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Equity Gilt Study 2018

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PLEASE SEE ANALYST CERTIFICATION(S) AND IMPORTANT DISCLOSURES STARTING AFTER PAGE 137.

“One machine can do the work of 50 ordinary men. No machine can do the work of one extraordinary man.”
Elbert Hubbard

“Technology is a word that describes something that doesn’t work yet.”
Douglas Adams

“The sad thing about artificial intelligence is that it lacks artifice and therefore intelligence.”
Jean Baudrillard

“We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology.”
Carl Sagan

“Any sufficiently advanced technology is indistinguishable from magic.”
Arthur C. Clarke

“The science of today is the technology of tomorrow.”
Edward Teller

FOREWORD

Equity Gilt Study 63rd Edition

The pace of technological innovation has quickened in recent years, with rapid advancements in areas such as the digital economy and machine learning beginning to influence every part of our lives. These developments bring obvious benefits to society, in the form of new products and services, lower prices, and greater efficiency. But they are increasingly raising important questions as well. Some entail a moral or ethical dimension, such as data privacy or the proliferation of "fake news", where society will need to balance the costs and benefits of fully exploiting the power of our new capabilities. Other questions, more germane to this publication, are economic and financial in nature. While technology is often considered to have primarily micro implications, it is clear to us that the cumulative impact of the current wave of technological innovation is increasingly having macro effects.

Nowhere is this more obvious than in the effect of technology on work. The advent of self-driving cars and cashier-less checkout has led to speculation of a future without jobs. Yet we are experiencing record-low unemployment throughout the developed world. In Chapter 1, we discuss why we think the rapid expansion of the capabilities of machines and computers does not portend a jobless future – in fact, far from it. But we do conclude that technology has played a major role in the puzzling lack of wage growth across the global economy, even with rock-bottom jobless rates. And for those who point to mediocre productivity as indication of a lack of meaningful technological change, we show there are often long lags before technological innovations show up in productivity statistics.

In fact, the effects of technology on how we work and how we consume are so meaningful that the standard metrics for measuring and achieving economic progress may no longer be relevant. Does the manufacturing-based concept of GDP truly capture the state of a digital economy? Could new technologies lead to re-shoring and change traditional EM development models? Is inflation ever coming back? We discuss these problems in Chapter 2.

That is not to say that we see every technological innovation through starry eyes. Despite the hype around crypto currencies, in Chapter 3 we argue that such 'alt-coins' are not the primary value proposition of blockchain and distributed ledger technology. The more useful adoptions could be in smart contracts, asset custody, payment and settlement systems, although improvements over the status quo will be difficult to achieve. For now, crypto technology appears to us to be a solution in search of a problem.

Still, the hype around Bitcoin and other digital assets has taken the investing community by storm. In Chapter 4, we develop a number of frameworks to value such currencies. In our view, fundamental demand for these assets comes from low-trust sectors of the global economy, while speculative demand comes from the developed world. Our analysis indicates that speculative interest in digital currencies may have peaked.

The *Equity Gilt Study* has been published continuously since 1956, providing data, analysis and commentary on long-term asset returns in the UK and US. In addition to the macro discussions, this publication contains a uniquely deep and consistent database. The UK data go back to 1899, and the US data (provided by the University of Chicago) begin in 1925. We hope this year's effort lives up to the publication's rich history.

Jeffrey Meli
Co-Head of Research

Ajay Rajadhyaksha
Head of Macro Research

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CHAPTER 1

Robots at the gate: Humans and technology at work

Ajay Rajadhyaksha
+1 212 412 7669
ajay.rajadhyaksha@barclays.com
BCI, US

Aroop Chatterjee
+1 212 526 9617
aroop.chatterjee@barclays.com
BCI, US

Christian Keller
+44 (0) 20 7773 2031
christian.keller@barclays.com
Barclays, UK

Tomasz Wieladek
+44 (0) 20 3555 2336
tomasz.wieladek@barclays.com
Barclays, UK

A strange phenomenon has gripped the world economy in recent years. A new leap in technological innovation, spurred by advances in machine learning and robotics, is generating fears of a jobless future. Yet every major economy appears to be producing millions of jobs, pushing unemployment rates down to historical lows. Moreover, wage growth and overall inflation have remained puzzlingly low, despite rock-bottom jobless rates. We explain how technology is reshaping the global workforce, not eliminating it.

Our key findings

- **Major economies have all experienced record low unemployment – 4.1% in the US, 2.4% in Japan, 3.6% in Germany, 4.3% in the UK[1] – counteracting fears that clever robots are taking over human jobs.** We see two main reasons why technological changes have gone hand-in-hand with job creation:
  - There is a time lag between the introduction of a technological disruption and a measurable impact on the workforce. In the first decade after introduction, soft automation, where only parts of a job are automated, is more dominant than hard automation, where technology fully substitutes labor.
  - History indicates that new technologies do not necessarily reduce the number of available jobs. The advent of the car meant the loss of horse-related jobs, but the creation of many more roles in service stations and other related industries.
- **While technology does not portend a jobless future, it can often be a force for wage disinflation.** We believe that soft automation is to blame: the reason why technology exerts a downward gravitational pull on wages is because for the first several years or even decades, even the most path-breaking technologies end up automating specific tasks within a job, not the job itself. In doing so, technology frequently ends up lowering the skill-set needed to do a job, in turn expanding the pool of potential workers, which then acts as a drag on wage growth.
- **Finally, advances in technology have failed to lead to a spurt in per capita productivity growth.** From 2005 to 2015, the OECD estimates that aggregate productivity in 30 major economies was just over 1%, compared with 2.5% in the previous decade – a marked decline in productivity and global growth. We believe that time lags are to blame: even the most productivity-enhancing inventions take several years and sometimes decades to truly become part of an economy, and only then does the impact show up in the productivity statistics.

[1] All numbers as of end of January 2018.

Three economic puzzles

Wage growth across the global economy has been puzzlingly low

There are three separate but related economic puzzles that motivated our research. First is the question of why wage growth – across every major economy – has been so anaemic for the amount of labour market slack. This phenomenon is true in a large number of countries, including the aforementioned US, Germany, Japan and UK. In each case, unemployment rates are at or below historical lows and have been so for a while. And in each case, both real and nominal wage growth is extremely low for the level of the jobless rate. For example, the last time the US jobless rate was at the current level of 4.1%, the employment cost index (ECI)[2] was around 4% yoy (nominal). It is currently at 2.6% (Figure 1). Put another way, the last time the ECI was at today's level, the unemployment rate was a full 3 percentage points higher, at just over 7%, underlining how strange the current wage environment is. Central banks have repeatedly underestimated this phenomenon. For many years, the Federal Reserve Board's one-year out forecast for the US economy sharply under-estimated how quickly the unemployment rate would fall and yet over-estimated how quickly wages and inflation would rise.

FIGURE 1

Wage growth has been puzzlingly weak given the low level of the unemployment rate

Source: Bloomberg, Barclays Research

Given the hype regarding technological progress, how does one explain the weak productivity data?

A second puzzle is the lack of productivity in an era of technological progress. There has been a groundswell of excitement about a new generation of technologies, especially those focused on machine learning and Artificial Intelligence, which are reshaping the workplace. Futurists such as Ray Kurzweil and academics like Erik Brynjolfson have waxed lyrical about these new technological leaps. The IMF, the OECD as well as think-tanks such as the McKinsey Global Institute have published study after study discussing how advances in machine learning and robotics could boost productivity and growth. And yet, the productivity numbers over the past decade have been hugely disappointing. From 2005 through 2015, labour productivity growth in the US averaged 1.3% per year, down from the trajectory of 2.8% average annual growth that was sustained over 1995-2004. Other economies are experiencing similar decelerations. Between 2005 to 2015, the OECD estimated that aggregate productivity in 30 major economies was just over 1%. For the previous decade, the same number was close to 2.5%, a stunning decline in productivity and thereby in global growth, particularly amidst the touted breakthroughs in technology.

[2] We use this because it has a longer history than the average hourly earnings series.

Robust job creation, weak productivity and technological progress: can the three co-exist?

The productivity paradox[3] can be reconciled by acknowledging that it takes an economy several years to decades to figure out how to use a technology productively and to integrate it fully. A critical mass of capital stock needs to be built up in the new technology, consumer behaviour needs to adjust, and often companies have to adapt to new business models, all of which takes time. And until that happens, productivity presumably does not benefit. But if this theory is correct, then we are confronted with a third puzzle: how does one reconcile these long-term lags in productivity statistics with the massive job creation seen in recent years? Doesn't the fact that millions of new jobs have been created mean that an economy *has* figured out how to use a new technology? If so, why is productivity still so weak?

In this chapter, we attempt to provide answers to all three economic puzzles. The common thread, we believe, is rooted in the way that recent technological breakthroughs are changing the global workplace. This is not a new phenomenon; there are lessons to be drawn from past such periods of leaps in technology, and the impact on the nature of work.

Box 1: Solow's paradox and other historical examples of lags between technology inventions and implementations

Steam engine: The first crude steam powered machines to pump water date back to the 17th century, with the first patents obtained in Spain (1606) and England (1698). The first commercially successful true 'engine' (i.e. generating power and transmitting it to a machine) came around 1712 (T. Newcomen), with further significant improvements in 1763-1775 (James Watt) by using air pressure pushing a piston into the partial vacuum generated by condensing steam, instead of the pressure of expanding steam. As the development of steam engines progressed through the 18th century, various attempts were made to apply them to road and railway use, but it was not until the use of high-pressure steam, around 1800, that mobile steam engines became a practical proposition. The first full-scale working railway steam locomotive was built in the UK in 1804, allowing for the first railway journeys. The first half of the 19th century saw great progress in steam road-vehicle design, and by the 1850s it was becoming viable to produce them on a commercial basis. Hence, roughly 150 years lay between the initial invention and its commercial implementation.

Electricity: At least half of U.S. manufacturing establishments remained unelectrified until 1919, about 30 years after the shift to polyphase alternating current began. Initially, adoption was driven by simple cost savings in providing motive power. The biggest benefits came later, when complementary innovations were made. Managers began to fundamentally re-organize work by replacing factories' centralized power source and giving every individual machine its own electric motor. This enables much more flexibility in the location of equipment and made possible effective assembly lines of materials flow.

Diffusion of 'portable power': Combining the contemporaneous growth and transformative effects of electrification and the internal combustion engine.

Computers: It wasn't until the late 1980s, more than 25 years after the invention of the **integrated circuit**, that the computer capital stock reached its long-run plateau, at about 5% (at historical cost) of total non-residential equipment capital. It was at only half that level 10 years prior. Thus, when Solow pointed out his now eponymous **Solow's paradox**, the computers were finally just then getting to the point where they really could be seen everywhere.

Technology and the future of work

Over the centuries, technological progress has evoked both fear and fascination, especially in terms of its impact on labor. Even as the Industrial Revolution irrevocably changed the trajectory of human progress, the leading voices of the 19th century remained divided on how it could affect workers. One of the most influential economists of all time, David Ricardo, flip-flopped publicly on the issue. In 1821, he stated that while he had previously felt that using machinery in production was a general good, he was now more worried about the substitution effect on labor. And the discussion was not always academic – the Luddite movement in the UK was an early example of workers resorting to violence to protest the use of technology in textile factories.

[3] Often referred to as Solow's paradox

The debate about the impact of technology on society is an age-old one

As the decades passed, the Industrial Revolution led to a visible, and overwhelming improvement in living standards. But the debate – over how technology affects work and whether it is an unequivocal positive – continued to wax and wane. It reared its head in the 1960s in the US, when President Lyndon Johnson set up a commission to study the issue of automation on jobs. The commission noted that "technology eliminates jobs, not work". But it did acknowledge that the pace of technology on the workforce was severe enough that the government considered radical measures such as "guaranteed minimum income", "government as the employer of last resort", etc.

In the past few years, the debate has been renewed, on various fronts. No less a technological luminary than Bill Gates has suggested that it might be time to tax robots. The idea of basic universal income has resurfaced, with Finland launching a two-year pilot last year. Elon Musk and Mark Zuckerberg engaged in a public war of words a few months ago on the risks and opportunities of Artificial Intelligence[4]. After a few decades of abeyance, the age-old debate – on how technology will change the future of work – is back with a vengeance. To understand this phenomenon, we first look at ways in which human skill-sets differ from machines.

Waiting for Skynet

The concept of a sentient machine (that can do everything humans can, and more) has been part of pop culture for decades, especially since the first Terminator movie was released in the mid-1980s. But there is an even longer history of mankind's fascination with the concept of an all-powerful Artificial Intelligence. In 1957, the US Navy developed an early generation AI called Perceptron using early-stage artificial neural networks. After a press conference by its creator Frank Rosenblatt, the New York Times reported[5] that the US Navy expected this new machine to be able to "walk, talk, see, write, reproduce itself and be conscious of its existence." Six decades later, we are still waiting for Skynet[6].

Humans have traditionally had advantages over machines in two areas – cognitive skills and sensorimotor skills

This example highlights how, even as machines have made inroads into areas ripe for automation, as well as in many knowledge-intensive tasks, humans retain a huge advantage in two areas. One is in the area of sensorimotor skills – the ability to take input from our senses and perform tasks (which are not strictly codified) based on that input. A robotics researcher at Carnegie Mellon called Hans Moravec famously articulated this in what is now called Moravec's paradox. He pointed out that higher-level reasoning takes far less computational resources for a machine than even low-level sensorimotor skills. In other words, while machines have now progressed to the point where they can convince many of us that we are talking to a human, even very advanced robots are far clumsier physically than a young child. Marvin Minsky (who founded MIT's AI laboratory) made a similar point. He noted that the most difficult human skills to re-create in a machine were those that were unconscious to us, even though they are very complex processes from a machine standpoint; examples include the ability to do simple tasks such as unscrew a jar, walk over uneven terrain, etc.

The other related area where humans retain a big advantage relates to cognitive functionality – the capacity to learn, perceive, understand context, and make decisions based on often incomplete information. A large number of tasks performed in a modern economy depend on this ability. It is easier to explain this with examples: Consider something as simple as content moderation, the task of making sure that objectionable views and videos are not posted on social media. Every social media site has added thousands and thousands of content moderators in recent years, including titans such as Facebook and Instagram. One would expect these technological leaders to use machines

[4] https://www.usatoday.com/story/tech/news/2018/01/02/artificial-intelligence-end-world-overblown-fears/985813001/

[5] "New Device learns by doing", *The New York Times*, July 8, 1958 – while the *NY Times* link is not available, please see a digital link to a 1996 paper where the article is quoted: *https://pdfs.semanticscholar.org/f3b6/e5ef511b471ff508959f660c94036b434277.pdf*)

[6] Referring to the fictional neural net-based Artificial Intelligence that is the main villain of the Terminator movie series.

for the purpose, but the ranks of human content moderators keep growing. Why is that? Because machines are unable to distinguish between what humans instinctively know as right or wrong. Aaron Schur, senior director of litigation at Yelp, recently noted that machines cannot understand if a user himself is posting a racist review or merely describing racist behavior at a company[7]. One is objectionable, the other is not.

In the same vein, when Apple's personal digital assistant Siri was released with the iPhone4S in late 2011, the results were underwhelming. Siri had trouble understanding many questions on a normal, busy street. And even in a quiet room, it got several answers wrong, not due to a lack of knowledge but due to not understanding the context. For example, Siri could not correctly give directions from Boston to New York, and when asked where Elvis was buried, launched a search for the address of a person called Elvis Buried.[8] Context is key, but computers cannot understand it. Decades ago, US Supreme Court Justice Potter Stewart made the same point. When describing his threshold test for "hard-core pornography", he famously uttered the phrase "I know it when I see it". Humans know how to make such subjective judgments. Machines don't.

Polanyi's Paradox

Many human skills are 'tacit' and learned over time

In 1966, philosopher Michael Polanyi wrote a book called 'The Tacit Dimension', which goes a long way towards explaining why humans possess the advantages mentioned above. The book argued that human knowledge is often 'tacit' – learned by us through cultural memory, tradition, etc. Evolution and genetic memory are also part of this mix; mankind retained body parts that served specific functions and ended up (through the course of evolution) discarding those that did not. Humans learn from experience – indeed, that has arguably been the driver of humanity's progress over the centuries – while machines do not. As a result, humans have skills and abilities that are second nature and easy for us to do, but extremely difficult for computers to imitate.

Polanyi's paradox states that we "know more than we can tell". Many of the tasks that humans perform without thinking every day are because of this tacit knowledge that we have, which is difficult to articulate. But if we cannot articulate it, how can we codify it such that machines can understand? After all, computers are hyper-literal; they do not get sarcasm, intuition, etc. They do exactly what humans tell them to, which is why they need simplified environments in the physical world and precise information in both the physical and digital worlds to function. But if that first step – of telling a computer exactly what to do – is not possible, the advantages humans possess remain in place.

Why are we so excited *now*? Isn't there always some technological progress?

A confluence of several factors has now made machine learning possible

The only alternative would be if machines could do what humans can, namely learn from experience, either first or second hand. But what if machines could learn on their own? It would completely change what they can and cannot do, including in the field of work. This is the most important breakthrough – the one that has everyone proclaiming AI as the new frontier – a number of conditions have been fulfilled which together are finally able to let machines learn. In our view, the three most important conditions that have allowed for the rise of machine learning are:

- The rise of Big Data
- A continued decline in data storage costs
- Consistent and sharp declines in the cost of computing power

[7] https://www.law.com/therecorder/sites/therecorder/2018/02/05/5-takeaways-from-tech-leaders-content-moderation-conference/
[8] "Siri: Your wish is its command, some of the time," Salvador Rodriguez, *Los Angeles Times*, 29 June 2012.

FIGURE 2
Technology is getting smarter - and cheaper

Data is predicted to double every 2 years

Almost everything we do creates data, from global imports and buying coffee to medical implants and social media.

Source: IDC, 2017

Size of the global datasphere

1 zettabyte = 1 trillion gigabytes
About 200-250 average-length songs usually equal one gigabyte of data.

Data storage costs have plummeted

Data processing and storage capacity now seem limitless, while costs continue to drop. And more data leads to faster, smarter innovation.

Source: Mearian, Lucas, Computerworld 2017

Cost to store 1 GB of data

Transistors on integrated circuits nearly double every 24 months

With cheaper computing power, it's now affordable to run simulations using vast quantities of data. This means artificial neural nets can extract more rules and patterns, greatly improving machine learning.

Source: Moore's Law

Growth in computing power over time

The rise of Big Data

Consider the rise of Big Data. The world creates massive amounts of data, for two reasons. First, economies are increasingly digitized. There are coffee shops in New York City where the authors of this article are now unable to buy a cup of coffee with cash; this would have been unthinkable ten years ago. Every time we buy coffee with either a digital wallet or a credit card, a new data point is created. RFID readers, security cameras, and a million other things now exist in the physical world that all create data. Second, human behavior has changed, with far more of it moving from the physical to the online world. Billions of people every day snap digital photos, send instant messages, post online, tweet, and consume streaming media. IDC, a leading market intelligence firm, estimated in early 2014 that the total amount of data created in the world in 2013 was around 4.4 zettabytes. [9] One zettabyte is a trillion Gigabytes or 10^21 bytes. To provide context, 200-250 songs of 3 to 5 minutes each can usually fit into one Gigabyte of data. Now multiply that by a trillion.

More importantly, IDC also estimated in that report that the digital universe would double every two years for the next several years, reaching 44 zettabytes annually by 2020. In 2017, IDC updated its estimates; not only did its 2020 forecast seem to be on track, but the report estimated that the global data-sphere would grow to 160 zettabytes by 2025[10] (Figure 2). Admittedly, both these reports were sponsored by large data storage companies (EMC in 2014 and Seagate in 2017) and there can be very significant errors in estimating something as amorphous as all data generated globally. But related estimates by other sources (such as Cisco estimating total internet traffic growth, IBM estimating data created every minute, etc.) all end up with the same conclusion – global economies generate an enormous amount of data, and it continues to grow at an exponential pace.

A collapse in costs – in data storage as well as computing power

The rise of Big Data, a collapse in computing costs, and a collapse in data storage costs – all at roughly the same time

But even if the world economy is creating data at this dizzying pace, is it feasible to capture and store it? As it turns out, as data generation has exploded upwards, data storage costs have plummeted. Computerworld reported earlier this year that data storage costs have gone down 41% per year for the past 60 years[11]. A gigabyte of capacity cost $2mn 60 years ago (not adjusted for inflation). Now it costs 2 cents (Figure 2). The collapse in data storage costs has allowed companies to store increasingly large amounts of data, right when there is far more data to store. There is likely a causal link here: part of the reason why there has been a focus on making data storage cheaper might be that there has been an explosion of data created in the first place.

