, as we've seen thus far. At the same time, engineering needs will continue to drive the creation of new smaller sub-protocols to better address issues overlooked by larger ones. Additionally, due to the nature of network diversity, the value that can be captured by one single protocol may have an upper limit it can reach before being forked. Because all data at the protocol level is open source and can be copied, network forks can serve as a significant check on protocol size and applicability – if a network gets too big and the needs of a certain sub-user group are not being met, developers can simply copy everything and start their own. As the market progresses, engineering teams will continue to create new and alternative protocols, pushing the environment to become more crowded and competitive for individual protocols. Those that are most successful at cultivating user growth will in turn become disproportionately popular due to the funneling effects of speculation.

Over time, as the protocol layer evolves, we anticipate that opportunities at the application layer will similarly grow. App usage today is very minimal, but just as it took time for applications like email to develop after internet protocols were established, expansion in the protocol layer should lay the foundation for more crypto-native applications to be created going forward. Decentralized apps may even be necessary for network growth, though the extent remains to be seen. Value in the protocol level will always hinge on developers' ability to effectively scale user networks, and well-designed cryptonetworks should have an incentive structure that mitigates initial scaling risk. The most successful protocols will ultimately be those with developer teams who are focused on long-term value creation within their networks, rather than quick pops of token value, in order to create sustainable scale. For example, the founder of Aragon, an upcoming network that provides a framework for managing other cryptonetworks akin to Carta (formerly eShares) for private companies, is fostering development of the protocol's community by giving tokens away for free to an initial set of users, who are all using the platform to host blockchain projects. Networks designed with this in mind should be able to achieve meaningful scale regardless of what apps are built on top of the protocol. However, as the market evolves it may become increasingly crucial to create competitive applications in tandem with new protocols to jumpstart network growth, or attract the initial users necessary to power community development. YouNow's announcement of their social media video app, Rize, in conjunction with the launch of its Ethereum-based cryptocurrency PROPS, would be an example of this approach. YouNow's goal is that the attraction of the application will drive the usage of PROPS tokens, stimulating the growth of the network and avoiding initial scaling challenges. Down the line, if and when usage of decentralized apps develops, specialized user interfaces may similarly gain traction. However, the industry today is still in very early innings – much of the infrastructure needs to be put in place before we see activity beyond the protocol layer.

Figure 4
Annual fundings total



Source: ICO Funding – Coindesk.com, 2014-2017; Venture Funding – Pitchbook, 1997-2000.

ICOs
Initial Coin Offerings (or ICOs) are fundraising mechanisms for new crypto projects. These projects crowdfund their capital through token offerings, in lieu of equity, in exchange for other cryptocurrencies like Bitcoin and Ethereum. Estimates put the total funds raised through ICOs in 2017 between USD 3.7 - USD 6.8 billion. In June and July 2017, the amount of money raised through ICOs surpassed early stage venture capital funding totals for the first time. Additionally, continuing with the comparison to the internet bubble, the amount raised in ICOs over the past few years has tracked the trajectory of technology funding in the late 90's (figure 4).

Until recently the largest ICO on record was the USD 257 million Filecoin ICO completed in September 2017. This will undoubtedly be eclipsed by Telegram, the encrypted messaging platform from Pavel and Nikolai Durov, founders of the Russian social network vk. Telegram is raising USD 1.2 billion across both a pre-ICO raise and ICO to build out a blockchain-based messaging platform akin to WeChat. While many have scoffed at the proposed valuation range of USD 3-5 billion, the current Telegram app already has a user base approaching 180 million and expected to reach 200 million in the first quarter of 2018.

Despite the volume, the market is still very young, making it prone to substantial corrections and fluctuations in value. There is also some concern over the long term viability of ICOs and the potential for substantial new regulation. As with any new opportunity, there is a lot of current noise in the market, and it is highly likely that we will see significant losses from weaker assets. Some venture capitalists have estimated that 75-80% of projects will likely disappear. Investors need to consider these risks when deciding whether and how to participate.

How to invest in the crypto asset class
If the crypto market continues to track the late 90's NASDAQ, then we remain in the frenzy period and there is more pain to come. Some have asked

whether a crypto investment thesis requires taking losses now to understand the space and potentially reap the gains later. Our view is that it ultimately comes down to one's time horizon and chosen vehicle for investment. While often publicly tradeable at an earlier stage, cryptoassets are ostensibly investments in technology startups and should be approached as such. These are complex projects and as a baseline one should not invest without a detailed understanding of the opportunity. Unless one is buying Bitcoin as an alternative store of value akin to gold, it could make sense to outsource any crypto exposure to a professional technology investor. Indeed, venture capital and hedge funds have popped-up in recent years to take advantage of the developing asset class.

Venture capital funds were the earliest institutional participants in the Bitcoin/blockchain phenomenon, making equity investments in blockchain-enabled companies, many of which were initially at the application or user-interface level. Over time, as understanding grew around value accruing to the protocol layer and coincident with the development of tokens to incentivize this growth, some venture firms began investing aggressively in tokens. Simultaneous with this rise in token issuance and in trading volumes, crypto-focused hedge funds began proliferating. While some were started by traditional asset managers moving into crypto, many of these funds have been founded by developers and early adopters of Bitcoin as well as employees of early applications like Coinbase. While some of the hedge funds employ a trading strategy, many of them take more of a venture capital approach, investing in pre-ICO rounds when projects are still in the very early stages of protocol development. Pre-ICO rounds are typically structured as convertible notes, which convert into a predetermined number of tokens at ICO. These notes are called SAFTs, or Simple Agreement for Future Tokens, an homage to the SAFE (Simple Agreement for Future Equity) notes pioneered by the Silicon Valley based-accelerator, Y Combinator. SAFT notes are typically the domain of well-connected angels and institutional investors and often come with high minimum investments (Telegram's pre-ICO minimum is USD 20 million).

Venture capital, either structured as a traditional venture fund or a long lockup hedge fund, is one approach to investing in the asset class. We're currently in the early innings of the crypto build out. And these are ostensibly technology startups and potential investors might do well to approach investing in them from this perspective. Just as with traditional startups, it takes years and sustained resources to build out the requisite technology for a new protocol or application, while benefiting from the guidance and experience offered by seasoned technology investors. Indeed, many crypto founders are building lockups (often 3-5 years) into their pre-ICO rounds in exchange for a significant discount to the ICO price, incentivizing patient investors over traders. Furthermore, in the event of a downturn, venture capital's ability to drive terms and access competitive situations should only increase as more fickle capital runs for the exit.

Risks

There are of course significant risks to investing in cryptoassets.[4] We classify these risks broadly as being (1) structural (2) technical (3) custodial (4) cyclical or (5) regulatory. This is not meant to be comprehensive.

There are of course significant risks to investing in cryptoassets.

1) **Structural:** One of the primary concerns around investing in these assets is the token structure itself. One does not typically own equity in these protocols or dApps and thus does not have a legal claim on the assets. Nor does one have traditional governance rights that go along with equity. Counterintuitively, the ability to fork a blockchain is a helpful check on bad governance. If one doesn't like the direction the core team is taking a project, the community can simply "fork" it. We saw this with the Decentralized Autonomous Organization (DAO) hack when a contingent forked Ethereum to Ethereum Classic. To be sure, there will be instances where investors invest in something of value and unusual circumstance prevents them from realizing that value, but this issue exists with conventional startups as well. Additionally, there is an open question about how to attribute value across those companies that have raised both equity and a token. Some companies that have issued a protocol token, like Ripple with XRP and Protocol Labs with Filecoin, are sitting on multi-billion US dollar balance sheets in these tokens (as well as Bitcoin needed to purchase their tokens). In theory, tokens could be liquidated and the proceeds distributed to equity holders – though thus far teams have resisted the urge to do so.

2) **Technical:** Unsurprisingly, there are also substantial technical challenges and risks to building a crypto project. It is generally accepted that blockchain systems can only maintain two of the following three conditions: (1) scalability, (2) security and (3) decentralization, and that any improvements to two will inevitably come at the expense of the third. As a result, scalability has been a challenge. For instance, due to limitations in the block sizes on Bitcoin's blockchain, Bitcoin is only able to process a maximum of around 4-7 transactions per second (TPS), while Ethereum can handle around 15-20 TPS. By comparison Visa processes close to 2,000 TPS, with a peak rate significantly higher than that. Solving this scaling problem, without compromising on security or decentralization, perhaps through techniques like parallel computing or sharding will be crucial to mainstream adoption.

3) **Custodial:** The immutability characteristic of blockchain technology serves to strongly identify ownership through the use of cryptographic signatures known as private keys. Because an individual token's entire record of transactions is published publicly, the "private key" mechanism (a random 256-bit number (in the case of Bitcoin), is necessary to allow one user to "sign" over ownership to another. An algorithmic derivative

of the "private key", known as a public key, then verifies that the signature providing a transfer of ownership is correctly matched. If the public key serves as a kind of post office box for where to send Bitcoin, the private key is what opens the lock. Because private keys dictate ownership, their security is vital. Simply storing it on a computer can be somewhat risky as that computer is connected to the internet. Thus many opt for a a hardware wallet, essentially a dedicated device like a USB. Others take an even lower-tech approach, called cold storage, effectively just writing the private key number on a piece of paper and storing in a lockbox. While these offline methods are extremely secure, this system of storage makes transactions rather cumbersome. Not surprisingly, the vast majority of holders store their cryptocurrency on exchanges, which use "hosted wallets", servers holding private keys in a centralized database. While these exchanges allow for more convenient transactions they have also proven susceptible to hacks. The first notable breach occurred in 2011 at Tokyo-based exchange Mt. Gox, when 750,000 Bitcoin were stolen. A string of attacks followed, for instance when 120,000 Bitcoin were stolen from Bitfinex in 2016, demonstrating that even reputable exchanges with advanced security measures are not immune to the risks of online private keys. Such an inverse relationship between convenient transactions and secure custodial ownership highlights that the tradeoffs between (1) scalability, (2) security, and (3) decentralization, as noted above, have yet to be effectively solved. Given these constraints, many institutional investors currently employ a hybrid approach, storing most of their tokens offline, and then placing small amounts into an online account for transactional liquidity.

4) **Cyclical:** There are also risks as to where we are in the cycle. As shown above, the price of Bitcoin is tracking that of the 1994-2003 NASDAQ. In many instances, prices of publicly traded tokens have appreciated well beyond where fundamentals support. Ripple has de minimis revenue, but is sitting on billions of US dollars in ERP tokens. At one point the founder of Ripple, Chris Larsen, was worth USD 59 billion (on paper), more than Mark Zuckerberg. Similarly, Protocol Labs has a multi-billion US dollar balance sheet, but no income statement. Moreover, many pre-ICO projects are raising money on little more than a technical white paper. This is clearly unsustainable. The irrational exuberance pervading the market is maybe best exemplified by some non-crypto-related public companies superficially changing their name and/or strategy to include "blockchain." We found 30 such examples of this, including Bioptix (Riot Blockchain) and Long Island Iced Tea Corp (Long Blockchain Corp). Long Island Iced Tea announced their "pivot" to blockchain and experienced a 500% rise in their shares, while Eastman Kodak stock rose almost 400% after announcing a proposed "KodakCoin." This mirrors activity in the late 90's where companies added "web" or "dot com" to their names or strategies looking for similar market reception. We may be in the initial phase of a multi decade long trend, but investors still need to understand the near term downside volatility likely in many of these tokens.

5) **Regulatory:** Finally, in addition to the various risks described above relating to the nature of cryptoassets and markets for trading them, investors must also consider the risk associated with the nascent and rapidly evolving global regulatory framework for cryptoassets. We explore these risks further in the Appendix to this article.

Conclusion

The crypto-economic paradigm is consistently underappreciated by media narratives. The idea that this is merely the next tulip bulb mania will gain steam as the price of headline currencies like Bitcoin and Ripple continue to trend lower. Instances of fraud in cryptoassets will continue, as use cases and attack surfaces expand, likely leading to greater regulation (see appendix). Challenges like scaling and throughput will become increasingly acute. As it was in prior bubbles, it will be emotionally difficult to invest through and following the collapse.

Blockchains, tokens and ICOs could prove fundamentally disruptive to established hierarchies as the only non-regulatory solution to the antitrust trap created by our incumbent tech-aggregators. They can enable machine-to-machine communication and payments, while mitigating single points of failure. More broadly, they have the potential to further democratize societies while alleviating some of our persistent income inequality. But utopianism aside, as in prior periods of innovation, the markets may benefit from what could be the next technological revolution.

Appendix
Blockchain, ICOs, and the regulatory environment

Perhaps the greatest challenge in establishing an encompassing regulatory framework around blockchain, cryptocurrencies, and ICOs is the lack of understanding of the fundamental technology itself. Proponents of blockchain, ICOs and such recognize the need for functional and somewhat standardized policies if these concepts are to evolve and thrive. For regulators, this is easier said than done. In order to effectively regulate, they are attempting to define standards around a developing technology which they don't fully comprehend while trying not to stifle innovation or detract from the operational efficiencies associated with decentralization. Thus far, their approach has not been consistent.

Inconsistency, it seems, has defined the debate around ICOs. Coin offerings, have emerged as an alternate source of capital in recent times. The concept though still new, has managed to grow at a remarkable pace; from USD 100 million in 2016, ICOs raised between USD 3.7-6.8 billion in 2017. Decentralized (lacking in central authority) ICOs shredded the red tape around traditional fundraising methods, lowered the cost of raising capital, and provided opportunity to a broader set of investors, including retail investors. This unprecedented access to capital has made the investment landscape rife for manipulation and fraudulent activity and piqued the interest of regulatory bodies around the globe. Regulators struggled to establish whether an ICO should be considered a token or a security. With no definitive statement forthcoming, and the ability of these offerings to tap financing channels that stretch beyond traditional banking systems and national boundaries, the regulatory debate further intensified and various countries and jurisdictions found themselves taking distinct positions.

China, for example, took a more stringent approach and altogether banned ICOs. In September 2017, The People's Bank of China declared ICOs illegal and asked for an immediate halt on all related fund raising activity[5]. Banks were forbidden from offering services to ICOs and money already raised was to be refunded. South Korea followed suit. Per a Business Insider article, South Korea's Financial Services Commission stated it has "serious concerns about the fact that the current market funds are being pushed into a non-productive speculative direction"[6].

In the U.S., while no drastic measures were enforced, it became abundantly clear that the current environment of non-regulation was unlikely to prevail. In July 2017, the Securities and Exchange Commission (SEC) determined that the tokens offered by the decentralized autonomous organization ("DAO") were securities and should have been registered as such. The DAO was a decentralized venture capital fund which was going to be used to fund projects on the Ethereum ecosystem. Investors received DAO tokens in exchange for Ether and became a part of The DAO community. This ICO raised USD 150 million in Ether and was a purported success till a hacker compromised a third of the assets. The DAO hack was a prominent instance and one of the first to evoke SEC scrutiny. In September, the SEC created a new Cyber Unit to expressly focus on decentralized ledger technologies and ICOs in a bid to curtail cybercrime. Soon after it was formed, the unit filed its first ever fraud charges related to an ICO against PlexCorps and two of its founders, alleging that the company promised to deliver exorbitant returns in an unlikely time frame. Additionally, the SEC also brought charges against a businessman, Maksim Zaslavskiy and two of his companies for offering coins that were supposedly backed by real estate investments and diamonds that in fact did not exist.

The actions taken by various regulatory bodies have reaffirmed that this corner of the market is not immune to regulatory oversight. Although, the consistency of such oversight globally as well as locally remains challenged. Regulators maintain that they will view substance over form in determining how to label a "token". To elaborate on this approach, U.S. securities law practitioners cite the Howey Test (named after the seminal U.S. Supreme Court case for determining whether an asset is a security)[7] as one way of establishing substance; irrespective of what the offering is labelled, if it can't pass the Howey Test, it will probably be defined as a security. Among the conditions of the Test, there is one that confuses the most. It stipulates that if any profit comes from the efforts of a promoter or third party, or put another way, if any profit is mainly from outside of the control of an investor, then the offering might be a security. This broad application of the condition has raised concern from the purveyors of cryptoassets as it further obscures the difference between a utility token and tokenized securities. A utility token represents a participation interest that can be used to fund infrastructure development. These tokens may also represent future access to the company's product or service. However, in a public statement published on the regulator's website in December, SEC Chairman Jay Clayton explained that if a "token" such as described above, drives an expectation of profit through an increase in value or via trade, then it fits the definition of a security and should be regulated as such[8]. A demonstration of this assertion was provided by the SEC as it ordered Munchee Inc. to halt its ICO.

