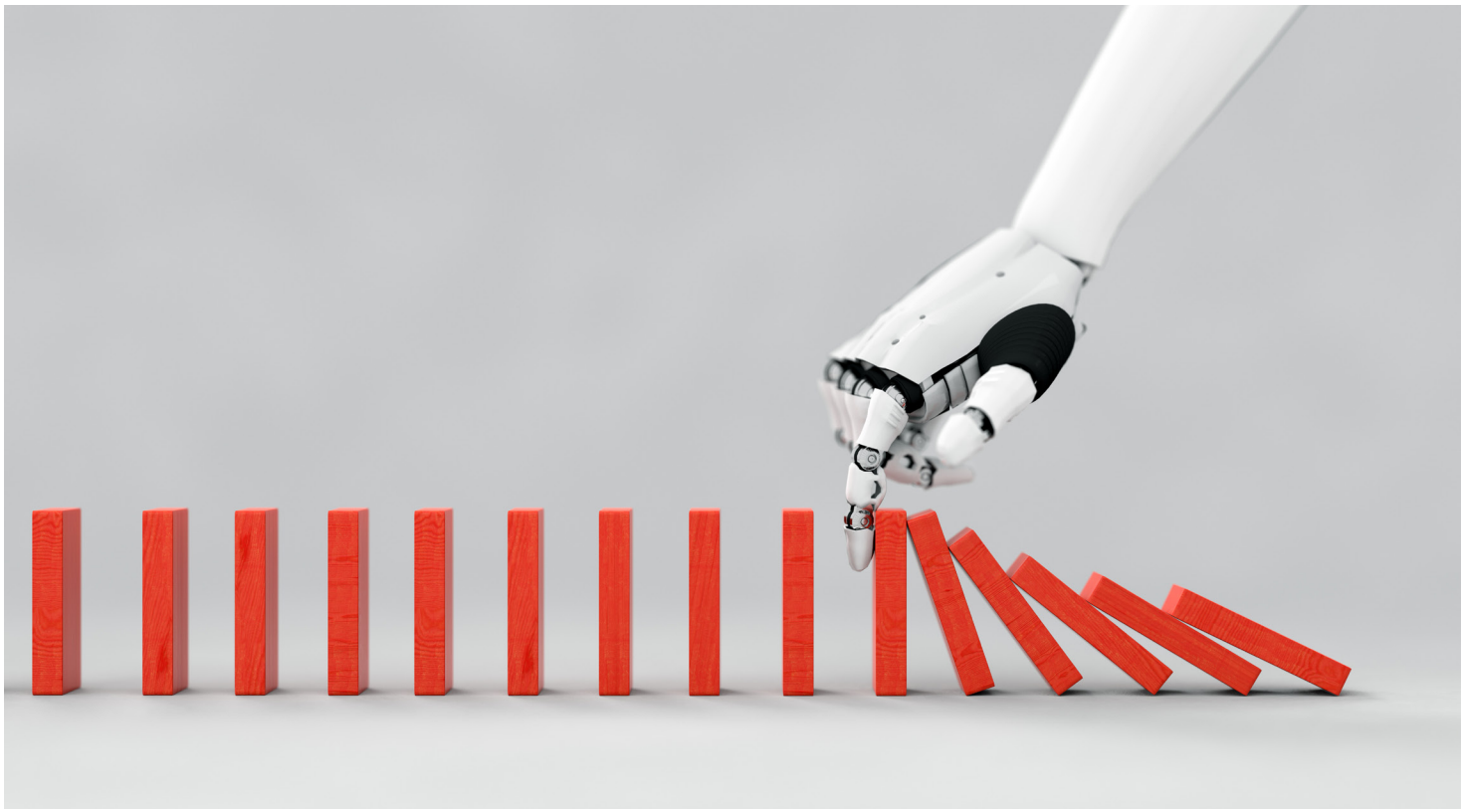

The Technology Frontier: Investment Implications of Disruptive Change

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Technological progress predates Silicon Valley by at least one million years, when humans first lit a controlled fire in the Wonderwerk Cave in South Africa – generating warmth, cooked food, and protection from predators.[1] Since then, the pace of technological change has been highly non-linear – the flute was invented over 35,000 years ago, the wheel only 5,500 years ago – with accelerations and decelerations in between.[2]

While we do again appear to be in an era of rapid technology-driven disruption, one might ask whether this era of technological change is truly different. We believe the answer is a categorical "yes", for three distinct reasons.

First, the pace of technological change is unprecedented. While it took on average 121 years for countries to adopt steam and motor ships after they were first invented, it took only 16 years for personal computers and 7 years for the internet (Exhibit 1).[3]

Second, technological innovation has gone global. Tightly integrated cross-country supply chains have fostered "reverse innovation."[4] Firms in industries as varied as advertising and healthcare have been using technology developed in emerging markets to drive growth in developed markets, for example, where mobile-advertising platforms developed in India have been rolled out globally and mobile healthcare delivery services developed in Kenya are being introduced to patients in Europe.

Cross-country collaboration has been further enabled by the speed and cost-efficiency with which code and IP can be transferred between countries, relative to the traditional model of foreign direct investment and large-scale talent transfers to emerging markets. Building off this local knowledge base, China in particular has taken the lead in a number of high-tech fields. China leads the world

in the mass implementation of AI-enabled facial-recognition, and China's share of the highest performing supercomputers globally is up from 15% in 2014 to 32% in 2017.[5]

Third, technologies today are merging previously disparate fields between the physical and digital worlds, in areas such as biogenomics, the internet-of-things and 3D printing. Imagine, for example, the prospect of a "neural bypass" surgery in which an AI-driven chip inserted into a quadriplegic patient's brain allows them to control limb movements with their thoughts. Ten years ago, this would have seemed like science fiction. Yet, as first reported by the journal *Nature* back in 2016, today this is possible.[6] Similarly, farming – perhaps the oldest, most physical industry humans have undertaken – is beginning to digitize, with smart sensors and satellite imagery being used to increase productivity and conserve water and energy.

A world in rapid technological flux will profoundly change many aspects of human life and work. Our focus is on the investment implications of disruptive technological change. To date, the investor lens has been somewhat narrowly focused on the tech sector itself and venture capital-backed startups. We believe institutional investors should broaden their aperture and view technological change across at least three dimensions:

Macroeconomic implications. Why are we not seeing rapid technological change translate into rising productivity? We argue in Section 1 that the boost in productivity is coming, but there is an inevitable lag between technological innovation and the spread of tech-enabled productivity improvements to a wide number of firms – a lag that has been exacerbated in this technology cycle by the fact that several near-term technological benefits are being captured by a few "winner take all" firms, while other companies lag significantly behind the adoption curve.

Industry implications. Since technological change is impacting companies far beyond the formal IT sector itself (think Amazon's impact on retail or Netflix's on media), the very idea of a "tech sector" may no longer make sense. In this new environment, how should we think about the investment implications of technological change on other sectors of the economy? In Section 2, we illustrate new investment opportunities in the real estate, energy, and consumer goods sectors.

Portfolio implications. Beyond specific sectors and asset classes, technological disruption can impact the fundamental nature of how portfolio-wide opportunities and risks are assessed. We believe the current wave of technological change will reshape how chief investment officers (CIOs) evaluate the risks and rewards of investing in companies at risk of tech-driven disruption, the investment strategies and vehicles they choose, how they assess their in-house teams and external managers, and how technological, regulatory, and political risk are increasingly interconnected. This is the focus of our concluding section.

While technological disruption may pose risks to investors' portfolios, it also opens a new set of investment opportunities. We hope that institutional investors find the next three chapters a useful and informative guide to navigating this current wave of rapid technological change.

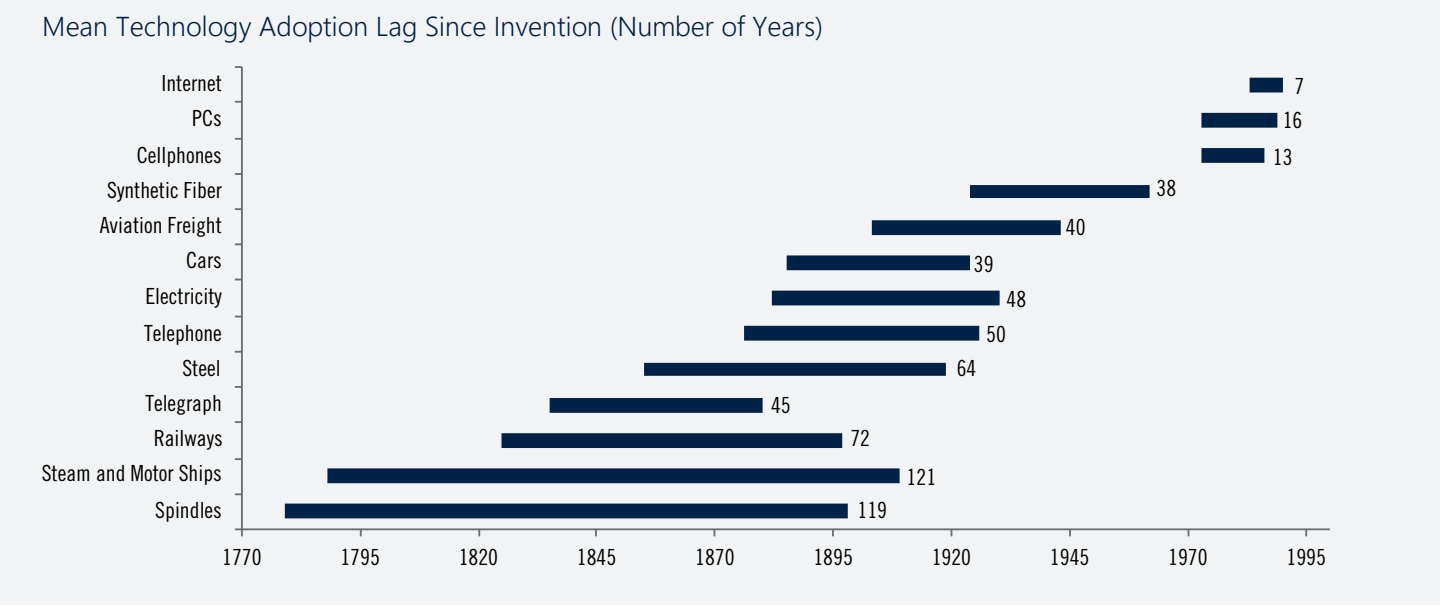


Exhibit 1: Technologies are Being Adopted Across Countries at an Accelerating Pace
Source: Diego Comin & Martí Mestieri, 2018. "If Technology Has Arrived Everywhere, Why Has Income Diverged?," American Economic Journal: Macroeconomics, volume 10(3),pages 137-178
Note: The adoption lag represents the average number of years that it has taken for a representative set of countries to begin using new technologies from their date of invention.