The third condition to fall into place is the continued decline in computing costs. In 1965, Gordon Moore (who co-founded Intel) observed that the number of transistors on integrated circuits doubled approximately every two years, and forecast that this could continue for at least another decade. The prediction proved uncannily accurate for more than 50 years. It is a remarkable statistic, and has no parallel in other industries – planes do not double in speed every two years, cars do not consume half as much oil every two years, etc. Brian Krzanich (Intel's current CEO) noted in 2015 that the pace of advancement had now slowed to two-and-a-half years instead of two, which is still an incredible rate. Computing power continues to cheapen at an exponential pace and is now trillions of times cheaper than it was a few decades ago, thanks to the exponential power of Moore's Law (Figure 2). As noted earlier, machine learning uses artificial neural nets; the technology has been around for decades. What is different now is that computing power is cheap enough for companies and economies to run computer simulations of how billions of neurons behave, allowing machines to thereby extract rules

[9] https://www.emc.com/leadership/digital-universe/2014iview/executive-summary.htm
[10] https://www.seagate.com/files/www-content/our-story/trends/files/Seagate-WP-DataAge2025-March-2017.pdf
[11] https://www.computerworld.com/article/3182207/data-storage/cw50-data-storage-goes-from-1m-to-2-cents-per-gigabyte.html

and patterns from vast quantities of data (for more information on the rise of AI technology and its commercial applications, please see Chapter 4, "Artificial Intelligence: A Primer").

In other words, recent developments in machine learning are less about the development of a completely new technology and more about its becoming commercially viable, while at the same time having a large quantity of data to use. It is easy to see how all three conditions need to be fulfilled together for machine learning to truly take off. You need the existence of Big Data, the ability to capture and store it, and also enough cheap computing power to make sense of it.

Machine learning: doing what humans do

Machines have traditionally not had the ability to learn, but that is now changing…

So what is all the hype about, and exactly what is involved in machine learning? Computers are great at following rules. If a credit card borrower has a FICO score below 600, the interest rate on his credit card should be at a certain level – that's a rule a computer can follow. Add in more rules and you get an algorithm – still no problem as long as the computer's existing code is set up to handle it. But machine learning represents a fundamental change. It is a subset of the much-abused term 'Artificial Intelligence' and is grounded in statistics and mathematical optimization. The computer is fed with vast data sets and a few general parameters to point it in the right direction. Then the machine executes computer simulations of how biological neurons behave, uses that to recognize recurring sequences in the data, and writes its own rules. Suddenly, it is no longer limited to applying algorithms that a human wrote; the machine is designing its own. This is far from a perfect explanation of the technology around machine learning and AI, which we discuss in more detail in Chapter 4.

Machine learning has vast applications, especially when coupled with other innovations

…with enormous applications in the workplace

Machine learning algos not only recognize patterns in the data, but also then analyze them and allow the machine to respond in ways that have not been specifically programmed. The algorithms keep iterating over data sets, allowing the machine to keep learning and to spot new patterns. And once a machine spots a new pattern, it can instantly be 'learned' by other machines linked to the same platform. For example, Tesla CEO Elon Musk has emphasized that "The whole Tesla fleet operates as a network. When one car learns something, they all learn it"[12]. In addition, the bigger the size of the data set, and the more time the machine learning algos spend with it, the more they end up learning from their mistakes and getting better. One place where this improvement is immediately apparent is in spam detection. Spam rates across every major email provider have gone down sharply in recent years (to around 0.1% from the low single digits) as machines become better at 'learning' what is spam and what isn't. Similarly, machine translation is improving rapidly for a similar reason – the ability to learn. In a WSJ article titled "The Language Barrier is About to Fall", technology expert Alec Ross argued that near-simultaneous translations were likely only years away at this point[13].

More generally, recognizing patterns in data and then making predictions is an important skill-set employed by humans in a massive number of knowledge intensive industries. What is 'experience' in humans is 'machine learning' for computers. The applications are massive, and across a range of industries, including but not limited to financial services, the insurance industry, IT, manufacturing, retail etc. In 2016-17, the McKinsey Global Institute broke down hundreds of industries in the global economy into thousands of tasks[14]. The think-tank estimated that with existing levels of machine learning, automation could end up

[12] http://fortune.com/2015/10/16/how-tesla-autopilot-learns/
[13] https://www.wsj.com/articles/the-language-barrier-is-about-to-fall-1454077968
[14] https://www.mckinsey.com/~/media/McKinsey/Global%20Themes/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary.ashx

playing a significant role in nearly half of all activities in the modern economy. As with the development of artificial neural networks, the constraints are not technological in nature. Instead, the big hurdles are the cost of new automation, changes in consumer behavior, regulatory constraints etc.

One current leader in machine learning usage is online retail, where predictive analytics are used for product recommendations. The 'frequently bought together' option on an e-commerce website (such as Amazon) pushes buyers into spending more than they planned to when they logged on. The parameter that the machine is looking to optimize for is to increase the value of the virtual shopping cart. It does so by finding patterns in previous orders, what products on the Amazon website the customer seems interested in, whether this customer's profile fits a certain subset of customers, when the purchases happen, what is the average order value, what is the frequency of orders, past ratings or reviews from the customer, etc. Netflix is another leader in this field; its engine tries to maximize the amount of time a user spends on Netflix. The company's recommendation engine looks at what a user is watching, what he is searching for, and whether there are similarities to other users' patterns. If so, it recommends shows and movies that those other users have shown interest in. Its engine will also highlight shows and movies that share similarities with shows and movies that a user has already watched. And all the while, the machine learning algos absorb new data, learn from it, and improve.

Machine learning does not portend a jobless future, for many reasons…

Machines that constantly improve and develop skills that have historically been the domain of humans – it sounds like the stuff of which labor union nightmares are made. As we noted at the start of this report, fear of technology wiping out jobs does emerge periodically and is starting to surface again. In 2013, Carl Frey and Michael Osborne (Co-directors of the Oxford Martin Program on Technology and Employment at the University of Oxford) published a famous paper where they posited that as many as 47% of all US employment was at risk from automation. And in 2015, the BoE warned[15] that as many as 15 million jobs in the UK and 80 million in the US could be at risk from automation and machine learning. On the other hand, despite all the excitement over recent technological developments and related fears about the impact on workers, the US is close to all-time lows in its the jobless rate (at 4.1%). The same is true of most other major economies. This is hardly symptomatic of a world in which machine learning is leaving the labor force jobless, at least for now.

Will technology take away our jobs?

Most mainstream economists now acknowledge the "lump of jobs" fallacy; i.e. they agree that there is no such thing as a fixed amount of work. If technology automates away existing jobs, new jobs of a different nature eventually take their place. The transition is not smooth and can wreak havoc on individual communities (as seen in the death of 'factory towns' across the United States). But eventually, new jobs usually take the place of the old. At the turn of the last century, more than 40% of the US population was engaged in agriculture. Now the number is below 2%, even as the vast majority remains gainfully employed.

Technological innovations often sharply increase product demand, cushioning job losses

Technology gains can sharply change demand for a product, as well as lead to new types of jobs being created

There are several reasons why technology has never ended up making jobs scarce. First, technological gains often change the demand for a product, mitigating job losses in that specific sector. Consider the construction sector, which a century ago used wheelbarrows and hand shovels as the primary means of moving earth. The development of bucket wheel excavators and other earth-moving machines completely changed the nature of work in that sector. But as technological gains made constructing buildings more affordable, it also increased demand for the product (in this case, buildings). A five floor apartment complex

[15] https://www.theguardian.com/business/2015/nov/12/robots-threaten-low-paid-jobs-says-bank-of-england-chief-economist

might have been the talk of the town in the days before Caterpillar Inc, but suddenly, skyscrapers were not only possible, but probable. The quality of housing stock improved, more focus shifted to areas such as designing the interiors, and per square foot consumption of real estate rose sharply. A hundred years later, construction remains one of the biggest employers in most developed countries.

This phenomenon – of technological development sharply increasing demand for a product – has been observed across the centuries. Rapid productivity growth as a result of technological advancement often generates price declines, which in turn pushes up demand. For example, job creation in the British textile industry went up sharply between 1810-1840, decades after the introduction of the power loom, because demand for textiles exploded as they became cheaper. This pattern does not hold in every case, of course. There is only so much demand per capita for agricultural products, no matter how much costs fall. Demand for necessities hits a satiation point more quickly than say, demand for manufactured goods. A family of four can go from one personal tablet per family to two (or more) devices per person as costs per unit keep falling, but they are unlikely to eat eight times as much, no matter how much the cost of food falls.

Technology creates new industries, which in turn create more new industries, and so on

Another driver behind new job creation is usually the new technology that is making an existing one obsolete. The advent of the modern automobile decimated industries that supported the horse-and-buggy system, the main mode of conveyance until then. Farriers, companies that made bridle reins and horse saddles, companies that kept stables across the country, the army of people who swept up horse dung from city streets – they all found themselves suddenly at a loss as their mother industry vanished in the space of a few decades. But in their place, a number of new industries arose, with more job creation. Workers in Detroit's assembly lines, car mechanics, garages, gas stations – these were all job spin-offs of the new technology. And in some cases, the second order effects were more important for job creation, as new technology spurred complementary developments. For example, a national highway system would have made little sense in the era of the horse carriage. But it very much did with the arrival of the internal combustion engine, which led to households traveling far more than they previously would have, which in turn led to the development of road-side motels and restaurants. Highways in turn helped facilitate the development of the long-haul trucking industry, the largest non-college employer in the United States. In an earlier era, the steam engine ultimately led to the development of coal-fired railroads, with all the job creation involved in building rail cars and rails themselves, managing the railway system[16], etc.

New professions are always being created. 'App developer' was not a job definition 15 years ago. Now there are millions of such developers worldwide. In July 2016, Apple CEO Tim Cook tweeted that app developers had earned a cumulative $86bn by the end of 2017[17]. This number does not even include apps in the Android universe. As mentioned earlier, content moderation is another new profession that is growing quickly[18]. And the jobs of the near future include data scientists and bio-statisticians that will try to take advantage of new sources of data capture, among others. None of these existed a few years ago. More generally, Autor (2015) makes the point that household consumption has largely kept pace with household incomes over the decades, and incomes have benefitted from the gains in technology through lower prices for consumers, profits distributed to shareholders, and higher wages for workers (though not always at the pace of productivity gains). Indeed

[16] Still one of the largest employers in many Third World countries like India
[17] https://www.apple.com/newsroom/2018/01/app-store-kicks-off-2018-with-record-breaking-holiday-season/
[18] Facebook plans to double its current content moderation team in 2018. http://fortune.com/2018/03/22/human-moderators-facebook-youtube-twitter/

robust aggregate demand and economic growth as a result of technological advancement become the engines for job creation. Overall, technology has tended to create more jobs than it destroys, at least until now. MGI (2017) [19] estimates that 15.8 million jobs were created in net terms with the adoption of computer technology since 1980. Many of these jobs are created in other sectors, particularly services sectors. As the work-week has declined due to productivity increases, people now consume far more services than they have historically. And that leads to new job creation.

Is past always prologue?

Just because human ingenuity has always found a way in the past doesn't guarantee the future…

Of course, just because human ingenuity has in the past always found a way to mitigate the impact of job-killing technology does not guarantee that the same will hold true in the future. Futurist Martin Ford has noted that the jobs of the future are likely to be ones that are highly unpredictable (where a human might have an advantage adapting), or involve building complex personal relationships (relationship managers, doctors and nurses, primary care providers, etc.) or require genuine creativity. But even these categories of jobs might be theoretically vulnerable. For example, surgeons already use robots widely in surgeries; micro-robots can perform surgeries at microscopic levels (still under the direction of a human) that surgeons cannot manually perform. Human judgment is still essential, but might become less so with the development of machine learning platforms in the medical field. With the development of machine vision, machines could also be better equipped to make medical diagnoses. One of the world's best hospitals, Memorial Sloan Kettering, is partnering[20] with IBM's Watson Oncology to identify individualized, evidence-based treatment options for cancer patients. This trend is spreading in other areas as well. AI has been involved in creating a successful Europop album[21] and another has beaten the human world champion in the Chinese game of Go (a game with a substantially larger number of moves than chess, where human intuition was considered a major advantage over machines). As such, it is not out of the realms of possibility that machines might someday write an award-winning novel or create an original art masterpiece.

…but a future where machines permanently and sharply reduce the number of jobs available remains hugely unlikely

But in our view, such possibilities are at least decades away, and might never come to pass. Much of the impact of technology in an economy depends not just on what is technically feasible, but also on how human attitudes evolve. It is difficult (at least for the foreseeable future) to imagine a parent being comfortable with their small baby being attended to only by a robot, without any human supervision. Similarly, patients are still likely to be skeptical of having life-or-death surgeries being performed on them by machines, without an attending surgeon. After all, what happens if there is a sudden technical glitch?

"This time is different"

Hence, while we understand that there is no absolute guarantee that the current technological disruption will not permanently shrink jobs available for humans just because that has always been the case in the past, we very much support this point of view. We would argue that in every past period of technological disruption, jobs that were thought of as completely safe from the impact of automation ended up being impacted. In that sense, this wave of disruption is no different from ones in the past.

Technological change creates its own challenges too (and in the process creates new jobs). For example, several medical experts have warned that 'Internet Addiction Disorder' is a real, medical concern and addiction clinics are springing up to tackle this problem. Another example is China rapidly becoming a global leader in clean technology, in part because a previous wave of industrialization has badly polluted its environment. Similarly, the CDC reported a few years ago that food allergies had increased significantly in recent years, especially among

[19] McKinsey Global Institute, "A future that works," January 2017
[20] https://www.mskcc.org/about/innovative-collaborations/watson-oncology
[21] http://www.bbc.com/culture/story/20180112-is-this-the-worlds-first-good-robot-album

schoolchildren[22] one reason offered is that the increased use of GMOs (genetically modified organisms) that increase crop yield also reduce bio-diversity and lead to allergies that didn't previously exist. The weight of historical evidence as well as common sense very much suggests that the "lump of labor" argument will remain a fallacy.

Technology can and does hold down wages

But while technology does not portend a jobless future, it can often be a force for wage disinflation. At first glance, this is not intuitive. After all, don't technological gains improve productivity? And shouldn't this, in turn, cause per capita wage growth?

Soft, not hard automation

Soft automation has a much bigger impact than hard automation and plays a big role in holding down wages…

As it turns out, this phenomenon – lots of job gains at a time of technological innovation, with little in the way of wage gains – is not unique to the current business cycle. It has happened repeatedly in the past. For example, textile output rose dramatically in the early 19th century, with the introduction of the power loom, and so did jobs in the sector, but wage growth failed to keep pace. Closer to home, the IMF showed empirically that technology is the biggest reason why the US labor share of income has been on a secular downward trajectory since the turn of the millennium[23], even as the recovery has seen robust job creation. The IMF concluded that the routinization of tasks within a variety of industries and occupations empirically explained a little over half (they estimated 44% to 57% depending on the occupation) of the decline in labor's share of national income.

The reason that technology exerts this downward gravitational pull on wages, we believe, is because for the first several years, or even decades, even the most path-breaking technologies end up automating specific tasks within a job, not the job itself. This is consistent with both history (which shows that technology takes a long time to substitute entire occupations) and recent work done on the subject. For example, a recent Mckinsey study[24] argued that about 60% of all jobs could end up with around a third of the constituent tasks being taken over by technology. But the study also forecasted that only 5% of jobs would end up being fully automated. Soft automation (where certain parts of a job are automated away by technological change) has far more of an effect for the first few decades of technological disruption than hard automation (where technology fully substitutes for labor).

…mainly by making a job easier, reducing the skill set required, and thereby expanding the potential labor pool

One of the easiest ways to explain the impact of soft automation is with the example of one of the largest employers in the US – the trucking industry. The American Trucking Association (ATA) states that there are 3.5 million[25] truck drivers in the country. The BLS numbers are somewhat different (depending on the definition of who should be called a long-haul trucker, but BLS data also confirm that the trucking industry is one of the largest employers in the country. There has arguably been very little in the way of hard automation in the trucking industry. Tesla recently introduced a truck with self-driving technology, Uber has been experimenting with a few driverless trucking routes, and the chief executive of Waymo stated that driverless trucks may become mainstream before driverless cabs[26]. Meanwhile, the ATA has said that there is currently a shortage of truckers, and it will only grow over the next few years[27]. Clearly, technology has so far had a negligible impact in terms of cannibalizing trucking jobs.

[22] https://www.cdc.gov/healthyschools/foodallergies/
[23] "What Explains the Decline of the US Labor Share of Income?…", IMF Working Paper 2017
[24] https://www.mckinsey.com/global-themes/digital-disruption/harnessing-automation-for-a-future-that-works
[25] http://www.trucking.org/News_and_Information_Reports_Industry_Data.aspx
[26] https://www.bloomberg.com/news/articles/2017-09-13/waymo-ceo-says-self-driving-trucks-may-come-before-taxi-service
[27] http://www.trucking.org/article/New%20Report%20Says-National-Shortage-of-Truck-Drivers-to-Reach-50,000-This-Year

Yet nominal wage growth for long-haul truckers has been shockingly poor over the years. The National Transportation Institute has estimated that the median trucker wage in 1980 was a little over $38,000. It was one of the best ways to join the US middle class without a college degree. Nearly four decades later, the ATA reported that the median annual salary for truck drivers was around $46,000. Even after allowing for some false precision around the estimates, this is a surprising statistic. If trucking pay had simply kept pace with inflation from 1980 onwards, the median wage should by now be several multiples of $38,000. In real terms, wage growth in the trucking industry has been sharply negative, even as lots of trucking jobs have been created and even as a shortage persists. We believe technology – in the form of soft, not hard, automation – is the main reason[28].

When power steering became mainstream in long-haul trucks, it was arguably an important development for the trucking industry. Suddenly, physical strength was not a huge prerequisite to drive a 'big rig', thereby expanding the potential pool of people who could do the job. The introduction of rear-view cameras was likely another seminal development. The authors of this article have a hard time backing their cars out of a garage without using a rear-view camera; we can only imagine how useful such cameras are when driving an 18-wheeler full of potential blind spots! Cruise control, automatic braking technology, radar – every such micro-innovation ended up making it easier and easier to drive a long-haul truck. What was once a skilled job became less so with every new improvement, which in turn expanded the potential labor pool greatly. But it also explains why wage growth has been disappointing in the sector, even with lots of job creation. This pattern tends to get repeated in many industries.

Technological leaps lead to parts of a job becoming easier as what can be automated away is. This expands the potential labor pool in that industry, but also dampens wage growth. We don't mean to imply that cyclical factors, such as supply-demand imbalances in labor, are completely eliminated. For example, in the case of trucking, the median nominal wage barely grew between 1980 to 2013, held down by technological improvements – a long-term structural factor. But the median wage did grow at a healthy 15% cumulative from 2013-17 in that industry, as a booming economy created a shortage of truck drivers[29]. In other words, while the longer-term structural impact of technology on wages has played a dominant role over decades, cyclical factors do have an effect, especially over shorter periods of time.

This process – of technological change holding down wages in specific industries – has greatly sped up in the last several years

The trucking example is of an industry where steady improvements in technology have undercut wage growth for decades. In the last decade, this process has sped up in other sectors. Consider the experience of London black cabs since Uber entered the city in 2012. Becoming a black cab driver in London famously involves mastering "The Knowledge", a highly detailed compendium of the city's roads, streets and buildings. The process takes two to four years, can cost tens of thousands of pounds, and involves memorizing thousands upon thousands of street names and landmarks. Drop-out rates are high, but passing the test has historically been considered a ticket to the British middle class. Uber's entry into London, coupled with improved mapping technology, changed all that. Five years after Uber entered the London market in 2012, there were far more Uber drivers than black cabs, the Uber app had been downloaded 3.5 million times in London, and black cab drivers had staged a series of protests about how Uber was destroying their livelihood. Technology allowed "The Knowledge" to be digitized into an app that anyone could use, reduced the skill set needed to be a cabbie in London and thus expanded the labor pool of potential cab drivers, and drove down black cab drivers' wages.

[28] Though de-regulation of the trucking industry definitely played a role in the first few years after 1980
[29] https://www.bloomberg.com/news/articles/2018-03-28/america-s-truckers-haul-in-bigger-pay-amid-tight-labor-market

Who stole my productivity?

But doesn't technology also lead to a spurt in per capita productivity growth? And in that scenario, shouldn't per capita wages go up commensurately? That has clearly not happened – productivity slowed down by more than a percentage point (on average) in the OECD in the decade following 2005 compared with 1995-2004.