According to the SEC's press release, California-based Munchee, was selling digital tokens to raise capital for its blockchain-based food review service. It was seeking USD 15 million in capital for app improvement and creating an ecosystem where token holders could use tokens to buy products and services. During the offering, the SEC found that the company emphasized the expectation that efforts outside of the investor could lead to an increase in the value of the tokens and that the company would also create a secondary market where these tokens can be traded. These factors would have led investors to believe that ultimately their investment in tokens would yield a return, and therefore based on the precedent set in The DAO matter, the SEC concluded that these tokens exhibited substance of a security and moved in to stop the ICO from

proceeding. Munchee refunded investor proceeds after the SEC intervened[9]. While this example helps illustrate how an expectation of return can shift the label, it is still unclear how this would apply universally given that many of the projects raising coins hardly exist beyond a whitepaper.

Although not all jurisdictions might apply the same yardstick to ICOs, regulators ultimately want to derail issuers from circumventing laws and regulations to raise capital, prevent fraud, and protect retail investors, a sentiment now being echoed by many ICO friendly countries as well. Switzerland and Singapore, both welcoming of ICOs issued warnings that they will bring enforcement actions against offerings that did not abide by regulation. Swiss based issuers had raised about USD 600 million through ICOs in 2017[10]. Favorable ICO hubs such as Gibraltar, recently introduced the world's first ICO legislation. The Gibraltar Financial Services Commission ("GFSC") will draft a law that will aim to regulate the promotion, sale, and distribution of digital tokens and will be the first of its kind to be developed specifically for ICOs[11]. Meanwhile back in the U.S., during the Senate Banking Committee hearing in February 2018, SEC Chairman Jay Clayton and Commodity Futures Trading Commission ("CFTC") Chairman Christopher Giancarlo agreed that there might be need for an interagency approach to define regulation while being thoughtful of the efficiency, innovation and economic growth presented by cryptoassets and decentralized technologies. To limit this type of advancement under onerous regulation can only serve to hamper growth at home while creating arbitrage opportunities for locations that present themselves as "safe havens".

While no ICOs have been registered with the SEC, ICOs like Filecoin have claimed a common exemption under Regulation D which provides exemption from securities registration by only allowing "accredited investors" to participate in the offering. Many who had feared that SEC regulations might curb enthusiasm for ICOs, were proven wrong by Filecoin, which emerged as the largest ICO of 2017. In fact, some even argued, that limiting the offering to "accredited investors" was what helped raise the amount that it did. After all, "accredited investors" are typically high net worth investors who can afford to commit larger check sizes.

As rules and regulations around decentralized technologies begin to take form, venture capital and growth funds see an opportunity to invest in the burgeoning compliance landscape. Sacks Ventures, Fifth Wall Ventures, and Valor Equity Partners invested in Harbor, a company that will address the regulatory challenges of trading private securities on blockchains, including ICOs. Harbor is a blockchain technology company that will build a decentralized compliance protocol and one of its first initiatives will be to standardize compliance at the token level allowing issuers to meet jurisdictional standards irrespective of where they are based.

With a lot of the regulation around decentralized technologies in flux, it will be important to see how this area of the market will develop. Whether rules from the twentieth century will be carried into the twenty-first century, or a new form of regulation will emerge for a new brand of technology. It remains to be seen if regulatory intervention really is the "beginning of the end" for blockchain technology as eloquently stated by Emin Gun Sirer, a professor at Cornell University who was famously the first to identify gaps in The DAO's security infrastructure before its unfortunate collapse; or if regulation will actually walk hand in hand with innovation to propel this technology into the next phase of its cycle in a sustainable fashion.

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Notes

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"The long-term secular growth feels pretty unstoppable given the power of this technology and the talent flocking to the space."

Interview with Chris Burniske

Chris Burniske
Partner at Placeholder, a New York venture capital firm specialized on decentralized information networks; first public fund manager to invest in bitcoin in 2015 (at ARK Invest), regular contributor to the Wall Street Journal, the New York Times, Bloomberg and Fortune.

Chris Burniske is a partner at Placeholder, a venture capital firm based in New York City that invests in decentralized information networks. We spoke with him about his new book, Cryptoassets: The Innovative Investor's Guide to Bitcoin and Beyond, and wanted to learn more about his views on the challenges and opportunities presented by this emerging asset class.

Risk & Reward
What led you to write a book about the crypto asset industry?

Chris Burniske
When I was first talking with my co-author, Jack Tatar, we realized that thus far there had been two generations of crypto books. The first was focused on Bitcoin, because up until 2013-2014 Bitcoin was the only show in town. The book that best exemplified that generation would be Digital Gold.

When Bitcoin went through a long and painful descent in 2014, we started to see an explosion of books focused on blockchain technology, void of the assets. The book that would be most associated with that era would be Blockchain Revolution by Alex and Don Tapscott. When I was talking with Jack in the summer of 2016, we realized that we'd seen Bitcoin books, we'd seen blockchain books, but we hadn't really seen a book that covered the space from the perspective of the asset class as a whole and that it was probably time for a book along those lines. When we started writing in December of 2016, we had no idea what 2017 would be like, and so it felt like riding a tsunami. But our timing turned out to be great.

Risk & Reward
What do you think are some of the most commonly held misconceptions pertaining to blockchain, Bitcoin and crypto assets in general?

Chris Burniske
The most important misconception to address is that not all of these are currencies in the strict sense of the word, where the economic definition is a means of exchange, store of value and unit of account. And this is precisely why we titled the book "Cryptoassets": to break people of the conception of these assets soley as currencies. While some of them are indeed crypto currencies, many of them are crypto commodities (like Ethereum or FileCoin or Golem) and others are crypto tokens. We explore these distinctions more in the book and our other writings.

The important takeaway here is, this is the native asset class for information networks as well as their coordination mechanism to incentivize the supply

side to provide utility to a network. And that utility can be very broad. Thus we are seeing over a thousand crypto networks right now. It's not that each one of those networks is trying to be a currency that replaces the US dollar. Most of them are not at all focused on replacing the US dollar or becoming a universal currency.

There's also a lot of confusion about whether these networks are anonymous. The important thing to realize with open blockchains is that they are pseudonymous – but perfectly transparent. So while it may not say that Chris Burniske is selling Bitcoin (it would instead represent my identity in different symbols), any identity can be tracked down through network forensics, and law enforcement has used the transparency of blockchains to their advantage before.

The final thing I would say regarding misconceptions is that the media continues to recycle a lot of old stories, especially around illicit activity. There's an interesting paper that was published by the Central Bank of Germany, University College of London and University of Wisconsin-Madison that goes through three stages of Bitcoin development, which also apply to other crypto networks. First, there are the very early tech adopters. Then there is often the sin activity, where we saw things like the Silk Road. Now, we're emerging into the legitimate enterprise era where mainstream attention and focus is building for mainstream applications.

Risk & Reward
What do you believe poses the biggest challenge to the continued growth of the crypto asset space?

Chris Burniske
I don't know that I can synthesize it to one thing. And I would say that the long-term secular growth feels pretty unstoppable given the power of this technology and the talent flocking to the space.

That said, I think in 2018, we have a regulatory headache to deal with from a lot of the bad behavior in ICOs (initial coin offerings) in 2017. And so we're seeing that manifest in the market. There's a lot of fear, uncertainty and doubt, much of which is merited. That said, over the long term, regulatory clarity will be helpful.

Another challenge, as we get deeper into mainstream adoption, will be for the industry to focus more on the user experience and product design, as opposed to such a heavy emphasis on the technology. If we don't do that, it will be hard for people to begin using these systems.

Risk & Reward
That's a good segue into our next question, which concerns use cases for crypto. Which current or near-term use cases do you think are under-appreciated by the broader population, or the crypto community specifically? Are there use cases that are being overestimated?

Chris Burniske
I'll start with overestimated. I think that any use case aiming to get the average Joe or Jane using a crypto network is likely overestimated in the short to medium term. The reason I say that is there is so much human and machine infrastructure that still needs to be built if we truly are looking to re-decentralize the web. A lot of those things are in "version one" state, and all of those components need to work together seamlessly to provide a user experience for the mainstream that is on par with current web user experiences.

That could be five to 10 years out, maybe even more for a lot of use cases – and so I'm always a little hesitant, especially as an investor, to engage with those crypto networks. While it's easily understandable, there's too much anticipation around how quickly the mainstream will adopt these things; we can learn lessons from the Internet there. In the 80s and early 90s, before the first mainstream web browsers were created, there was no such thing as the web to disseminate all of the information about how the Internet was getting started. And so it was really just the developer community and the engineers who were buzzing about it. We are really in that same era for crypto right now. So I think that maybe the mainstream under-appreciates how much cool infrastructure is being built for developers, and how excited developers are about it. The best metric for that is to see the influx of talent coming into crypto all over the place.

For example, I was talking last week with Dan Boneh, a famous computer science and cryptography professor at Stanford. He said that their smartest students are all drawn to machine learning or crypto. I think if you follow the talent you will generally be directionally correct with your forecast for technology.

Risk & Reward
On a related note, what most excites you about the current or next generation of crypto projects being created and the high level of technical talent flowing in today? Is there something different and interesting about how people are now approaching the space?

Chris Burniske
I think I'm most interested by the human and machine infrastructure being built so clearly with Ethereum, where we have a smart contract platform. But there are lots of competitors like EOS or DFINITY that are also coming online. There are several interoperability solutions like Polkadot and Cosmos. There is also scalable computation, cloud storage, mesh networks, VPNs (virtual private networks) and transcoding. There is just so much hard tech being built right now, which goes back to my prior answer.

The reason this excites me is that once we have built out a lot of those protocols, then the really exciting mainstream use cases will start to materialize, many of which we couldn't possibly have anticipated. So I'm excited to see how that plays out. The other broad trend in the space is more thoughtfulness around mechanism design, which deals with how you incentivize people to do to things if you start with your desired output. What are all of the inputs that you need to construct in order to get people to perform that output? And that's organizing and incentivizing human activity in a really granular way with a potency that I don't think we've ever had before – so that's also really exciting for me.

Risk & Reward
Apart from custody issues, what are some of the additional barriers you see to the expansion of the crypto asset investor base, particularly to institutional investors?

Chris Burniske
I think the most important barriers to more institutional adoption right now are the brand risk resulting from the reputational overhang of the crypto asset industry, as well as regulatory uncertainty. You could analogize investors' current situation to the decision to purchase incumbent or emerging software in the 2000s. CTOs didn't get in trouble for buying IBM or Microsoft because it was consensus that you would buy those products. And so everyone kept on doing it, even if they didn't really think they were necessarily the best products.

Meanwhile, Linux was percolating up, but people didn't want to touch it because there was a lot of uncertainty, a lot of brand risk. You could get fired for buying Linux in a way that you couldn't get fired for buying Microsoft. And I think that the same psychology weighs in for crypto assets, where your potential downside for getting involved as an institutional investor, at least in a public way, could be much greater than your potential upside. This is the source of that behavioral inertia.

I think there is also just a lack of traditional capital market vehicles and things that easily fit into the tax regime or custodial regime that a lot of institutional investors are accustomed to. An obvious example would be the launch of a Bitcoin ETF. More well-recognized and understood vehicles like that would help.

Risk & Reward
You've been on the forefront of developing a framework for valuing crypto assets. Can you briefly describe the approach you've been working on and how it might evolve over time?

Chris Burniske
I would break the question into two parts. Just as in equities, we have relative valuations like price-to-sales and intrinsic valuations like discounted cash flow (DCF). In the crypto space, we're seeing innovation on both fronts.

On the relative valuation front the most popular metric has been something called the "Network Value to Transactions" (NVT) ratio where you take the network value, which is synonymous with market cap, and divide it by on-chain transaction volume of the asset.

For instance, Bitcoin network value is in the USD 100 billion plus range divided by on-chain transaction volume. We use on-chain transaction volume because that is the core utility of a blockchain underlying a network, just as the core utility underlying a stock price is its earnings. The NVT ratio is therefore very similar to a P/E ratio. There are different approaches to NVT representing different lengths of moving averages or ways to compute particular transaction volumes.

My partner Joel Monegro has been an advocate for using trading and transacting volume. I historically have not done that because transacting volume is analogous to the GDP of an economy and FX volume is typically not incorporated into GDP. But we could see experimentation with the network value to trading and transacting volume ratio, which may make a lot of sense for something like Bitcoin that's operating as the reserve currency of the crypto asset ecosystem.

The intrinsic valuation space is also seeing a lot of experimentation. In the summer of 2017, I put forth an "equation of exchange" model that treats a crypto network as an economy, as I mentioned earlier.

For example, if you look at FileCoin, you can estimate for this year and every year going forward the price/gigabyte charged for storage by the network. You can predict the quantity of gigabytes stored using total addressable market and penetration within that market. If you multiply that price times quantity you get the GDP of FileCoin's network in that year.

So if we look at the equation of exchange, it's M (monetary base) multiplied by V (velocity) equals PQ (Price x Quantity). If I want to solve for the necessary monetary base, I can take that PQ and divide it by an assumed velocity. Alex Evans is doing work to actually compute velocity within this framework with the basic idea that the network value or monetary base of a crypto asset can be determined by looking at its current and future GDP divided by velocity. If you get a value for 2025, you discount that value back to the present using a discount rate.

Risk & Reward
There has recently been a lot of focus by the media and regulators on initial coin offerings (ICOs). What are your thoughts on the valuations and the amounts of capital being raised in connection with these ICOs?

Chris Burniske
I think the most important thing for people to realize is that ICOs are not synonymous with crypto. They are one mechanism that became very popular in 2017 as a means to launch a crypto network – but they are not the only way. They have also often been used to raise massive amounts of capital in a relatively irresponsible way. So I'm not particularly a fan of ICOs in general, and I think the SEC is going to crack down on them in the US as unregulated securities offerings.

Let's compare Ethereum, for example, which did an initial coin sale in 2014. They raised USD 18 million at the time, which seems like a lot to fund about a year of development. They launched their network about a year later. So Ethereum was able to build everything it was able to build with USD 18 million in about a year. I have a hard time being convinced that any other network needs more money than that and more time than that.

And so generally I think teams have gotten carried away with raising too much money. It's leading to a lot of feature creep and lack of discipline, and that will ultimately work to the detriment of those teams, especially because if you go back to the idea of mechanism design and using a crypto asset as the coordination mechanism to incentivize the supply side, you need to give away your asset.

Bitcoin gives away 12.5 Bitcoin every 10 minutes, which in a 24-hour period equates to just under USD 20 million at the current market rate. Bitcoin is giving that away; it is minting that out every 24 hours in exchange for the secure clearing and settling of Bitcoin transactions. That is how Bitcoin got to scale. Bitcoin didn't get to scale by raising USD 200 million or USD 800 million and trying to buy its way to success.

So I think ICOs that think they can buy their way to success are in for a painful future, and I think we will see the pendulum swing back to people organically mining or giving away their assets in exchange for human work or other ways to incentivize the supply side of the crypto network.

Risk & Reward
Silicon Valley is still generally considered to be the hub of web innovation and much of technology innovation in general. Is this also true for crypto asset innovation, or is it more geographically dispersed?

Chris Burniske
Well, the crypto movement has made it so that capital is a commodity. If you talk with entrepreneurs, for example I spend a lot of time in Argentina, they have historically been starved for capital because they can't afford to live in Silicon Valley. So they try to network with VCs and other entrepreneurs to fund their projects. Now, it doesn't take that much money to launch a protocol. And if you launch a protocol and experience early success, then that catalyzes a lot of capital and resources around you.

And you can launch a protocol from anywhere in the world – so that, I think, is stealing Silicon Valley's thunder. I got my undergraduate degree from Stanford and I lived in that area for about four years. When I go back now, Silicon Valley feels kind of 'off' to me. It feels like the West Coast Wall Street, and it feels like it has lost its way a bit from creating projects that really re-engineer society. Instead, it's focused on these small iterations within apps or designing products for Silicon Valley. But the majority of the world is not Silicon Valley. And so, I would predict that we are seeing the long, slow decline of Silicon Valley, and that will be accelerated by crypto networks.

Risk & Reward
Thank you for your time today, Chris. We really appreciate you sharing your views and wish you the best of luck with your new book.