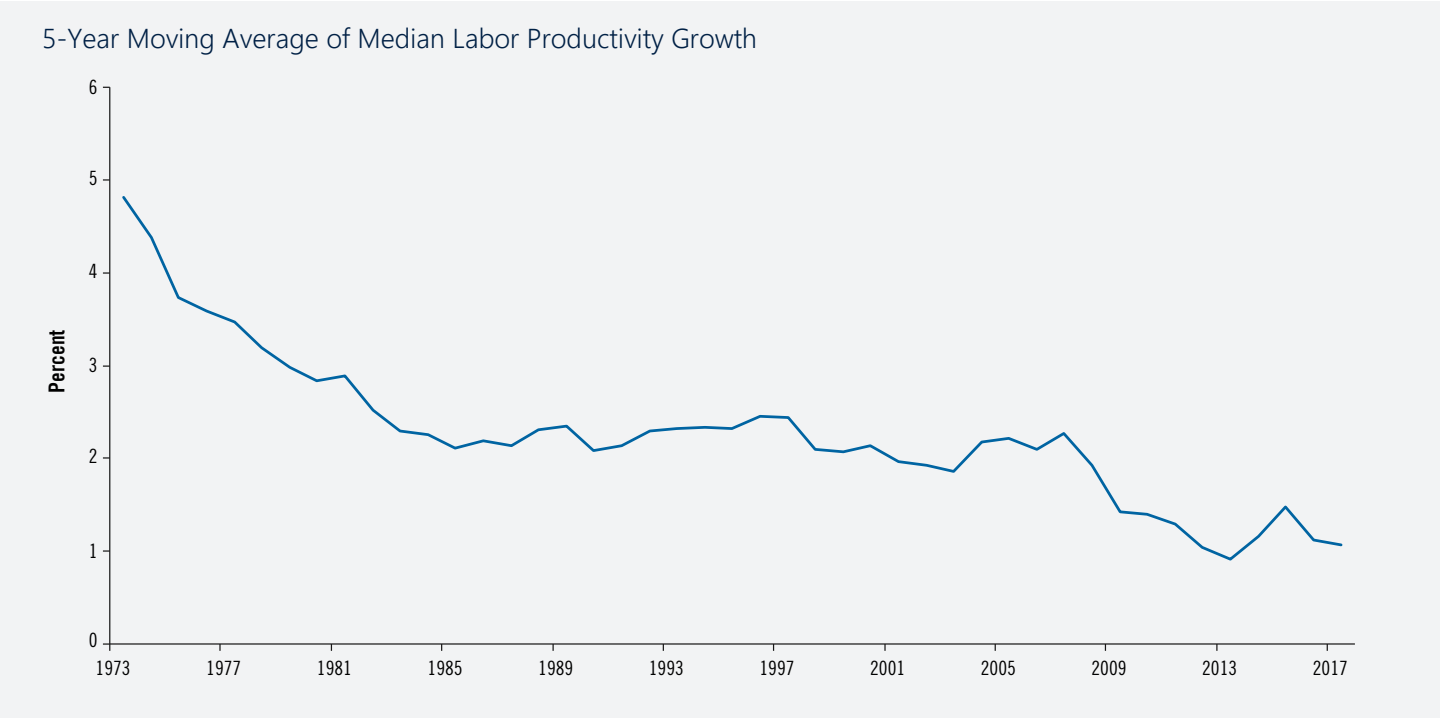


Exhibit 2: Global Labor Productivity Growth has been Declining Since the 1970s
Source: Conference Board, as of September 4, 2018
Note: Labor productivity is defined as GDP per hour worked, by country.

Section One: Technology and the Productivity Puzzle

How can technology transform every aspect of our world and yet not reveal itself in the productivity statistics (Exhibit 2)?[7] Why aren't the multitude of powerful innovations – smartphones, cloud computing, big data, artificial intelligence, genomics, and more – lifting labor productivity in the U.S. and other advanced economies? The answer to this question is of great importance as productivity is critical in determining long-term macroeconomic growth, real wages, and the attractiveness of assets and prospective returns available to investors.[8]

We believe rapid technological change and digitization will in fact drive significant labor productivity growth globally but have not yet been picked up in the aggregate productivity statistics for four primary reasons.

Slow Diffusion of Technology Across Sectors

First, the adoption of new technologies is still highly uneven across sectors, driven by the time and investment required (both in the technology itself, and the business process and personnel changes required to take advantage of new technologies) by firms outside of the IT sector. McKinsey's Industry Digitization Index highlights this divide: while some sectors are on the forefront of digitization (e.g., information and communications technology, media, professional services, advanced manufacturing, and oil and gas) other major industries (such as construction, agriculture, healthcare, and government) lag far behind.[9]

The wave of technological advancement in the late 1990s is a useful reference point. From 1995 to 2000, IT-producing firms represented nearly 60% of overall productivity growth, as they developed cutting edge technologies built on the Internet. From 2000 to 2007, IT-using firms began adopting these new technologies, and together the two sectors combined represented ~90% of productivity growth over that period.[10] We may very well see a similar story play out in the current wave of innovation: technology is invented in the IT sector, and only over time do a critical mass of firms in other industries reap the benefits of adoption.

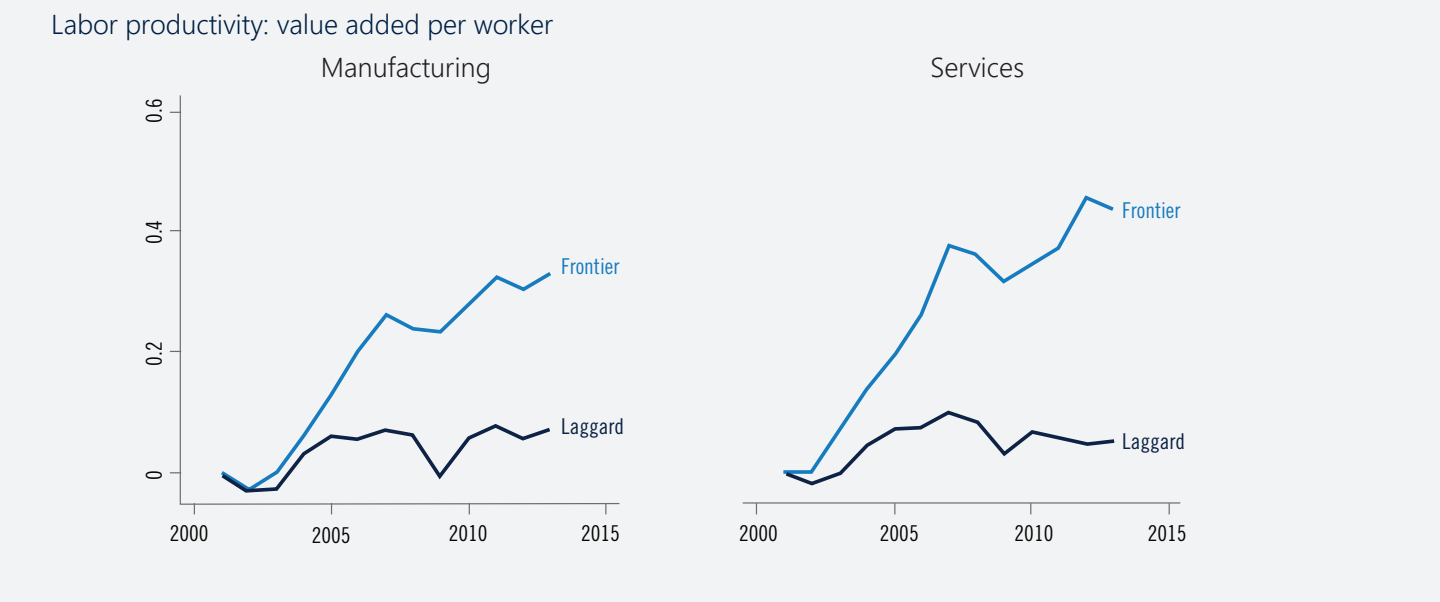


Exhibit 3: The Labor Productivity Gap Between Global Frontier Firms and Laggards is Widening
Source: Dan Andrews, Chiara Criscuolo and Peter Gal, 2015. "Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries," OECD Future of Productivity: Main Background Papers

Winner Takes All

Second, the productivity gains from many recent technologies have been concentrated in a small group of firms while the rest of their sectors have remained largely undigitized or unable to compete against the superstar firms. These "frontier firms" – younger, more profitable, and more patent-intensive – tend to be the first to adopt cutting-edge technologies, and fundamentally diverge from the rest of their sector in terms of productivity growth (Exhibit 3).[11]