Productivity slowed down sharply in the mid-2000s, well before the financial crisis

The productivity slowdown across the OECD is not just an academic issue; it has massive economic consequences. By 2013, the US economy would have been almost two trillion dollars larger if productivity had stayed on the path of the prior decade[30]. And that gap has only gone up over the past five years, as productivity has stayed anaemic relative to the 1995–2004 experience. Methods of estimating productivity can vary, but every reputed source we looked at (including the IMF, the OECD, the BLS, work done by the San Francisco Fed, various academics, etc.) led to two conclusions:

1. Productivity in every major economy slowed sharply over the past decade-plus, in stark contrast to the decade prior.
2. This slowdown comfortably predated the Great Recession, starting around 2005 in most countries.

Productivity slowed sharply down across the globe from 2005, well before the Great Financial Crisis

Consider productivity behavior in the US (the epicenter of the 2008 crisis) in the past decade. John Fernald of the San Francisco Fed showed[31] (productivity and potential output before, during and after the Great Recession) that even though the housing and finance sectors were instrumental in causing the financial crisis, they could not be blamed for the productivity slowdown. For one, when the bubble burst, the productivity slowdown in finance-related sectors was less than that in non–finance parts of the economy. Second, it was not concentrated in states where financial services are an outsized portion of the economy, such as New York. And third, US housing wealth peaked during the 2005-07 period, while the productivity slowdown itself started at the end of 2004.

So if the Great Recession is not to blame, what is? How on earth does one explain that most of the path-breaking leaps in technology that we noted earlier – the digitization of economies, the collapse in data storage costs, the leaps in machine learning, etc. – largely occurred after 2005, even as productivity slowed sharply? Why should one believe that machine learning and AI developments are truly game-changers if they are not causing a jump in productivity and thereby growth? Is all the talk about how the AI revolution is changing industries and economies just that – talk?

Strong job creation does not mean an economy has integrated new technology

It takes an economy several years to decades to integrate a path-breaking new technology effectively

A related question arises, as we highlighted earlier – how does one logically reconcile the strong job creation of recent years with the claim that it takes economies many years to figure out how to productively use a technology? After all, doesn't the very fact that lots of people are finding jobs mean that the economy has managed to integrate a new technology, implying that productivity should be boosted at the same time? As it turns out, this is not true. The main reason is to do with the learning curve that a workforce has to scale when it comes to a new technology. Bryjolfson, Rock, Syverson[32] have illustrated this well using the example of self-driving cars. They make the case that even with autonomous vehicle production going mainstream, the workers employed in production and operation of manual vehicles are immune from job losses for a significant period. It will take many years before the production

[30] https://www.frbsf.org/economic-research/files/wp2014-15.pdf
[31] https://www.frbsf.org/economic-research/files/wp2014-15.pdf
[32] http://www.nber.org/papers/w24001

of autonomous vehicles is at a scale where it affects the jobs of existing vehicle operators. Meanwhile, employment in the auto industry will likely increase to handle new R&D and engineering challenges associated with autonomous vehicles; the marginal labor added by producers of self-driving vehicles will exceed the marginal labor displaced for many years.

In general, when companies restructure themselves to take advantage of new technology, they inevitably spend far more time and effort on training their workforce than on new software and hardware needs. Building up capital stock, configuring new business models, creating economies of scale, changing consumer behavior – all of these are important parts of an economy incorporating new technology, and they can take many years. But perhaps the hardest and slowest part is building up the human capital. Plentiful job creation in a period of technological upheaval does not necessarily mean that an economy has figured out how to make a technology more productive; it can mean that the workforce is scaling a new learning curve.

Mis-measurement, hype and other explanations

Mismeasurement and false hype are not the main reasons behind the productivity slowdown

That still does not explain, of course, why productivity has been so poor. One plausible explanation is simply that the data is wrong; i.e. that productivity is being under-estimated in an increasingly digitized economy. After all, both labor productivity and Total Factor Productivity (TFP) estimates depend on a GDP framework to estimate value added. But it is not enough to simply blame mis-measurement; the argument has to be that mis-measurement in the last decade is far worse than in the past. A number of recent studies cast doubt on this hypothesis[33], showing that mis-measurement cannot explain away the recent productivity slowdown. Even away from these studies, it is hard to intuit why mis-measurement errors would suddenly worsen around 2005 (the start of the decade-long productivity slowdown) to the point where they explain the 1%-plus slowdown in global productivity from 2005 onwards (relative to the 1994-2004 experience).

Another explanation could be that the new technologies are simply not as transformative as the optimists hope. Academics like Robert Gordon have argued that the recent wave of technological changes pale in comparison to past waves such as the steam engine, the automobile, aviation, electricity etc. Indeed, history provides many examples where new technologies did not live up to the initial excitement. Nuclear power never brought down energy costs to near zero, fusion energy has never materialised as expected, and since the end of Concorde flights there has been no more passenger travel at supersonic speeds. Even today's high expectations regarding AI are already much behind the prediction Minsky made in 1967: "Within a generation the problem of creating 'artificial intelligence' will be substantially solved".[34] This pessimistic explanation would mean that productivity growth is indeed low and will remain low, as the expectations regarding the new technologies prove overly optimistic. It is impossible to dismiss this hypothesis ex ante, but there are strong reasons for a more optimistic explanation that is internally consistent. For example, if recent technological developments are over-hyped and without macro impact, why then are those same technology shifts creating such a drag on global wage growth?

[33] The 'mismeasurement hypothesis' has been put forward by Mokyr, 2014; Alloway, 2015; Feldstein, 2015; Smith, 2015. However, using different methodologies and data, Cardarelli and Lusinyan (2015); Byrne, Fernald, and Reinsdorf (2016); Nakamura and Soloveichik (2015); and Syverson (2017), all present evidence that mismeasurement cannot be the primary explanation for the productivity slowdown.
[34] Marvin Minsky, 1967, p. 2

There are always long lags between technological leaps and related productivity spurts…

Long lags means that weak productivity is consistent with a period of sharp technological progress

We believe that given the long lag effects, low productivity is perfectly consistent with a period of rapid technological innovation. This pattern – of technological leaps not showing up in productivity and growth data for several years – has occurred in the past as well. For example, the great technological leaps of the previous century were arguably the steam engine and its applications, followed by the automobile and electrification of the economy. These developed in the years just before and right after the turn of the twentieth century. Yet, as Figure 3 shows (Robert Gordon Brookings paper 2015), productivity languished in the 20 years between 1900 to 1920, even as all of these game-changing inventions were making it into the mainstream. By contrast, look at the period from 1940 to 1980. Productivity growth averaged 1.5% or more in every decade, including a dizzying 3.3% between 1950 to 1960, a period not associated with economy-changing technological leaps. In this context, the productivity experience of the past decade (even with the emergence of machine learning and other technological jumps) suddenly does not seem so outlandish. And it does not diminish the possibility that the technological breakthroughs of recent years could fundamentally reshape many areas of the economy.

FIGURE 3

Annual growth rate of total factor productivity for ten years preceding years shown

Source: Gordon, R. (2015). US Economic Growth is Over: The Short Run Meets the Long Run. https://www.brookings.edu/wp-content/uploads/2016/07/tt20-united-states-economic-growth-gordon.pdf

In 1882, the Edison Electric Illuminating Company of New York started lighting up parts of Manhattan. This was a truly revolutionary technology, with arguably immediate effects on productivity, since it lengthened the working day and allowed people to use their time productively even when it was dark. But it was 1925 (more than four decades later) by the time half the homes in the United States finally had electricity (National Park Service). Automobile adoption has a similar history. Karl Benz, whose name would eventually headline one of the world's largest car companies, had an internal combustion engine car running on the streets of Germany in 1885. He was not the only one. Gottlieb Daimler independently produced another automobile around roughly the same time. A few years later, Henry Ford started selling his own cars in the US. But even 15 years later, by the turn of the century, just 4,000 such cars had been sold in the US.

Twenty years after the initial hype, e-commerce is finally living up to its promise

E-commerce is a more recent example. The rise of the Internet by the early 1990s was supposed to up-end all retailing. Pets.com was supposed to revolutionize sales of pet supplies. Etoys.com was supposed to do the same for toy sales. WebVan was going to do the same thing for groceries. All three went bust within a few years. By 2000, after several

years of hype, e-commerce sales were barely half of 1% of all retail sales. Seventeen years later though, the hype is starting to feel justified. The Census Bureau estimated that online sales were nearly 10% of all retail sales in Q3 2017, and grew at over 15% annualized while all retail sales grew in the low single digits. Second and third tier retail malls all across the US are in trouble as anchor tenants get squeezed by online sales. The mere rumor of an e-commerce giant planning to enter a new retail sector can shake the stocks of leading companies in that sector. When Amazon bought Whole Foods, for example, the stocks of several leading grocery chains dropped sharply. The retailers that are now online leaders needed time to understand how to reshape their business models to take full advantage of the opportunity of the Internet. They needed time to change consumer behavior and to refine the logistics of efficient order fulfilment, package delivery, etc. And at this point, online retail seems set to make far bigger inroads into 'brick and mortar'. It is clear that the excitement around online retail was ultimately justified, if initially premature.

… but adoption of a new technology can turn exponential after it hits critical mass

It takes time to build up critical mass in a new technology, and supplemental innovations play an important role in adoption

So why do these decades-long lags exist between a technology coming online and the effects showing up in data? As time passes, economies of scale kick in on the production side, consumer behavior starts to adapt, companies using the technology refine (and often change) their business models, and supplemental innovations greatly increase adoption. In the case of electricity, while Edison is credited with the technological breakthrough of a viable light bulb, it was Samuel Insull who made the business feasible. The Institute of Energy Research notes that Insull was the pioneer in consolidating small electricity providers to create economies of scale, mastering the economics of the power grid, refining the company's business model (including offering to power streetcars, different electricity pricing schemes, etc.) and generally drove widespread adoption. This led to electricity prices dropping virtually every year between 1902 to 1930. Electricity adoption was also greatly helped by relatively small technical developments, such as improvements in power generators, high voltage power lines (which delivered power to the suburbs), etc.

Supplemental innovations also played a role in auto penetration. The electric starter greatly increased the ability to use the automobile (instead of cranking by hand) and encouraged usage, even though it was a minor innovation relative to the internal combustion engine. As noted earlier, just 4,000 cars had been sold by the year 1900 (15 years after cars were running in Germany), but more than 350k were sold in the year 1912. And by 1927, the Ford car company by itself had sold 15 million Model Ts! If a technology truly makes an impact, adoption ultimately occurs at an exponential pace. And the impact does ultimately show up in the productivity and growth statistics, but with longer lags than intuition might suggest.

Challenges ahead

In sum, we believe that technology is fundamentally re-shaping the nature of work, and this process is likely to accelerate in the coming decades. This is far from a recipe for a jobless future and should eventually cause a jump in productivity, as has happened after past technological spurts. But technological progress is not an unambiguous positive and comes with a host of challenges for policy makers.

Technological change has always posed new questions…

The Industrial Revolution polluted skies and rivers (especially in its birthplace in the United Kingdom), led to terrible working conditions on assembly lines, and exploited child labor (as caricatured in virtually every Dickens novel). It also led to a massive concentration of power and wealth, and gave rise to the original 'robber barons'. Over time, society found solutions. Child labor was outlawed in most economies, and primary education made compulsory. The US passed the Sherman Anti-trust Act in 1890 and forced the break-up of Standard Oil

a few years later. Income tax collection became more progressive and governments spent more money on public goods. The UK passed its Clean Air Act in the 1950s (partly in response to the Great Smog of 1952), and other economies followed.

The challenges posed by technology echo the past in some respects, though not in others. One recurring challenge in the past few decades is that geographical areas that are heavily dependent on one industry are especially vulnerable to technological change in it. A hollowing out of the middle class, a rise in school drop-out rates, a higher share of children raised in single parent homes, increased risk behavior, and in recent decades an opioid crisis: all of these can be blamed, at least in part, on technological changes (often coupled with globalization) leaving certain geographies economically destitute. The prescribed solutions tend to include government help in retraining and re-education, a strengthening of the social safety net including in health care, attempts to diversify an area's local footprint (witness the number of cities that aggressively bid to be chosen as Amazon's second headquarters recently).

Another challenge involves job and wage polarization. Autor and Dorn showed in a 2012 paper[35] that high skilled non-routine jobs, as well as non-routine manual employment, were less likely to be affected by technological shift, but middle skill workers were likely to be negatively impacted, including through depressed wage prospects. Moreover, education may not be the panacea it once was; empirically, the 'education premium' has slowed in recent years. Data scientists and on-call plumbers might both have a future, but not workers in jobs that can be routinized away. More targeted re-training, including vocational courses tailored to the digital age, is likely to be part of the solution.

…and society has typically found answers

There are a host of other areas that will challenge policy makers of the future. Do large tech platforms such as Google, Facebook and others have too much power? Are network effects an unfair advantage and do they encourage monopolistic behavior and stifle the rise of new startups? Do data privacy laws need to be strengthened given the explosion in social media? There are already signs that regulators, especially in Europe, are starting to respond to these challenges, including through anti-trust related fines on Google, new laws that prevent tech firms from using low tax havens, regulation that makes large platforms more responsible for the content they allow to be posted, etc. And more radical solutions might well be needed as this new wave of technology leads to wealth creation that is ever more concentrated. For example, a national wealth fund (akin to Norway's sovereign oil fund) that allows the general population to benefit from the economic benefits of technology might someday make sense. Historically, society has always found a way to absorb the positive effects of technological change while responding to the challenges such change poses; that is likely to be true in the future as well.

Macroeconomics of machines: More questions than answers

The rapid technological changes of recent years are also up-ending the world of macro-economics. How best to measure an economy in a digital world when the prevailing metric is the manufacturing-focused concept of GDP, that often fails to capture digital quality improvements, the build-up of intangible capital, etc.? What impact could robotics and 3D printing have on existing off-shoring models? What are the implications of a sharing/gig economy? Is it time for central banks to rethink the 2% inflation target? We answer these and related questions in Chapter 2 of this publication, 'The Macroeconomics of Machines'.

[35] http://www.ddorn.net/papers/Autor-Dorn-LowSkillServices-Polarization.pdf

CHAPTER 2

Macroeconomics of the machines

Christian Keller
+44 (0) 20 7773 2031
christian.keller@barclays.com
Barclays, UK

Tomasz Wieladek
+44 (0) 20 3555 2336
tomasz.wieladek@barclays.com
Barclays, UK

Iaroslav Shelepko
+44 (0) 20 7773 3557
iaroslav.shelepko@barclays.com
Barclays, UK

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The effects of advances in technology are typically thought of as microeconomic in nature, affecting market structures and pricing behaviour. But evidence is mounting that these micro effects now aggregate to meaningful and lasting macroeconomic consequences, possibly explaining why our traditional macro models struggle to explain the 'puzzles' behind weak output growth, low productivity, muted wage increases and subdued inflation. This may require adjusting the theories that guide our economic analysis, including on monetary policy, public finance and development strategies.

Our primary findings

- **Growth is becoming increasingly difficult to measure in a digital economy, and likely underestimated by current methods.** Our manufacturing-focused concept of GDP does not include digital products' consumer rent and also struggles to capture properly the effects of sharing and disintermediation, quality improvements and intangible capital. Depending on the methods used, annual growth rates are estimated to be up to almost 3/4ppt higher if adjusting for the digital economy.

- **Inflation is likely lower than official estimates, and technology is affecting its underlying dynamics, in particular through wages developments.** Challenges in quality adjustments suggest that official inflation rates may at times be over-recorded by as much as 1%. Besides lowering inflation rates through improving quality, falling IT prices and intensified competition (e-commerce), technology is also affecting underlying inflation dynamics through the labour market (automation).

- **New technologies could turn globalisation on its head.** Advances in robotics and 3D printing could bring increased re-shoring, in part reversing the earlier creation of global value chains, and accelerate premature de-industrialisation. This could pose challenges for traditional development models and, thus, the ability of developing countries to climb the income catch-up ladder.

- **Policymakers will have to consider the implications:** First, policy analysis needs to expand beyond GDP when assessing societies' progress and well-being. Moreover, the focus of economic policies may shift from efficiency towards distribution, as machines may bring abundance but not necessarily equity. For public finance, this may imply temporary and possibly permanent income support measures, but securing a tax base may be challenging. Central banks may need to adjust to a world where inflation can be less easily controlled within inflation targeting regimes.

FIGURE 1

From the printing press to the global internet, technology has evolved, and human societies with it

1 1890 and earlier

1440 Gutenberg Printing Press
1480 Sea astrolabe
1589 Mechanical knitting machine
1608 Telescope
1630 Slide rule
1765 Watt's steam engine
1790 Sewing machine
1816 Telegraph
1867 Dynamite
1879 Light bulb

2 1891–1910

1893 Diesel Engine
1895 X-ray
1898 Polyethylene / Plastic
1903 Gas turbine
1909 Television broadcast

3 1911–1930

1911 Cloud chamber
1915 Tank
1928 Penicillin

4 1931–1950

1931 Electron microscope
1933 FM radio
1935 Nylon
1938 Nuclear fission
1941 Polyester
1947 Hydraulic fracturing
Transistor
1948 Atomic clock

5 1951–1970

1953 Video tape recorder
1956 Hard disk drive
1957 IBM 610
Sputnik 1
1960 Laser
1967 ATM (Barclays)
1970 Pocket calculator

6 1971–1990

1971 Email
Intel 4004
1972 Magnavox Odyssey
1973 Capacitive touchscreen (CERN)
1975 Altair 8800 (Microcomputer revolution and internet protocol suite)
1980 Flash memory
1982 CD-ROM
1984 Cell phone
1990 World Wide Web
Hubble Space Telescope

7 1991–present

1992 Text messaging
1993 Apple Newton
Mosaic (Web browser)
1995 DVD
Windows 95
1996 USB ports
1997 Netflix
1998 Google
2000 Bluetooth
2001 iPod
2003 iTunes Music Store
2004 Facebook
2005 YouTube
2006 Twitter
2009 Bitcoin
2013 Bitcoin ATM

Note: Labour productivity index (1760=100) created using UK and US data. UK data from 1760 to 1889 taken from BoE's 'a millennium of macroeconomic data for the UK'. US historical series from 1890 to 2017 created using Kendrick (1961) and BLS (non-farm business sector; real output per hour) data. US and UK historical series spliced together to arrive at a longer data history starting from 1760 up until 2017. Source: Kendrick (1961), BLS, BoE, Barclays Research

New machine age: More than AI

Combination of new technologies

The 'new machine age' began in the mid-1970s…

… and accelerated in the 2000s

We broadly define the 'new machine age' as a development originating in the 1970s with the creation of integrated circuits and the related rise of (personal) computing power, which were then complemented in the 1990s and 2000s by the internet and other elements of new information and communication technology (ICT) (see Box 1). While the previous chapter focused on the possibilities of artificial intelligence (AI) and machine learning, a broader set of technological changes is driving economic change, including:

- **Digitisation**: For many digital products, marginal costs are (near) zero. This implies large economies of scale that lend themselves to 'winner takes all' outcomes and create a tendency towards natural monopolies. Digital products also blur the line between consumer and producer, as, for example, everyone can contribute to the production of online content (the birth of the 'prosumer').
- **3D printing**: Additive manufacturing (3D printing) facilitates the transition from 'mass production' to 'production by the masses'.
- **Robotics**: Rapid recent progress in robotics may overcome Moravec's paradox: that low-level sensorimotor skills require enormous computational resources (much more than high-level reasoning). New industrial robots are more versatile, cheaper and can be used in many more areas, including services.

'New' in the historical context

'Creative destruction' is not new, but the speed and scale of the current episode could be

One question is whether the effects of these new technologies will be different than those created by technologies in the past. Technological change and related structural economic change, including the decline of certain occupations and the rise of new professions, are nothing new in principle. History is full of examples of this process, described by Schumpeter as 'creative destruction'. These incidents create painful adjustment costs for some, but over time seem to have the positive net effect of creating more jobs with higher productivity and better pay for all (Figure 1). However, given the speed, scale and scope with which recent technologies are revolutionising our world, this new machine age could be truly different from previous episodes. While the question will remain unanswered for now, attempting to understand these ongoing developments and their consequences is very much warranted: these changes are affecting economies and societies, creating 'winners and losers' and posing challenges for policymakers.

Box 1: Key steps in the digital revolution

1970s-1980s: **Integrated circuits** – Tiny processors and memory on microchips, miniaturising and greatly speeding up calculations. The arrival of modern, fast personal computation meant for the first time serious computational assistance for the economy, eg, computer-aided design programs, real-time inventory tracking.