Tailoring multi-asset multi-factor strategies

By Joo Hee Lee, Ph.D., Dr. Harald Lohre, Jay Raol, Ph.D., and Carsten Rother

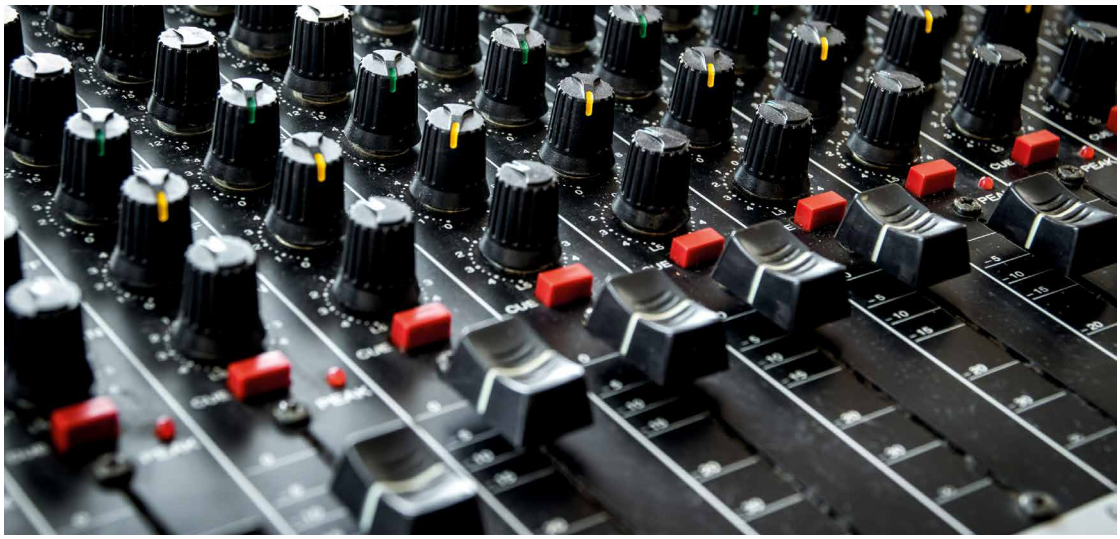
In brief
To sharpen the top-down allocation perspective of their investments, investors are keen to identify and manage the most salient drivers of risk and return. For many years, the focus was on traditional market risks, such as equity, duration or credit risk. This framework can be considerably advanced when examining a given investment through the factor investing lens, which accounts for style factors, such as carry, value, momentum and quality. We put forward a variety of approaches, ranging from the traditional multi-asset allocation to factor-based tail-hedging, factor completion and a fully diversified multi-asset multi-factor proposition.

Factor investing cuts through the traditional way of organizing an investor's asset allocation. But not every investor can simply overhaul their investment process and go directly for the magic bullet solution – especially if an allocation to traditional asset classes is already in place. So, how do multi-asset factors work in such a context?

Recent years have seen rapid development in the ability to diversify through factors in an attempt to construct more efficient and better risk-managed portfolios. In the process, it is obviously necessary to identify the most salient drivers of assets' risk and return. Thus, we developed a diversified risk parity strategy that maximizes diversification benefits across asset classes and style factors.[1] The ensuing top-down allocation combines traditional market premia associated with equity, duration and credit risk as well as style factor premia associated with carry, value, momentum or quality style investments.

Striving for maximum diversification in a multi-asset multi-factor world
Style factor investing has a long history in both academic research and quantitative equity investing. Yet the general notion of style factors to explain the cross-section of asset returns also extends to other asset classes: e.g., the phenomenon that recent winners outperform recent losers applies not only to equities, but is also pervasive for commodity, rates and FX investments.

Clustering styles across asset classes
While adding such style factor strategies can serve to advance a given portfolio's diversification, the flip side is that the quality of portfolio optimization suffers from increasing the size of the variance-covariance matrix. Aggregate factor analyses are



designed to overcome these shortcomings, but it is a challenge to create and organize the factors in the multi-asset space. Adopting a pure style factor view, it seems straightforward that single factor strategies that follow the same style should be aggregated across asset classes, rather than aggregating different styles within asset classes. For instance, an aggregate momentum style factor would be based on equity momentum, commodity momentum, rates momentum as well as FX momentum. Aggregate carry, value and quality factors are built in the same vein.[2]

To investigate the merits of integrating these four top-down style factors into a traditional asset allocation, we likewise aggregate three market risk factors for traditional asset classes. Following the method used for our previous analysis, we consider equity, duration and credit risk factors. The equity and bond factors derive from aggregating global equity and bond index futures. The credit risk factor is based on US investment grade and high yield investments.

Diversified risk parity

A diversified portfolio allocation is best suited to ensuring balanced and effective harvesting of premia from market risk and style factors. Specifically, a diversified risk parity strategy (DRP strategy) maximizes portfolio diversification in a way that resonates with the intuition that 'a portfolio is well-diversified if it is not heavily exposed to individual shocks' (Meucci, 2009).[3] A DRP strategy incorporating these general building blocks would allocate equal risk budgets across asset classes and factors, as depicted in figure 1, such that each aggregate asset class and style factor accounts for one-seventh of overall portfolio volatility.

Given this parsimonious structure, the DRP strategy can handle complex portfolios comprising many asset classes and factors without compromising the stability of the variance-covariance matrix.

A diversified portfolio allocation is best suited to ensuring balanced and effective harvesting of market risk and style factor premia.

Maximum diversification in a multi-asset multi-factor world

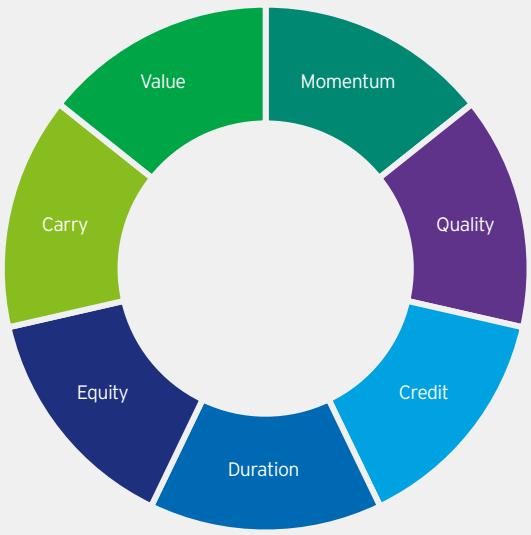
To illustrate the strategy's characteristics, figure 2 depicts weights and risk allocation for a DRP strategy subject to standard investment constraints, such as long-only and full investment constraints. Still, the corresponding risk allocation is fairly balanced across global asset class and style factors. On average, the risk profile corresponds to 6.44 effective bets[4] out of 7 (= 3 market + 4 style factors) that would constitute the unconstrained optimal solution.

Thus, although DRP takes into account evolving market dynamics, its factor allocations will be far from over-fitting or over-reacting to markets. Below, we demonstrate how to integrate factor investing and the notion of DRP into the toolkit of a traditional asset allocator.

Monitoring and managing market and style factors

Despite the mounting evidence of style factors' relevance, the predominant allocation paradigm is centred around traditional asset classes. However, there will always be implicit factor tilts embedded in traditional asset allocations, even if style factors are not managed explicitly. Obviously, it would be more appealing to assume explicit control of these style factor tilts. Utilizing style factors in the risk and portfolio management of multi-asset solutions can

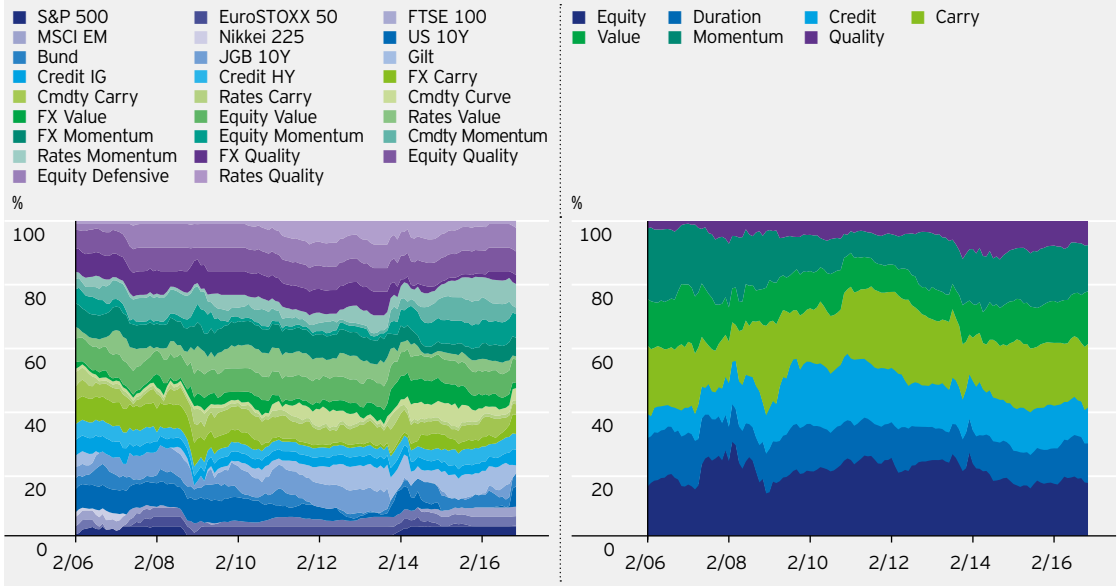
Figure 1
Diversified risk parity: building blocks and stylized risk allocation



- **Equity**
  Equity risk is rewarded
- **Duration**
  Time value of money
- **Credit**
  Credit risk is rewarded
- **Carry**
  High yield assets tend to outperform low yield assets
- **Value**
  Cheaper assets tend to outperform expensive ones
- **Momentum**
  Recent relative winners tend to outperform recent relative losers
- **Quality**
  High-quality/low-risk assets tend to have higher risk-adjusted returns than low-quality/high-risk ones

Source: Invesco. For illustrative purposes only.

Figure 2
Diversified risk parity: weights and risk allocation



The left chart plots the single factor and asset allocation of the diversified risk parity portfolio. The right chart decomposes its systematic volatility by relevant market and style factors.
Sources: Bloomberg, Invesco, Goldman Sachs. Data period: 31 January 2006 to 31 December 2016.

be highly beneficial. At the very least, one can prevent unwanted exposure to factor risks that way. At best, one can optimize the overall risk profile along market and style factors to efficiently harvest the associated asset and factor premia.

Traditional asset allocation through the factor investing lens

To illustrate the relevance of style factors, we x-ray a traditional multi-asset allocation in terms of its global market and style factor exposures. In particular, we consider a client whose strategic asset allocation is one-third in global equities, one-third in global government bonds and one-third in corporate bonds.[5]

To flesh out the risk exposures of this allocation over time, we linearly map the returns R of the underlying 11 market assets and 15 style factors on the seven factors F:

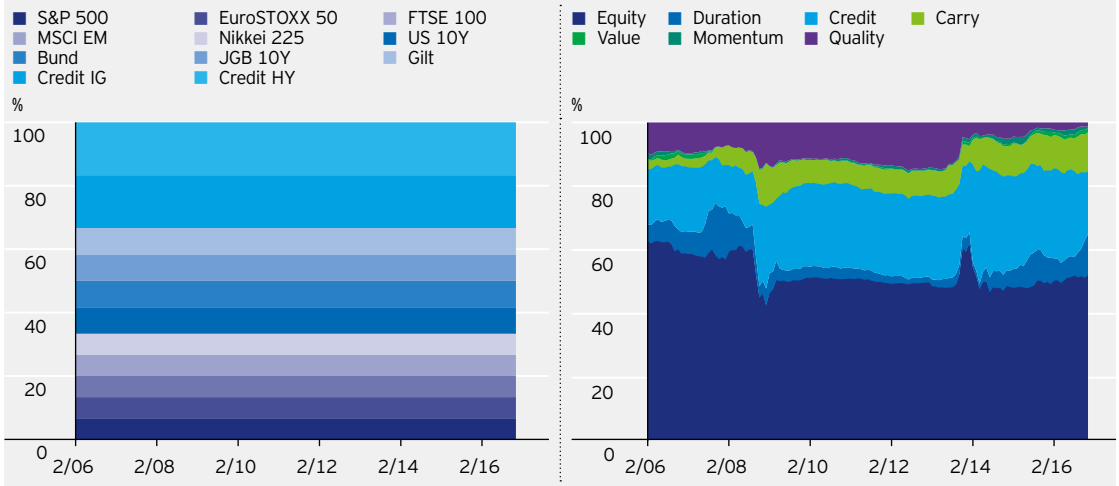
$$R = B'F$$

where B is a 7 x 26 matrix containing the factor sensitivities. In turn, the variance-covariance-matrix Σ of returns R can be decomposed as:

$$\Sigma = B'\Sigma_F B + u$$

where Σ_F is the global factor variance-covariance-matrix and u captures the idiosyncratic variance.

Figure 3
Traditional asset allocation through the factor investing lens



The left chart plots the single factor and asset allocation of the strategic asset allocation. The right chart decomposes the volatility of this allocation by relevant market and style factors.
Sources: Bloomberg, Invesco, Goldman Sachs. Data period: 31 January 2006 to 31 December 2016.

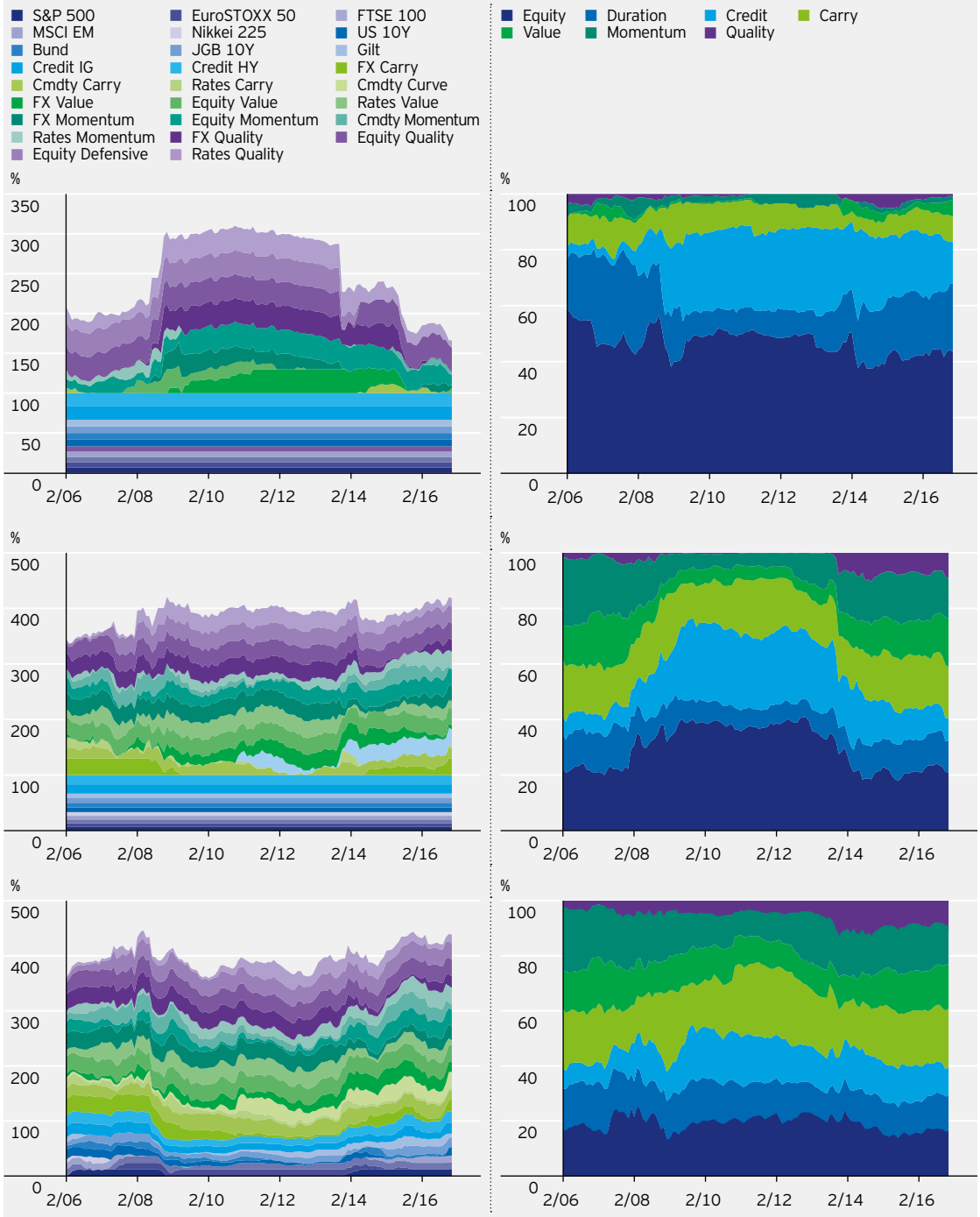
Equipped with this linear risk model, we can decompose the systematic portfolio volatility of the above strategic asset allocation (see figure 3). Notably, half of the portfolio's volatility is attributed to equity risk. Also, there is a strong exposure to pure credit risk, whereas duration risk adds only marginally to overall portfolio risk. Finally, there are notable implicit exposures towards the carry and quality style factors. On average, this risk profile corresponds to 3.61 effective bets over time. Thus, one is only partially exploiting the diversification spectrum available in the underlying multi-asset multi-factor universe. With 7 being the maximum number of effective bets, there is obviously room to further improve the risk allocation.

Tapping factors for multi-asset multi-factor management

In this section, we present alternative ways of embracing factor investing and the notion of

Figure 4

Multi-asset multi-factor strategies: weights and risk allocation



The left chart plots the single factor and asset allocation of the multi-asset multi-factor portfolios. The right chart decomposes the systematic volatility of this allocation by relevant market and style factors. The first row relates to the tail hedge portfolio, the second row to the factor completion portfolio and the third row to the pure diversified risk parity portfolio (levered 4 times).
Sources: Bloomberg, Invesco, Goldman Sachs. Data period: 31 January 2006 to 31 December 2016.

diversified risk parity from the perspective of a traditional asset allocation.