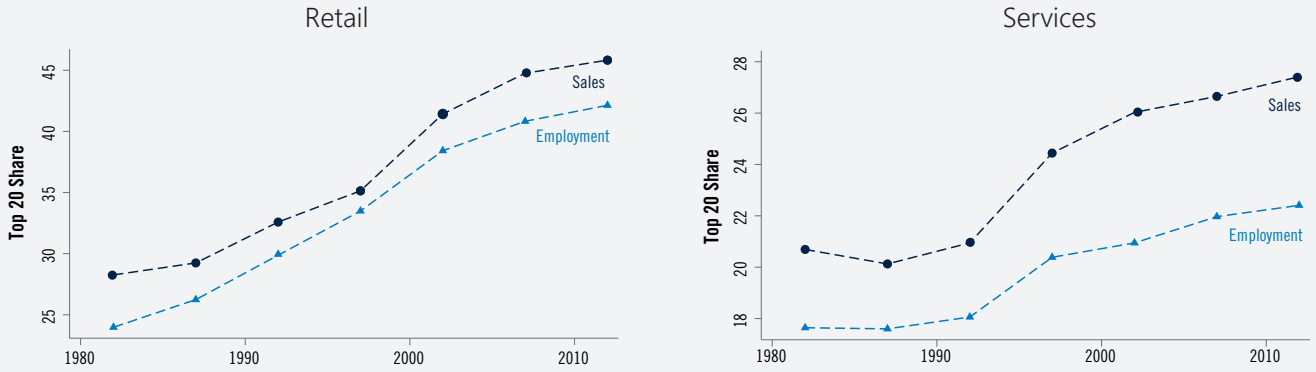
Under these conditions, a single firm often emerges with a dominant market share (e.g., Amazon in retail and as a third-party platform, Uber in transportation, AirBnB in home sharing, Google in search, and Netflix in streaming content). This "winner takes all" model means new entrants can rapidly displace long-lived institutions and blaze a trail of destruction. Indeed, sectors with leading digital firms have begun to see significant concentration – with this rising concentration positively and significantly correlated with investments in proprietary IT systems and the growth of patent intensity.[12] This is already playing out in the U.S., where there has been significant industry concentration across major sectors since the 1980s both in terms of sales and employment (Exhibit 4). For example, digitization of the U.S. retail sector has led to significant industry concentration: Amazon's 2017 e-commerce sales were 2.3x more than those of Walmart, Target, Best Buy, Nordstrom, Home Dept, Macy's, Kohl's, and Costco combined, and accounted for 43% of total U.S. e-commerce sales, up from 33% in 2015 and 25% in 2012.[13]

This "winner take all" trend is not just playing across the large digital platforms. As information and communications technology prices continue to decline, larger firms have proven more capable of exploiting technology-driven opportunities. For example, large retailers have invested in proprietary technology and complementary human and organizational capital to develop deeply integrated supply chain networks, allowing them to offer more variety at a lower cost than smaller "mom-and-pop" stores.[14]

By capturing productivity gains from new technologies in a single, dominant player with network or scale benefits, this trend towards a "winner takes all" economy acts as a near-term dampener on broad productivity gains among the other firms in a sector. And unfortunately for new entrants, while patents and large legal teams can be used by leading firms such as Apple or Netflix to defend their IP, it is difficult for smaller firms to prevent their advancements such as algorithms or knowledge-based capital from spreading.[15] As a result, leading firms can sometimes undercut new entrants by copying their approach. One example is Instagram's launch of the Stories feature, replicating a key feature of Snapchat – and leading to a significant decline in Snapchat usage growth.[16]

Over time, the most productive firms will steadily win out. While this outcome is not predetermined, as these firms – either the monopolistic giants or new attackers – take a larger share of the global economy, aggregate productivity should increase in-step.

4A: Industry concentration has increased across key sectors in the U.S.



4B: Industry concentration has increased across key sectors in Europe

Share of gross output produced by the top decile of firms (as measured by sales)

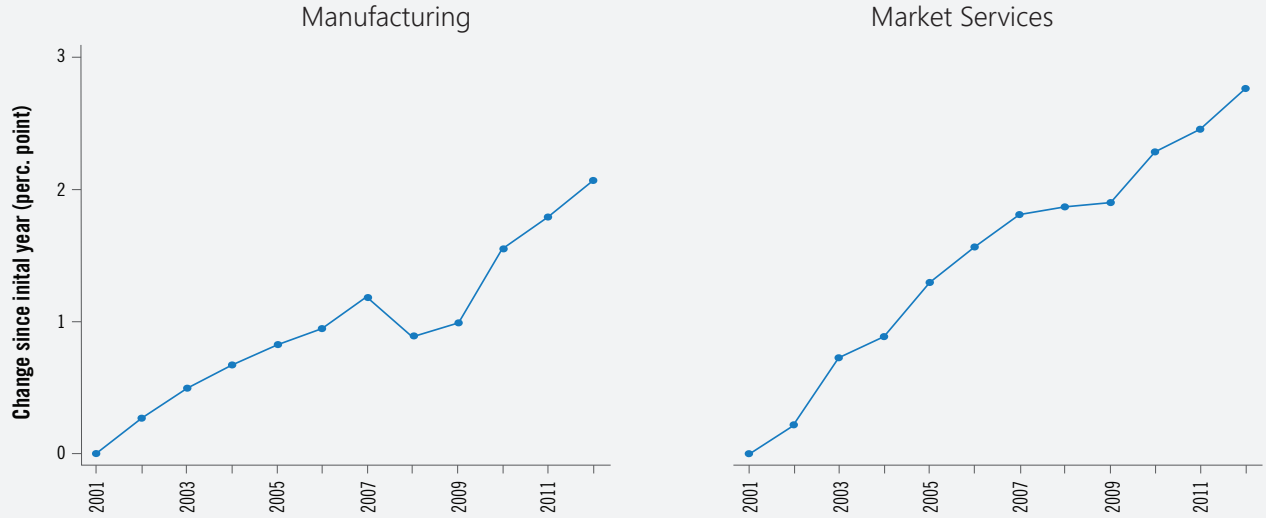


Exhibit 4

Source: David Autor et al., 2017. "The Fall of the Labor Share and the Rise of Superstar Firms." National Bureau of Economic Research Working Paper Series. OECD Multiprod, Criscuolo (2018) via Van Reenen, John, "Increasing Differences between firms: Market Power and the Macro-Economy", Kansas City Fed, August 31, 2018

Note: Countries included in the study include Belgium, Germany, Denmark, Finland, France, Norway, Portugal and Sweden. Gross output measures the value of products produced or sold to a firm's customers, including both intermediate users and final consumers. The measure may differ slightly from 'total sales' due to accounting rule differences across industries.

Measuring Productivity Gains from Technological Change: An Army of Red Herrings?

An often heard view is that slow productivity growth is simply an issue of mismeasurement: the benefits from technology are real, just not appropriately captured in the national accounts. While there is some truth to this argument, we believe this explanation is largely a red herring. Yes, there are measurement concerns, but they have always existed and are in no way unique to this current wave of technological change.

Two hypotheses are generally raised. The first argument is philosophical. Many benefits from technological change are felt in social welfare, but not captured in GDP: our smartphones can capture and share photos at zero cost, and with GPS can prevent even the navigationally challenged from getting lost, but the value and personal satisfaction is not captured by GDP.* The second argument is technical: some economists worry that the price indices underlying national accounts data do not appropriately capture new products or quality improvements from one generation of technology to the next, suppressing true GDP and productivity growth. It is estimated this effect leads GDP growth in the US and the UK to be underreported by 0.35 to 0.66% annually.[17]

Both of these concerns clearly have merit; however, neither phenomenon is unique to the current wave of technological change and have been longstanding sources of measurement error. For example, in the mid-20th century GDP captured the direct sales and advertising revenues from the advent of television, but failed to account for the broader benefits of having a new form of entertainment in our homes. Similarly, while it is inarguably difficult to capture quality improvements in price indices, this problem has also existed for decades. Most recently during the dot-com era, new goods and services were regularly introduced (and the computers that powered these advances were updated yearly, if not more often), yet technology-driven productivity growth showed up and indeed accelerated through the late 1990s and early 2000s.[18]

We do not question whether GDP or productivity is mismeasured – it almost certainly is. But while there are no doubt longstanding biases in the calculation, to account for the recent deterioration in productivity growth those biases must have become markedly worse. There is currently no compelling empirical evidence to suggest that is the case.

* According to Hal Varian, chief economist at Google, the number of photos taken worldwide has increased from 80 billion in 2000 to 1.6 trillion in 2015, while the price per photo has declined from 50 cents to 0 cents. However, this doesn't show up in GDP measures since the price index for photography includes the price of film, photos are mostly shared and not sold, and GDP declined when cameras were absorbed into smartphones.

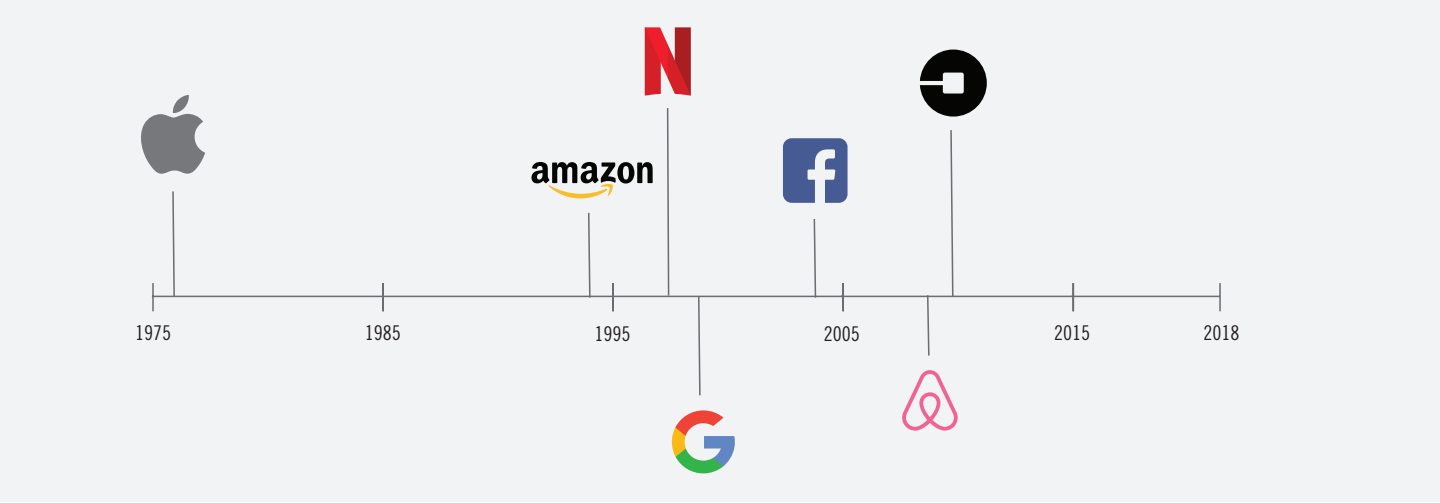


Exhibit 5: Today's Technology-Intensive Corporate Giants Have Taken Years to Reach Their Current Size
Source: Company Websites

Productivity as a Lagging Indicator

The history of technological change tells us to be patient: converting new technologies into productivity gains requires new business investment as well as ancillary changes in processes, personnel and behaviors that have always taken longer than expected (Exhibit 5). It also requires firms to figure out how to apply new technologies, which often get stuck in the R&D phase, to their industries.