1990s-2000s: **Internet** – Connection of digital processes: linking of computers into networks via cable or satellite. Internet becomes a commercial entity, web services emerge, and computing resources are shared through the cloud. In a virtual economy, interconnected machines and software mean that physical processes can be executed digitally. Production processes can be unbundled and located across geographies wherever cheapest. Global value chains (GVS) are created, bringing about 'hyper-globalisation' (see also *The Future of Globalisation*)

Since 2010s: **Sensors** – Cheap and omnipresent sensors (radar, gyroscopic, magnetic, chemistry, pressure, temperature, moisture, etc), connected through wireless networks can collect vast amounts of data, available for analysis by intelligent algorithms. This makes possible computer vision, machine recognition of objects; language processing and translation, face and voice recognition, and digital assistants.

Source: McKinsey (2017), Barclays Research

Micro in nature, but macro in consequence

New technologies typically disrupt individual markets…

In principle, the direct implications of the new technologies are microeconomic in nature. Indeed, in their assessment of the 'new economy' in 2001, DeLong and Summers concluded that "the principal effects...are more likely to be 'microeconomic' than 'macroeconomic'."[1] They noted that the new technologies create the "possibility of lower average unemployment" and perhaps diminish "the inventory driven component of the business cycle", but overall judged these macro effects to be rather negligible. Instead, they note that "the microeconomic effects...are likely to be far-reaching", highlighting the powerful effect that zero marginal costs and increasing returns to scale could have on the functioning of markets.

…but the scope of the digital revolution today seems to aggregate to macro effects

However, one and half decades and a global financial crisis later, the question of the macro effect may present itself in a different way: have the technology revolution's originally microeconomic effects added up to meaningful macroeconomic consequences? Perhaps the smoothing of business cycles through better inventory management was not the only and perhaps not the most powerful macroeconomic effect to consider. A number of macroeconomic puzzles have either emerged or deepened over the past 15 years, related to weak economic expansion, low productivity and wage growth, difficulties in reaching inflation targets, and a relentless decline in labour's share of overall national income.

Technology could therefore play a key role in explaining recent macro 'puzzles'

Some of these questions are related, and all are unlikely to have simple explanations, with the global financial crisis bearing some responsibility in recent years. However, against the evidence of rapid growth in robotics and the powerful disruption of traditional economies through e-commerce and technology-driven platforms (Uber, Airbnb), it seems plausible that technology is playing an important secular role. Some of these trends are more recent, while others are visible in the data since the mid-1970s, coinciding with the revolution in computing power and, thus, what we consider the beginning of the 'new machine age'.

FIGURE 2

Digital revolution has accelerated over the past decade

Source: Barclays Research

[1] J.B. DeLong and L. Summers (2001).

Economic growth in a digital world

Misery of measurement: The limitations of GDP

Proliferation of digital services leads to measurement issues

Perhaps the most fundamental question is how we measure economic progress and whether this is affected by the digital revolution we are experiencing (Figure 2). In the most direct, narrow sense, it is about correctly measuring growth – capturing the expansion of economic output, which allows us also to answer questions about productivity (the relationship between output and input) and per capita income. In a broader context, however, it is also about whether *output growth* is still the most adequate way to define the success of policies. Neither of these questions is new, but they have become much more pressing in a world where technologies profoundly change the structure of economies and the ways in which goods and services are produced, exchanged and consumed.

GDP was designed to measure production-based economies

The well-established metric for economic growth – gross domestic product (GDP) – has always presented a number of challenges. Since its underlying System of National Accounts (SNA) was developed in the late 1930s (by Simon Kuznets), it was clear that it was a measure of 'production', not a nation's welfare or even individual well-being. Although this is pointed out at times (including in Robert Kennedy's famous quote that GDP "measures everything except that which is worthwhile"), GDP growth rates and GDP per capita are typically equated with 'living standard' or, even more broadly, 'success' in mainstream reporting. This may have been a justifiable simplification in a manufacturing-dominated world where meeting the demand for tangible goods (cars, TVs, refrigerators, etc.) was at the heart of improving people's lives. However, with the rise of the service economy and, in particular, the digitisation of goods and services, the challenges to the concept of GDP have been compounded.

The services component was always less well measured

When GDP was first introduced, manufacturing accounted for a large share of the core advanced economies, and the SNA concept was designed primarily to measure physical production. Since then, however, services have systematically grown in importance: from still less than 15% after WWII to over 50% today (Figure 3). Measuring output and prices for services is inherently more difficult than for goods. Services cover a wide range of activities and are often customised, making their basic unit of production, as well as differences in quality and changes over time, hard to define. The difficulty that statistics have with services is reflected in the fact that the SNA still breaks down manufacturing with much greater granularity than services, even though services now make up a much larger share of the economy.

FIGURE 3

Services today account for more than 50% of US GDP…

Note: GVA data available only from 1947. Data prior to 1947 spliced using BEA data on services share in GDP. Source: BEA, Barclays Research

FIGURE 4

… and the digital economy is spreading rapidly

Source: *www.internetworldstats.com*, Barclays Research

Digitization exacerbates GDP's conceptual shortcomings

Computerisation and digitisation have amplified these issues (Figure 4). Services have become ever more complex, they are difficult to locate across jurisdictions, and the lines between manufacturing and services, as well as between work, domestic activity (home production) and leisure, are increasingly blurred.

Value of free digital product: Missing the *consumer surplus*

Digital goods, when free, are excluded from GDP

Digitised goods or services are often free; and without an observable market price, the SNA, by definition, excludes them entirely from GDP.[2] But just because the consumption of a digital product does not involve a monetary transition does not automatically mean that it is of zero value to the consumer. Thus, the current treatment of digital products within the SNA systematically underestimates the value generated by the digital economy.

Non-rivalry and network effects enable digital goods…

However, capturing the economic value of digital products is complicated by their particular characteristics: they are often non-excludable, ie, once on the internet, it is difficult to exclude anyone from consuming them, and they are non-rival, as their consumption by one agent does not affect their consumption by others. Indeed, their value may even increase with the number of users (network effects). Moreover, beyond the initial fixed costs, digital products have (near) zero marginal cost: they can be easily replicated, stored at negligible costs and sent over large distances. Indeed, given that the basic condition for economic efficiency is that price be equal to marginal cost, such a digital good *should* be priced at zero.

… to create large consumer surplus, not captured in GDP

This phenomenon of consumers having to pay less for something than it is worth to them is also not new to economics. The difference between what consumers would be willing to pay for a good or service and what they actually pay is the concept of *consumer surplus*. It has mainly been discussed in the context of public goods (eg, national defense, lighthouses, free-to-air radio and television) (Figure 5), which share many characteristics with digital goods (non-excludability, non-rivalry, zero marginal costs) and are (or, for the sake of economic efficiency, should be) provided free of charge.

Using input costs likely underestimates effect on GDP

As the issue of free public goods is addressed in the SNA by measuring the value of inputs used in their production, one approach could be to capture the digital economy in a similar way: eg, use the advertising value involved with digital products as the input value for their production (Figure 6). However, when marginal costs are near zero, the true value of a good is unlikely to be captured by such a cost-based approach. Indeed, advertising expenditure is

FIGURE 5

Consumer rent for regular private goods

Source: Barclays Research

FIGURE 6

Consumer rent for free digital goods

Source: Barclays Research

[2] It is true that firms that provide digital products may charge others for advertising space, but for aggregate GDP this is a wash under the current SNA treatment: treated as intermediate input, the same value is for the industry that sells the advertising space but subtracted from the industry that pays for it. Only if, as a consequence of the advertising, additional goods and services are sold would GDP increase. See also Bean (2017).

only a small share of GDP, typically resulting in low estimates for the value added from the digital economy. The approach also ignores the value of digital services produced without requiring compensation, such as blogs and Wikipedia entries, which are freely produced by participants without advertising. This is one of the aforementioned examples in which the digital economy blurs the line between producer and consumer, leading to the term 'prosumer' in a digital economy.

Treating data flows as proxy for digital production has its own shortcomings

Another approach within the existing SNA framework would be to treat *data* in a manner similar to goods. This would put the focus on measuring data generation, flows, use and storage as a way of capturing digital activity. Hence, the mere growth of internet traffic becomes a proxy for growth in the consumption of digital product. However, this raises other questions: eg, how to treat increased data flow in a year when, given the usual flat rate internet subscription fees, the subscription price remains unchanged. It would imply a large 'quality improvement' in internet service, in turn requiring a downward revision to official price statistics; thus, higher real GDP growth would be associated with lower inflation.

Digital goods' value added is also difficult to locate in space

An additional complication for both approaches is the aspatial nature of digital products: while it may be possible to locate the consumer who downloaded a product, the location of production is less clear. Digital products are easily sent long distances and across jurisdictions. This is a non-negligible issue, as it could alter the measure of imports and exports and, thus, add to or subtract from a country's GDP.

Experimental methods could help establish 'shadow prices' for digital goods…

…as a way to capture consumer surplus

One way to capture consumer surplus more directly would be to value the amount of time a person gives up to access the digital product: ie, estimate the *opportunity cost* based on the assumption that every hour spent on the internet could otherwise be used working or for leisure activities. Treating the wage rate as the *shadow price* of leisure has some tradition in economics and has been used to compute value for non-market home production activities, such as cooking, ironing and cleaning. Recently, experimental methods (so-called choice experiments or lotteries) have been used to determine shadow prices for digital products: consumers are asked directly for the price that they would, in principle, be willing to pay for access to services (such as Facebook and Instagram) or, alternatively, that they would demand for giving up the relevant service.

Overall, annual GDP growth rates are likely underestimated by between 0.1pp to 0.75pp

Measuring consumer surplus this way can imply a significantly higher GDP, as much as an additional 48% in some studies. Other, more conservative, expenditure-based methods produce estimates from 0.1% to 5.5% (Figure 7 and 8). Expressed as gains in annual GDP growth rates, estimates vary similarly from 0.10pp to 0.75pp. However, the key message is

FIGURE 7

Measures for consumer surplus from digital products vary…

Note: * wtp = willingness to pay, ** wta = willingness to accept. Source: See list of articles in Figure 9, Barclays Research

FIGURE 8

…with some implying significantly high growth rates

Source: See list of articles in Figure 9, Barclays Research

FIGURE 9
Consumer surplus estimates

CS, bn $ (2015)	CS, share GDP (2015)	Type	Method	Source
22	0.12%	Broadband	Expenditure, survey WTP	Greenstein, McDevitt (2009); Syverson (2016); Barclays Research
64	0.35%	Broadband	Expenditure, survey WTP	Rosston, Savage, Waldman (2010); Syverson (2016); Barclays Research
96	0.53%	Broadband	Expenditure, WTP	Dutz, Orszag, Willig (2009); Syverson (2016)
132	0.73%	Broadband	Expenditure, WTP	Nevo, Turner, Williams (2015); Syverson (2016)
150	0.83%	Free content	Expenditure on on-line ads	Nakamura, Samuels, Soloveichik (2017)
324	1.79%	Free content	Survey WTP	Brynjolfsson, Eggers, Gannamaneni (2017); Barclays Research
439	2.42%	Free content	Value of time	Brynjolfsson, Oh (2012); Barclays Research
995	5.49%	Internet access	Expenditure, value of time	Goolsbee, Klenow (2006); Syverson (2016)
8646	47.72%	Free content	Survey WTA	Brynjolfsson, Eggers, Gannamaneni (2017); Barclays Research

Source: Barclays Research

that GDP misses a great deal of consumer rent associated with free digital products, and this will only increase as the digital economy grows.

Disintermediation and 'sharing': Lowering GDP

While new digital services are not fully reflected in GDP…

… the activity they replace is recorded a loss of GDP

While quantifying the value of digital goods may be the most fundamental challenge, the digital economy creates a host of additional complications for GDP measures. These challenges may not be new in principle, but are now present in such unprecedented scope and scale that they are difficult to neglect. Consider the dramatic disintermediation caused by internet–based business models. By directly connecting customers, suppliers and producers, they cut out the middlemen (eg, the travel-booking industry) and their related service commissions. Instead, the job is done directly by the consumer, reducing transaction costs and improving efficiency. However, in the SNA, this means that activities previously undertaken by the market economy (for a market price) have now become part of 'home production', which, by convention, is not counted as part of GDP. Hence, the ongoing disintermediation shifts activities outside the GDP boundary, driving it lower. For example, while the vast service Wikipedia provides to millions goes unnoticed by GDP, the loss in sales of encyclopaedia books will reduce GDP. Certainly, if the consumer's cost savings then lead to some other activity, this could be offset, but only if it falls into one of the categories captured by GDP.

FIGURE 10
'Sharing': When households become hotels

Note: European markets are Germany, Italy, Spain, and the United Kingdom. The number of hosts shown in this figures are 'hosts who hosted'. Source: Airbnb (2017), "Airbnb data for OECD study", Barclays Research

FIGURE 11
Ecommerce: When competition comes through the internet

Source: US Census

'Sharing' likely overstates actual prices, reducing measured real GDP growth

The 'sharing' economy is another example in which the lines between work and leisure/ business and household become blurred and activities are shifted outside the scope of GDP (Figure 10). The sharing of accommodation (Airbnb) or transport (ZipCar) implies a shift in ownership to rental on demand. This is conceptually not entirely new to the SNA, but shifts rapidly growing activities to unincorporated individuals. Beyond the issue of whether this distorts labour market statistics and measures of household income – similar to those participating in the 'gig economy' (eg, through sites such as Freelance.com or TaskRabbit, see Box 4) – it also raises questions about the correct measure of prices (Figure 11). For example, if price information is sourced entirely from businesses (as in the case of the UK's ONS), the likely lower prices that consumers pay for rooms rented on Airbnb rather than traditional hotels would not be picked up in official statistics. This implies the use of an elevated GDP deflator (ie, too much inflation) and lower real GDP growth, a phenomenon that presents a broader challenge in a world of rapidly changing products where statisticians have to control for quality effects. Box 5 explores these effects in greater detail.

Quality improvements: Over-recording inflation at the expense of growth

Digitisation–driven quality improvements often lead to overstating inflation and understating GDP growth

Prices and their changes over time are also crucial for another important issue that has been magnified by the rapid advances in technology: accounting for quality improvements. Failing in this can lead to a biased measure of real GDP growth. Statisticians measure GDP-included activities at their market prices, then have to determine which part of the change in price was due to inflation and which was from an improvement in quality. Again, this has always been the case, but has become much more complicated with the rising share of digital services and rapidly evolving electronic goods.

The Boskin commission found that failing to account for ICT quality changes overstated US CPI by 1.1% per year…

In 1996, the Boskin Commission in the US calculated that because of the rapid advances in a few goods such as computers and phones, the US had overstated US CPI inflation by 1.1pp per year and, by the same token, underestimated real GDP growth (because of excessive GDP deflators). The changes that were implemented thereafter were meant to reduce the bias to 0.6pp from 1997 onwards. In his 10-year review of the commission work, the US academic Robert Gordon argued that due to quality improvements, the bias was back to between 0.8pp to 1pp. Similar reviews in the UK (eg, Paul Johnson's in 2015) also emphasised the need for adequate price adjustments, as did recent reports by the ONS. In January 2018, ONS officials highlighted a "disconnect between the technical performance and the economic measurement of [the telecoms] industry" related to telecoms' offering of much improved data and network services at unchanged market prices in recent years. As a

FIGURE 12
UK investment in intangibles exceeds that in tangible capital

Source: Goodrige, Haskel and Wallis, NESTA Working Paper 14/07

FIGURE 13
Intangible investment is crucial across economies

Source: Corrado, Haskel, Jona-Lasinio and Iommi (2012)

…but despite methodological improvements, this 'bias' was back to 0.8-1% by 2006

consequence, the real growth of this sector (and, thus, aggregate GDP) was too low, while the related inflation measures were too high.[3] This is unlikely to be an isolated example for the UK, illustrating the ongoing challenges of reflecting rapid ICT changes properly in the existing GDP and inflation measures. Following the numbers provided by Gordon, we think that the overstatement in CPI inflation could be as large as 0.6-1% per year.

Intangible investment: Just consumption to GDP

GDP accounting classifies intangible capital as intermediate consumption…

A final measurement issue relates to the definition of *investment*. In an economy that shifts from (physical) capital-intensive to knowledge-intensive production, *intangible capital* becomes increasingly important. This encompasses all assets contributing to the long-term accumulation of knowledge (including human capital), research and development, or information stored in software. Although key for driving economic growth as a complement to physical capital, the SNA considers the acquisition of intangible assets to be intermediate *consumption,* rather than investment.

… neglecting intangibles' role in driving growth and productivity

This (mis)classification is not negligible. Some estimates suggest that in economies such as the UK, investment in intangible capital has surpassed physical capital investment since the early 2000s (Figure 12). Indeed, recent academic research suggests that treating intangible assets in the same way as physical capital would significantly increase the overall recorded investment for many economies and reduce some of the current differences in investment between countries (Figure 13).[4] Furthermore, omitting intangible investments can also add *J-curve effects* to productivity measures. When national accounts fail to account for the production of intangible capital that has not yet led to an increase in measured final output, this implies a loss of output (lower GDP). Later, the returns from the stock of this unmeasured capital create measured output, which is then incorrectly attributed to total factor productivity (TFP)

Technology and prices: 'Good' deflation?

Technological disinflation

Inflation rates have fallen since the 1980s …

Inflation rates have been falling around the globe, from historically high levels in the 1970s and 1980s to very low levels at the start of the 21st century. Better monetary policy regimes (ie, inflation targeting) and economic liberalisation, including more flexible labour markets

FIGURE 14
Collapsing prices in ICT directly affect inflation

Source: *http://www.mkomo.com/cost-per-gigabyte*, Barclays Research

FIGURE 15
Competition from new business models

Source: Wei and Mozur 2014; Metropolitan Transportation Agency (New York), http://www.mta.info/; Golovin 2014, Barclays Research

[3] *Financial Times,* 18 January 2018.
[4] Bean (2017)

and open trade (ie, globalisation), especially the integration of China with the global economy, have contributed to this global disinflation. This was widely regarded as a positive development, as inflation stabilised around (low) official inflation targets in parallel with robust output expansion, signifying a 'great moderation'.

…and continued to fall since the 2008 global financial crisis

In the aftermath of the 2008-09 global financial crisis, however, inflation rates fell below official targets, in some cases into outright deflation. Central banks embarked on unorthodox measures such as QE and negative interest rates to push inflation higher, but with limited success. The severity of the crisis, along with the high unemployment and large (and possibly underestimated) output gaps it created, could explain this initially. However, even as growth recovered and unemployment rates fell to levels typically associated with full employment, inflation remained suspiciously absent.

Globalisation's moderating effect on inflation may have peaked …

…but the disinflationary effect from technology has not

This raises the question of whether beyond the cyclical drivers, secular trends may be at work. Our previous research (*Equity Gilt Study 2016, Fight to bring back inflation*) concluded that global inflation trends seemed to have been increasingly driven by a 'common global factor' even before the global financial crisis and that labour market factors had likely become most relevant. In line with this, recent research suggests that GVCs could play an important role in global disinflation.[5] Although this globalisation through expansion of GVCs seems to have stalled, technological change has not. Could technology be behind the common factor that is lowering global trend inflation?

Technological progress can, in principle, affect inflation through three channels:

1. A direct effect on prices for technology products;
2. Effects on (retail) margins through changes in market structure and competition; and
3. Effects on firms' production costs through efficiency gains and automation.

Technology lowers inflation directly through cheaper ICT products…

The first channel is well documented by the sharp declines in computing equipment and ICT-related hard- and software (Figure 15). As explained above, the effect may often even be underestimated because of improper adjustments for quality improvements when measuring inflation. The other two channels warrant further exploration.

Amazonification and the pressures from e-commerce

…and indirectly through intensified competition and pressure on margins

The second channel works in various ways: the internet and technology reduce barriers to entry: digitisation allows any firm, including small, niche firms and start-ups, to reach potential customers faster and at a lower cost across the globe. This increases competition for incumbents from foreign competition, as well as from digital firms invading non-tech sectors (Figure 16). The rapid rise of e-commerce accelerates this by creating extreme price transparency and comparability. As a consequence, consumers can switch their purchases to cheaper online sources, which may force (traditional) retailers to lower their prices. The emergence of large lower-priced online sellers such as Amazon has magnified this spillover effect on (traditional) retailers' prices (the Amazon effect). As the share of online retail increases, the differential between on- and offline prices will have a growing influence on inflation.