Tail-hedging using style factors
As a modest first step to allowing factor investing into the traditional asset allocator's toolkit, one might consider adding a style factor exposure in the pursuit of better risk management. In this vein, we provide a portfolio optimizer with both traditional asset and factor returns. While we fix investments in traditional assets to equal the strategic asset allocation, we allocate style factor weights such that ex-ante portfolio risk is minimized. Thus, one could think of the additional factor allocation as a minimum-variance or tail hedge. From the first row in figure 4, we learn that the quality factors in equity, rates and FX are particularly useful in hedging portfolio risk. In addition, equity and FX momentum help achieving the optimization objective.

Indeed, the corresponding strategy volatility (6.2%) is reduced relative to the benchmark volatility of the strategic asset allocation (7.1%), as set out in table 1. What's more, the devastating benchmark drawdown of 25.2% is reduced by more than 10 percentage points to -14.3% by including the tail hedge factor allocation. Obviously, this risk mitigation also increases risk-adjusted performance (as demonstrated by the Sharpe ratio of 1.30). However, in terms of diversification, the pick-up is rather modest: the average number of effective bets increases from 3.61 to 3.92. This marginal increase derives largely from the reduction in equity risk exposure vs. the pick-up in duration risk implied by the style factor allocation. While this observation makes sense from a pure tail-hedging perspective, we will investigate ways to achieve a more diversified risk allocation.

Factor completion based on diversified risk parity
To more directly balance the overall portfolio's risk profile, we consider an alternative strategy that we label factor completion. Essentially, this strategy endeavours to integrate a factor portfolio that optimally completes the risk allocation of a given strategic benchmark asset allocation. To this end, we first extract implicit asset and factor return forecasts from the optimal diversified risk parity allocation. In an unconstrained portfolio optimization, these return forecasts would simply yield the DRP allocation. Given the benchmark allocation, we provide this diversified risk parity view to a mean-variance portfolio optimization in which the underlying strategic benchmark asset allocation is again fixed.

The second row of figure 4 illustrates the corresponding weights and risk allocation. Now that we seek to balance risk and return based on the above view assumption, the overall allocation steps more strongly into a broad style factor completion portfolio. As a result, the risk allocation over time is considerably less concentrated in equity risk, yet there is a limit to equity risk reduction given the strategic benchmark allocation constraints. However, the diversification benefits of the factor completion solution are sizeable, as represented by 5.58 effective bets on average. These benefits arise from the fact that equity risk accounts for only a quarter of the risk budget, while the style factors carry, value and momentum play a more prominent role given their larger nominal weights (or leverage). While the strategy's volatility is on par with that of the benchmark strategy, we have succeeded in reducing the maximum drawdown relative to the tail hedge portfolio by a further 3 percentage points.

Pure diversified risk parity
To effectively maximize portfolio diversification, we need to lift the investment constraints that have fixed the strategic benchmark allocation in the preceding examples. To still live up to the client's risk profile, we additionally need to lever the diversified risk parity allocation. As a result, the risk allocation exhibits reduced equity risk exposure at a total number of bets of 6.46 (see final row of figure 4 and table 1). Note that this pure DRP approach would more than double the annualized return of the benchmark strategy. Given a single-digit drawdown of -8.6%, the pure DRP portfolio posts a highly attractive return to drawdown ratio of 1.39.

The presented framework naturally lends itself to exploiting tactical asset allocation signals while still embracing the merits of diversified risk parity. A future article will investigate the inclusion of trend signals, which allow investors to meaningfully operationalize the common trend style permeating many asset classes.

Table 1
From traditional multi-asset to multi-asset multi-factor management

Performance statistics	Benchmark	Tail hedge	Factor completion	Pure DRP
Return p.a.	4.9%	9.3%	12.9%	12.0%
Volatility p.a.	7.1%	6.2%	7.3%	7.1%
Sharpe ratio	0.56	1.30	1.57	1.49
Maximum drawdown	-25.2%	-14.3%	-11.4%	-8.6%
Calmar ratio	0.19	0.65	1.13	1.39
Number of bets	3.61	3.92	5.58	6.46
Turnover	0.0%	8.6%	19.8%	28.3%

Simulated past performance is not a guide to future returns. The table provides simulated performance figures for four multi-asset multi-factor strategies from the perspective of a US-dollar investor.
Sources: Bloomberg, Invesco, Goldman Sachs. Data period: 31 January 2006 to 31 December 2016.

Conclusion
Style factors are salient drivers of returns for several asset classes. Traditional asset allocations tend to be minimally balanced across style factors and would benefit from explicit management of both asset and factor exposures. Based on a meaningful set of market and style factors, we have illustrated a reasonable allocation mechanism centred around a diversified risk parity view. The ultimate outcome of a diversified risk parity strategy is a highly sophisticated portfolio solution that benefits from better building blocks as well as technical advancements in portfolio construction. This article highlights the strengths and flexibility of this novel technique in creating multi-asset multi-factor portfolios that can serve various clients' needs.

Traditional asset allocations tend to be minimally balanced across style factors and would benefit from explicit management of both asset and factor exposures.

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Notes

1 See Investing in a multi-asset multi-factor world, Risk & Reward, #3/2017.
2 To obtain risk-balanced aggregate asset class and factor returns, the aggregate factor return time series derive from a risk parity weighting of the underlying constituents. The set of constituents is the same as the one in Risk & Reward #3/2017, op. cit. Return calculations are from the perspective of a US-dollar investor; all returns are either in local currency or USD-hedged.
3 To this end, the set of three asset classes and four style factors are first translated into uncorrelated risk sources. Running a risk parity strategy along these uncorrelated risk sources then provides maximum diversification, cf. Lohre, Opfer and Ország (2014), Bernardi, Leippold and Lohre (2018) and our previous analysis in Risk & Reward #3/2017.
4 The effective number of bets relates to the number of uncorrelated risk sources represented by a given allocation through time. Mathematically, it is computed as

$$N_{Ent} = \exp\left(-\sum_{n=1}^{N} p_n \ln p_n\right),$$

cf. Meucci (2009). For a completely concentrated portfolio, it holds that $N_{Ent} = 1$, whereas for a fully diversified portfolio $N_{Ent} = 7$.
5 Within asset class buckets, we assume a simple equal-weighted allocation scheme across the constituent single assets.

Responsible investing in focus: Emerging market bonds

By Julie Salsbery and Shane Gallagher

In brief

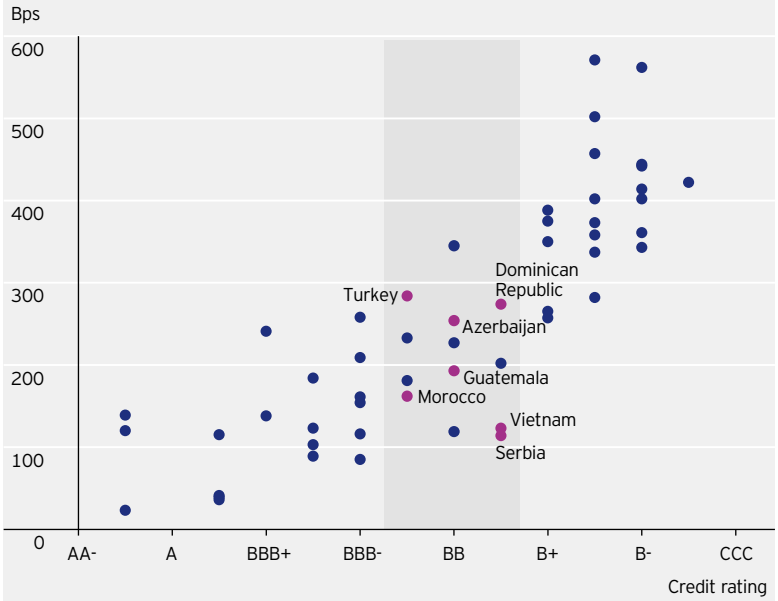
Invesco Fixed Income believes ESG-focused fundamental analysis can improve the assessment of emerging market sovereign risk. However, we find that identifying effective ESG indicators is critical when it comes to anticipating market performance. We also find that, for emerging market sovereign bonds, RI has historically resulted in comparable returns, or even outperformance. There is also a strong case in favour of active rather than passive investing. Indeed, there appears to be no place for passive investing when it comes to RI in emerging market bonds. Furthermore, two case studies show that RI has the potential to generate positive outcomes for future generations. We conclude by summarizing Invesco Fixed Income's own RI approach.

This paper addresses three questions that often arise when considering investing through an ESG lens: Can an ESG-focused fundamental analysis improve the assessment of investment risk? What is the impact of ESG investment objectives on returns? Is RI likely to have an impact on the world and help lead to better future outcomes? We believe that emerging market bonds offer some compelling insights into these questions.

Figure 1 highlights that emerging market countries with similar fundamental credit ratings can be valued quite differently by the marketplace.[1] We analyzed historical data to find out whether ESG factors help explain these differences in valuation.

In theory, differences in ESG factors could be behind disparate valuations among countries with similar credit quality. Basic economics suggest that

Figure 1
EM Sovereign spread versus credit rating (selected countries)



Note: Purple dots indicate countries with BB credit ratings that also hold a BB ESG rating.
Sources: Bloomberg Barclays, Invesco. Data as at 20 October 2017.

The acronyms ESG and SRI come up a lot these days, but their meaning is often unclear. ESG refers to three areas of analysis (environmental, social and governance) that can be used to help determine the likely impact of corporate behaviour on future financial performance. The acronym SRI is less clearly defined, and can mean "socially responsible investing" or "sustainable, responsible and impact" investing. For this paper, we adopt a broad interpretation and use the term Responsible Investing (RI) to represent investing in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs. Generally, we view ESG as non-financial attributes used by analysts to help assess risk, while RI is viewed as a set of client-specified guidelines used by portfolio managers to construct client portfolios.

sustainable long-term growth, a key factor in debt sustainability (and, therefore, credit quality), is based on three factors of production: land, labour and capital. ESG analysis can provide insight into these factors of production. For example, environmental factors can help determine whether natural resources (land, water and air) are being used in optimal and sustainable ways. Social factors can be used to analyze the efficient development and utilization of a country's labour resources by assessing health, safety and education metrics. And governance relates to the legal and financial underpinnings that are critical for access to capital.

Correlation between spreads and ESG metrics has been weak...

But, according to our analysis, the evaluation of ESG metrics and ratings does not significantly help to explain historical differences in valuation. The shaded area in figure 1 highlights those countries with credit ratings of BB-/BB/BB+. The purple dots designate sovereigns that are also rated BB for ESG factors.[2] The purple dots show that, despite similar fundamental and ESG ratings, disparity in valuations persists.

In our view, this disparity is due to two factors. First, as with fundamental credit ratings, ESG ratings tend to be backward-looking and often change with a considerable time lag. In other words, market valuations adjust more quickly to incoming information than do ratings. Second, and more importantly, political developments have exhibited powerful and more immediate impacts on valuations. Historically, political regimes have dramatically influenced environmental, social and governance outcomes through their policy choices. To highlight this point, figure 2 shows that Brazil's ESG score remained steady from 2009 to 2017, even though the country was besieged by political turmoil and yield spreads widened versus the index.[3]

... but underlying factors that drive governance may be helpful

But while Brazil's stable overall ESG scores failed to sufficiently warn of its impending political scandal and the resulting market fallout, underlying signals within the governance aspect of ESG analysis did. For emerging markets, we believe governance factors tend to have the greatest impact on both credit quality and changes in market valuations.[4] One way to illuminate the impact of governance is by analyzing the World Bank's Worldwide Governance Indicators (WGIs), which take into account factors such as political stability and the rule of law.[5]

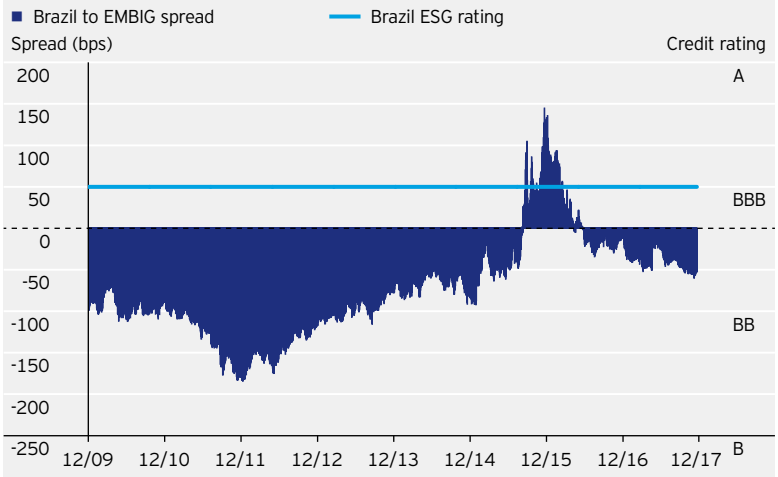
Governance factors tend to have the greatest impact on both credit quality and changes in market valuations.

Taking the weighted average of the World Bank's six key governance indicators, we found that Brazil's overall governance score fell by 10 points from 2010 to 2016. Only Egypt (-11 points) and Mozambique (-22 points) saw their scores fall by more over that period. The two driving elements of Brazil's overall decline were declines in the scores for control of corruption (-4 points) and political stability (-3 points). These underlying indicators pointed to the eventual deterioration in political conditions.

Thus, although Brazil's overall ESG scores (figure 2) did not help assess or foresee investment risk, the underlying governance metrics did provide the right signals.

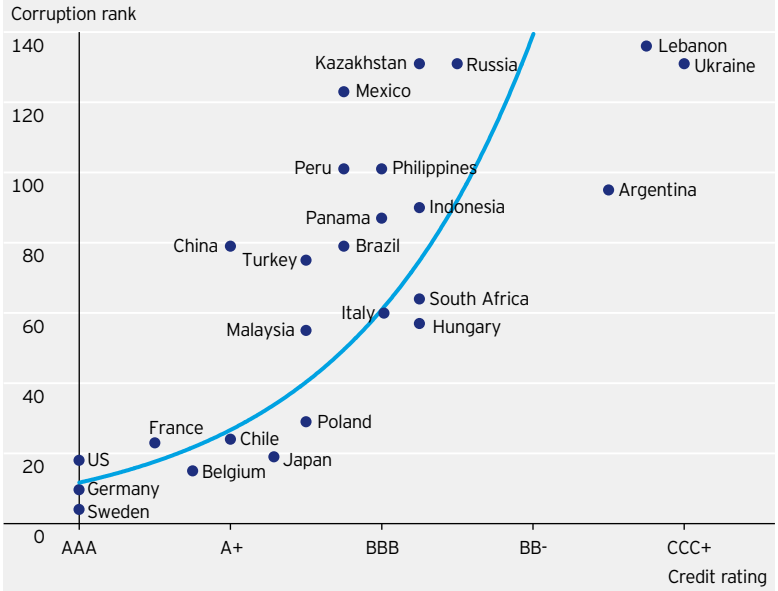
A simple chart (figure 3) showing selected sovereign rankings in terms of level of corruption versus its credit rating shows a positive correlation – high

Figure 2
ESG ratings: constant even through turmoil



Sources: MSCI, J.P. Morgan. Data as at 31 December 2017. EMBIG = J.P. Morgan Emerging Market Bond Index Global.

Figure 3
Corruption rank higher in weak credit names (selected countries)



Sources: World Bank, Invesco, Bloomberg Barclays. Data period from 1 January 2012 to 30 June 2017. Composite ratings are an equally weighted average of available long term foreign currency issuer ratings provided by S&P, Moody's and Fitch via Bloomberg.

credit quality countries tend to have lower levels of corruption and vice versa. This correlation suggests that, as the level of corruption improves (declining corruption), so should credit quality. Sovereigns should move down and toward the left on the chart and this should correspond to better market performance.

Indeed, our research shows that countries on an improving trajectory with respect to governance broadly outperformed the J.P. Morgan Emerging Market Bond Index - Global Diversified (EMBI-GD) from 2012 to July 2017.[6] We compared the weighted average score of all six World Governance Indicators for each country in the index and compared the change in that score to the country's annualized return. Since the global financial crisis, 71% of countries with improved average governance scores outperformed the index, while 75% of countries with falling scores underperformed.[6]

While a focus on governance appears to improve assessments of investment risk, changes in the political environment were often the most important signal. Unfortunately, when it comes to politics, even if a risk is known, as was the case in Brazil, it is difficult to forecast either the timing or impact of political developments, emphasizing the importance of active assessment.