Similarly, e-commerce has taken longer than originally anticipated to reach its current impact. With much hype, Phil Brandenberger fundamentally changed the retail sector by making the first ever online purchase in 1994, using his credit card to buy a compact audio disk.[19] Analysts spoke about how e-commerce would drive down margins, increase customization, and, at some point, expand into a "really big business."[20] Yet, even though e-commerce was first adopted in 1994, it took nearly 25 years for sales to approach 10% of total retail volume, as complementary investments in distribution infrastructure, secure payment systems, and customer "retraining" took quite a long time.[21]

This generation of technology will likely play out in a similar fashion. For example, according to a 2017 study by MIT and BCG, almost 85% of executives believe AI will help their companies obtain or sustain a competitive advantage – and yet only 20% actually incorporate AI in any of their products or processes.[22]

The Global Digital Divide

The slow spread of new digital technologies, and the potential productivity gains from them, is exacerbated by the limited global penetration of even basic Internet access. Nearly 60% of the world's people are still offline and do not participate in the digital economy, with a sharp divide between Asian emerging markets such as Korea, which has among the highest broadband usage in the world, and many sub-Saharan African economies where less than 10% of the population has Internet access.[23]

Furthermore, even in some emerging markets with high rates of technology adoption, digital adoption has not led to a digital dividend. This is due to a lack of the ancillary "analog" investments, unequal access to the Internet, and a lack of foundational regulations that create a robust business climate and let firms leverage digital technologies effectively (Exhibit 6). The absence of these required reforms limits the ability of a range of countries to benefit from the leapfrogging power of new digital technologies. However, we believe that over time they will catch up and drive productivity upwards, as seen with prior technologies such as the green revolution or globally integrated supply chains.

Despite the long lags and slow diffusion, it is important for long-term investors not to lose sight of the most likely end outcome: since 1995, industries either producing IT or using it intensively have accounted for nearly all US productivity growth.[24] This current wave of technological innovation will be equally important in driving global productivity and growth – and while we will need to be patient to see this impact accumulate over time, it is coming, and investors need to be prepared.

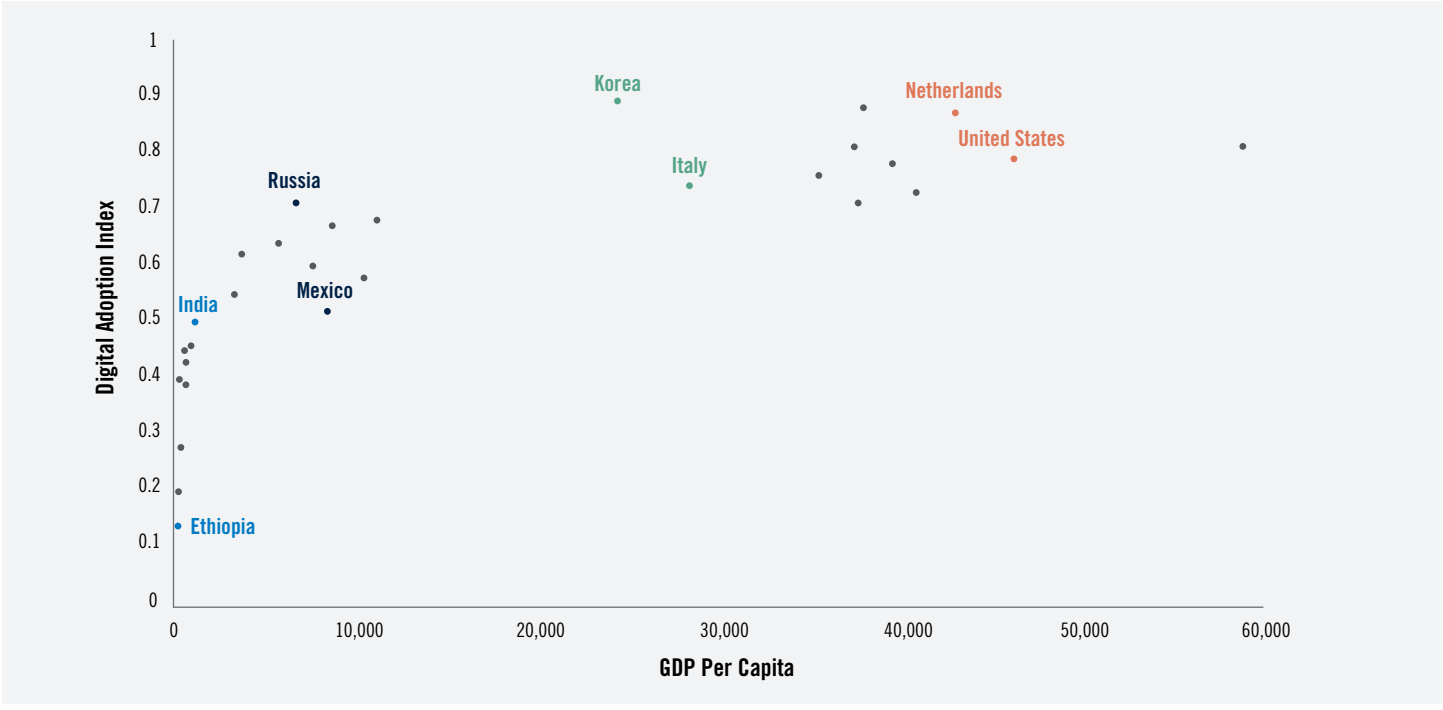


Exhibit 6: Digital Adoption Varies Significantly Even at Similar GDP Per Capita Levels
Source: World Bank Databank, as of August 17, 2018
Note: The Digital Adoption Index represents an estimated rate of adoption of new technologies by governments, people and businesses in a given country.

Section Two: Technology Beyond Tech's Borders

Rapid technological change is vital to understand because its impact extends far beyond small start-ups – and indeed far beyond the formal "tech" industry. The current wave of new technologies will radically reshape the business and investment opportunity set across all industries globally, and across companies both small and big.

While this broad diffusion will take time, ultimately this is where the power of technological change will be unleashed. The initial investments required are already being made: companies as diverse as Caterpillar, FedEx, Under Armour and Domino's Pizza are investing in artificial intelligence capabilities, while at one point in 2017 UnitedHealth Group was hiring the largest number of tech workers – nearly 15x the number being hired by Amazon.[25] Sectors as diverse as payments, entertainment, gaming (e.g., e-sports), transportation, logistics, and media and content are likely to be transformed as they adopt new technologies.

We illustrate the wide-ranging and sometimes unexpected investment implications of technological change through deep-dives into three sectors that collectively comprise over 30% of US private sector real GDP: real estate, energy, and consumer products – three "real world" sectors where the current wave of technological change is creating new investment opportunities and risks.[26]

Real Estate

New technologies are changing how we work and how we live – changes that will, in turn, fundamentally transform how real estate is developed, used, and repurposed. While some of these changes in real estate could be slow-moving at first, the cumulative impact will be immense.

The elastic mile. Technology is fundamentally altering the "time-distance value proposition". Historically, there has been a premium paid for real estate that optimizes the tradeoff between time and distance. For example, people are willing to pay more to live close to where they work, shop, or go to school, or to commuter hubs that get them to these destinations. Yet, emerging technologies may dramatically change the opportunity cost of traveling. For example, flexible and remote work schedules and locations are on the rise, enabling employees and entrepreneurs to potentially structure their residential choices around entertainment and comfort, rather than access to the office. Similarly, the shift from bricks-and-mortar retail to e-commerce may reduce the benefits of multifamily housing adjacent to major retail outlets but increase the value of last-mile distribution centers and warehouses. As a result, investors will need to evaluate investment opportunities keeping in mind the shifting time-distance trade-offs in a world with a higher share of flexible work locations and online delivery options. While proximity to friends and community will always be important, developments such as flexible work locations and online shopping – as well as autonomous vehicles that will allow riders to use their commuting time more productivity (e.g., working, sleeping, or leisure) – might, for example, significantly reshape the relative importance of measures such as "walk scores" and "transit scores" in evaluating real estate opportunities.

From car ownership to car travel. While still in their early stage of adoption, autonomous vehicles are expected to accelerate the changes in the time-distance tradeoff described above. Furthermore, car ownership could be radically down when combining automated cars with the rise of a sharing economy (as epitomized by companies like Uber) – America's current parking footprint, often in prime real estate, is estimated at over 500 million parking spaces, consuming more land than Delaware and Rhode Island combined.[27] Cars in the US stand unutilized 95% of the time.[28] The effects of the broad adoption of autonomous cars – both passenger vehicles and commercial vehicles – on the movement of people and goods could have quite dramatic effects on real estate (Exhibit 7).