[5] BIS/Borio 2017,

Box 2: AirBnB and Uber's impact on the UK's GDP growth and price deflators

AirBnB and Uber are popular digital services providers, which have significantly disrupted the markets they operate in. They affect GDP and price measurement in different ways, which we try to illustrate for the UK:

AirBnB is a platform that allows home owners to rent out underutilized space, effectively competing with hotels. As pointed out in the Bean Review, Gross Value Added in the UK's accommodation sector, which is about 0.7% of the economy, is deflated by a weighted average of the services PPI and the CPI, which include hotel prices, but not AirBnB prices. Analysis by Priceeconomics (2013) suggests that renting a flat through AirBnB was 20% cheaper than a hotel, while renting a single room was 50% cheaper. It is of course difficult to know if the quality of the provided services is higher or lower, which depends on whether guests prefer access to a kitchen over the many amenities available at a hotel. Regardless, this line of argument suggests that excluding AirBnB prices from the price deflator means that the real gross value added is actually understated. Furthermore, if surveys do not full capture the use of AirBnB, and not all of the income is declared in taxes, even the nominal value added could be understated. But how much do these effects matter quantitatively? The Bean review cites AirBnB research that indicated a spend of £243 million and suggests that the real gross value added of accommodation services would be higher by 0.7% as a result. Given that this sector makes up only 0.7% of the overall economy, this seems small at first sight. However, if this effect was translated to the overall economy, the magnitude would clearly be much larger.

Uber, a company that matches drivers in a given area to demand for taxi services, can at least be partially picked up in national statistics through cost of input measurement. According to the Bean Review, the Department for Transport surveys the licensing authorities every two years to record new private hire vehicles, which also include those drivers who rely on app-based services like Uber. The latest data, collected in 2017, suggests that the number has increased 30% since the introduction of Uber in the UK, equating to roughly 20,000 more private hire vehicles per year (Figure A), while the number of taxis stayed flat. Uber is thus at least partially picked up in national accounts through the cost of acquiring one production input, the car, to run the business. Figure B shows that the output per worker in this sector, labour productivity, rose initially, but then began to fall. This is because a rise in competition likely reduced the margin (profits) of individual taxi drivers. At present, therefore, each additional Uber driver adds to GDP at a decreasing rate. However, this does not include the consumer surplus from access to more easily available transportation services. Overall, the case of Uber illustrates the challenge of fully capturing the value added by digital services, even if some information on the costs of inputs is available.

Source: Priceeconomics (2013), The Bean Review (2016), Department for Transport, UK Office for National Statistics

FIGURE A

Uber led to a 30% in UK Private Hire Vehicles since 2012…

Note: Department for Transport, Barclays Research

FIGURE B

…but productivity in the sector rose at first before declining

Source: UK ONS, Barclays Research

FIGURE 16
Technology and prices: 'Good' versus 'bad' deflation

Source: Barclays Research

Digital enterprises' scale creates savings that are passed on to consumers…

…while low entry barriers may curtail their monopoly power

The Amazon example also hints at a second way that the market structure channel works: digital technologies, with their (near) zero marginal costs and important network effects, lead to 'winner takes all' outcomes: the emergence of dominant firms with the market power to force traditional and smaller participants out of the market. A priori, the effect of this change in market structure on inflation is ambiguous: on the one hand, such dominant firms can lower prices because of their lower costs, but once they have gained (quasi-) monopoly market power, they can use this to increase prices. In practice, however, overall price pressures appear to be primarily downward, as these firms seem to pass on significant cost savings to consumers. Indeed, the ease with which new competitors can enter the digitised market (ie, contestable markets) may mean that even dominant firms cannot translate market dominance into increased pricing power.[6]

Automation: Machine versus wage

Wages are the underlying driver of inflation

The third channel of technology-driven effects may be the most complex but also the most relevant, since it will likely have the most persistent effect on inflation dynamics over time. It relates to the relation between labour and capital and the question of whether technology improvements are predominantly labour-augmenting (complements) or -saving (substitutes).

Productivity gains typically have led to higher wages

When technology acts as a complement to labour, the associated productivity boost is a positive supply shock that translates into lower prices (a positive supply shock), which could be seen as 'good' disinflation (or even 'good deflation') (Figure 16). At the same time, higher productivity should also translate into higher wages, which, by increasing disposable income/aggregate demand, should over time exert some upward pressure on prices, thus offsetting the deflationary effect. For example, it has been argued that 1880-1913 represents a case of 'good deflation' for the economies of the US, the UK, and Germany: technology drove aggregate supply to expand more rapidly than demand, causing prices to fall at a moderate rate (with the additional complication that this occurred under the gold standard).[7]

[6] Bank of Canada (2017).
[7] Bordo/Lane/Redish (2004): *Good versus bad deflation: Lessons from the gold standard.*

But if machines substitute rather than complement labour, wages may not rise

In contrast, in 'bad' deflation, the demand-supply gap is driven by a decline in aggregate demand. This could be the case when productivity improvements are achieved by technologies that mainly substitute labour (eg, automation) because then, next to the positive cost saving/supply shock, the disinflationary effect is magnified by the negative demand effect from falling wages and lower employment.

Disentangling these effects in practice may be challenging, but labour market-related developments over the past decades suggest that new technologies affect wage inflation. Beginning in the mid-1970s to early 1980s, coinciding with the breakthroughs and expansion of personal computing, data on wages, income and productivity suggest that some of the assumed laws of economics may have become unstuck:

- Median wage and productivity growth, which maintained a constant and strong relationship for 150 years, seem to have decoupled, as wages have been weaker than can be explained by the recent slowdown in productivity.
- Wages and the unemployment rate – the much relied-upon Phillips curve dynamic – has weakened, as wages have not accelerated despite low unemployment, suggesting a significant flattening of the curve.
- Labour's share of income, assumed to be stable in macroeconomic models, has declined continuously and significantly.[8]

Productivity gains since the 1970s have not translated into higher median wages

Since the mid-1970s, median wage compensation has started to diverge from labour productivity. Hence, during a period that included phases of both slow and rapid productivity growth (eg, 1995-2004), wage growth has not kept up with productivity developments (Figure 17 and 18). Technological change is unlikely to be the sole factor affecting the relationship: declining unionisation and other changes in wage bargaining powers have likely played a role, but it is nevertheless striking that this relationship held relatively stable over the previous 100 years, when all other possible factors underwent large changes as well.

The ICT revolution benefitted skilled workers…

In the previous chapter, we discussed in more detail how new technological advances are affecting wage developments and employment. One highlight is that computer technology has led to significant income shifts between workers with different skill sets. It has created downward pressure on routine activities – typically, middle-skill, middle income jobs – that can be substituted. At the same time, it has resulted in higher wages for activities – typically, higher-skill jobs – that would be complemented by technology.

FIGURE 17

Wages have decoupled from productivity since mid-70s

Source: EPI analysis of data from BEA and BLS, Barclays Research

FIGURE 18

…with the median wage, in particular, lagging significantly

Source: EPI analysis of data from BEA,BLS, and CPS ORG, Barclays Research

[8]Karabarbounis and Neiman (2013); Kaldor (1957).

FIGURE 19

Automation is becoming a real and present possibility…

Source: Arntz, M., T. Gregory and U. Zierahn (2016), Barclays Research

FIGURE 20

… which thus far has mainly affected middle-skilled workers

Source: WDR 2016 team, based on ILO Laborsta (various years), The International Income Distribution Data set (I2D2) (World Bank, various years), National Bureau of Statistics of China (various years), Barclays Research

…but routine-skills jobs began to disappear…

…leading to stagnant wages in the affected sectors

This 'routine bias' also means that sectors requiring manual-non routine tasks – typically lower-skill jobs – have largely escaped the pressure from substitution through technologies so far, leading to a *polarisation* (a hollowing out of the middle). As the scope of automation expands, such 'technologically stagnant' service sectors (eg, health care, education, food and accommodation) could experience pressures as well. Hence, if anything, it seems that future automation will continue to limit the room for wage growth for middle- and low-skilled workers (Figures 19 and 20). As a consequence, it may never regain the significant role it played in inflation dynamics in the past.

Trade and development models revisited

Re-shoring and the end of Global Value Chain trade?

Global value chains exploit labour cost differences…

The distributional effects associated with globalisation in advanced economies – eg, manufacturing workers suffering from intensified import competition – have created a political backlash. Among the most prominent examples are the recent trade and tariff

FIGURE 21

Not only have wages slowed, but labour's share in GDP has also declined…

Source: AMECO, Barclays Research

FIGURE 22

… as labour has been substituted for capital

Source: Charles, Hurst and Schwartz (2018), NBER WP 24468

policies in the US, which explicitly state the intention to protect domestic industries and bring manufacturing jobs back to the US. Reports of some 're-shoring' of activities back to the US may be seen as success of such policies. However, something more structural may be going on, driven by technology rather than policy.

…but new technologies make such differences less important

… allowing for re-onshoring of activity

As discussed in *The Future of Globalisation*, the core concept of GVCs is to split production processes into intermediate steps in order to exploit factor income differences (typically due to different factor endowment) between countries. This dispersion of the production process across countries automatically means that more trade takes place for a given final output. Hence, much of the trade increase since the 1990s can be explained by the integration of EM economies into GVCs, especially China. However, recent progress in technologies such as 3D printing and new collaborative robots may turn this around: 3D printing unifies production back into one integrated process rather than a differentiated chain. At the same time, cheap collaborative robots make access to inexpensive manual labour less important, if not unnecessary.

Premature industrialisation and the developments ladder

This could challenge the industrialization model that developing countries followed in the past seven decades

This not only puts into question certain GVCs, but also raises questions about the fundamental development model for poorer countries. Long before GVCs and the rise of China, other economies such as Taiwan and Korea successfully moved their abundant and cheap labour from less productive jobs in agriculture into export-oriented manufacturing positions. With industrialisation, productivity improved, wages rose and so did income per capita, similar to China's development more recently. As these economies catch up, they tend to shift from investment to consumption, implying somewhat lower trade intensity. The shift in comparative advantage associated with becoming richer implies that other, less developed EM economies will take over from the more mature EM economies. Indeed, the shift of textile and other labour-intensive manufacturing from China to Vietnam and Bangladesh (as Chinese wages have increased) is an example of this. Firms move on and their GVCs move with them. Further destinations could be the labour-rich economies in Eastern Africa, assuming an extrapolation of past developments.

FIGURE 23

The spread of cheaper robots …

Source: IFR, Kuka, Barclays Research

FIGURE 24

… makes off-shoring to cheap labor destinations obsolete

Source: VW, Barclays Research

Collaborative robots make the abundance of cheap labour less of a production advantage

Because robots can modify the relative factor intensities in the production of goods and services, they sever the link between cheap labour and the location of unskilled manufacturing activities. In other words, to the extent that relative factor endowments determine the international division of labour, the use of robots, also including technologies such as 3D printing, can move the location of manufacturing back to advanced economies. Admittedly, the challenge is not entirely new. Although industrialisation has historically been synonymous with development, recent trends show that many developing countries – especially in Africa and Latin America – have witnessed their share of manufacturing employment and output shrinkage long before they have attained income levels comparable with those in more developed economies. Such 'premature deindustrialisation' began as early as the 1980s and 1990s.[9] It has continued since, and the spread of new automation technologies and AI could accelerate it (Figure 25).

In principle, emerging and developing economies could also use robots. In fact, each year since 2013, China has bought more industrial robots than any other country, and it is expected to maintain its front-runner status (even if robot density – robots per industrial workers – there is still lower than in Germany, Japan, and Korea) (Figure 24). However, China embarked on its government-backed robotisation strategy in response to a shrinking working-age population and rising labour costs. But it makes less sense for developing economies that still have a large pool of cheap labour. The major challenge for these countries is to create jobs for a large number of low-skilled entrants to the labour force, such as in many parts of Africa. Deploying robots under current cost structures and low-skilled to high-skilled worker ratios could drive production costs up, rather than down.

May developing countries have to revert to lower value-added commodity exports?

Paradoxically, the new labour-substituting technologies could move global trade back toward the world that existed before the initial ICT technologies of 1980s and 1990s enabled the creation of GVCs, with north-south trade dominated by exports of raw materials against finished industrial goods. Raw materials, including new demand for materials such as lithium and cobalt/nickel for the production of batteries will continue to be needed and are often highly concentrated in particular geographies.

FIGURE 25

Automation could accelerate 'premature deindustrialisation', raising doubts about traditional development strategies

Source: Employment data based on Timmer et al. (2014), and GDP per capita is obtained from Bolt and van Zanden (2014) and are measured in $1990GK. The year in which the manufacturing employment share peaked is given within parentheses, and a fitted OLS regression line is also shown.

[9] See Rodrik, D. (2015), "Premature Deindustrialization";

Policies in a machine age

Beyond GDP: Measuring well-being

Policy may need to be based on more comprehensive measures than GDP

There is an ongoing discussion between economists and experts in statistical offices around the world about how to deal with some of the shortcomings of the traditional system of SNAs to help capture the new digital economy more accurately. Some technical progress will be made, without doubt. However, for practical and conceptual reasons (reproducibility of results, objectivity, transparency of methods, etc.), most statistical experts argue against the inclusion of reservation prices and shadow prices in official GDP measures in order to reflect the full welfare effects of digital products.[10] Given that it is this unmeasured consumer surplus where the economists see the largest effect, this is likely to leave lingering doubt about the appropriateness of the concept of GDP for a world transitioning from goods manufacturing to digital services.

This raises the philosophical question of what to include…

However, it also raises a more philosophical question: while the welfare gains from digital products are undoubtedly large, how many of these effects should be included in the core macroeconomic measure of GDP? Or should they instead be identified in data designed to gauge quality of life beyond GDP? Different measures may be needed for different policymaking purposes. Thus, a more promising approach could be a systematic attempt to capture the important dimensions of welfare and well-being in data sets that complement GDP and other macroeconomic aggregates (Figure 26).

FIGURE 26

Recent OECD initiatives aim at measuring societies in more comprehensive ways than GDP per capita

Source: OECD 2017

[10] For example, Reinsdorf and Schreyer (2017)

FIGURE 27

Material conditions and perceived quality of live can diverge significantly

Source: OECD 2017

…but any new measure of welfare will likely focus on quality of life as well

Moving beyond GDP requires indicators of well-being and welfare that cover the broader dimensions of life, economic and otherwise. A strategy taking into account the link between digitalisation and well-being should aim to assess the effects of digitalisation across the major dimensions of quality of life. These measures could be highly relevant for politicians and policymakers, even if not reflected in GDP or consumer price indexes. The OECD initiative to capture 'well-being' is going in this direction. These new measures show that countries' rankings for 'material conditions' and 'quality of life' often diverge materially (Figure 27).

Public finances: Focus on income support and taxing capital

Globalisation lifted many EM citizens out of poverty…

… but led to stagnating incomes for DM middle classes

In *The Future of Globalisation*, we highlighted how global trade and the integration of emerging market economies in global value chains have led to dramatic changes in global income distribution. The so-called elephant graph measures the real income changes of different percentiles of global income distribution since the late 1980s (Figure 28). Its shape suggests that real incomes for populations in EM economies (main body) have improved significantly over the period, while those for middle income groups in advanced economies have stagnated (lower trunk) and the incomes for those in the top percentile have surged (upper trunk). Hence, while not benefiting everyone equally, globalisation has helped to lift the incomes of large segments of the world's comparatively poorer population.

FIGURE 28
Could the 'elephant' chart over time turn into …

Source: Branko Milanovic (2012), Barclays Research

FIGURE 29
… a potentially more extreme distribution?

Source: Barclays Research

In the future, technology could distribute income gains increasingly to capital owners

This may no longer be true if the effects of technology rather than trade dominate in the coming decades. As automation creates pressure across global labour markets, future income gains could be concentrated in the very highest percentile of the global distribution. Indeed, Chinese manufacturing wages are already being pressured by automation in the same way that Chinese labor pressured US manufacturing wages in previous decades. If automation ends up playing an ever-greater role in workplaces, it could hold down wage growth in more parts of the economy, meaning that the labour share of income will continue to fall as the capital share rises. If, in parallel, capital ownership is concentrated further – also a trend of past decades, in part because of the 'winner takes all' tendency of the digital economy – income and wealth distributions could become extremely skewed. Expressed graphically and exaggerated for illustration, the elephant's bulky body would be flattened and all gains would shift towards the very tip of its trunk (Figure 29).

An abundance of economic output could be accompanied by rising inequality

Hence, policymakers could face a situation where technology facilitates rapid and cheap production of both physical and digital goods, but is paralleled by increasing measures of inequality and wage stagnation. This could fundamentally alter the criteria to assess economic policies. In a traditional production-based economy, the focus of 'good' policies was on improving productivity. In an economy where the highest productivity is achieved through the use of machines, distribution is likely to become a larger focus

Policy focus on helping workers transit between jobs and on compensating the permanently displaced

This greater focus on distribution may not necessarily mean *universal income,* a concept to which societies may react differently. While forms of permanent income support may play a great role at some point, the immediate challenges may be to educate and train humans to use new technologies as complements, rather than substitutes. If substituted nevertheless, retraining and transitional support will be key to helping workers adjust to new occupations. Put differently, policies need to ensure compensation for those displaced: economic theory never denied that structural change (eg, through free trade or new technology adoption) can create winners and losers, but it suggests that if the gains made by the winners are sufficient to compensate the losers' losses – ie, no one is worse off as a result – the change is for the better. However, such compensation, even if theoretically possible and required for the 'greater good', rarely takes place in practice. Future policy might need to play a bigger role in changing that.

Financing this expenditure could be a challenge

Financing such expenditures through revenue will be a challenge. A falling wage share in GDP and the 'casualisation' of labour (gig economy) make the taxation of labour income more difficult. Taxing individual robots or machines, as sometimes suggested, may be intuitively

appealing (the robot replacing the human worker also as taxpayer), but makes less sense conceptually. Robots are assets of the owners of the overall capital. The challenge is, thus, to tax capital, which is typically difficult to maximise because of its high mobility.

Challenges for monetary policy

Central banks set specific targets to stabilize inflation

…and rely on interest rates to stabilize activity

In recent decades, many central banks have formally adopted a version of inflation targeting (IT) as their main monetary policy strategy. In simple terms, they set interest rates to lean against the business cycle and, hence, ensure that inflation returns to target. In an overheating economy, the central bank can increase interest rates to slow demand and ease price pressures. In a bust, it can reduce interest rates to stimulate demand to push the economy closer to full employment, thus raising price pressures. While not uniform and with different designs, central banks in advanced economies have generally set targets of 2% that they aim to achieve over the medium term.

Technology could challenge this strategy…

…via broken Phillips curves…

…which make activity less responsive to interest rates…

…and reduce the frictions that made 2% the right target

Technology challenges inflation targeting in several ways. The relationship between unemployment (capacity constraints) and wage growth (inflation pressures) – the Phillips curve – has been central to this mechanism. But competition from labour-saving technology could lead to weaker underlying nominal wage trends. This means that policy needs to stimulate activity more to get the same outcome. At the same time, the rise in wage inequality will likely make activity less interest rate sensitive, as richer households have lower marginal propensities to consume. In addition to challenging the policy transmission mechanism, technology may also raise doubts about the 2% target itself. A key argument for positive inflation has been nominal wage rigidity, ie, workers would be resistant to taking nominal wage cuts. Real wage cuts through inflation would thus grease the wheels of the labour market. But the rise in labour market flexibility and allocative efficiency due to technology may make this unnecessary. In addition, economists (eg, Tobin) typically highlight that some inflation is needed to allow for real price adjustments, including to wages, without reducing nominal wages. This seemed true in a world of sector- or even nationwide wage bargaining through unions, where it seemed psychologically impossible to agree on a nominal reduction. In today's world of more flexible and fragmented labour markets (the gig economy), this assumption may no longer reflect reality.

Finally, minimum inflation was deemed necessary to allow the real interest rate to go potentially below zero, given that a zero nominal interest rate was deemed the lower bound. However, negative interest rate policies over the past years have shown that the lower bound may not be zero, but possibly minus 100-150bp – or roughly what is deemed the

FIGURE 30

Global core CPI trend inflation is significantly below target…

Source: OECD Main Economic Indicators, Barclays Research

FIGURE 31

…as a result of weak manufacturing wage trend inflation

Source: OECD Main Economic Indicators, Barclays Research

opportunity cost of holding cash – and in the future it may be even be lower: in a cash-free economy with central authority, negative interest rates could in principle go lower still.

Inflation remains a monetary phenomenon, but technology may make calibrating policy to reach 2% more difficult

In sum, the traditional arguments for a certain rate of positive inflation may not be invalid but have at least become less compelling. While Nobel Laureate Milton Friedman's famous statement that 'inflation is always and everywhere a monetary phenomenon' may hold in principle, calibrating policy to achieve a 2% target precisely could become more difficult, as a host of central banks have discovered over the past few years. If this assertion is correct, it is not clear if central banks should continue to follow inflation targeting frameworks with the current specifications.