Traditional emerging market bond investing versus RI: comparable returns, different drivers

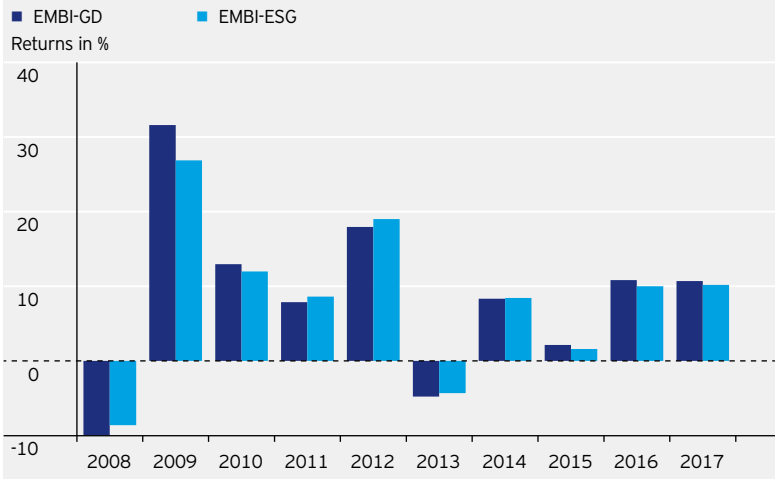
Our research also shows that returns for emerging markets sovereign bond investors have been generally comparable between traditional and ESG-focused investing (figure 4). In other words, it is not a foregone conclusion that investors must reduce their return expectations to achieve RI goals. To compare outcomes, we used the J.P. Morgan Emerging Market Bond Index - Global Diversified (EMBI-GD) and an ESG-subset comprised of sovereigns rated BBB or better for ESG criteria by MSCI (EMBI-ESG).

The annual returns in figure 4 highlight some important points. First, returns are positively correlated and are similar in magnitude each year. Second, in up markets, the ESG-subset performed comparably to the traditional index, but outperformed in each down market (2008 and 2013). Therefore, although the EMBI-GD modestly outperformed on an annualized basis (8.4% annualized versus 8.2% for the EMBI-ESG), the lower downside capture and lower volatility (8.4% versus 8.7%) suggest slightly better risk-adjusted returns for the ESG-subset (figure 5).

We believe the lower risk profile of the ESG-subset was likely due to the high correlation between credit quality and ESG quality, but we were surprised by the similarity in ESG returns compared to the overall index. Disaggregating the returns into the portions from yield and capital appreciation shed some light

Stronger ESG metrics were rewarded in the marketplace with capital appreciation.

Figure 4
Limited downside capture, limited upside give-up



Sources: MSCI, J.P. Morgan, Invesco. Data as at 31 December 2017. Returns are total return, annualized, in US dollars. EMBI-GD is J.P. Morgan Emerging Market Bond Index - Global Diversified. EMBI-ESG is ESG subset comprised of sovereigns rated BBB or better for ESG criteria by MSCI. **Past performance is not a guide to future returns.**

Figure 5
Annual risk and return metrics for EMBI-GD vs EMBI-ESG

in %	EMBI-GD	EMBI-ESG
Return	**8.4**	**8.2**
Return from yield	6.3	5.6
Return from capital appreciation	2.1	2.6
Volatility (annualized)	**8.7**	**8.4**

Sources: MSCI, J.P. Morgan, Invesco. Data period from 31 December 2007 to 31 December 2017. Returns are total return, annualized, in USD. EMBI-GD is J.P. Morgan Emerging Market Bond Index - Global Diversified. EMBI-ESG is ESG subset comprised of sovereigns rated BBB or better for ESG criteria by MSCI. **Past performance is not a guide to future returns.**

(figure 5). As anticipated, the slightly higher credit profile of the ESG subset meant that less of the return came from yield, as higher quality bonds typically have lower interest rates. There was a substantial offset for this lower yield in the form of greater capital appreciation in the ESG-subset. We believe this outcome – countries with stronger ESG metrics were rewarded in the marketplace with capital appreciation – ties back to our earlier finding that 71% of countries whose average governance score improved outperformed the index.[6]

These details help set future expectations for investing in the emerging markets sovereign space. Two conclusions are notable:

- Sovereigns with higher fundamental credit quality may naturally exhibit higher ESG quality, but the reverse is not necessarily true. Countries seeking to build a sustainable debt profile may recognize that good environmental, social and governance practices may help them achieve their long-term growth and financial objectives. But countries that happen to score well on ESG factors do not necessarily also have good financial metrics and a lower probability of default. Careful analysis on both fronts is required.

- Capital appreciation can only go so far in bonds. Unlike equities, whose share prices can rise without limit as markets reward good practices, ESG practices can push bond prices only so high given limits on how low interest rates can go. A subset of an EM bond index consisting of higher quality (and thus lower yielding) bonds may underperform the broader market that includes higher yielding assets.

Given these insights, we believe a passive approach is unlikely to yield the best returns when it comes to ESG-focused portfolios. A passive approach, as highlighted by our ESG-subset, would gain exposure to those countries that already carry a higher ESG rating and, therefore, a potentially lower yield. Our analysts are focused on finding those countries setting ESG policies in the right direction for the future. In this way, we would expect to capture greater capital appreciation potential.

The opportunity for impact is especially high in emerging market bonds

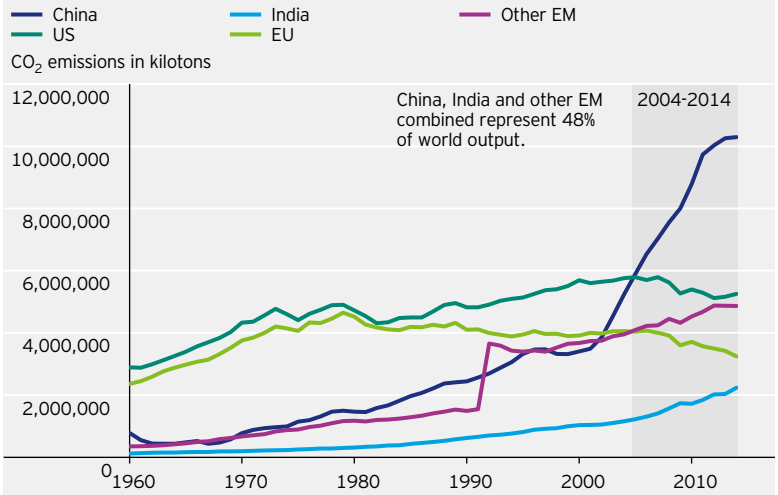
Under the ancient Hippocratic Oath, doctors should "first, do no harm." But, in the modern world, we expect more from doctors. We also expect their services to lead to improved health. The same can be said for RI. Initially, ESG-minded asset owners asked asset managers to invest their funds in a manner that did not negatively impact future outcomes. However, more and more, we are seeing asset owners interested in having their investment choices make a positive contribution to our collective futures. This new phase of RI is where Invesco Fixed Income sees the most potential within the emerging markets.

The emerging markets are, by definition, at an earlier stage of development in a number of areas, many of which are closely related to environmental, social and governance issues. Given their early stage of development, and the fact that emerging economies represent the bulk of the world's natural resources and human capital, we believe investment dollars spent with deliberation have the potential to create a significant impact.

If a client wishes to support efforts to reduce greenhouse gas emissions, a focus on emerging markets, rather than developed markets, could make a greater positive impact.

For example, if a client wishes to support efforts to reduce greenhouse gas emissions, a focus on emerging markets, rather than developed markets, could make a greater positive impact. While developed countries have led the charge in reducing emissions, emerging market emissions comprise a significant and rapidly growing proportion of overall emissions.

Figure 6
China's CO_2 emissions



	World share	10-yr growth
China	28%	+97%
India	6%	+94%
Other EM	13%	+23%
US	15%	-9%
EU	9%	-20%

Source: World Bank. Data period from 31 December 1959 to 31 December 2014.

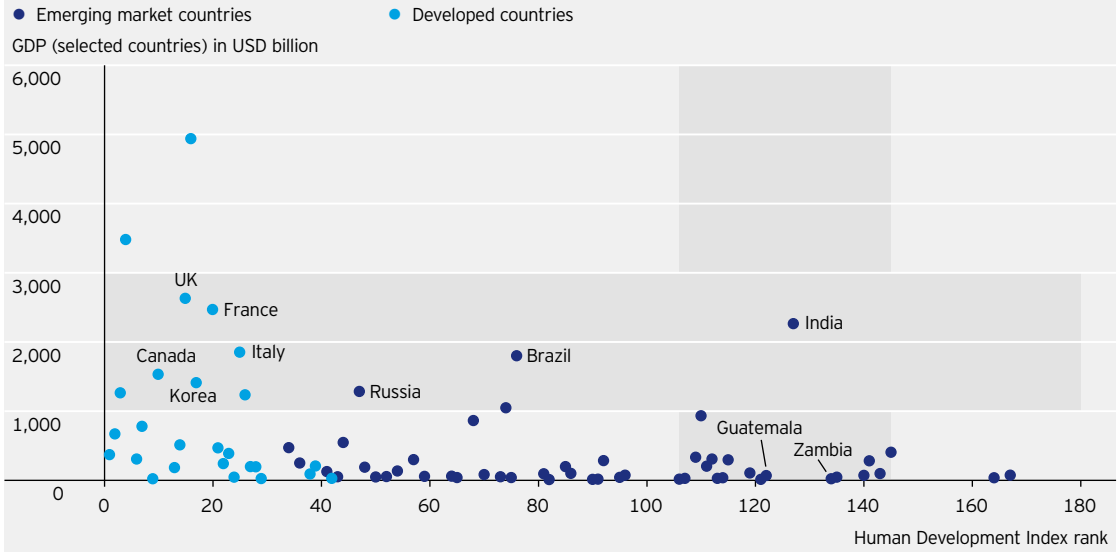
Emissions from China, India, Russia and developing countries in Latin America and the Middle East together represent nearly half of total global greenhouse gas emissions.[7] Similarly, investors seeking to make a positive impact on social issues have a wide range of emerging market levers to pull, especially when it comes to improving education and reducing poverty.

To illustrate the above points, we look at two case studies: Chinese CO_2 emissions and human capital development in India. In both cases, there is still much room for improvement – and thus immense potential for positive impact generated by investment in these countries.

Figure 6 shows that China alone represents 28% of world CO_2 emissions, and its output has increased by 97% over the past decade, offsetting reductions of 9% and 20% in the US and European Union, respectively. Clearly, focusing investment dollars to support green energy initiatives in China could have a huge impact. Despite issuing its first green bond as recently as 2015, China has already emerged as the world leader in this field, with more than USD 60 billion in total green bond issuance.[8]

For investors seeking a social perspective, emerging markets can also offer plenty of opportunities. For example, India is the world's sixth-largest economy, its fourth-fastest growing economy (projected at 7.2%[9]) and is its largest democracy. Yet, from a human development standpoint, it ranks 131 out of 188 countries – putting it at the same level as much smaller countries such as Bhutan, Timor-Leste, Vanuatu and Tajikistan (figure 7). India's healthcare

Figure 7
Country GDP versus Human Development Index rank



Sources: United Nations Development Programme, World Economic Organization. Data as at 31 December 2016.

has also lagged. Its infant mortality rate is 35 per 1,000 live births, placing it nearer to the 54/1,000 ratio seen in fragile, conflict-plagued regions than Germany's 3/1,000 ratio, for example.[10] Similar results are found with respect to education. India ranks in the 23rd percentile for adult literacy – below Uganda, Cambodia and Syria.[10]

Conclusion: The Invesco Fixed Income approach to RI in emerging market bonds

With the above findings in mind, the approach we take to achieving our clients' dual objectives of maximizing return on capital and delivering on ESG principles is highly active. We believe an active approach is necessary to ensure that investment objectives are aligned with ESG goals, that performance targets are appropriately set and have the best chance for success, and that agreed-upon outcomes are measurable over time.

We find that focusing on the United Nations' Principles for Responsible Investing (UNPRI) and Sustainable Development Goals (SDGs) can be helpful in aligning client priorities with investment opportunities. As seen in figure 8, the UN's 17 SDGs are well-attuned to common RI themes. If a client is interested in

Figure 8

Source: United Nations, http://www.un.org/sustainabledevelopment. Invesco supports the Sustainable Development Goals.

We find that focusing on the United Nations' Principles for Responsible Investing (UNPRI) and Sustainable Development Goals (SDGs) can be helpful.

positively influencing environmental issues, such as reducing CO_2 emissions, investments can be aligned with goals 6, 7 and 13-15. A focus on social or human development issues can be guided by SGDs 1-5. Each SDG has several underlying goals (169 individual targets in total) that can be further coordinated with investment opportunities. The United Nations Conference on Trade and Development (UNCTAD) estimates that meeting these targets will require USD 5-7 trillion in investment each year from 2015-2030, the bulk of which is expected to come from private capital.[11]

Attracting the needed resources will likely be challenging. But we believe it is possible and are therefore optimistic that many of these important objectives can be met. To quote Archimedes: "Give me a lever long enough, and a fulcrum on which to set it, and I can move the world." We believe RI is a very strong fulcrum, and the lever becomes longer with each new RI mandate.

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Notes

1 Average of Moody's, S&P, and Fitch. Market valuation expressed as spread (sovereign yield over risk-free rate).
2 ESG ratings are provided by MSCI using proprietary information and technology to assign to each sovereign entity a rating for Environmental, Social and Governance scores as well as an aggregate. For more information on MSCI's rating process, visit https://www.msci.com/esg-integration
3 In late 2015 and early 2016, Brazil's government was rocked by a scandal involving Petrobras, Brazil's national oil company, which ultimately resulted in the removal of dozens of high-ranking politicians, including President Dilma Rousseff.
4 Consequently, Invesco's EM ESG ratings assign a 60% weight to Governance versus 25% for Social and 15% for Environmental.
5 The World Bank's Worldwide Governance Indicators capture six key dimensions of governance: Voice & Accountability, Political Stability & Lack of Violence, Government Effectiveness, Regulatory Quality, and Rule of Law; www.govindicators.org
6 J.P. Morgan Emerging Market Bond Index - Global Diversified, World Bank, Invesco; data from January 2012 to July 2017.
7 World Bank; data as at 31 December 2014.
8 Ken Hu, CIO, Invesco Asia-Pacific, China green bonds: A sustainable asset class, October 2017.
9 World Economic Forum, 9 June 2017; www.weforum.org
10 World Development Indicators, Invesco; data as at 15 November 2017.
11 United Nations Development Programme Website: "What kind of blender do we need to finance the SGS", 13 July 2017.

About risk

Emerging markets investing requires awareness of specific market risks, such as potentially lower levels of market liquidity and greater volatility. 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.

Currency management with style

By Dr. Martin Kolrep and Dr. Harald Lohre

In brief
Currency hedging is often approached with an all-or-nothing mentality: either full hedging of all foreign exchange (FX) positions or no hedging at all. As a more nuanced alternative, we suggest systematically harvesting the benefits of the FX style factors carry, value and momentum. In particular, we demonstrate how these factors can expand the opportunity set of traditional asset allocation when pursuing either FX factor-based tail-hedging or return-seeking strategies.

There are good reasons to believe that the optimal currency hedge lies between the two extremes of a full hedge and no hedge at all. We believe that it pays off to have a closer look at currency style factors for determining a beneficial currency allocation.

Investing in international bond and equity markets is often imperative for diversifying one's investments. Yet, the associated currency risk of a direct investment can be considerable, so that a lack of currency hedging could significantly impact portfolio performance.[1] On the other hand, a full currency hedge might undermine the potential diversification benefit inherent in foreign exchange (FX) holdings. Indeed, academic research suggests that determining the optimal FX exposure requires a more nuanced approach, cf. Black (1989/90).

Academic research suggests that determining the optimal FX exposure requires a more nuanced approach.

In a previous article[2], we explored optimal currency hedging by adopting a risk-based perspective. In particular, we considered minimum-variance hedges for their risk reduction benefits in multi-asset or equity portfolios. The present article will advance

this line of thinking through a view-based perspective using informative currency views for portfolio optimization. Forecasting currency returns is often considered difficult, if not impossible. Yet, the academic literature has demonstrated several currency characteristics that allow investors to exploit the cross-section of FX rates by tilting their currency allocation accordingly.

The most prominent characteristic is the yield associated with a given currency investment. Ultimately, the yield gives rise to the well-known carry trade, which exploits the difference between higher-yielding vs. lower-yielding currencies. Alongside yield, there are further relevant currency characteristics, such as short-term momentum or value, cf. Asness, Moskowitz and Pedersen (2013), Barroso and Santa-Clara (2015) or Menkhoff, Sarno, Schmeling and Schrimpf (2012a, 2012b, 2017). Below, we will explore the benefits of integrating the three FX style factors carry, value, and momentum into a traditional multi-asset allocation.