"Future proofing" real estate. While some of these technological changes might seem far off, investors must begin adapting their investment strategies today to navigate an evolving, and inherently illiquid, real estate market. This will require building in the flexibility to convert assets, potentially through higher capital costs or more thorough planning. In turn, owners of such newly constructed, flexible, state-of-the-art assets will experience greater demand and will be compensated by higher rents from tenants that are able to extract more value out of their spaces. Parking garages offer a prime example. Given the eventuality of technologies such as autonomous vehicles, garages are now being designed with level floors (rather than ramps) and higher ceilings to allow for easy conversion to alternate uses such as delivery terminals. Industrial and logistics warehouses globally are another example, where it may be prudent to construct buildings with clear heights in excess of near-term tenant demand to meet future demand for higher racking systems. And in the U.S., there is potential value in ground-up investing in state-of-

Potential Winners	Potential Losers
Larger logistics distribution hubs	Car dealerships and some related businesses
Suburban multifamily housing	Transit hubs
Tech related markets	Paid parking garages
Repurposed garage spaces in malls and condos	Transit-oriented hotels

Exhibit 7: Potential Impact from Autonomous Vehicles

the-art multifamily housing, with building infrastructure that has package space to store e-commerce deliveries and cold storage for delivered groceries; retrofitting these elements would often be cost prohibitive or physically impossible.

Retail, reinvented. We have seen a "tale of two sectors" playing out between physical retail and logistics markets. As e-commerce sales have grown, the demand for physical retail has weakened, with a likelihood of further store closures, bankruptcies and nonrenewal across most developed markets.[29] In contrast, demand for the logistics centers that enable online sales has been growing in most parts of the world. Logistics providers are taking space to meet increasingly challenging consumer-oriented supply chains, notably relating to rising demand for same-day delivery – leading to a demand for infill and "last mile" locations that serve major population centers.

However, not all is doom and gloom in the retail sector. Amazon's purchase of Whole Foods in mid-2017 will be an interesting experiment in the potential value of a strong physical retail presence in an omnichannel model. Increasingly, landlords are looking for ways to differentiate by offering a mix of service and experience-oriented tenants in their malls and centers, such as restaurants, salons, and fitness centers. At the same time, online retail platforms are increasingly opening physical stores, blurring traditional lines and demonstrating that retail asset owners need to actively respond to ongoing changes in retailer business models and consumer shopping habits. Meeting the needs of increasingly impatient consumers may well require retailers to shift from "same day" to "one hour" delivery – leading the old-fashioned retail storefront to be reinvigorated and reinvented as part brand experience, part "last mile" warehouse for seamlessly meeting the physical and digital demands of a customer base looking for near-instant retail gratification. Zara has begun experimenting with this concept, enabling its retail locations to ship directly to consumers that have made online purchases; other retail firms may follow.[30] Overall, online retail may help streamline "over-retailed" markets (such as the U.S.), but it is likely a smaller group of forward-looking, higher quality bricks-and-mortar stores will continue to thrive.

Tokenization. The combination of blockchain ledger technology and smart contracts could, in theory, allow the securitization of real estate assets at the single asset level, broken down into practically limitless fractionalized units accessible to retail or institutional investors. Examples of tokenization or unitization in the real estate market already exist. BrickX, an Australian real estate company, breaks down properties into 10,000 fractional units which are sold to investors via an initial offering and can then be traded on an in-platform secondary market, reducing the illiquidity often associated with real asset investments. The adoption of tokenization is likely far off in markets such as the U.S. that have more liquid investment markets, established regulatory environments, and deeply entrenched ownership and transfer processes. But investors may find greater future opportunity in markets that don't have deep, liquid REIT markets and that might benefit from the additional title security of distributed ledger technology. While tokenization of the real estate market is nascent at this point, long-term institutional investors will want to monitor developments in this space.

Energy

The energy sector has long been at the forefront of technology, both analog and digital. In the 21st century, the combination of horizontal drilling and hydraulic fracturing has opened access to vast oil and gas reserves and fundamentally changed the role the U.S. plays in global energy markets. Going forward, the introduction of new energy extraction and power generation technologies will continue to reshape the sector – radically lowering the cost of accessing energy, while enabling renewables to play a larger role.

Diversifying across production methods and geographies. The most disruptive – and environmentally controversial – innovation in the oil and gas industry in the last decade, shale fracking with horizontal drilling, has reshaped the exploration and production industry. By opening access to reserves in Texas, Pennsylvania and North Dakota, fracking has shifted the balance of pricing power away from traditional OPEC energy producers and helped give rise to independent operators such as EOD and Anadarko. These players can respond rapidly to price spikes and dips and have helped transform the industry's slow multiyear boom-bust cycles to faster, shallower price fluctuations.

Among traditional producers that now must navigate these shorter cycles, investors may want to focus on firms that are diversifying their production in two ways. First, investors should look for producers that have taken steps to complement long-term, capital-intensive projects like deepwater exploration with shorter-cycle (and capital light) shale opportunities in North America. Second, investors may want to closely monitor fracking developments outside North America, such as projects in Argentina, Russia, China, and select Middle Eastern countries. BP, for example, recently invested over $12bn on a horizontal drilling and fracking project in Oman.[31] Investors should recognize, however, that there is a robust debate on the global expansion of fracking, as key infrastructure – including access to water and sand, copious data on subsurface geology, a built-in pipeline network, and ownership structures that incentivize development – are limited outside of North America.

Capturing cost advantages beyond fracking. With further cost reductions from fracking likely limited in the near-term, firms have begun turning to advanced robotics, automation and big data to drive production costs down and increase productivity still further – essential in an environment of lower crude prices and rising labor costs.

Advanced drilling systems are a key piece of the puzzle. For example, automated pad drilling systems allow rig operators to drill groups of wells more efficiently by "walking" a drilling rig to the next drill site, instead of having to break the rig down and reassemble it at the new location.[32] Advanced drilling technologies such as steerable drills and measurement-while-drilling systems allow operators to pinpoint exact locations of reserves, make real-time adjustments to drilling paths to reach those reserves, and as a result extract increasing volumes of oil and gas while using fewer workers (Exhibit 8).[33] And as more drilling processes become remote or fully automated, small teams of technical specialists sitting in operation centers miles away are beginning to replace skilled laborers on the ground.[34] These tools are already being put

into practice; Norwegian oil company Equinor recently developed an offshore drilling rig designed to run without a single human on board.[35]

Underlying the success of these advanced drilling techniques are analytical capabilities that can capture vast amounts of geological information, process it quickly, and provide actionable insights to rig operators on the front lines. Some of the largest operators are choosing to develop this knowledge base in-house: EOG Resources, for example, has developed over 60 in-house apps to boost returns and increase production by aggressively hiring data scientists and computer-science graduates from the University of Texas at Austin.[36] In other cases, oilfield services firms are looking to sell data analytics tools to the sector; for example, in 2017 Schlumberger launched a cloud-based platform that aims to be a central clearinghouse for industry data and a platform for advanced analytics.[37]

These and other advanced technologies will continue to drive global production costs lower – and firms that are unable to keep up will have trouble surviving over the long term. Against this backdrop, asset owners should carefully evaluate their investments in the sector to ensure their portfolio companies are investing appropriately in cost-saving technologies and staying ahead of the sector's relentless cost pressures.

Emergence of cost-effective renewable power. Even as the cost to recover traditional energy sources comes down, cost effective access to renewable energy sources (such as biofuels, geothermal energy, solar, and wind) is growing at a rapid pace – contributing to a nearly ten-fold increase in global renewable energy consumption since 2000.[38] While renewables do not pose a direct threat to the oil and gas market in the near term – global energy demand is simply too high and the declining production of many mature oil fields will likely curtail global supply – the development of renewable power generation, paired with advanced battery technologies, is altering the energy landscape.

Even though costs have dropped significantly (solar power production costs, for example, have dropped by over 50% in the last five years), the intermittent nature of many renewables have prevented them from taking a larger place in the grid. Advances in both battery technology – enabling longer-term storage – and an emerging "smart grid" that can better balance power supply and demand will help make the contribution from renewables more stable. And network firms such as Cisco and ABB are developing smart grid technologies that will allow utilities to automatically identify and isolate outages, helping them get power back up and running more quickly. This combination of increased supply, better storage, and more-efficient demand management will allow renewable power to take a more central role in power grids.

For investors, the increasing demand for energy storage technologies may create attractive investment opportunities. Metals used in advanced batteries – such as cobalt and lithium – are generally sourced from a limited number of emerging market countries such as the Democratic Republic of Congo, while demand is expected to increase; McKinsey expects there to be nearly 140mn electric vehicles, a major user of advanced batteries, on the roads by 2030. The stage may be set for significant price volatility and the emergence of new competing materials in the coming years. At the same time, renewables are changing the types of financing needed in the utility space. Unlike a traditional power plant, battery projects often have lifespans of less than five years – and by the end of that time, new technologies have emerged that make older projects obsolete. Similarly, grid modernization projects incorporating new communications technologies only have lifespans of 5 to 10 years. Investors used to much longer-duration opportunities in the utility space will need to adjust their expectations accordingly as they aim to identify the right mix of duration, yield and risk for investments in the sector.