We estimate global core CPI trend inflation at just over 1%

…driven by lower global wage trend inflation since 2003

Our own estimates of global core CPI trend inflation (first discussed in *The fight to bring back inflation*) suggest that the underlying trend in inflation has fallen significantly over time to reach 1.1% today. This occurred despite significant monetary policy easing in recent years, which suggests that powerful secular trends likely contributed to the weakness in inflation (Figure 30). Indeed, Figure 31 suggests that, at least since 2003, global manufacturing wage trend inflation is perhaps responsible for this secular decline in core CPI inflation. If manufacturing employees are happy to accept stagnating wages because of fear of being substituted, then monetary policy will have a difficult time stimulating inflation, as suggested by the recent situation in Japan, where workers shortages have translated into lower output rather than higher wages.

If central banks, despite these secular trends, try to push inflation to 2% at all costs…

…financial instability could be the unintended result

If technology reduces the real effect of monetary policy and leaves the optimal inflation target below 2%, pursuit of the 2% target risks creating financial cycles and instability. Friedman's monetary phenomenon would certainly occur somewhere, but perhaps in financial markets or in specific sectors of the economy, eventually leading to sector boom-and-bust cycles. To avoid exacerbating the business cycle, we therefore believe that prudent central banks may want to adopt a greater degree of flexibility, such as the introduction of bands around their inflation targets.

Box 3: The nature of work and the flatness of the Phillips curve – back to the future?

Technology is also fundamentally changing the nature of work and employee-employer relationships. Technology has made work is increasingly 'divisible', separating work processes into many parts. This facilitates automation and the potential substitution of human labour. But it has made the remaining parts of human to become more flexible: the jobs done by humans may no longer have to be performed at a certain location at a certain time within strict formal arrangements. As jobs become less structured and more task-oriented, there has been an increase in self-employment, part-time working and special contractual arrangements (e.g. zero-hours contracts). This is often referred to as 'casualisation' of work, or 'gig' economy.

This creates a very different environment for wage negotiations than the union-dominated bargaining processes that were typical for the 20th century. Certainly, critics may argue that such new, less formal arrangements may be sought by employers simply as a means to reduce costs. But they also do seem to clearly reflect a desired flexibility on the part of many of those who seek work, in particular among younger workers and those who have not participated in the labour market under traditional formal employee relationships. As Andy Haldane (2017) notes, this change in the nature of work could in some ways be interpreted also as a shift 'back to the future'—a world where artisanal and task-based jobs may more resemble the pre-industrial revolution era, when most workers were self employed and worked in small businesses.

The available historical wage and output data are of course partial and imperfect, but they nonetheless tell an interesting story: when constructing UK Phillips curves over four periods – 1500-1700 (pre-Industrial Revolution), 1860-1950 (post-Industrial Revolution), 1950-1977 and 1977-2016 (post-war period) – only the two post-war Phillips curves conform to what economist consider 'typical': only the 1950-1977 and 1977-2016 curves have a clearly positive slope (less slack in the economy is associated with higher wage inflation) and an intercept that is positive (reflecting positive trend inflation), where by the more recent curve (1977-2016) is clearly flatter. In contrast, the post-Industrial Revolution (1860-1950) has also a positive slope but has an intercept associated with an average inflation rate of around zero. The latter is also the case for the pre-Industrial Revolution curve (1500-1700), but in addition, this one is also almost entirely flat. This shape – a flat slope with an intercept suggesting zero average inflation – most closely resembles the Phillips curves operating in the more recent past. Certainly, this similarity may be explained by a number of factors—not least the questions one may have around data from before 1700. However, the pattern supports the narrative that technology changing nature of work and the related process of wage formation: away from formal, structured relationships with collective wage bargaining, towards a more flexible, divisible, individualistic workforce, which leads to a flatter Phillips curve relationship.

Source: Haldane (2017), Thomas and Dimsdale (2017)

Literature

1. Arntz, M., Gregory. T. and U. Zierahn. 2016. "*The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis"*, OECD Social, Employment and Migration Working Papers No. 189

2. Arthur, W. B., McKinsey Quarterly October. 2017. "Where is technology taking the economy?"

3. Brynjolfsson, E. , Rock, D. and C. Syverson. 2017. "*Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics"* NBER Working Paper No. 14007

4. Bean, C. 2016. "*Independent Review of UK Economic Statistics*"

5. Berger, T. and C. Frey. 2016. "*Structural Transformation in the OECD: Digitalisation, Deindustrialisation and the Future of Work*", OECD Social, Employment and Migration Working Papers No. 193

6. Bivens, J. and L. Mishel. 2015. "*Understanding the historic divergence between productivity and a typical worker's pay. Why It Matters and Why It's Real*", Economic Policy Institute, Briefing #406

7. Bolt, J and J. van Zanden. 2014. "The Maddison Project: collaborative research on historical national accounts", Economic History Review, vol 67, no. 3, pp. 627-651.

8. Bordo, M, Lane, J and A. Redish. 2004. "*Good versus bad deflation: Lessons from the Gold standard era*", NBER Working Paper No. 10329

9. Borio, C. 2017. "*Through the looking glass*", BIS speeches, OMIFF City Lecture, London.

10. Brynjolfsson, E and J. Oh. 2012. "The Attention Economy: Measuring the Value of Free Digital Services on the Internet", 33rd International Conference on Information Systems.

11. Brynjolfsson, E. and A. McAfee. 2014. "The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies", W. W. Norton & Company.

12. Brynjolfsson, E., Eggers, F. And A. Gannamaneni. 2017. "Using Massive Online choice Experiments to Measure changes In Well-being", MIT Initiative of the Digital Economy.

13. Charles, K., Hurst, E. And M. Schwartz. 2018. "*The Transformation of Manufacturing and the Decline in U.S Employment*", NBER Working paper No. 24468

14. Charbonneau , K., Evans, A., Sarker, S. and L. Suchanek. 2017. "Digitalization and Inflation: A Review of the Literature", Bank of Canada Staff Analytical Note 2017-20

15. Corrado, C., Haskel, J., Lasinio, C. and M. Iommi. 2012. *"Intangible Capital and Growth in Advanced Economies: Measurement Methods and Comparative Results"*, IZDA DP No. 6733

16. Dutz, M., Orszag, J. and R. Willig. 2009. "*the Substantial consumer Benefits of Broadband connectivity for U.S. Households*"

17. Giles, C. 2018. "*ONS's crossed telecom wires raise questions over inflation figures*", Financial Times, 18 January 2018

18. Golovin, S. 2014. "*The economics of Uber*", Innovation and Competition Policy.

19. Goodridge, P., Haskel, J. and G. Wallis. 2014. "UK Innovation Index 2014", Nesta Working Paper 14/07.

20. Goolsbee, A and P. Klenow. 2006. "*Valuing Consumer Products by the Time Spent Using Them: An Application to the Internet*", NBER Working Paper No. 11995

21. Gordon, R.J. 2006. "*The Boskin Commission Report: A Retrospective One Decade Later*", NBER Working Paper No. 12311

22. Greenstein, S. and McDevitt, R. 2009. "*The Broadband Bonus: Accounting for Broadband Internet's Impact on U.S. GDP*", NBER Working paper No. 14758

23. Haldane, A. 2017. "*Work, Wages and Monetary Policy*", Speech given at the National Science and Media Museum, Bradford

24. Kaldor, Nicholas. 1957. "A Model of Economic Growth". The Economic Journal, vol 67, No. 268, pages 591-624.

25. Karabarbounis, L. and B. Neiman. 2013. "The Global Decline of the Labour Share". NBER Working paper No.19136

26. Kendrick, J.W., assisted by M. R. Pech, 1961. "Productivity Trends in the United States". NBER General Series No. 71

27. Milanovic, B. 2012. "Global Income Inequality by the Numbers: in History and Now - an overview". Policy Research working paper No. WPS 6259, Washington, DC: World Bank

28. Nakamura, L., Samuels, J. and R. Soloveichik. 2017. "Measuring the "Free" Digital Economy Within the GDP and Productivity Accounts". Working Paper, No. 17-37, Research Department, Federal Reserve Bank of Philadelphia

29. Nevo, A., Turner J. L. and J. W. Williams, 2015. "Usage-Based Pricing and Demand for Residential Broadband". NBER Working Paper No. 21321

30. OECD. 2017. "How's Life? 2017: Measuring Well-being". OECD Publishing, Paris

31. OECD. 2017. "OECD Digital Economy Outlook 2017". OECD Publishing, Paris

32. Priceonomics, 2013. "Airbnb vs Hotels: A Price Comparison"

33. Reinsdorf, M. and P. Schreyer. 2017. "Measuring Consumer Inflation in a Digital Economy". 5th IMF Statistical Forum

34. Kennedy, Robert F. 1968. Remarks at the University of Kansas, March 18, 1968

35. Rodrik, D. 2015. "Premature Deindustrialization". NBER Working Paper No 20935

36. Rosston, G. L., Savage, S. and D.M. Waldman. 2010. "Household Demand for Broadband Internet Service". TPRC 2010

37. Stansbury, A and L. Summers. 2017. "Productivity and Pay: Is the link broken?". NBER Working Paper 24165

38. Syverson, C. 2013. "Will History Repeat Itself? Comments on "Is the Information Technology Revolution Over?". International Productivity Monitor, Centre for the Study of Living Standards, vol 25, pages 37-40, Spring

39. Syverson, C. 2017. "Challenges to Mismeasurement Explanations for the US Productivity Slowdown". Journal of Economic Perspectives, vol 31(2), pages 165-186

40. Castle, J. and D. Hendry. 2014. "The real wage–productivity nexus". CEPR's Policy Portal

41. Timmer, M. et.al. 2014. "The World Input-Output Database (WIOD): Contents, Concepts and Applications". GGDC Research Memorandum 144, Groningen Growth and Development Centre

42. Thomas, R. and N. Dimsdale. 2017. "A Millennium of Macroeconomic Data". Bank of England OBRA dataset

43. United Nations Conference on Trade and Development, 2016. "Robots and Industrialization in Developing Countries". Policy Brief No. 50

44. Mozur, P. and J. Perlez. 2014. "Gregarious and Direct: China's Web Doorkeeper". New York Times

45. World Bank. 2016. "World Development Report 2016: Digital Dividends". Washington

46. Yang, S. and E. Brynjolfsson. 2001. "Intangible Assets and Growth Accounting: Evidence from Computer Investments"

CHAPTER 3

Crypto technology: A solution still seeking a problem

Joseph Abate
+1 212 412 7459
joseph.abate@barclays.com
BCI, US

Marvin Barth
+44 20 3134 3355
marvin.barth@barclays.com
Barclays, UK

Zoso Davies
+44 20 7773 5815
zoso.davies@barclays.com
Barclays, UK

Tomasz Wieladek
+44 20 3555 2336
tomasz.wieladek@barclays.com
Barclays, UK

Despite tremendous hype over the potential for crypto technologies in money and finance – specifically, blockchain and distributed ledger technology – we see little likelihood of widespread adoption in any area in the near future. Crypto currencies may have a home in low-trust corners of the global economy, but broader adoption of crypto technologies faces critical challenges and strong incumbents.

Our primary findings

- **Adoption of crypto technologies faces four critical challenges:** 1) acceptance/trust; 2) sovereignty/regulation; 3) privacy; and 4) irreversibility. At present, existing technologies appear to be sufficiently good, or even better, to deter broad crypto technology adoption in money and finance.
- **Adoption of crypto currencies – a specific use case of crypto technologies – provides a case study in the four critical challenges to adoption:**
  - In wealthy societies, adoption appears primarily speculative and thus likely temporary.
  - More durable potential long-run demand likely will come from low trust and opportunity economies and criminal enterprise, based on crypto currencies' ability to facilitate trust in transactions without legal enforcement that may outweigh privacy and irreversibility costs.
  - But sovereign power likely will restrict usage to only weaker states and the criminal shadows of the global economy.
- **Incorporating those lessons, we examine five areas of money and finance where crypto technologies may hold promise: 1) fiat money substitutes; 2) smart contracts; 3) asset custody; 4) settlements; and 5) payments.**
  - In each area, we find that incumbent technologies retain significant advantages over crypto technologies at their current stage of development, and the four critical challenges we identify still represent significant hurdles to crypto technology adoption.
  - Finally, history suggests that the ultimate beneficiaries of crypto technology adoption likely will be incumbent financial institutions, rather than disruptors.

Blockchains and distributed ledgers, collectively crypto technologies, continue to generate extensive excitement about their potential. In *Fintech primer vol. 3 – Blockchain* (9 March 2016), our equity colleagues laid the foundation for some scepticism regarding effective uses of these technologies that we largely still hold. Since its publication, there have been significant developments in crypto technology in general and the uptake of crypto currencies in specific. We reflect upon those to update our conclusions regarding crypto currencies and potential uses of crypto technologies.

In the first section, we introduce four critical challenges that we see to crypto technology adoption. We then examine the specific application of crypto technologies in non-sovereign currencies as a case study in the factors that lead to adoption and the role of the critical challenges we identify. We then reconsider applications of crypto technologies in six potentially promising areas of money and finance. Finally, we consider who might be the long-run winners of eventual adoption of crypto currencies.

Critical challenges for crypto technology adoption

Crypto technology must address four challenges

One of our key points is that there is nothing new under the sun as regards the application of crypto technologies in money and finance. Most of the problems crypto currencies propose to solve already have incumbent solutions that may be difficult to dislodge, particularly if they are Pareto superior to – that is, more desirable than – *current* crypto technologies. To dislodge incumbents, crypto technologies will have to overcome four critical issues that reoccur across the proposed uses we consider:

- **Acceptance/trust:** The willingness of a critical mass of others to trust and accept a new platform or vehicle for transactions. All new monetary and financial technologies face issues of trust and acceptance. Crypto technologies offer new means to facilitate trust in multi-party transactions, but must gain acceptance (generally) without sovereign support amid widely used and trusted incumbent technologies.

- **Sovereignty/regulation:** Nearly all sovereigns have the ability to dictate the type and form of transactions allowable within their borders and, in some cases, beyond. This imposes a requirement that new monetary and financial technologies adhere to sovereign prerogatives. A widely touted advantage of crypto technologies is that they enable transaction trust without a legal structure or sovereign interference, but this puts them in direct conflict with sovereign priorities, including seigniorage, tax collection and regulation of finance and commerce.

- **Privacy:** For many if not most transactions, participants desire at least a degree of privacy that shields their transactions from others, while at the same time, sovereigns desire the ability to monitor transactions for legality. A potential short-coming of crypto technologies is their (current) lack of privacy; distributed ledgers make public all transactions contained on blockchains and experiments have shown that the public keys in the blockchain record can be traced to individuals, unmasking any privacy. While newer crypto offerings attempt to address this, successful efforts likely will meet with government suppression.

- **Irreversibility:** Another desired attribute of transactions is reversibility: the ability to unwind the transaction if it was in error or if one or more parties to the transaction fail to deliver on the expected terms. Blockchain and distributed ledgers provide means of contract or transaction enforceability without a supporting legal structure, but lack recourse or reversibility in the cases of errors or fraud.

Box 1: Blockchain in 18th Century France[1]

Blockchain is an extension of much older value transfer technology, dating to the era of metallic money and horses.

Consider the problem facing Le Nicolais and Company in August 1763. How do you transfer a large amount of money from Laval, a textile manufacturing town located 190 miles west of Paris, to the capital – and through the crime-ridden Bois de Boulogne? LeFebvre estimates that on average, the mail and news travelled at 10-12km/hour between major cities. Special fast couriers travelling at full gallop might travel faster, at over 14km/hour.[2] Three thousand livres was equivalent to 125 louis d'or, the standard gold coin in France at the time. Each golden louis bore the king's (Louis XV's) likeness and weighed 6.75g (Figure 1). Thus, 3000 livres is just under 30 ounces (1.86lbs) of coins.

Le Nicolais and Company solved their problem like many of their contemporaries – and, indeed, many of their predecessors in prior centuries. They wrote a bill of exchange: a negotiable instrument authorizing payment of a certain sum to a particular individual (Figure 1, right). The note was 'accepted', or verified in blockchain parlance, by the bank or merchant on whom the note was drawn. Once accepted, the payee could pass the note along to another person or hold it to maturity. Passing the note or transferring it to another owner before maturity meant exchanging it for less than its face value. In our example, M. Morange, a Paris merchant, accepted the note.

In an era of chronic illiquidity and inelastic credit with no central bank, discounted bills of exchange freely circulated, much like paper money today. Markets existed in all major cities in which merchants regularly accepted and discounted these bills of exchange. Each step in the value transfer chain requires trust – although in an era before instant communication, credit reporting bureaus, and deposit insurance – this was largely a matter of personal networks. M. Morange was vouching for the creditworthiness of Le Nicolais and Company – not just to the payee (La Roche and Queneau), but to every other person in the subsequent value chain. He likely was personally known to the community of Paris merchants and bankers who at some point handled this note. Significantly, each trusted that M. Morange himself was creditworthy. Blockchain replaces the personal network with digitized verification – or proof of work in an unpermissioned distributed ledger – in order to transfer value.

Our 18th century blockchain was kicked off almost immediately after the note was written and reached Paris. Indeed, the reverse of this note is a kind of public access blockchain or recorded history of the note's existence: La Roche and Queneau paid it over M. Vallienne on August 19, 1763. He, in turn, passed it to Mr. Granger, four days later. As far as we can tell, M. Granger was the final recipient: he received his 3000 livres (in coin) on November 20, 1763 from M. Morange. He canceled the note by crossing out his signature.

Finally, this note was not recorded or taxed by the royal authorities. In later years, bills of exchange were regularly taxed. Often taxes were applied to the underlying paper, which might have a special watermark or be stamped with a royal cipher or seal. This paper could only be purchased at official stationers.

FIGURE 1

French bill of exchange, 1763

de Laval le 15 aoust 1763 pour L 3000.

Monsieur au vingt Novembre prochain il vous plaira payer par cette premiere de change a l'ordre de Messieurs George La Roche et Queneau trois mil livres en especes au cours de ce jour valeur en Compte avec les dits Sieurs que vous passerés suivant l'avis des

accepté

Vos très humbles Serviteurs

p.r Le Nicolais et Cie

A Monsieur

Monsieur Morange Negt riche St Denis aux armes de portugal

a paris

French, Louis d'or, 1726

Source: Abate collection

[1] All the notes and coins in this piece are from J. Abate's collection.
[2] *The Great Fear of 1789*, G. Lefebvre, Pantheon Books, 1973. Translated from the French by Joan While.

Crypto currencies as a case study in adoption

Much of the focus of crypto technologies has been on crypto currencies as a sovereign-free alternative to 'fiat' currencies. Because crypto currencies are the most well developed and widely used crypto technologies at this point, they make a useful case study for understanding some of the advantages, disadvantages and potential uses of crypto technology in other areas. Crypto currency is a specific use of blockchain and distributed ledger technology. It is a unit of account encoded on a blockchain that is used to transfer value, much like electronic cash. Crypto currency is a form of non-sovereign money, that is, a means of exchange that is not backed by laws and the tax collecting authority of a government. Thus, while it may be accepted as a medium of exchange, unlike sovereign 'fiat' currencies, it is not legal tender required for tax payments and whose acceptance in private transactions usually is legally mandated. Crypto enthusiasts might be surprised to learn that similar instruments have been around in some form for centuries and that the near-complete absence of private money in advanced economies is probably as much a testament to its checkered past as it is to confidence in fiat money.

Crypto currencies also well illustrate all four of the critical challenges that all crypto technologies face. All non-sovereign monies have had to deal with the problems of trust and acceptance in the absence of support from a sovereign balance sheet and legal authority. Similarly, they have, at some point, confronted sovereign prerogatives related to seigniorage – the interest governments earn from issuing money – tax collection, and regulation of finance and commerce. The related concern of privacy, which runs afoul of government attempts to regulate and tax commerce, also has affected all non-sovereign monies, but crypto currencies face additional privacy concerns related to blockchain records of all transactions stored on publicly viewable distributed ledgers. Furthermore, crypto currencies face the issue of irreversibility in the event that acceptance fails: there is no recourse against issuers in the event no one accepts it.