A taxonomy of FX style factors

Carry

The carry trade involves buying currencies with the highest short-term interest rates and selling currencies with the lowest short-term interest rates. Uncovered interest rate parity would suggest that any interest rate advantage is offset by FX movements. However, currency depreciation has historically fallen short of the interest rate differential, and in many cases the return of the carry trade was actually boosted by currency appreciation.

In rationalizing carry trade returns, Burnside, Eichenbaum, Kleshchelski and Rebelo (2011) link the carry premium to a 'peso problem' (i.e. the negative event justifying the return may simply not yet have occurred). In fact, the unwinding of carry trades over the course of the global financial crisis has led to a pronounced period of negative returns for the carry strategy. In particular, FX carry does not perform when there are liquidity squeezes or increases in FX volatility.

To construct an FX carry portfolio, one needs to engage in the forward exchange market. To buy or sell a given currency *i*, one enters a forward contract at time *t* that prescribes the forward price $F^i_{t,\,t+1}$ for one euro (EUR) expressed in foreign currency units (FCU). With S^i_{t+1} as the spot price of one EUR in FCU, the return (in EUR) of a long position in a foreign currency *i* at time *t* will be:

$$r^i_{t+1} = \frac{F^i_{t,t+1}}{S^i_{t+1}} - 1$$

The currency ranking underlying the FX carry trade is based on the interest rate spread or the forward discount fd_i on the currency *i*:

$$fd_{i,t} = \frac{F^i_{t,t+1}}{S^i_t} - 1$$

We consider a universe of G10 currencies and the top three currencies with the highest forward discount form the long leg of the carry trade based on an equal-weighting scheme. Conversely, the three currencies with the lowest forward discount form the short leg, again equally weighted. Rebalancing of the carry portfolio would occur at monthly intervals.

Momentum

Momentum is a pervasive feature of capital markets that extends to the FX domain. To exploit price momentum effects, we consider buying 3-month winners and selling 3-month losers. Analogous to the carry portfolio, the momentum portfolio is rebalanced monthly. The top three winner and the bottom three loser currencies constitute the long and short leg, both equally weighted.

There seems to be no systematic risk that would explain FX momentum returns. Notably, FX momentum returns are relatively sensitive to transaction costs, cf. Menkhoff et al. (2012b). They are less related to business cycle risk than to currency characteristics, but FX momentum returns are higher in currencies with higher idiosyncratic volatility and a high country risk rating. FX momentum strategies are particularly suited to exploit flight to quality events that vex FX carry trades. Therefore, FX carry and FX momentum strategies are mutual diversifiers.

Value

To identify undervalued or overvalued currencies, one may refer to purchasing power parity (PPP) as a measure of fundamental value. PPP ultimately stipulates that goods should cost the same across countries. Currencies whose real exchange rate (RER) deviates significantly from 1 may then be viewed as undervalued or overvalued. To exploit long-term reversal effects in FX markets, we construct the value portfolio by buying currencies with the lowest 60-month change in the RER and selling currencies with the highest 60-month change in the RER.

At its heart, the FX value strategy seeks to exploit the reversal of currencies that have overshot their PPP values. This approach tends to work best for extreme outliers. When it comes to determining which measure of PPP to use, Asness et al. (2013) use the 60-month deviation from uncovered interest rate parity. Based on their approach, we compute the cumulative real depreciation of currency *i* as:

$$Q_{i,t-60,t} = \frac{S_{i,t}\,CPI_{i,t-60}\,CPI^{Eurozone}_t}{S_{i,t-60}\,CPI_{i,t}\,CPI^{Eurozone}_{t-60}}\ .$$

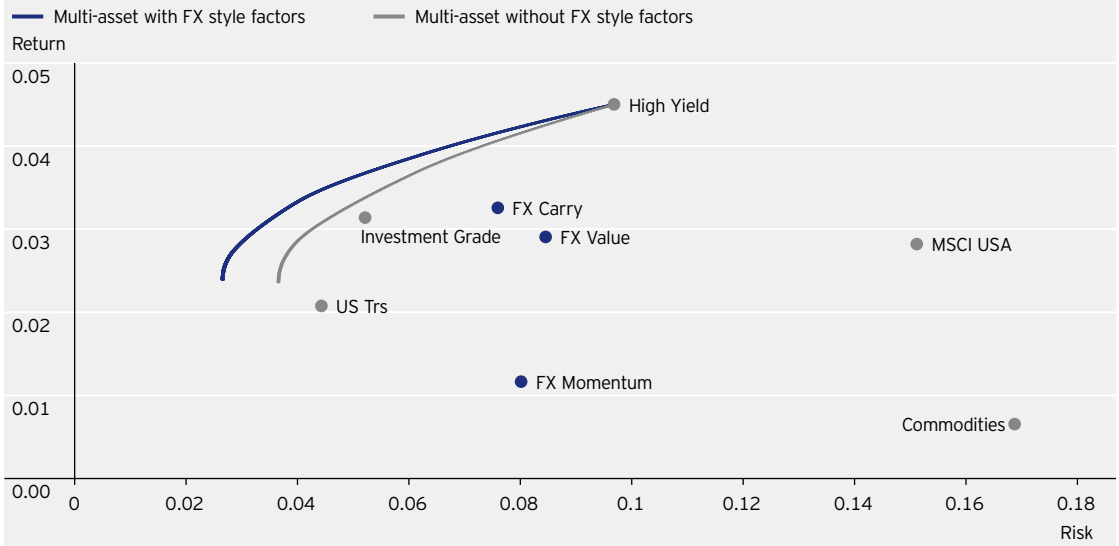
Portfolio construction is identical to carry and momentum portfolios in that we rebalance monthly, applying equal weights in the long and short legs.

FX style factors vis-à-vis multi-asset classes

We will now demonstrate the mean-variance properties of FX style factors relative to traditional asset classes. Figure 1 depicts a mean-variance diagram of the three FX style factors carry, value and momentum, as well as five traditional asset classes as given by US equity, US Treasuries, US corporate bonds (investment grade and high yield) and commodities.[3]

First, we inspect the investment opportunity set of traditional multi-asset investors based solely on the latter five asset classes. In particular, we take the

Figure 1
Mean-variance spanning of FX style factors and asset classes

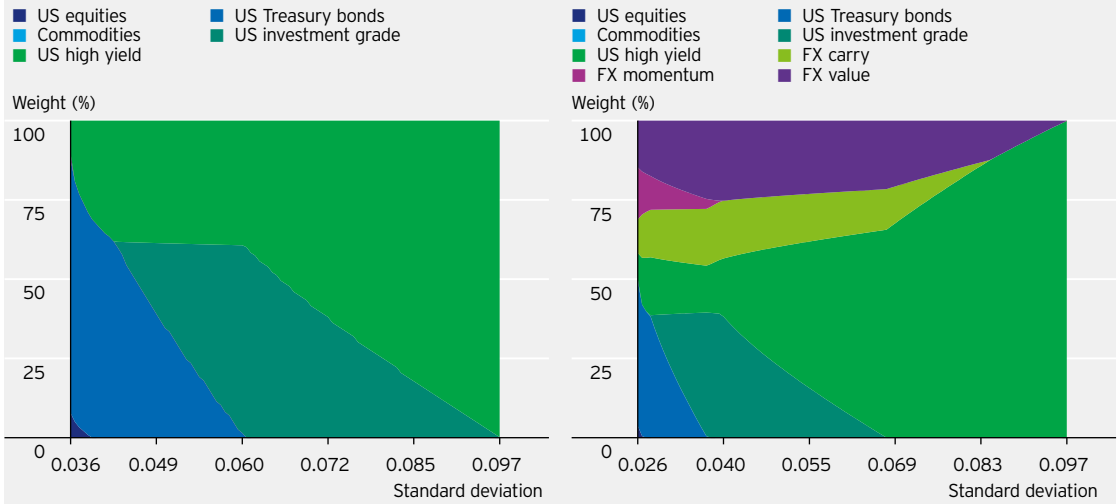


Simulated past performance is not a guide to future returns. The figure depicts two efficient frontiers based on different sets of underlying asset classes or FX style factors. Based on the traditional asset classes equity (MSCI USA), government bonds (US Treasuries), US corporate bonds (High Yield and Investment Grade) and commodities, all of which denoted with grey dots, we compute the multi-asset efficient frontier (grey line), see footnote 3 for a description of the relevant indices for the traditional asset classes. Next, we add FX style factors to compute the efficient frontier (blue line) based on FX style factors (blue dots) and asset classes. The underlying mean-variance optimizations are subject to full investment and short-sale constraints. Mean-variance inputs are derived from monthly excess return data over the sample period from 29 January 1999 to 31 December 2016. Both risk and return figures are annualized. Asset class returns are fully hedged from the perspective of a EUR investor.
Sources: Bloomberg, Invesco.

perspective of a EUR investor who is fully hedging USD/EUR exposure. The left chart in figure 2 shows the ensuing mean-variance allocations along the efficient frontier for the five multi-assets only. Going from left to right, we learn that a more defensive investor would have allocated towards government bonds, whereas the latter allocation for less risk-averse investors gives way to investment grade and high yield credit positions.

Adding the three FX style factors to the mix would significantly expand investors' opportunity set.

Figure 2
Efficient frontier allocations: FX style factors and asset classes



The figure depicts the two spectrums of efficient frontier allocations based on two different sets of underlying asset classes or FX style factors. The left chart is based on the efficient frontier for traditional asset classes: equity (MSCI USA), government bonds (US Treasuries), US corporate bonds (High Yield and Investment Grade) and commodities, see footnote 3 for a description of the relevant indices for the traditional asset classes. The right chart is based on the efficient frontier that additionally considers the three FX style factors carry, value, and momentum. Data inputs are derived from monthly excess return data over the sample period from 29 January 1999 to 31 December 2016.
Sources: Bloomberg, Invesco.

Second, adding the three FX style factors to the mix would significantly expand investors' opportunity set. The ensuing efficient frontier including FX styles shifts considerably to the northwest compared to the multi-asset-only allocation.[4] Obviously, the inclusion of the FX carry and value factors is expanding the portfolio return perspective. Still, judging from the corresponding mean-variance allocations, we learn that all three FX style factors crucially enhance the tail-hedging capabilities of any multi-asset investor, as demonstrated by their large portfolio weights in the minimum-variance portfolio.

While FX momentum does play a role, especially for very defensive allocations, we see that FX value is beneficial across the whole spectrum of risk profiles. Likewise, allocation to the FX carry trade replaces some of the high yield allocation, reflecting its close association with genuine equity and credit risk.

FX style factor investing for a multi-asset portfolio

Note that the above mean-variance spanning analysis for the FX style factors should be taken with a grain of salt. The corresponding allocations all represent stylized optimal mean-variance allocations that result from knowing the full return history. To investigate the potential out-of-sample benefits of FX style factor investing, we need to build allocations based on the information available at the time of each rebalancing. As we want to focus on FX factors, we fix the five multi-asset weights according to a standard risk parity scheme. Taking the perspective of a euro investor, we first fully hedge the USD exposure and then consider further allocating towards FX style factors. In particular, two approaches are investigated:

1. *Tail-hedging* as given by a minimum-variance hedge consisting of FX style factors

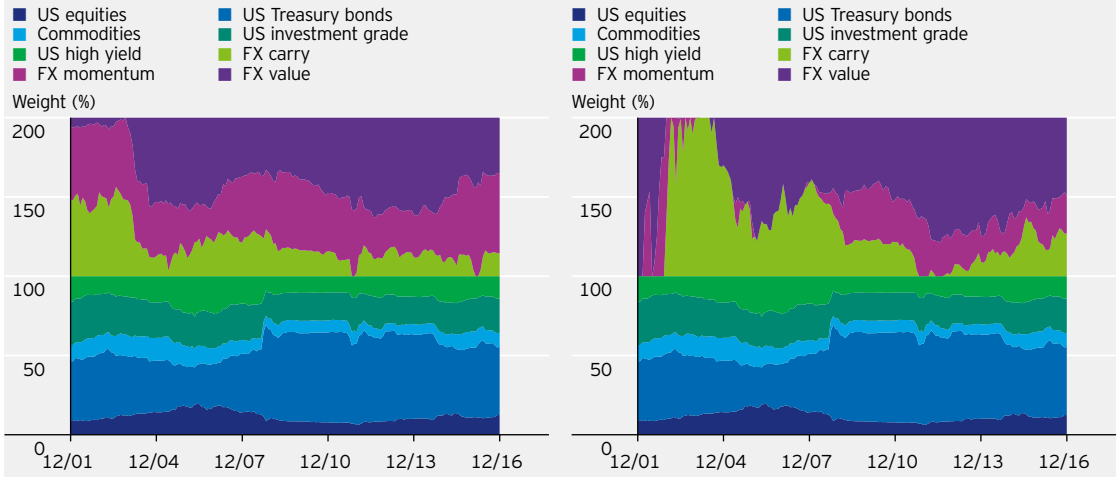
2. *Return-seeking* based on mean-variance investing using historical average FX style returns as return estimates

In both cases, we restrict the FX style factor weights to 100% (on top of the traditional asset allocation that is fixed to the 100% risk parity strategy). These constraints allow the overall strategy to stay within risk limits. While this objective could also be couched in a more elaborate risk-budgeting framework, this approach is straightforward in carving out the stylized facts of adding a factor-based currency overlay to a multi-asset portfolio. The out-of-sample period is 31 January 2002 to 31 December 2016, reflecting the use of 36 months to calibrate the inputs of the first mean-variance optimization. Subsequently, we estimate parameters based on an expanding window over time.

The left chart in figure 3 depicts the allocation weights over time for the tail-hedging strategy based on a minimum-variance optimization with FX style factors. Naturally, the fixed underlying asset allocation exhibits quite a conservative risk profile resonating with the risk parity paradigm. Unhedged, a euro investor would see annualized volatility of 8.8% (see table 1). Equipped with the three FX style factors, the same investor could bring this figure down to 6.0%. Interestingly, the tail-hedging FX style allocation would have mostly combined FX value and FX momentum, rather than the equity-like FX carry trade. Given that the latter's resemblance to equity became most apparent over the course of the global financial crisis, the tail-hedging strategy hardly participated in the drawdown of the carry trade because of its exposure to the antagonistic players FX momentum and FX value.

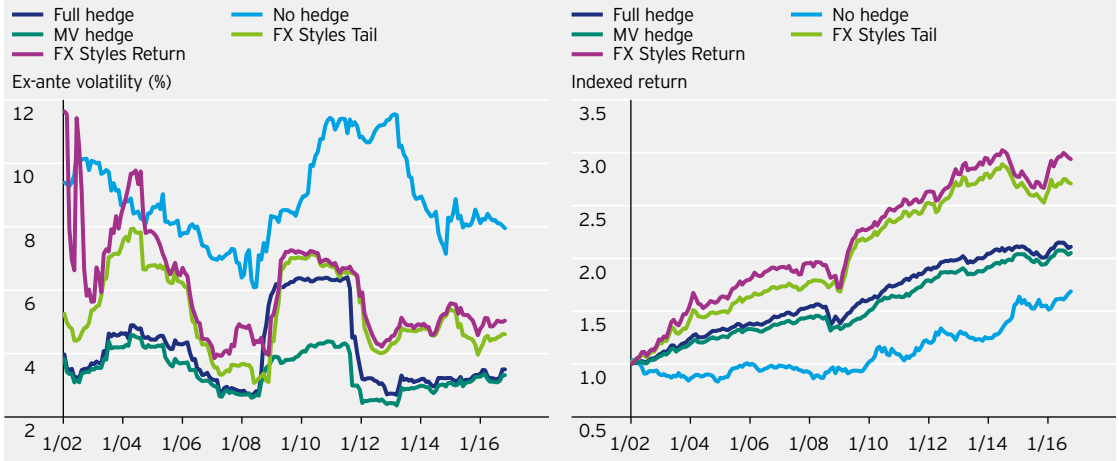
It is also worthwhile to compare the tail hedge based on FX style factors to one based on the underlying EUR/USD allocation. We know from a previous Risk & Reward article (#1/2017) that a minimum-variance investor would often hedge most, but not all, of the FX exposure. In figure 4 (left chart), we plot the ex-ante volatility from this hedge based on EUR/USD vis-à-vis alternative optimizations. It turns out that the tail hedge based on FX style factors is halfway between the hedge based on EUR/USD and

Figure 3
Tail-hedging and return-seeking with FX style factors: allocations



The left chart depicts the asset and FX style factor allocation for the tail-hedging strategy based on FX style factors over time; the right chart depicts the asset and FX style factor allocation for the return-seeking strategy based on FX style factors. See footnote 3 for a description of the relevant indices for the traditional asset classes underlying the risk parity asset allocation.
Sources: Bloomberg, Invesco. Data as at 31 December 2016.