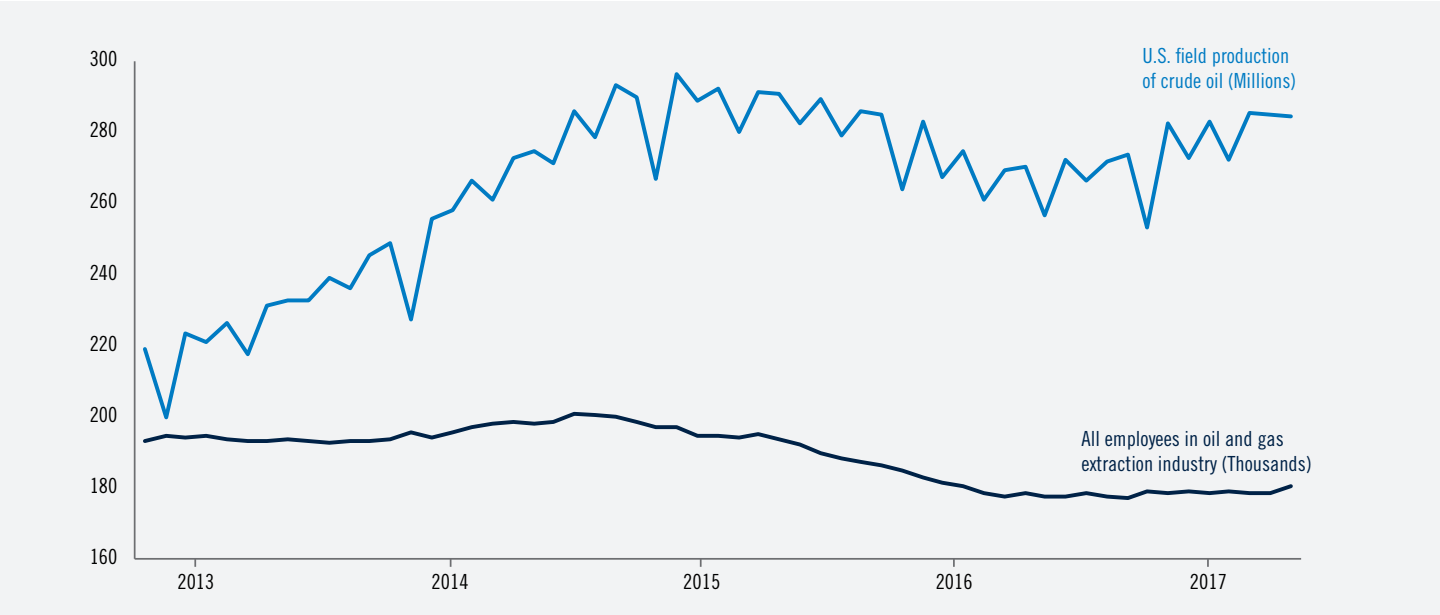


Exhibit 8: U.S. Oil Producers are Growing More Efficient, Extracting More with Fewer Workers
Source: Bureau of Labor Statistics and U.S. Energy Information Administration, as of May 3, 2018.

Consumer Goods

From social media to predictive analytics, the technological table stakes for consumer goods firms have never been higher. There are opportunities and challenges for small brands and global retailers alike, and investors will need to carefully choose where to place their bets based on a detailed evaluation of the firms that are best positioned to execute against that opportunity.

Small brands go global – and wholesalers suffer. Social media platforms such as Instagram and YouTube are allowing users to discover and build an emotional connection with brands from around the globe; witness the rise of Kylie Jenner's billion-dollar makeup brand in just three years. And globally integrated shipping networks developed by Amazon and other distributors mean that once the customer connection is made, brands can reach their consumers anywhere in the world – even remote villages in the Himalayas.

As a result, the power of traditional brick-and-mortar stores over consumer decisions is waning. Instead, as brick-and-mortar stores become showrooms, born-online brands are expanding from the digital into the physical world: firms like Bonobos and Warby Parker have actively built real-world storefronts or kiosks to drive online sales. Select traditional luxury brands that have prioritized maintaining a close connection with their consumers have succeeded here as well – for example, premium brands such as Bottega Veneta and Burberry have successfully gained market share in countries such as Brazil.[39]

As a greater share of customers' brand discovery moves into the digital world, investors will need to carefully evaluate the firms in their portfolios – culling firms whose role as gatekeeper is being disrupted and ensuring the firms they do invest in can successfully maintain a brand connection to their customers both online and offline.

Predictive analytics become table stakes. Just as technology is enabling consumers to find new brands, artificial intelligence – swiftly becoming the plumbing of the retail sector – enables brands to discover and understand the needs of their consumers globally, potentially even before the consumer knows. Advanced analytics can take in information about consumers' desires from a growing range of sources – their online purchases, social media interactions, Google and Alexa searches, smartphone and health device data, GPS routes on walks and commutes, etc. – and enable companies to create personalized messages and targeted advertisements, pushing information to the consumer based on their mood, preference, location and behavior rather than having to wait for them to request it in a store visit or online search. Amazon has even obtained a patent for "anticipatory shipping," a process for delivering products before a customer has even ordered them.[40]

As exponentially more data is collected and analyzed to deliver a seamless experience to consumers, scaled companies with the analytical resources and capabilities to mine that data are likely to drive consolidation in the market, moving ahead of older firms less able to leverage technology in understanding their customers' needs across their online and offline lives. Amazon's dominance of e-commerce sales is just one example.[41] Strong-branded, vertically integrated consumer product companies with direct-to-consumer distribution, speed-to-market advantages, flexible supply chains, and pricing power are likely to thrive.[42]

In this era of rapid digital evolution, investors need to understand how their portfolio companies – smaller, niche brands and global retailers alike – are investing in, and executing on, the cutting-edge technologies that hold the promise of cementing customer loyalty over the long term.

The shifting ground beneath investors' feet in real estate, energy and consumer goods are examples of a broader trend: the rapid creative destruction that disruptive technological change is unleashing across the global economy. In Section 3, we suggest actions institutional investors might want to consider as they explore these broader, portfolio-wide implications of the current wave of technological change.

Section Three: Portfolio-Wide Implications of Technological Change

While the current wave of technological change is intense, the pace of diffusion and potential impact varies significantly across sectors, regions and asset classes. How then should CIOs think about the implications across their portfolio? We believe long-term institutional investors should evaluate five possible actions to reap the benefits and avoid the risks of the current wave of disruptive technologies.

Position the Portfolio for Growing Obsolescence Risk

The economies of scale and network effects embedded in new technologies can rapidly displace traditional incumbent firms or even digitally-savvy firms late off the block. A single firm often emerges with a dominant market share (e.g., Amazon in retail and as a third-party platform, Uber in transportation, AirBnB in home sharing, Google in search, and Netflix in streaming content). This "winner takes all" model means new entrants can rapidly displace long-lived institutions and blaze a trail of destruction, with small differences in quality or cost creating large variations in success. This is not just happening in the tech sector. Industry concentration has increased across manufacturing, finance, services, utilities, transportation, retail trade, and wholesale trade alike.

Ironically, at the same time that new technologies have accelerated the death of traditional models, investor demand for longer-term investments has risen. In the U.S., for example, the average maturity of U.S. corporate bonds has increased from 9.5 years in 1996 to more than 15 years in 2017.[43] And investors are facing pressure to further lengthen the duration of their investments, for example as people are living longer and pension plans and life insurers adjust their portfolios to match the lengthening liabilities.[44] Additionally, the low-yield environment post-crisis has put pressure on investors to reach for additional yield by lengthening loan duration.

While lengthening maturities is not a new phenomenon, today's unprecedented pace of technological change can exacerbate the risks investors must weigh when making long-term buy-and-hold debt investments or illiquid investments in private assets, real estate or infrastructure. Those risks can include whether or not a

firm survives long enough for a successful exit or to repay their debts: fixed income investors may recall that Eastman Kodak issued $250mn of eight-year duration senior secured bonds – $50mn more than originally planned – less than twelve months before the firm filed for Chapter 11 bankruptcy.

Faced with growing obsolescence risk, there are two concrete steps that asset owners should consider. First, CIOs may consider forming a cross-asset-class team to evaluate the impact of technological change across all their holdings. This could include a combination of periodic market studies to see which asset types, securities, or sectors face a higher risk of obsolescence from disruptive technology as well as case-by-case qualitative assessments of individual portfolio companies that may be underinvesting in technology and have a higher likelihood of being left behind.

Second, long lock-up or long-duration investments (in particular those with credit portfolios – where investors may bear the risk, but not the upside, of technological change) may require a closer look to build in adequate safeguards given the fast pace of technology driven disruption. Asset owners should work closely with their investment managers to understand what the risks to their portfolio could be, and to identify tools (such as covenants or secured debt in the private markets that provide extra protection against secular shifts, or structured products in public markets) that could help limit the impact of such an event while still ensuring portfolio goals are adequately met.

Develop an Investment Framework to Identify Technology-Driven Leaders

Leading firms not only outperform laggards in their stock market returns, but also drive returns of the market overall. Indeed, since 1926, the top-performing 4% of companies have been responsible for all of the net wealth creation generated by U.S. equity markets.[45] As we discussed in Section 2, in recent years the best performing firms in a given sector have radically diverged from those at the bottom (Exhibit 9).