Necessary traits of money: Trust and acceptance

Any money must possess three key traits: act as a unit of account; be a store of value; and be accepted by others as a medium of exchange. All three traits, but particularly the last two, require trust and, under the right circumstances, can be fulfilled by both sovereign and non-sovereign monies. However, sovereignty can convey a distinct advantage in the second and third traits. The taxing authority of a sovereign gives its liabilities, including its fiat money, value. While that value is intimately tied to the fiscal strength of the sovereign's balance sheet and tax base – a concern raised by many crypto currency advocates – in most countries, at most times, the faith and credit of a sovereign bestows some level of value to its currency. More importantly, the sovereign's power to insist that taxes be paid in its currency or to require that all other transactions within its sovereign domain accept settlement in its legal tender ensures that others will accept it as a means of exchange. Guaranteed acceptance as a means of exchange conveys value.

But sovereign money has not always existed, or existed in sufficient quantities, to meet the needs of commerce, or, on occasion, been trusted. These periods in history gave rise to non-sovereign monies.

Box 2: A brief history of private money[3]

As private money, crypto currency is not new. While several general themes behind the issuance of private money, we consider the two identified below as most relevant to crypto currency: sovereign acceptance and special purpose money.[4]

Sovereign permission

A creditworthy issuer's private money is of little value if the sovereign forbids the existence of any money other than its own. At its most basic level, private money challenges the sovereign's ability to collect taxes, earn seigniorage and regulate financial markets and commerce. This makes crypto – much like its paper money ancestors – vulnerable to regulation and outright bans.

Indeed, consider the 'free banking' period in the US (1816-63) and in Scotland (1716-1845). In both countries, banks were able to issue their own paper. In the US, circulating non-metallic money was mostly privately issued paper by state-chartered banks (Figure 2). These were able to issue convertible notes (that is, into government-issued silver and gold coins) subject to state requirements on reserves, interest rates, and capital. Banks generally were weakly capitalized and had short lifespans, given their tendency to make speculative and illiquid investments in land and railroads. Note issuance, rather than deposits, was often their principal source of financing. Notes regularly traded at a discount to their stated face value in coin, often in relation to the distance to the bank's office (where it could be redeemed for coin).

FIGURE 2

State chartered bank issues, 1850s

Source: Abate collection

The wide distribution of notes and the slowness of information meant that those issued by banks that had already failed might continue to circulate far from the original town of issue. The Federal government stopped this activity during the Civil War, when it imposed a 10% tax on the issuance of notes by state-chartered banks. This not only put an end to the inadequately backed state paper but eliminated any competition for its own, non-convertible notes. Bank-issued paper made a comeback with the National Banking Acts of 1863 and 1864, but from nationally chartered banks that had to back their scrip with US Treasury debt, effectively providing a sovereign backstop.

Most developed countries haven't moved to ban crypto currencies outright. But the ability to move large values outside the view of tax authorities is unlikely to win many fans at the treasuries of developed economies. Crypto currencies – like gold – are treated as an asset subject to capital gains taxes. It is not hard to imagine that some versions of crypto currency with features designed to make it more untraceable will eventually be banned, or at least subjected to intense regulatory scrutiny.

[3] We limit our discussion to paper money whose value is based on trust.
[4] The other two – safekeeping and a lack of trust in the sovereign – we consider in Appendix C.

Special purpose money

The ability to design crypto currency with various features designed for specific activities is also not unique. Instead, special purpose money – some of it even sanctioned by sovereign authorities – also has a long history. Mintage of silver and gold coins was erratic, and throughout the 18th century, there was a persistent shortage of low value copper coins. This led to the creation of low value notes that, once the accumulated value reached a certain level, could be exchanged for coins.[5] In most instances, this paper was not legal tender – only the coins were. Special purpose money was usually local and frequently did not circulate outside a particular town or, in some cases, outside of a prisoner-of-war camp. Issuing local-use currency in prisons was also a security measure in that prisoners would not be able to bribe guards or have the financial resources for escaping. An extreme version of limited purpose money was issued by authorities in towns under military siege (Figure 3.).

FIGURE 3

French, Siege of Lyons, August 9 – October 9, 1793

Source: Abate collection

Acceptance and trust

Non-sovereign money is not legal tender…

Non-sovereign currencies are at a distinct disadvantage, as their value and their acceptance by others cannot be guaranteed. Bills of exchange and 'free banking' notes derived their initial value from trust in the solvency of the issuer and belief that others would accept them in future transactions. As acceptance of these non-sovereign monies grew, both their use as media of exchange and the value of their acceptance increased. But non-sovereign monies' value proved fragile: without taxation authority and sovereign enforcement of acceptance, privately issued currencies were subject to perceptions (and the reality) of issuer solvency. Loss of confidence could lead to instantaneous collapse in acceptability as a medium of exchange and impossibility of redemption if the issuer was insolvent, a likely consequence of a run on the issuer (eg, the run on the South Sea Company at the heart of the South Sea bubble).[6]

…and trust that it will be accepted by others is a key hurdle

Trust that a crypto currency will be accepted by others is the key hurdle for adoption and its sole source of value. As with all non-sovereign currencies, acceptance is a fragile equilibrium without a sovereign guarantee. Indeed, sovereigns are competitors with the potential to suppress acceptance of challengers to their own fiat issues. But crypto currencies face acceptance challenges that other non-sovereign monies have not. Previous non-sovereign currencies had either intrinsic value (commodity money) or the backing of an assumed solvent entity that guaranteed repayment in the event others failed to accept its scrip. Additionally, paper non-sovereign monies guaranteed anonymity, whereas the public distributed ledgers of crypto currencies broadcast the history of all transactions recorded in the blockchain.

Crypto currencies are backed by no one, and there is no recourse if acceptance by others does not take hold. A finite supply of tokens is infinitely too much if no one accepts them. If a crypto currency is accepted by others as a medium of exchange, its value will be dictated by its

[5] See, *Stuff and Money in the Time of the French Revolution*, R. Spang, Harvard University Press, 2015
[6] See Appendix C.

supply and pool of users' transactions. Yet, just like past examples of sovereign money, this is a fragile equilibrium. Endemic frauds[7] or robberies via hacking may undermine confidence in a crypto currency as a store of value, and its acceptance by others. But unlike previous sovereign monies, there is no recourse in the event that acceptance evaporates. With commodity monies, the intrinsic value of the money is a backstop to its value. In prior cases of non-sovereign paper money, the recovery value of its issuers' assets (if any) was a backstop to value. Crypto currencies' value comes only from acceptance by others.

Crypto currency is vulnerable to sovereign suppression…

Crypto currency acceptance also is at acute threat from sovereign suppression. Sovereigns earn seigniorage from issuance of their own currencies, and the sums can be substantial: at the peak of its balance sheet expansion, the Federal Reserve remitted nearly $100bn to the US Treasury in 2015.[8] But crypto currencies' potential for anonymity is an even greater threat to sovereigns by better facilitating commerce the government forbids (eg, narcotics, arms) and hiding commerce the government taxes (eg, income, payments). While identification of individuals' public keys in the blockchain is feasible, unmasking privacy in crypto currencies, it is resource intensive and may be beyond the abilities of many less developed countries. Further, new crypto technologies are emerging that claim to obscure transaction identities completely. As a result of these threats, several governments have moved to partially or fully ban use of crypto currencies in their countries, including Bangladesh, Bolivia, China, Ecuador, Iceland, India, Nigeria, and Venezuela.[9]

Crypto currencies as a threat to themselves

…and competition from other crypto versions

Furthermore, like most species, crypto currencies face the greatest danger from their own kind: while any individual crypto currency may have a fixed supply, the potential supply of new, faster-transacting, lower-cost, more secure competitors is infinite. If a rival with superior transactional characteristics attracts sufficient acceptance, a tipping point reaction may lead to a collapse in use (and value) of an incumbent crypto currency.

2017 was a pivotal year for crypto currencies and technologies that illustrates well the tradeoffs between incumbency and innovation in the battle for acceptance. Figure 4 plots for ten crypto currencies with the largest market capitalizations – denoted by bubble size and used here as a proxy for degree of acceptance – their respective estimated peak transaction capacity versus transaction costs. For reference, the VISA interchange network processes 2,000 transactions per second at a cost of 0.05-1.9% of the transaction, depending on the merchant type and jurisdiction, and claims a peak capacity of 56,000 per second. While Bitcoin benefits from incumbency and name recognition, its transaction capacity and cost make it a far inferior medium of exchange relative to newer entrants. Bitcoin's slow speed and high costs led it last year to create Bitcoin Cash, which is on par with early rival efforts to address Bitcoin's speed and cost issues, Dash and Litecoin. But those three lag far behind Ripple and Stellar, which were developed specifically to be cheaper, high-volume international payment systems. Ethereum, the second largest crypto currency, presented a different alternative: rather than focus on speed and capacity – issues its developers are working to address – it offers a fully integrated crypto platform that allows for 'smart contracts', decentralized applications and organizations, and the potential for a user-defined 'smart economy'. This value proposition led to rapid uptake of its underlying currency, ether. Neo and Cardano have followed Ethereum's lead as crypto platforms, but each with its own twist: Neo aims to be regulatory compliant by enforcing digital identities, while Cardano boasts a peer-reviewed process that attempts to learn from the shortcomings of previous crypto technology iterations.

[7] "A company for carrying out an undertaking of great advantage, but nobody to know what it is", unknown pamphleteer in reference to a (likely fraudulent) venture at the time South Seas Company shares were inflating, 1720.
[8] 'Fed 2017 profit payments to Treasury fall to $80.2 billion,' *Reuters*, 10 January 2018.
[9] 'Crypto currencies by country,' *Dividend Magazine*, ThompsonReuters, October 2017.

FIGURE 4

Crypto currencies: market capitalization, peak transaction capacity and average transaction cost

Notes: Average transaction cost is based on most recent 90-day average, except Cardano, Dash, Neo, and Stellar, for which it is based on algorithm pricing terms.
Source: BitInfoCharts.com, Cardanodocs.com, Dash.org, docs.neo.org, Hackernoon, TheMotleyFool, and www.stellar.org.

FIGURE 5

Peak daily transactions and costs, various crypto currencies

Source: Coinmarketcap.com

Monero, a crypto currency, has gone in the opposite direction: it is specifically designed to have untraceable users and transactions, addressing the potential anonymity gaps of other crypto technologies, but potentially attracting greater sovereign suppression.

Each of these innovations – crypto platforms, modes of regulatory compliance, increased privacy, greater transaction capacities, and lower costs – shows the potential of crypto currencies to adapt to meet market place needs, but ultimately each still faces the hurdles presented by the four critical challenges and incumbency of existing technologies.

Crypto currencies are evolving into specific use money…

Indeed, the past year illustrates why we think it will be difficult for any single crypto currency to become the dominant medium of exchange. It is relatively easy to create a new crypto currency that is designed to meet a specific requirement or need. Historically, special purpose money typically has a short lifespan. Instead, as anachronistic as paper money is, its ability to multi-task means that it meets most of the various needs that crypto currencies purport to solve. Paper is private; transactions are anonymous; and, to some extent, regulations exist to enable officials to keep track (somewhat) of at least large values. But crypto currency appears to be evolving in the opposite direction. The proliferation of specific purpose crypto currency is the electronic equivalent of using euros to make online purchases, sterling to buy securities and dollars for in-person transactions. Initial coin offerings are an extreme illustration of this: they are the functional equivalent to store-issued coupons. Maintaining an accounting framework to keep track of multiple single-function currencies is highly inefficient. For a dominant crypto currency to emerge – for either legitimate or illicit activities – its functional use must be broad enough to challenge paper, specifically, large denomination bills such as the $100 and EUR500. Instead, our sense of recent developments is that crypto currencies are moving in the opposite direction; this fracturing based on use makes it unlikely one unit will come to dominate.

…and competing to establish acceptance

Figure 5 illustrates simultaneously the power of first-mover advantage in terms of acceptance and the threat to incumbency from innovation.[10] Bitcoin began 2017 with nearly a 90% share of

[10] One caveat to consider in interpreting these data is that it is difficult to separate out transactions that are "investments" from those where the crypto is used as a medium of exchange. Perhaps a better measure – assuming one could be created – would be to look at purchases of goods and services made with crypto. An example is the Federal Reserve Bank of Boston's *Survey of Consumer Payment Choice*.

the total crypto currency universe market capitalization, but by early 2018 that share had dipped (briefly) below 30% before recovering more recently to about 45%. Smaller incumbents such as Ethereum and Ripple, or Bitcoin fork Bitcoin Cash, with better technologies have taken the most market share over the last year (with respective gains of 14pt, 8pt and 5pt), but new entrants such as Neo and Cardano have come from nowhere in mid-2017 to market capitalization shares of 1.5-2.0% based on their technological offerings.[11] But while these start-ups show how innovation threatens incumbency, the decline in market share of other, smaller rivals from nearly a quarter of the total universe to less than 10% of total market capitalization illustrates that acceptance by others ultimately is the source of value for any crypto currency.

A cross-country study of factors behind adoption

A cross-country study of Bitcoin uptake offers insights into the motives and challenges to adoption of crypto technologies – not just currencies – and the likely pool of end-users that may define crypto currencies' potential value. We find that adoption as a currency is more likely in environments with low levels of trust and development; where crypto currencies may be more trustworthy than incumbent money or offer asset diversification not feasible in local markets; where sovereigns may have less ability to enforce regulation; and where the cost of irreversibility is outweighed by gains in trust, diversification or privacy. These findings suggest that crypto currencies are unlikely to gain widespread acceptance outside of underdeveloped economies. In contrast, we find that the price of crypto currencies appears to be driven by speculative behaviour in developed economies that is dependent on the flow of new entrants who show signs of running out.

While we do not have data on Bitcoin use by country, we can use Google Trends' search intensity of 'Bitcoin' as a proxy for interest in and potential use by country.[12] Figure 6 charts the dispersed but exponentially increasing relationship between internet penetration and Bitcoin interest by country. The relationship testifies to the effect of network externalities: the more connected people are, the faster and easier information and interest spreads. But the dispersion illustrates that other factors clearly play a role in Bitcoin interest. To account for the non-linear network effects, we use search interest inversely weighted by (divided by) internet penetration as a proxy for Bitcoin interest by country in exploring the other factors.

FIGURE 6

Weighted Bitcoin interest vs. intensity of money use, by country

Source: Google Trends, IMF, ITC Facts and Figures 2017, International Telecommunications Union

FIGURE 7

Weighted Bitcoin interest vs. societal welfare, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union, Legatum Institute

[11] Cardano and Neo existed before 2017, but the former did not begin to trade actively until 2017, and the latter underwent a rebranding and re-introduction with new technologies in 2017.

[12] A Bank of Canada study suggests a reasonable degree of correlation between Bitcoin-related Google searches and actual transactions; see Christopher S. Henry & Kim P. Huynh & Gradon Nicholls, *Bitcoin Awareness and Usage in Canada*, Staff Working Papers 17-56, Bank of Canada, November 12, 2017.

Is a fixed supply important?

Crypto currency advocates often point to their fixed supply (or fixed growth rate) as a key attraction, as it removes the ability of governments to undermine their value through inflation. But there appears to be little relationship between Bitcoin interest across countries and their respective rates of inflation (Figure 7). Nor is there a clear relationship across countries between interest in Bitcoin and the volatility of inflation (not shown). But that does not mean that there is no relationship between Bitcoin interest and the local money supply. Figure 8 shows the weak but negative relationship between M1/GDP – the monetary intensity of economic activity – and interest in Bitcoin. While inflation may not be the cause, countries with low usage of the local currency relative to economic activity appear more likely to have higher interest in Bitcoin.

Interest in Bitcoin is highest in both high and low welfare societies …

A much stronger, but nonlinear, relationship exists between Bitcoin interest and of societal welfare. Figure 7 plots weighted interest in Bitcoin versus the Legatum Prosperity Index, a broad measure of societal welfare that spans the economy, governance, opportunity, education, health, personal freedoms, safety, and social capital.[13] Bitcoin interest is highest at both ends of the spectrum: the highest and lowest welfare societies, but lowest on average in medium welfare countries. The dispersion is highest in countries with below-average welfare.

Looking into the subcomponents of societal welfare yields surprising insights into the sources of the two tails of interest. Personal freedoms, a measure of government intervention in people's lives, often touted as a benefit of crypto technologies in general and crypto currencies in specific, appears wholly unrelated to interest in Bitcoin across countries (Figure 10). Economic strength and governance (not shown) turn out to be weak predictors of interest, as well. But institutional development does appear important, at least for the lower tail of prosperous countries. The strongest relationship to interest in Bitcoin – by tightness of fit – is with country health scores, a measure that often proxies for institutional development and robustness (Figure 11). The closeness of fit appears driven by the lower tail of the distribution; ie, below a certain threshold the lower health outcomes, the greater the interest in Bitcoin, but above that threshold there is little difference in interest. Development issues likely also help to explain the relatively tight relationship with the entrepreneurship and opportunity subindex (Figure 12). In countries with few opportunities for or means of investment, crypto currencies may be one of the few ways to diversify

FIGURE 8
'Bitcoin' searches vs. internet penetration, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union

FIGURE 9
Weighted Bitcoin interest vs. inflation, by country

Source: Google Trends, IMF, ITC Facts and Figures 2017, International Telecommunications Union

[13] The Legatum Prosperity Index is a measure of country-level social welfare produced by the Legatum Institute. It measures welfare based on 110 questions divided into eight categories (subindices): Economy, Entrepreneurship and Opportunity, Governance, Education, Health, Safety and Security, Personal Freedoms, and Social Capital, the last being a measure of the 'glue' of society, particularly trust in fellow citizens and institutions.

FIGURE 10

Weighted Bitcoin interest vs. personal freedom, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union, Legatum Institute

FIGURE 11

Weighted Bitcoin interest vs. health, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union, Legatum Institute

savings out of domestic assets. The somewhat higher level of interest in the highest entrepreneurship and opportunity societies – which also are the richest – suggests high-risk tolerance speculation may play a role, as does the high concentration of holdings in most crypto currencies.[14]

…and is related to issues of trust and safety

Beyond institutional development and opportunities, Bitcoin interest across countries is most related to issues of trust and safety, again particularly in the lower end of the development spectrum. Figure 13 plots the relationship of weighted Bitcoin interest with the Legatum safety and security subindex, and Figure 14 shows the relationship to social capital, a measure of trust within a society. While the relationship between Bitcoin interest and safety or trust is relatively flat for above average countries, it is increasingly negative for countries with below-average safety and trust.

FIGURE 12

Weighted Bitcoin interest vs. entrepreneurship and opportunity, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union, Legatum Institute

FIGURE 13

Weighted Bitcoin interest vs. safety and security, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union, Legatum Institute

[14] Under constant relative risk aversion, risk tolerance rises with wealth. According to Bitinfocharts.com, the top 100 holders of Bitcoin hold 18.6% of its market capitalization; the same figures for Bitcoin Cash and Litecoin are 24.5% and 45.2%, respectively.

FIGURE 14

Weighted Bitcoin interest vs. social capital, by country

Source: Google Trends, ITC Facts and Figures 2017, International Telecommunications Union, Legatum Institute

FIGURE 15

Societal welfare vs. state hostility to crypto currencies, by country

Source: Legatum Institute, ThompsonReuters

The most likely uses for crypto currency are in low-trust, low-security environments

These analyses suggest that the most likely uses for crypto currencies – and crypto technologies such as smart contracts – are in low-trust, low-security environments with little institutional development and opportunity for alternatives. These likely are failed or weak states, or criminal enterprises, where trust, security and alternatives are in short supply. Without adoption by major central banks, demand for crypto currencies in well-functioning societies with strong institutions, rule of law and systems for adjudication is likely to remain either evangelical or speculative.

Yet governments in countries with low trust are unlikely to accept rejection of their currencies by their citizens without a fight. Figure 15 plots countries' Legatum Prosperity score versus a ThompsonReuters categorization of governments' legal stances towards crypto currencies from complete acceptance (0) to banning (4).[15] Nearly all the countries that ban crypto currencies are in the bottom half of the Legatum index, with Iceland – the only OECD country with capital controls – a notable exception. In contrast, sovereigns with strong institutions and payment and legal systems – thus little threatened by crypto currency adoption – are open to them.

Beyond crypto: Prospective applications

How might blockchain and distributed ledger technology be applied outside of currencies?

Blockchain and distributed ledger technologies have a large number of potential applications. Although using crypto currencies as a substitute for fiat money is the use case that has received the most attention, others include smart contracts, asset custody, and payments. In each use case, there are inefficiencies in the status quo that are theoretically addressable using these technologies. However, in none of these cases is the technology ready for application now. There are significant hurdles that would need to be surmounted, such as improvements in speed and process or the development of new trade protocols. In some cases, the potential gain likely justifies the required investment, although in most of the financial market use cases, the *status quo* appears to be efficient enough that we do not expect any medium-term deployment of these technologies.