Figure 4
Tail-hedging and return-seeking with FX style factors: performance



Simulated past performance is not a guide to future returns. The left chart shows the ex-ante volatility for various strategies; the right chart depicts the ensuing cumulative return. The "no hedge" portfolio is completely exposed to USD, whereas the "full hedge" portfolio hedges any USD exposure into EUR. "MV Hedge" is the partial hedge through minimum-variance based on the EUR/USD and "FX Styles Tail" is the minimum-variance hedge based on FX style factors (tail-hedging). FX Styles Return represents the return-seeking FX Style strategy. See footnote 3 for a description of the relevant indices for the traditional asset classes underlying the risk parity asset allocation.
Sources: MSCI, Bloomberg, Invesco. Data as at 31 December 2016.

the unhedged portfolio most of the time. However, while the hedge based on EUR/USD is more efficient in reducing risk, the hedge based on FX styles expands the return dimension considerably (see right chart in figure 4 and performance statistics in table 1).

To investigate whether a risk-loving investor would have been able to capture more of the performance upside through FX style factors, we have designed a return-seeking FX style allocation. In particular, we ran a mean-variance optimization based on a more offensive risk aversion[5], where the expected return inputs for the FX style factors simply derive from their historical average. The latter is estimated using an expanding window to allow for a true out-of-sample experience.

Given the potential instabilities of traditional mean-variance allocations, we further smoothed the optimization inputs using a classic view-refinement à la Black-Litterman (1991/92).[6] As expected, the ensuing FX style allocation is more offensive in that it allocates more strongly towards the FX carry trade. This change relative to the tail-hedging strategy comes largely at the cost of FX momentum, as illustrated by the right allocation chart in figure 3. As a result, the return-seeking strategy outperforms the tail-hedging strategy in times of a favourable carry trade. Yet, the associated drawdown in 2008/09 almost completely erodes this advantage. Still, up to the end of the sample period in December 2016, the return-seeking strategy again outperformed, albeit with a less pronounced allocation to FX carry.

While these two illustrative use cases document the diversification benefits of adding FX style factors to a traditional asset allocation, one has to acknowledge that our analysis relies on the ability to implement an outright long-short currency overlay. It is an open question whether these benefits continue to be relevant for a global investor who is incapable of following these allocations but merely intends to hedge existing direct investments – a question we shall investigate in a future article.

Conclusion

Investors often shy away from a sophisticated approach to their currency allocation, mostly because of a general fear of currency risks. Yet, it can be highly beneficial to systematically unlock pervasive risk and return patterns of FX style factors as formed by the currency characteristics carry, value and momentum.

Table 1
Tail-hedging and return-seeking with FX style factors: performance

Performance statistics	No hedge	Full hedge	MV hedge EUR/USD	FX styles Tail-hedging	FX styles Return-seeking
Return p.a.	3.9%	5.1%	4.9%	6.8%	7.4%
Volatility p.a.	8.8%	4.5%	3.9%	6.0%	6.9%
Sharpe ratio	0.24	0.75	0.80	0.85	0.82
Maximum drawdown	-19.8%	-12.3%	-9.6%	-12.6%	-12.3%

Simulated past performance is not a guide to future returns. The table provides simulated performance figures for five currency strategies from the perspective of a euro investor. See footnote 3 for a description of the relevant indices for the traditional asset classes underlying the risk parity asset allocation.
Sources: Bloomberg, Invesco. Data period: 31 December 2001 to 31 December 2016.

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Notes

1 Currency management in multi-asset portfolios, Risk & Reward #4/2015.
2 Risk-based currency management, Risk & Reward #1/2017.
3 To represent the traditional asset classes, we build on broad market indices. In particular, we use MSCI USA for US equities, Barclays US Aggregate Government Treasury for US Treasury bonds, Barclays US Aggregate Credit for US investment grade corporate bonds, Barclays US Aggregate Credit Corporate High Yield for US high yield and the Bloomberg Commodity Index for commodities.
4 In fact, in unreported mean-variance spanning tests based on Kan and Zhou (2012), we document this shift in the efficient frontier to be statistically significant. This finding applies to the joint use of the three FX style factors, but also to any single FX style factor when added to the five multi-assets in isolation.
5 The risk aversion coefficient is set to 2.
6 In particular, the parameter tau is set to 0.25 and the Omega matrix is assumed to equal the diagonal of the underlying assets' and factors' variance-covariance matrix.

Econometric time series models: Part 8

By Dr. Bernhard Pfaff

In brief

Bayesian Model Sampling helps in the search for a suitable model for a data-generating process. With this approach, various models are generated using different processes and then aggregated in probability-weighted terms into an overall model. Our empirical example (forecast of the USD/GBP exchange rate) shows this model to return better results than other models (classical multiple regression, AR(1) model, naive forecast model).

In our series, we have presented many different time series models and the user often can't see the forest for the trees. For even if a model passes all the tests, the "true" model can be quite different. Bayesian Model Sampling helps solve this problem. It also marks the end of our series.

Bayesian Model Sampling (or BMS) was introduced by Leamer (1978).[1] The starting point is a multiple regression model of the form:[2]

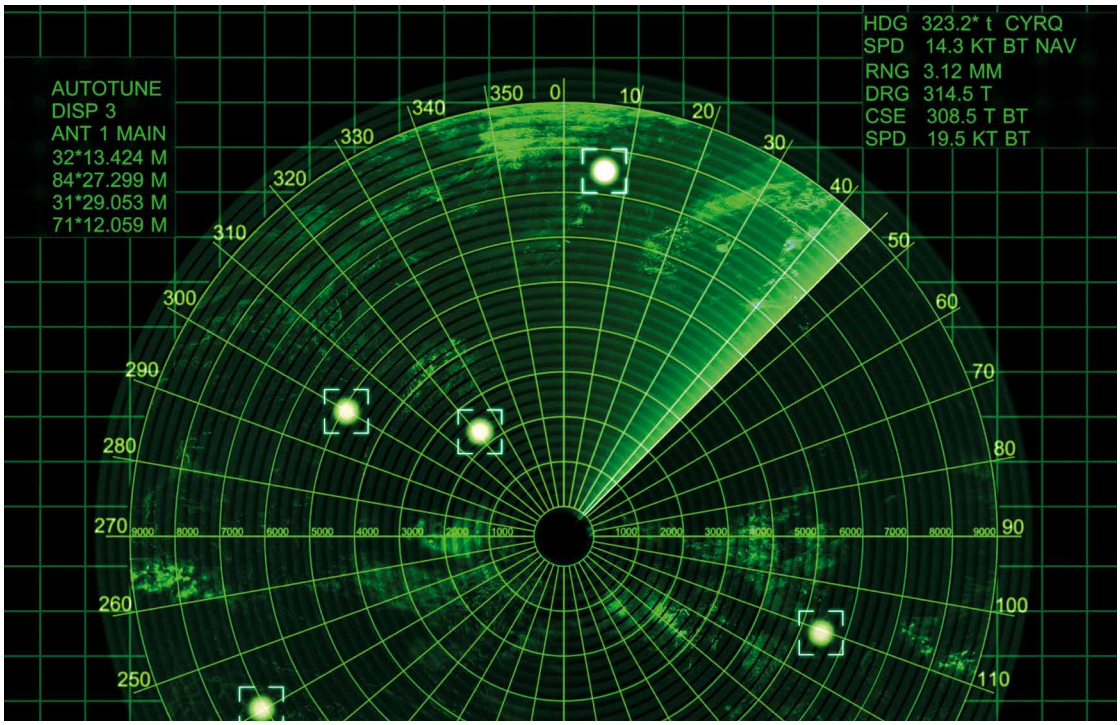
$$(1) \quad y = \beta_0 + \beta_1 x_1 + \ldots + \beta_K x_K + \varepsilon$$

with y denoting the dependent variable, $x_1, \ldots, x_K$ the K explanatory variables and ε the error process. The unknown coefficients of this single equation model are $\beta_0, \beta_1, \ldots, \beta_K$.

While a quantitative analyst generally does not know the data-generating process, he will probably know factors that might influence the dependent variable y. This is where BMS comes into play. It aggregates various possible models and weights them according to their probabilities. For a random coefficient β_h with $h \in 1, \ldots, K$, the distribution is:

$$(2) \quad P(\beta_h | D) = \sum_{j:\beta_h \in M_j} P(\beta_h | M_j) P(M_j | D)$$

The available data set is $D = \{y, x_1, \ldots, x_K\}$, and M_j the j-th model specification with $j = 1, \ldots, J$.



For K explanatory variables, the number of possible models is thus $J = 2^K$. The distribution for a coefficient β_h is the sum of the marginal distributions of the model weighted with the model probabilities $P(M_j|D)$. The model probabilities j are equal to the quotient from their marginal distributions and the sum of the marginal distributions of all possible models.

$$\text{(3a)} \quad P(M_j|D) = \frac{P(D|M_j)P(M_j)}{P(D)}$$

$$\text{(3b)} \quad P(M_j|D) = \frac{P(D|M_j)P(M_j)}{\sum_{i=1}^{2^K} P(D|M_i)P(M_i)}$$

The likelihood function $P(D|M_j)$ of the j-th model is then:

$$\text{(4)} \quad P(D|M_j) = \int P(D|\beta^j, M_j)P(\beta^j|M_j)d\beta^j$$

with β^j the coefficient set of the j-th model, $P(\beta^j|M_j)$ the accompanying probability distribution and $P(M_j)$ the probability that the j-th model is correct. This probability is also termed the Posterior Model Probability (PMP). Similar to this, the Posterior Inclusion Probability (PIP) shows the probability of a specific coefficient occurring if all models are aggregated. In an example with three equiprobable models, two of which with the coefficient β_i and onewithout, the PMP of each of the models would therefore be 1/3 and the PIP of the coefficient β_i 2/3.

Ultimately, what lies behind equations (3a) and (4) is the Bayes theorem according to which the a posteriori distribution is proportionate to the product of the likelihood function and the a priori distribution. Equation (4) is a normalization constant, so that the area beneath the density function equals one.

To complete the BMS, the a priori distributions of the unknown model parameters must be specified. A non-informative distribution is often assumed here for the constants and the error variance σ^2. In other words, no subjective expectations flow into the calculation, so that the distribution has no influence on the a posteriori distribution.

For the coefficient vector β_h of a model h, we use Zellner's g-prior (Zellner, 1986): this assumes that the expected value of the coefficient zero and the covariance matrix is

$$\sigma^2\left(\frac{1}{g}X_h'X_h\right)^{-1}.$$

Thus, parameter g is the only variable distinguishing the covariance matrix from that of the multiple regression model. A lower value for g implies that the user considers coefficients of zero to be more likely; conversely, if the value for g is higher, the user has greater doubts about this. In the borderline case $g \to \infty$, we derive a least-squares-estimate. Assuming a normally distributed error process ε, the distribution for β_h depending on g is:

$$\text{(5)} \quad \beta_h|g \sim \mathcal{N}\left(0, \sigma^2\left(\frac{1}{g}X_h'X_h\right)^{-1}\right)$$

By setting $g = \mathcal{N}$, a non-informative distribution is derived, the coefficient distribution of which equals the inverses of the product momentum matrix of X_h. Alternatively, g can also be set on the basis of an information criterion.

Furthermore, the user must define a distribution for the model specifications. In the simplest case, this can be the uniform distribution. But a binomial distribution with a predefined number of explanatory variables would also be feasible. Inclusion probabilities could also be defined for the individual explanatory variables.

At the beginning we mentioned that, for K explanatory variables, $J = 2^K$ models are possible. Thus, from as few as ten explanatory variables, 1,024 models have to be evaluated. BMS can therefore result in a great deal of calculation work. In practice, the Markov Chain Monte Carlo models (MCMC models) are often applied, in many cases using the Metropolis Hastings algorithm: starting from model M_i, a new model variant M_j is randomly generated. Afterwards, its likelihood function is determined:

$$\text{(6)} \quad p_{i,j} = \frac{\min(1, P(M_j))}{P(M_j)}$$

If the new model has to be rejected due to equation (6) (in other words, due to its low probability), a new model is generated in the next MCMC step. Otherwise the model is retained. If the Monte Carlo chains are sufficiently long, the frequencies of the individual models correspond to the a-posteriori probabilities being sought.

The two most common models used for random selection are the birth and death sampler and the reversible jump sampler. With birth and death, an explanatory variable is randomly selected. If it is already contained in model M_i, it is removed from the explanatory approach (death); otherwise it is included as a further variable (birth). The reversible jump is a combination of two sample methods. First, new models are generated by means of birth and death (which at a probability of at least 50% are retained). Second, an explanatory variable is randomly removed from the existing model and a new one added (also at 50% probability of selection).

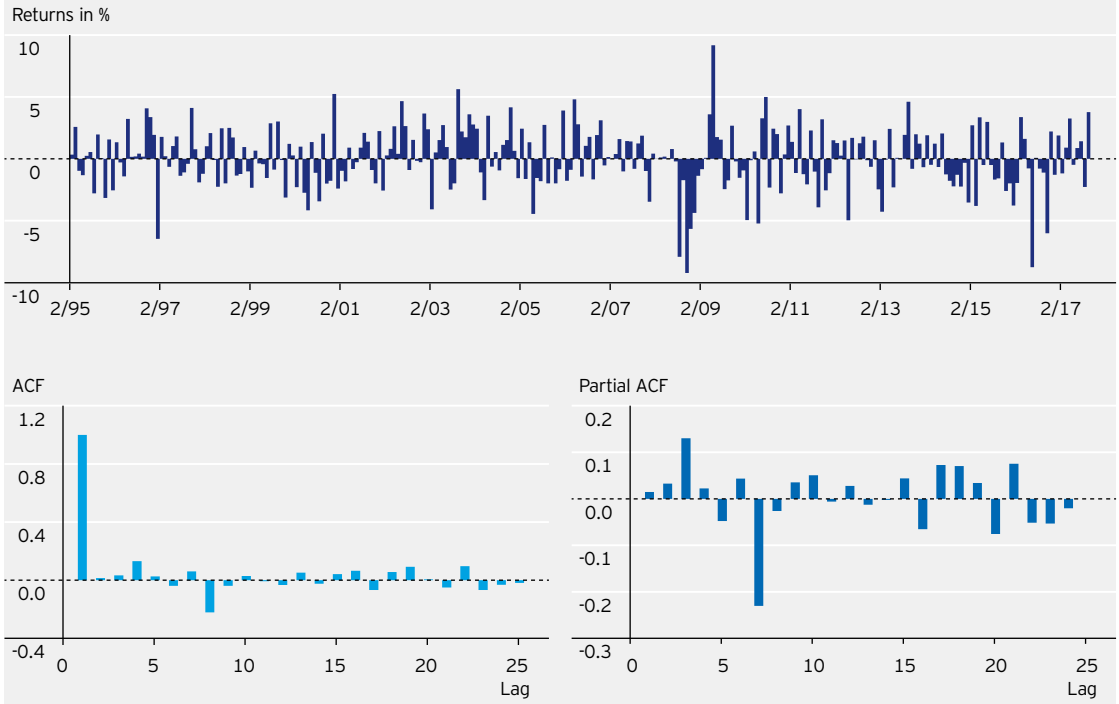
Empirical application

Using the USD/GBP exchange rate as an example, we now explain how BMS can be used for forecasts. In this, we assume purchases and sales of pound sterling using one-month forwards, with the positions being closed on expiry by taking out at a matching open position at the spot rate. The forecast covers the period February 1995 until September 2017, month-end values are used. Figure 1 shows the monthly returns and the accompanying autocorrelations and partial autocorrelations.[3]

The chart highlights the difficulties in making the forecast: both the autocorrelations and the partial autocorrelations (with the exception of the three-month and the seven-month lags) do not differ significantly from zero.

The investment returns of the following month were forecast with a multiple regression model. The

Figure 1
Monthly returns from USD/GBP investment with autocorrelations



Source: Invesco. Data as at September 2017.

dependent variable in period $t + 1$ was regressed to the values from period t. Explanatory variables are financial market statistics (one period lagged) and economic statistics (three periods lagged). For the three-month lag of the macroeconomic time series, allowance was therefore implicitly made for publication delay.[4] Twenty seven regressors were used.