Going forward, we believe the select subset of firms able to integrate technology to create lasting competitive advantage and high-earnings growth will be the ones driving a disproportionate share of investment returns. For investors, the key is not to bet on the companies in a sector or geography, but to proactively identify these higher probability technology-driven winners early on. Though this might require investors to invest in several firms initially, the goal is to steadily consolidate positions into the likely winner, based on tracking five characteristics demonstrated by companies well-positioned to succeed:

- **Firms that can capture network effects in their product offering.** While traditional barriers to entry such as capital constraints will always remain, network effects appear to be more significant barriers to overcome. This is not just true for social media platforms or digital products and services. As large firms amass more proprietary data by selling more products or services, they become even more efficient at providing customers the products or services they want, creating a greater incentive for consumers to use their product or service.[46] For example, airlines are now working to use data generated from prior flights to personalize passenger experiences and improve the quality of their flights, potentially leading passengers to pick the airline that best serves their needs.[47] And while consumer tastes will change and a new service or product might supplant incumbent firms, firms like Facebook that have created deep network effects appear more deeply entrenched and less prone to disruption. Under these conditions, small variations in quality can create the difference between a dominant firm that enjoys high profits and a losing firm that eventually dies out.[48]

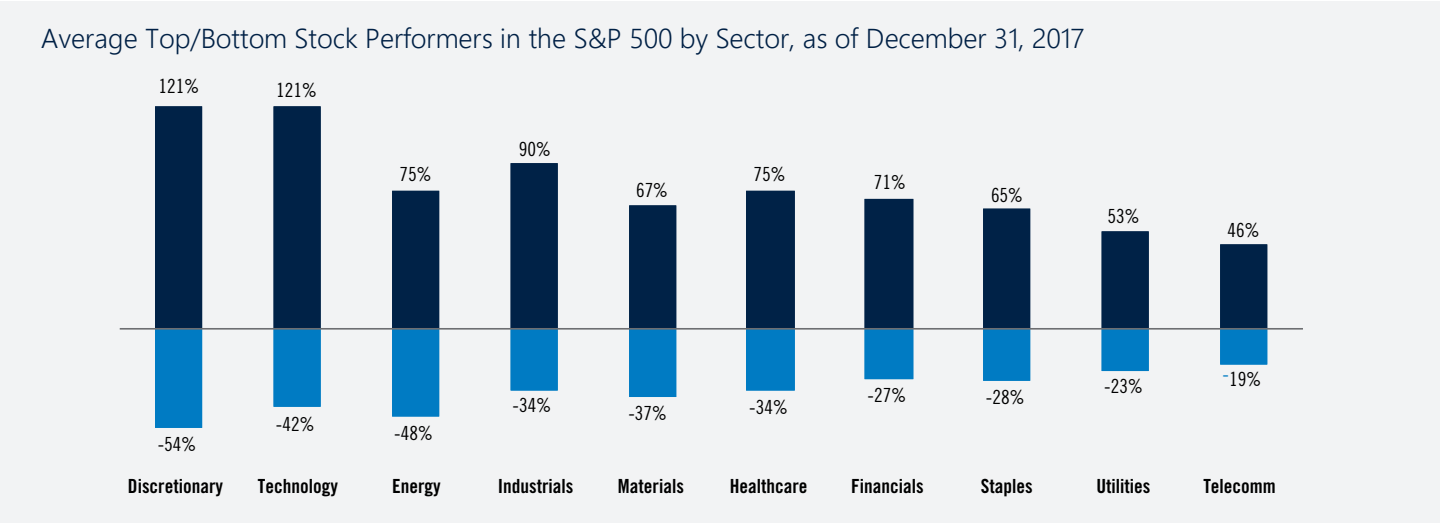


Exhibit 9: There is a Wide Divergence Between the Top and Bottom Performing Stocks
Source: IMF World Economic Outlook via Oyedele, Akin, "'The winner takes all': A $17 billion investor breaks down the huge opportunities lurking in a corner of the market that has spooked Wall Street," Business Insider, June 1, 2018

- **Firms that disproportionately invest in research & development, especially in proprietary mission-critical IT systems that others can't replicate.** Successful firms have placed a premium on developing proprietary technology, integrating it into their business processes, and planning for future technological disruption.[49] One measure is the level of investment in research and development: in the past five years, investment into R&D by the 1,000 largest firms has increased by over 50% to reach $700 billion.[50] This is no moon-shot exercise: ongoing investment into R&D has directly translated into strong investment returns for the firms that sustain it over time (Exhibit 10).
- **Firms that actively supplement in-house tech development with technology-driven M&A.** It's unrealistic to expect that every new technological advancement will be organic for every firm. M&A can play a key role – in effect, allowing firms to obtain both cutting-edge technology and the human capital needed to develop it further. Firms outside of the tech sector are embracing M&A to accelerate their development. In fact, in 2016 more technology firms were acquired by nontech companies than by other technology firms (excluding private equity deals) for the first time since the internet era began.[51] Whether looking at Ford's acquisition of Autonomic, a transportation architecture and technology provider, or L'Oreal's acquisition of ModiFace, a beauty tech company offering augmented reality solutions, non-tech firms are using strategic acquisitions to help digitize their products and services.
- **Firms that consciously structure their business models around the adoption of technology.** Investors should seek to understand how firms are structuring themselves to effectively integrate technology into their business processes and enhance their competitive advantages. Artificial intelligence, blockchain or big data are not effective in isolation; they require a deep ecosystem spanning areas such as legal, human resources, and operations to achieve the productivity enhancements that help firms emerge as leaders. Investors will want to understand how effectively portfolio companies are preparing for a technology-driven future by investing in complementary skills, management practices and business models.[52] For example, investors might want to ask if their portfolio companies have a Chief Technology, Chief Data, or Chief Transformation Officer, and if so, who occupies those roles. Additionally, investors might want to ask if the Chief Financial Officer is committed to deploying capital for technology projects, and if so, what is the funding approach (e.g., the share of funding going to technology maintenance versus technology development, investment in manager training to increase innovation). Given the competitive edge from proprietary cutting-edge IT systems and software, it is also revealing to diligence the spend on inhouse software developers rather than off-the-shelf technologies that other firms can more easily replicate.

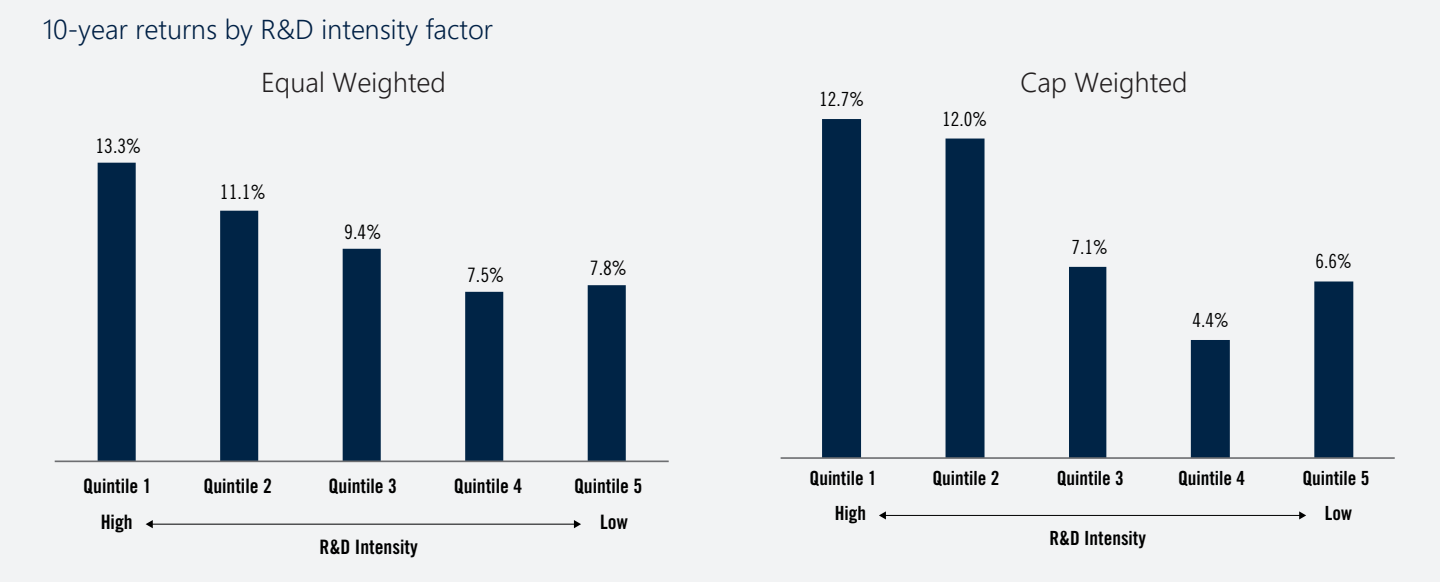


Exhibit 10: R&D Intensive Firms Tend to Out-Perform in the Equity Markets Over the Long Run
Source: S&P, as of June 22, 2018
Note: Return data is from 6/30/2008-5/31/2018 and captures the S&P Global Broad Market Index. R&D intensity factor is defined as the ratio of trailing four quarter R&D expenses to trailing four quarter sales.

- **Firms that disrupt new markets with defensible business models.** In many cases, the most disruptive, leading firms are those that enter an industry unencumbered with legacy structures or revenue streams that might be threatened by their innovative product or service. Yet, while entering a market with a disruptive product or service is a precondition for success, it is not necessarily enough for firms to emerge as the dominant player. Sustaining durable growth and long-term competitive advantage often requires an ability to capture more revenue streams from adjacent products or services.[53] Even if a blockbuster technology may create first-mover advantage, it is a firm's ability to continuously innovate and pivot that will protect it from competition. Netflix is a clear example. When Netflix began, it disrupted the movie rental market by creating a new DVD rental-by-mail service. Yet, it was Netflix's ability to offer streaming services and eventually generate original content that has allowed it to defend its market position and grow to a userbase of over 130 million subscribers.

However, a word of caution: while these characteristics will be important in determining the leading technology-driven winners of the future, they are necessary but not sufficient for long-term outperformance. In fact, research has shown that the market will regularly overpay for firms that appear to be poised for exponential long-term growth (the "lottery ticket" premium). Building a portfolio of all the firms that could potentially "hit the ball out of the park" can be quite costly. The dot-com bubble of the late 1990s provides a cautionary tale for investors: an over-emphasis on new growth metrics (such as clicks or "eyeballs") led to unsustainably high prices and the subsequent crash for many unsustainable business models. Successfully investing in technology-intensive sectors will require either skilled active fundamental managers who can gauge early signals of "winner takes all" even while the broad market may still be skeptical and consolidate stock or bond selections into the likely winners. Or it will take quantitative managers who can systematically proxy and exclude firms with "lottery ticket" type characteristics by identifying firms that are too expensive, have poor quality scores (e.g., weak profitability levels or balance sheets) and high volatility.

Look Beyond Venture Capital to Capture Technology-Driven Investment Opportunities

Of course, simply identifying technology leaders will not be enough; investors will need to work with their in-house teams or asset managers to figure out the optimal vehicle to access these investment opportunities. This is not purely a conversation about startups and disruptors; instead, investors will need to broaden their lens to ensure that opportunities are captured across a wide range of access points and investment vehicles.

- In public markets, although smaller tech firms may garner headlines, it is the adoption of technology by larger – often public – non-tech companies that drives a significant portion of overall long-term growth. For example, while startup wealth management platforms such as Wealthfront or Betterment have gained significant attention in the press, AI tools developed by the leading wirehouses and broker-dealers are already having a much broader impact. To participate in this growth, investors will need to identify which public companies (many outside of the IT sector) are best positioned to build, buy or adopt cutting edge technologies over the long term.
- While more difficult to access, investors should also take note of the large number of scaled technology companies that have chosen to remain private and are developing cutting-edge technologies away from the glare of the public eye. This is a growing pool: late-stage investments represented nearly $60bn in the second quarter of 2018, up nearly 150% year-on year and accounting for nearly two-thirds of global venture investments that quarter.[54] Whether by taking direct stakes or by working through asset managers, investors that want direct exposure to the latest technologies under development may want to consider late-stage private companies as a viable alternative to startups.
- The physical and digital infrastructure enabling the rapid growth of technology is another area for investors to consider. Real assets such as cellphone towers, distribution centers, and renewable power may offer attractive ways for investors to participate in the growth of technology without taking direct exposure to tech firms themselves. CIOs will want to understand how their real asset investments are poised to benefit (or are at risk) from technology trends.
- Finally, while asset owners have used venture capital (VC) investments to access new technology, as a whole the VC space may not always be the best way to do so. Among private equity firms, VC has on average delivered both the highest risk and lowest returns – averaging only 3% returns and generating effectively zero net alpha since 2000.[55] While select leading VC firms may deliver outsize returns, the long-term return data suggest that as a whole VC is not the best way for investors to access the long-term growth potential provided by disruptive technologies.

Evaluate how Alternative Data and Predictive Analytics are Being Used by Fundamental Managers

While some technologies may be less relevant for investment managers – it may take a more radical change than we forsee before investors can 3D print an asset allocation – predictive analytics, big data, and machine learning could have important implications for fundamental managers, and ones that institutional investors will want to consider carefully.

First, it is important to recognize that quantitative managers have been using new data, both big and small, for decades and have come to realize that big data are valuable as a new data source but clearly not a panacea.[56] The primary issue is that the bigger the datasets and the more complex the predictive analytics techniques, the greater the chances of data-mining: that is, of finding spurious patterns where there is no cause and effect and therefore no underlying predictive rationale.[57] These spurious correlations are wonderful to behold in back-tests but clearly less useful in a forward-looking investment context since an investor has no idea when the historical relationship will breakdown and fail to hold.

These tools hold promise for fundamental managers as well, but unlike quantitative firms, fundamental managers will also need to solve for the real risk of cultural clash between traditional analysts and data scientists trained to work with these new datasets. For successful fundamental managers that can bridge the gap, opportunities exist to improve both public and private investment strategies – for example, using natural language processing for sentiment analysis of earnings calls, using cellphone location data to measure retail foot traffic, or marrying proprietary real estate operating cost data with satellite imagery to provide insights on the drivers of tenant behavior. In the future, as available datasets grow and predictive models improve, managers may even be able to use predictions of climate change to drive better decisions on, for example, building placement and valuation.

As the lines between fundamental and quantitative approaches to portfolio management become increasingly blurred, investors will need to carefully evaluate how to effectively integrate predictive technologies into their investment process while avoiding the pitfalls. For asset owners that aim to bring some of these capabilities in-house, having a qualified team of skilled data scientists with access to high-quality datasets will be essential. Investors may want to consider partnering with specialized data clearinghouses – where traditional platforms like FactSet and new providers such as 1010Data have built platforms – to ensure that they can track, source, clean and use these new sources of information, while mitigating the associated risks such as material non-public information or potential privacy violations in individual-level data.

Whether applied to public or private portfolios, investors need to be thinking about ways that alternative data and predictive analytics can potentially help them identify new sources of alpha. As these tools become more commonplace, effectively integrating them into the portfolio management process will become key. Asset owners may want to spend time with their fundamental managers understanding if, where and how they expect to incorporate alternative data and predictive analytics into their investment process. Specifically, CIOs might want to add a section on technology preparedness in their request for proposals or due diligence agenda when evaluating fundamental managers. For example, CIOs might ask their prospective managers:

- How, if at all, has technology changed the front office investment management process in your organization over the past 5 years?
- How do you think about investments-oriented technology talent? Have you considered (or do you have) a data science team, and if so, how are your fundamental portfolio managers integrating the data scientists' perspective into their investment decisions?
- Have you evaluated, or do you already subscribe to, alternative or big data? If you are using alternative or big data, is the application primarily to produce quantitative trading signals or for generating additional investment insights that are then incorporated into a fundamental analyst's discretionary views?

Brace for a "Techlash"

The light or outdated regulations for many technology companies has led to several technology-centric firms aggressively taking advantage of limited local rules and regulation in a bid to win customers, reduce tax burdens and outmaneuver governments. Uber and AirBnB were among the first to take this actively combative approach, but they were certainly not the only firms to do so – some of whom (such as HR benefits provider Zenefits, which actively designed software to evade state licensing requirements) have spectacularly, and publicly, flamed out.[58]

As governments attempt to tighten regulation, technology firms could face significant regulatory uncertainty. The rise of social media-driven "fake news" has re-opened the question of content ownership, especially after Russia's alleged efforts to spread disinformation during the 2016-2017 US and French national elections. Data privacy is another key concern, and governments around the world have launched efforts to protect individuals' data, from the EU's General Data Protection Regulation (GDPR) to new laws in places such as India, Morocco, Brazil, South Africa and Taiwan.[59] Questions such as the optimal way to manage quasimonopolies, who owns the end data (firms, or the individuals whose data is collected), how that data is distributed, and who should take responsibility for content uploaded to social media continue to mount.[60] It remains to be seen how much appetite technology-driven firms have to self-regulate versus waiting for regulators to impose new regulations.[61]

Equally concerning, the race to develop advanced technology – and related disputes over intellectual property – now appears to be driving a significant portion of the tension between the U.S. and China. China has declared AI to be a strategic technology and has launched Made in China 2025 to spur local high-tech development.[62] As for the Americans, the White House has declared that "China has targeted America's industries of the future" and has acted to block Chinese tech firms from gaining a foothold in the U.S. by, for example, rejecting Ant Financial's acquisition of MoneyGram and by moving to block China Mobile's application to operate in the U.S.[63]

Faced with these growing geopolitical challenges, institutional investors will want to place "techlash" risk high on their agendas, ensuring regulatory risks are explicitly captured in their investment frameworks. CIOs may want to speak with their asset managers about how the entire portfolio is impacted by these regulatory changes: an investment thesis built around the benefits of capturing network effects could be undermined by antitrust litigation forcing a company to cap the size of its network, while portfolio companies that depend on accessing and leveraging user data could be threatened by aggressive data privacy restrictions. Investors should pay close attention to management discussions on areas such as data use or pricing strategies to ensure that their portfolio companies are both compliant with existing regulations and well-placed to respond to the changing regulatory landscape; in this fast-evolving environment, due diligence will be vital.

Investors will also need to incorporate the regulatory environment into their evaluation of new technologies and opportunities. As these cutting-edge technologies continue to emerge, governments will again play a role in determining which succeed and which fail. Even technologies explicitly designed to operate outside of governments' reach – most notably bitcoin – raise numerous legal and regulatory challenges for their users. Regulators' decisions of how to respond to these issues will shape the emergence of the technology for years to come – and investors will want to monitor both policymakers and the lobbying organizations that are seeking to influence the debate.

Conclusion

We are living in an age of rapid technological change. The impact of artificial intelligence, autonomous vehicles, augmented reality, and other disruptive technologies are just beginning to be felt – but whether at the macroeconomic level or within individual industries, the implications for investors' portfolios will be profound. As these advances become more deeply integrated into the global economy; investors will need to carefully evaluate their assumptions around economic growth and industry concentration; opportunities and risks in both digital and real-world industries; and their portfolio's overall exposure to the firms poised to capture the benefits of, or fundamentally at risk from, technological change. Longer term, these technologies have the potential to drive incredible societal progress. It is up to investors and their asset managers to capture the benefits while navigating the risks of our new technology frontier.

Appendix: Disruptive Technologies

	Breakthroughs	Defined As
	Mobile Internet	A combination of mobile computing devices, high-speed wireless connectivity and applications
	Adaptive / Artificial Intelligence	Software systems that can perform knowledge work tasks involving unstructured commands and subtle judgments
	Internet of Things	Network of physical objects that can communicate, sense and interact with their internal states or external environment
	Cloud Technology	Computer architecture enabling network access to a shared pool of computing resources.
	Advanced Robotics / Automation	A new generation with greater mobility, dexterity, flexibility, adaptability and ability to learn from and interact with humans
	Autonomous & Near Autonomous Vehicles	Vehicles that can maneuver with reduced or no human intervention; machine vision is a key enabling technology
	Genomics	Combination of gene sequencing techniques, big data analytics and technologies with the ability to modify organisms
	Energy Storage	Improvements in the size, power and cost of systems that convert electricity into a form that can be stored for later use
	3D Printing	A device to create physical objects from digital models
	Advanced Oil & Gas Exploration & Recovery	Accessing previously impossible-to-reach reserves of oil and gas
	Virtual Reality / Augmented Reality	An interactive, computer-generated environment that either is in place of, or is overlaid on top of, the real world
	Blockchain / Distributed Ledgers	An approach for maintaining consistent records among multiple counterparties without a centralized clearinghouse
	Nanotechnology	Artificial manipulation of matter on an atomic or molecular scale

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