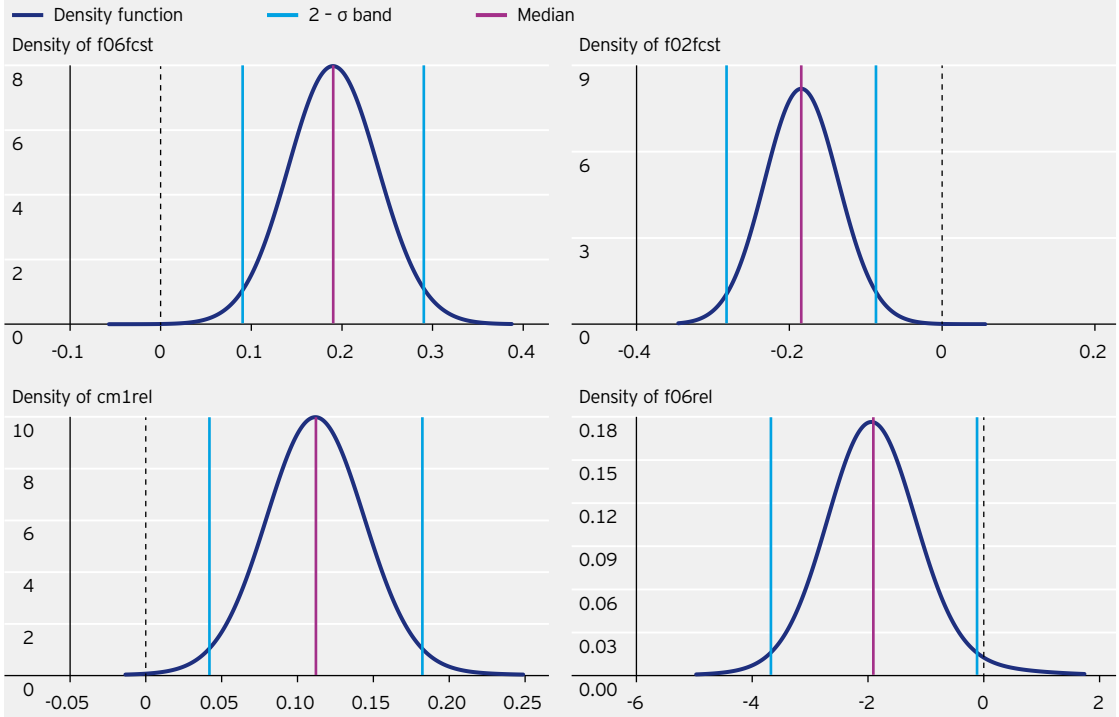
In all, there are 1.3421773×10^8 possible combinations of explanatory variables. Due to the high amount of calculation work involved, we have therefore opted for the MCMC model with a Markov Chain length of 10^5, making no allowance for the first 5×10^4 iterations (burn in phase). An equidistribution was assumed a priori; the parameters g were fixed with the Hannan-Quinn

Table 1
Coefficients

	PIP	Mean	Standard deviation		PIP	Mean	Standard deviation
f06fcst	0.997	0.191	0.050	b10rel	0.058	-0.087	0.115
f02fcst	0.997	-0.184	0.049	f12fcst	0.054	-0.037	0.055
cm1rel	0.827	0.112	0.035	ms1rel	0.049	0.007	0.016
f06rel	0.355	-1.895	0.894	mm1rel	0.047	-0.064	0.137
f02rel	0.254	-2.452	1.997	f12rel	0.046	0.068	0.181
f03rel	0.253	-2.205	1.784	cpilr	0.045	-11.137	31.637
cm2rel	0.196	0.055	0.042	gldrel	0.044	-0.003	0.035
ms1lr	0.153	-14.372	9.813	b05rel	0.044	-0.024	0.195
cpirel	0.140	-0.161	0.114	usdgbprsq	0.042	0.002	0.013
f03fcst	0.108	-0.067	0.053	eqirel	0.042	-0.012	0.057
f01rel	0.094	-0.317	2.868	b02rel	0.041	-0.009	0.447
vixrel	0.082	-0.008	0.008	iptlr	0.040	-1.717	13.413
iptrel	0.079	0.051	0.049	yldrel	0.040	-0.002	0.216
f01fcst	0.075	-0.050	0.050				

Source: Invesco.

Figure 2
Marginal densities of the four most important explanatory variables



Source: Invesco. Data as at September 2017.

criterion $g = \log(N)^3$; the variables chosen by way of birth and death. The best 3,000 models were used; table 1 shows the results.

The most important explanatory variables by far are the constant returns (the differences between the spot rates at time t and the six-month and two-month forwards at times $t - 6$ and $t - 2$). This is followed in third place by the constant return of the commodity index and then by the change in the deport/report of the British pound based on the six-month forward. On average, the 3.112×10^4 analyzed models contained 6 explanatory variables.

Figure 2 shows the marginal density functions of the coefficients. They are unimodal and their position parameters differ significantly from zero, as can be seen in the 2 - σ bands.

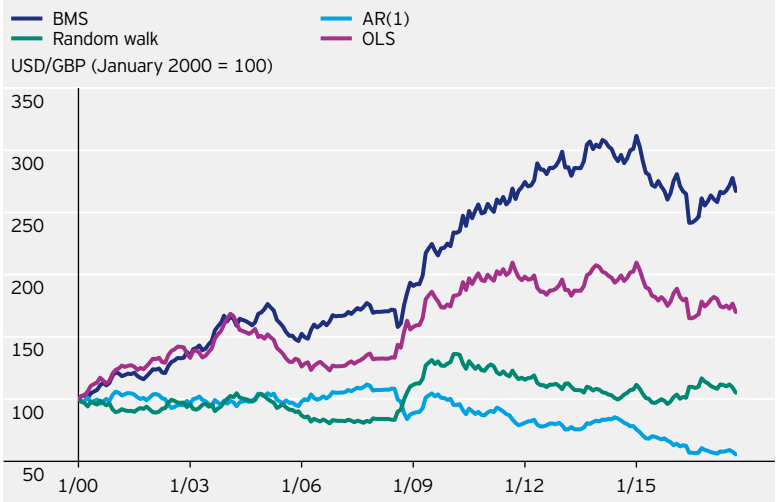
Finally, we backtested the benefit of the investment strategy. The positioning - i.e. the purchase or sale of the British pound at the one-month forward rate and closure of the position on expiry by taking out a matching open position at the spot rate - depended on the sign in front of the respective forecast value, and forecast values of the BMS were based on the respective three best models.

For comparison, we also analyzed the forecasts of an AR(1) model, the random walk model and a multiple regression model with all explanatory variables. For the BMS, the AR(1) model and the multiple regression model, the coefficients were re-estimated over a recursive estimate period from January 2000 until September 2017; the one-step forecasts are then based on these coefficients. Figure 3 shows the performance of the three forecast models.

The best result is achieved with the BMS concept followed by the multiple regression. The weakest result came from the simple AR(1) model. The greater usefulness of the BMS model compared with the multiple regression is most likely attributable to a more parsimonious parameterization and the aggregation of the forecast values. The performance statistics in table 2 confirm the results.

BMS delivers the highest risk-adjusted return and lowest drawdown. To examine the reasons for this,

Figure 3
Performance comparison



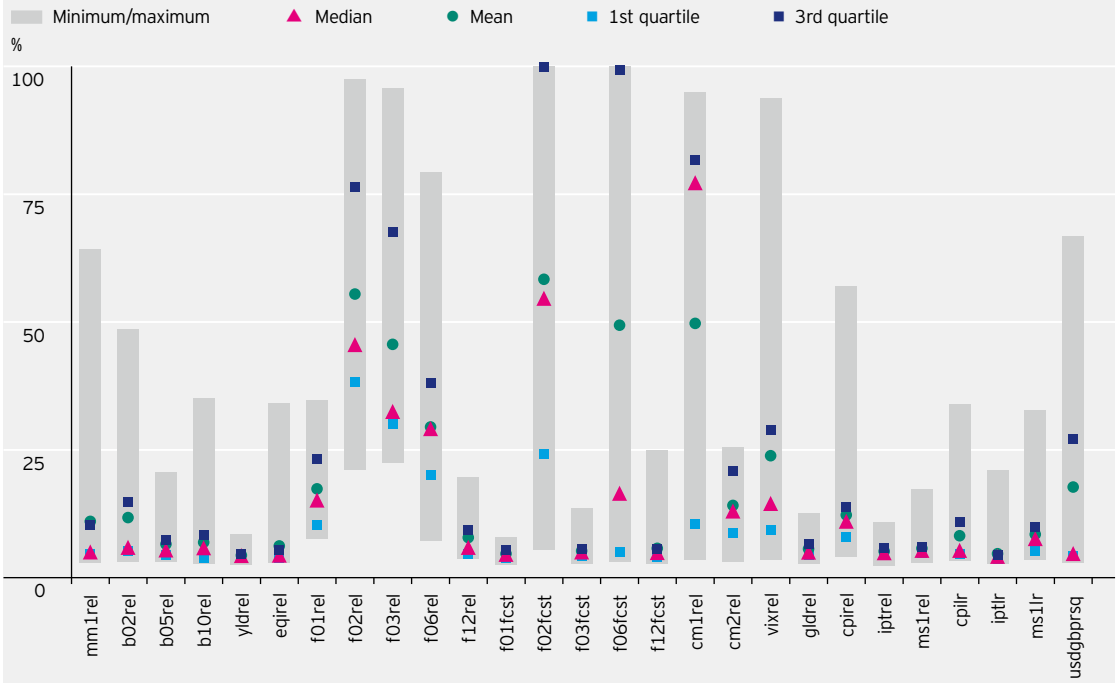
Source: Invesco. Data as at September 2017.

Table 2
Performance statistics

	BMS	AR(1)	Random walk	OLS
Return	5.31	-3.67	-0.10	2.65
Standard deviation	8.69	8.90	8.82	8.80
Information ratio	0.61	-0.41	-0.01	0.30
Average drawdown	3.96	14.75	11.80	6.25
Maximum drawdown	23.13	52.66	30.79	27.62

Source: Invesco.

Figure 4
Statistical ratios of the PIPs (backtest results)



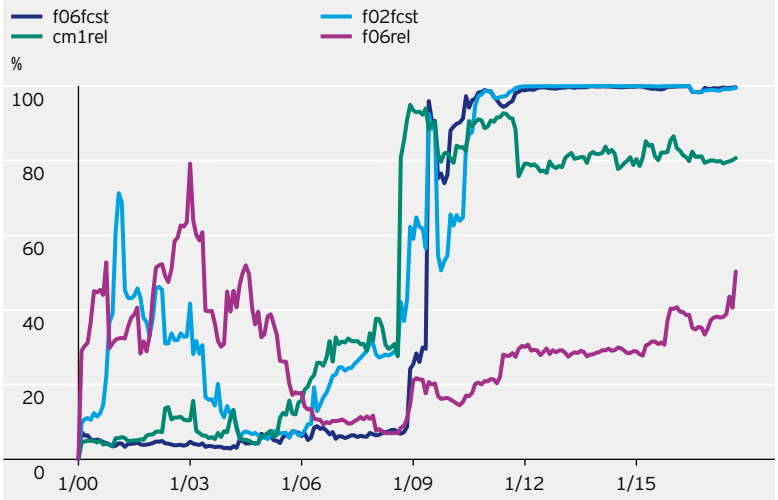
Source: Invesco.

we analyze the recursively-determined PIPs of each explanatory variable in the backtest period. Figure 4 shows the descriptive ratios minimum, maximum, median, mean, first and third quartile value of the respective PIPs.

The chart shows that the PIPs of the four most-important variables fluctuate very strongly. Other explanatory variables, such as the yield spread in the ten-year band ("yldrel"), are only of subordinate importance in the backtest period. The dynamic adjustment of the models is probably decisive for the performance.

This is also confirmed by the development of the PIPs of the four most important explanatory variables in figure 5. At the beginning of the control period they were of subordinate importance. However, the probability of them being included in a model rises noticeably during the subprime crisis. BMS can show this structural breach and allow for this in the forecasts.

Figure 5
Development of the PIPs of selected explanatory variables



Source: Invesco. Data as at September 2017.

Summary
In the final article of our series, we have seen how BMS can be helpful for selecting suitable forecast models and proved its worth in our empirical example. With BMS, different models are weighted with probabilities. Thus, like portfolio diversification, BMS ensures that all of your eggs are not in one basket.

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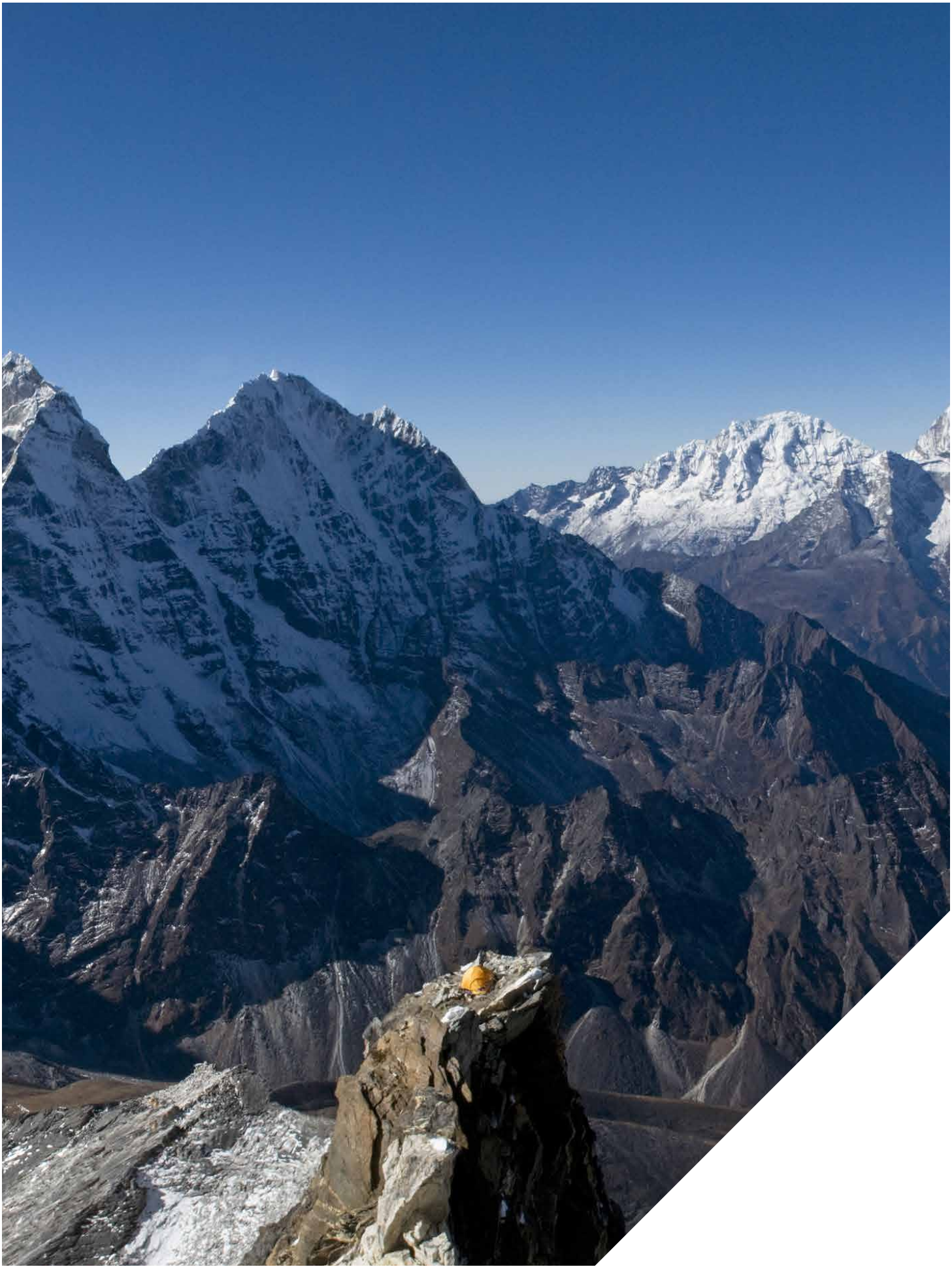
Notes

1 A general introduction to BMS with empirical applications and a summary of works published until the end of the 1990s can be found in Hoeting et al. (1999). Closely related to BMS is forecast pooling or forecast averaging introduced by Bates and Granger (1969), in which forecast values are aggregated from various models. A bibliographical survey is found in Clemen (1989).

2 To simplify the notation, we have left out the time index *t*.

3 All calculations were carried out using the free statistical programming environment R 3.4.2 (see R Core Team, 2017) as well as the CRAN packages bsts (see Zeugner and Feldkircher, 2015), PerformanceAnalytics (see Peterson and Carl, 2014) and zoo (see Zeileis and Grothendieck, 2005).

4 Data source was Thomson Reuters Datastream. The mnemonics of the raw data are: BBGBPSP, BBGBP1F, BBGBP2F, BBGBP3F, BBGBP6F and BBGBPYF (spot rates and forward rates); BBUSD1M and BBGBP1M (one-month money market rates); BMUS02Y(RI), BMUK02Y(RI), BMUS05Y(RI), BMUK05Y(RI), BMUS10Y(RI), BMUK10Y(RI) (performance indices of government bonds with maturities of two, five and ten years); BMUS10Y(RY) and BMUK10Y(RY) (generic current yields on ten-year government bonds); MSIUSA$(RI) and MSIUKN$(RI) (MSCI performance indices for equities); DJUBSTR(TR), GSCITOT(TR), GOLDBLN and CBOEVIX (commodities and volatility indices); USCONPRCF and UKCONPRCF (consumer price indices); USM1....B and UKM1....B (money supply M1) and USIPTOT.G and UKIPTOT.G (industrial production). From this raw data, corresponding (logarithmic) ratios and their changes were derived.



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