Fiat money substitutes

- Recent trends in crypto currencies suggest a move towards 'specialty' transactions vehicles like those on 'smart economy' platforms that may speed up international

[15] 'Crypto currencies by country,' *Dividend Magazine*, ThompsonReuters, October 2017.

payments, or privacy-enhancing electronic currencies that may be more appealing for illicit activities.

- Crypto currency is ideally suited for use in low trust environments. It is useful to move large values unobtrusively and as a means of tax and regulatory evasion.
- But by directly challenging the authorities' monopoly on money creation, crypto fiat substitutes are vulnerable to regulation and outright bans.

Recent developments in crypto currency technology suggest that trend adoption may come from specialty transactions demand. Broad adoption of crypto currency as a means for making fast international payments may develop on "smart economy" platforms such as Ethereum, Neo or Cardano, or as an international payment mechanism such as Ripple and Stellar. Ethereum, however, was specifically created as an institution-free platform for commerce and communication, hence likely would come into direct conflict with regulators. So, too is the strategy of newer crypto currency entrants Monero and Zcash, both of whom provided enhanced transaction privacy, masking participants and amounts transacted. Neo and, to a lesser extent, Cardano, in contrast, are designed to be compliant with regulators from the start. Neo's connections to and backing by the titans of China's economy have led some to speculate that it is positioning itself for adoption by the Chinese state.[16] But adoption of a crypto platform need not imply adoption of its underlying currency over the sovereign's own fiat currency.

We do not believe any crypto currency is likely to become legal tender in a developed economy

More importantly, we struggle to see how any government would willingly seek to undermine its sovereign authority by allowing an alternative unit of account to become a substitute for its issuance, threatening its seignorage and tax collection. As such, we believe that no crypto currency is ever likely to become legal tender in a developed economy.

Instead, we suspect that crypto's appeal is higher in the underground economy, which has always been cash-reliant, given the un-traceability of currency. But moving currency has become increasingly difficult. The US stopped printing large denomination notes (of $500 and $1000) by the late 1960s in an effort to reduce tax evasion and crime. For similar reasons, the ECB recently stopped printing the EUR500 note. As the supply of large denomination notes disappears, other means of transporting high values have increased. But even diamonds have become harder to smuggle, as recent rules marking stones were introduced in the last decade. Unsurprisingly, this has created demand for an alternative to paper currency that is discreet and hidden from the view of authorities.

Indeed, although criminal activities tend to be cash-intensive businesses at the retail level, the practical limitations on currency seem to be reducing the attachment to paper at the wholesale level, where cash mixes undetected with legitimate money and transactions. This might explain why the Drug Enforcement Agency's seizures of bulk cash have declined nearly 60% since 2010. For what's estimated to be a $64bn (illegal) drug economy that, at least at the retail end of the business, is very cash intensive, the amount of currency seized is surprisingly small. Only $337mn in bulk cash – or 0.5% of US drug "GDP" – was seized by the DEA in 2016.[17] The DEA notes that low bulk cash confiscation rates are partially tied to the fact that at the wholesale level, cash has been pushed aside in favour of other ways for hiding and laundering illicit money.

[16] 'Neo versus Ethereum: Why NEO might be 2018's strongest cryptocurrency,' Noam Levenson, Hackernoon, 6 December 2017.
[17] See "Drug Enforcement Agency: 2017 National Drug Threat Assessment Report".

Box 3: Frictionless money laundering

A cottage industry has developed that allows owners of "dirty" Bitcoins to convert them into legitimate, "clean" crypto currency. Laundering Bitcoins generally takes two forms – although we suspect that there are other, more sophisticated methods. In one, the Bitcoin proceeds from illegal activity are mixed with clean ones from other investors on an exchange though an intermediary. The intermediary "swaps" coins across different owners, so that the clean ones are returned to the owner of the dirty coins, which are then distributed throughout the exchange ("tumbling"). Alternatively, dirty coins are spent on low value transactions, and the change from the transaction is returned to another address (a process known as "peeling"). This new address repeats the same transaction, with the change returned successively to different addresses.

Smart contracts

- Blockchain and smart contracts can significantly reduce record keeping and verification burdens by shifting the recordkeeping from the counterparties in a transaction to the asset itself. The associated efficiencies are potentially meaningful where transaction volume is extremely high, such as tri-party repo.
- Replicating the flexibility built into the current system is an important hurdle to adoption. While true for even the simplest tri-party repo, more advanced use cases such as ABS transactions require even more judgement.

Built into most financial transactions is a multi-step verification process, which establishes who owns the asset, whether the owner has permission to sell it, where the asset is located or stored, along with instructions on its transfer. In most cases, this requires multiple ledger entries across different counterparties in an asset transfer, including the buyer, seller and custodian. These records need to be cross- and double-checked before and after the asset's transfer can be completed.

But ownership and transfer details can be encoded into the asset's 'DNA' via a permissioned blockchain. The public ledger programmed into the asset's DNA eliminates the need for cross-checking records across multiple corporate ledgers. Smart contracts can be designed to execute automatically, linking cash and trading accounts. Significantly, as the blockchain establishes a publicly visible record of ownership, the asset record does not have to sit in an account at a custodian bank for safekeeping. This fundamentally changes the nature of custodial relationships, as securities lending – for *any* blockchained asset – can now occur outside of a custody bank that traditionally has provided safekeeping and ownership records. Automatically executing contracts can be designed to perform a variety of functions that traditionally have been done by custody banks or exchanges: from calculating and collecting variation margin to asset transfers and securities lending. Blockchain and smart contracts mean that recordkeeping moves from the counterparties and the custody agent to the asset itself.

Tri-party repo

Can tri-party repo be blockchained?

Consider the specific case of tri-party repurchase agreements (repo). Repo is a collateralized loan where cash is exchanged for securities (such as Treasuries) and then reversed the following day. In a tri-party transaction, the cash and collateral move within an account or 'box' maintained on the balance sheet of the clearing bank. This is considerably more efficient than the alternative of delivery-versus-payment, where the counterparties have to make their own transfer arrangements.

After both counterparties agree to an exchange, their back offices contact the clearing bank to move the respective assets. But before the actual movement of cash and collateral, the

lender, borrower, and the clearing bank each have to confirm the location of the cash and collateral, initiating a double-checking process that spans three separately maintained ledgers. Although three-way trade confirmation is automated, it still requires some effort to prevent mistakes.

Now imagine each Treasury CUSIP existed on a blockchain. The blockchain would be updated with the owner's details, including bank information. The agreement to exchange cash and the CUSIP would represent a new block on the issue's blockchain. And since the cash and collateral both reside in a box at the clearing bank, it should be a relatively simple matter linking both sides of the transaction via the blockchain. A smart contract could be designed to unwind (reverse) the trade after exactly 24 hours.

The self-executing contract means that trade might be programmed to unwind at different times throughout the day. This frees cash and collateral to move throughout the day, rather than one specific time in the afternoon. This is important to some institutions: US Federal Home Loan Banks have an aversion to repo because their unwinding cash is not returned until late in the following afternoon, although their own cash needs are highest early in the morning. The free movement of cash and collateral throughout the day suggests that, at least in theory, it might be possible for an intra-day repo market to develop.

One hurdle to adoption is that there is flexibility built into the current system that would be important to maintain. In the *status quo*, there is the ability to modify the collateral pledged – for example, substituting one CUSIP for another – before the cash and securities are exchanged at the end of the day. Dealers and the clearing bank have developed sophisticated programs that can automatically do these substitutions based on an optimization algorithm. Significant investment would be required to convert existing collateral substitution programs into smart contracts, particularly given the importance of repo markets to market participants and regulators.

Smart contracts may struggle to handle collateral substitution...

At the moment, there is only one tri-party clearing bank and the prospects for new entrants are very low given the high cost of entry. We suspect the burden of converting tri-party to blockchain would initially fall to the clearing bank. But as this bank has no competitors, it would be easy for it to recoup its conversion costs. Most likely this would be accomplished via a widening in bid-ask spreads in the tri-party market.

ABS

A portfolio of assets – for example, credit cards – is assembled and financed through the issuance of asset backed debt. The portfolio is over-collateralized; that is, it holds more loans than the amount of debt issued. This is not the only type of securitization, of course. Other structures use subordinated debt in combination with a reserve (cash account) and excess spread. Asset-backed securities (ABS) typically are purchased by a variety of investors including money managers, banks, insurance companies, and, when funded with CP, money market funds. We consider some of the operational roles and plumbing details in a simple credit card (master trust) asset-backed program.

A servicer's role is to manage the credit card portfolio, as well as its associated cash flows. It processes the collection of the loan payments and remits them to a trustee, which then pays bondholders. In a credit card master trust, the servicer also determines the level of excess collateral the portfolio will maintain against its outstanding debt. The master trust servicer also can remove non-performing loans, replacing them with other, performing loans by requesting the borrower to post more collateral or retire debt. And the borrower also can post additional collateral, for example, to issue more ABS debt or to replace loans that are paid off.

So, where might blockchain fit in?

It is possible to put all credit card loans onto a blockchain. Each loan might have an embedded code identifying the originator and the note holder. These details could be used

to design a smart contract that automatically directs the loan payments to the asset-backed debt holders' accounts. In practice, we suspect that loan payments would be directed to a central, distribution account that itself would be governed by its own smart contract linked to a blockchain embedded into the asset-backed debt. It would be relatively simple to design a smart contract to distribute payments automatically to the asset-backed debt holders according to some pre-determined calendar schedule, much like automatic bill-pay. In theory, this removes the need for a servicer to process loan payments.

...Or collect on delinquent receivables in a credit card trust

But it may be difficult for blockchain to address some of the credit card master trust servicers' other functions. Designing smart contracts that automatically replace collateral as it pays down or is removed from the trust without some amount of judgment is considerably more challenging. And while blockchain and smart contracts could efficiently distribute incoming debt payments to ABS holders, it is unclear how the technology could be structured to collect on delinquent receivables or sell charged-off receivables. Separately, a blockchain would not remove the need for a trustee whose responsibility it is to represent noteholders in cases where there is a breach of trust disagreement such as the default of the servicer.

Asset custody

- Blockchain can be used to establish the provenance of an asset and prevent its transfer. This could reduce theft and reduce transaction costs associated with verifying ownership, such as title insurance.
- The key hurdle is converting asset holdings into blockchained digital registries, although the costs vary by asset, as some aggregated databases already exist, such as for real estate. In those cases, we see potential for nearer-term adoption.

Blockchain can establish asset provenance

Beyond simple recordkeeping, blockchain can be used to establish the provenance of an asset and prevent or authorize its transfer. In the case of an asset that doesn't change hands frequently, like a home, it is easy to develop a digital contract between the buyer and seller than updates the asset's blockchain. This could be linked directly with a bank whose mortgage financing would also be encoded into the home's blockchain. Similarly, mortgage payments encoded on the same blockchain could be processed directly into the servicer's accounts. Moreover, the property's chain would contain all tax data including liens and deed restrictions. In this example, there theoretically would be little need to pay someone to do a title search or buy title insurance.

New York City real estate

What role does title insurance play in a world with blockchained deeds?

The New York City Department of Finance maintains an online registry of real estate transactions dating back to 1966. The Automated City Register Information System (ACRIS) provides information on real estate transactions that, in addition to the names of the buyer and seller, includes data on the mortgage (amount and noteholder), as well as information about transfer taxes paid on the sale. The data also include the sales price of the unit and if the mortgage has been paid off. This database is searchable by name, location, and type of form (mortgage payoff data, for example, are recorded on the UCC financing statement. In theory, as these data are all readily accessible, there is little need to hire someone to do a title search or for the buyer to purchase title insurance.

As the information is already effectively in a centralized ledger, the next step of converting these records into a blockchain is relatively easy. Of course, not all localities have detailed, searchable real estate records, so the initial hurdle of converting paper records maintained at the town hall is likely to be expensive. But once this occurs, we expect the next step of blockhaining title transfers, school taxes, and mortgage payments quickly to follow.

But just as the blockchain be can used to record and authorize asset transfers, it can also prevent the movement or resale of assets. On the simplest level, the asset's digital DNA

could be encoded in such a way so that it cannot be resold or transferred outside a small list of authorized individuals. Jewellery or artwork could be registered in such a manner. This might not prevent the asset from being stolen and fenced or resold. But it would make transferring these ill-gotten assets to legitimate buyers much harder. Assets whose provenance is well verified and whose ownership is unequivocally established via the blockchain are theoretically easier to insure, as it would be difficult to bring an offline asset that was previously registered back into a legitimate chain of transactions.

Returning to our Treasury CUSIP blockchain, consider how a "do not transfer code" could be inserted that automatically prevents the sale of the security to buyers whose phone number has a specific area code. Unlike currency, which is transportable over borders, crypto assets might be programmed to become invalid if an attempt is made to use or transfer them improperly or in a sanctioned country.

Settlements

- Blockchain and distributed ledger technology could allow for immediate settlement, eliminating one form of operational risk. In addition, they could eliminate settlement failure or incomplete deliveries.
- However, this might not be desirable. Money laundering and customer identification requirements may require some timing gap in settlement, as does correcting mistakes. Overcoming these hurdles may require new trade protocols, such as different approaches to trusted or known counterparties.

In theory, blockchain and distributed ledger could allow for immediate settlement…

Discussions of Bitcoin and cross-border payments frequently highlight the potential for blockchains and distributed ledgers to eliminate delays in settlement. They point out how long it takes to send a payment from a US bank in dollars to an overseas institution in another currency – and the associated expense. We think that with smart contracts that execute automatically and blockchains linking payments to ownership transfer, immediate settlements are possible.

Immediate settlement eliminates one form of operational risk – settlement risk. This exists when there is a delay between the transaction agreement and the ultimate exchange of cash. Since the 1970s, banks have adopted real-time gross payment settlements in their processing of check and wire payments. While this reduces settlement risk, it is less efficient from the perspective of processing, as it requires significant amounts of intra-day credit.

Settlement failure

Despite significant technological improvements with respect to electronic payments, settlement failures are surprisingly common in some large markets such as Treasuries. Indeed, over the past several years, the volume of failed Treasury deliveries has increased, rising to approximately 4% of average daily trading activity.[18] Based on the distribution and type of incomplete deliveries, our sense is that this increase is tied to a pick-up in delivery instruction errors. Beyond the obvious question of why delivery instruction errors have increased, there is the issue of why technology is not able to solve this. After all, failing to deliver a Treasury as promised incurs a pretty hefty charge, not to mention the client's dissatisfaction. The increasing cost of fails should, in theory, motivate firms to spend more on technology to eliminate these settlement gaps.

Although the precise cause of the increase in incomplete deliveries is not well understood, our sense is that blockchain technology might help reduce their incidence. Smart contracts could, theoretically, eliminate settlement fails by authorizing the immediate release of cash

[18] See *Spontaneous failure*, January 17, 2018.

and Treasuries once certain pre-conditions had been satisfied (for example, upon receipt of a confirmation message).

…but legal and regulatory requirements mean that immediate settlement may not be desirable

That said, even in a post-blockchain world, immediate settlement might not be as optimal as faster settlement, for two reasons. First, because it is difficult to correct mistakes on a blockchain, it might be wise to have a longer "curing" period for settlements. Trades could be reviewed during a brief pre-settlement period to ensure the details are correct before the confirmation codes are sent.

Second, even if there were no risk of mistakes and transactions could be reversed easily, it might still not be possible or desirable for transactions to settle immediately. In many markets, investors are required to check whether the transaction satisfies anti-money laundering (AML) and know your customer (KYC) rules. Of course, it is possible for technology to solve this issue, as well. Firms could establish trusted counterparties whose trades settle immediately, while others go through a more thorough regulatory review process and settle later.

Payments

- Faster payments are possible with blockchain technology, and aspects of the existing payments infrastructure are arcane and impose delays on payments processing.
- But even in the simplest proofs of concept, such as a study at the Bank of Canada over a closed system of inter-bank payments, the current blockchain and DL technology was not much of an improvement over the existing model. More complicated applications, with more meaningful potential gains, would require substantial improvements in technology.

Faster and cheaper payment processing has attracted the most attention from blockchain enthusiasts. Recently, the Bank of Canada studied a proof-of-concept test – Project Jasper – that applied distributed ledger technology to interbank wholesale payments.[19] The BoC was interested in learning if its large value transfer system (LVTS) could eventually shift to a distributed ledger. On average, the BoC processes roughly C$175bn/day in these payments, via roughly 10 transactions every second. These are fairly simple transfers between the reserve accounts of member banks, all within a closed system on the BoC's balance sheet.

Transactions are mostly settled on a real-time gross settlement basis, that is, immediately as they come in. But this requires enormous amounts of liquidity, given the volume of transactions and a natural tendency to delay outflows while accelerating inflows. In the absence of intraday credit, no one would send out payments until they had first received their cash due. At the extreme, this creates a traffic jam: no one is willing to move first, so everyone's payments are held back. Central banks attempt to mitigate these effects by liberally providing intra-day credit – for a cost. That is meant to encourage banks to develop their own strategies that conserve the aggregate amount of liquidity the system needs to process payments. Liquidity savings mechanisms (LSMs) are designed to net down offsetting payments on a multilateral basis at different times throughout the day. But to be able to net down potentially offsetting payments, banks need to delay some outflows long enough to establish a backlog that can be netted against incoming flows. This requires them to determine which payments need to be cleared immediately, ie, on a real-time gross settlement basis, and which can be delayed long enough to build a pool of "net-able" transactions.

The challenge for the designers was first to create a settlement asset, a digital drawing right (DDR) on the BoC. The DDR was equivalent to a transferable reserve account balance, that is, a claim on a deposit at the BoC. The designers used Ethereum. DDRs would be exchanged on a real-time gross settlement basis using simulated data. In addition, the programmers built in LSM algorithms consistent with what banks already use.

[19] See *Project Jasper: Are Distributed Wholesale Payment Systems Feasible Yet?* J. Chapman, R. Garratt, S. Hendry, A. McCormack, and W. McMahon, Bank of Canada, Financial System Review, June 2017.

Program designers found that they could process about 14 transactions per second using an Ethereum-based DDR. Chapman *et al.* argue that this is probably sufficient to handle average daily processing requirements, but it could become insufficient and might already be so for peak payment flow days. The designers did note that it was possible to overcome the scalability issue by switching to a more centralized ledger that did not rely on consensus based verification. Instead, a distributed ledger that used a trusted 'notary' might eliminate the scalability problem. Designing a LSM for the DDRs using simulated data turned out to be significantly more challenging. As of mid-2017, program designers were still testing the algorithms.

Real-time gross settlement results were somewhat lackluster

Overall, the results from Project Jasper were somewhat lacklustre. Chapman *et al*. note, 'Current versions of distributed ledger technology do not provide an overall net benefit relative to current centralized systems.' Indeed, the results suggest that – at least for interbank payments – the most efficient distributed ledger seems to be one that is fairly narrow in scope and, instead of a broad consensus-based verification mechanism (such as is used in Bitcoin), relies on a single notary that updates a centralized DDR ledger.

FIGURE 16

Prospective applications of blockchain and distributed ledger technology

	Acceptance/Trust	Security/Regulation	Privacy	Irreversibility
Fiat money substitute				
Crypto currency	Acceptance outside low trust activity is likely to be low. Multiple specific-use currency may diffuse demand for crypto, reducing broader acceptance.	Major sovereigns are unlikely ever to grant legal tender status. Some cryptos are designed to be untraceable, which makes outright bans likelier.	Mixed. Newer crypto technologies claim absolute privacy, while first generation crypto technologies are traceable; full privacy may invite sovereign conflict.	In theory, this is no different than for paper currency. But it might be hard to enforce legally, depending on the nature of the transaction.
Smart contracts				
Tri-party repo	Trust unlikely to be an issue, but acceptance will require securities to be converted from book entry to blockchain, meaning acceptance requires overcoming.	All the transactions go through the "box" of one bank and are viewable. In theory, there would be no change over the existing framework.	How anonymous should counterparties be to each other? More fundamentally, how visible should a Treasury CUSIP's blockchain be? Should "write" access be through primary dealers only?	Settlement failure is somewhat frequent, likely reflecting human error. A reversibility process likely would be required, calling into question the value of blockchain efficiency gains.
ABS (credit cards)	No obvious trust issues, but agreement on blockchain format, structure and permissioning may be a hurdle.	Requires putting the credit card loans onto a blockchain. Write access would be controlled by originator and the note holder. But designing a contract that would collect or sell off delinquent receivables might be difficult.	We do not see any obvious issues: individual loans making up the collateral would be anonymous.	Misdirected payments encoded into the blockchain would be hard to correct without an additional offsetting transaction.
Asset custody				
Real estate	High. Records are already moving to electronic registries, so banks and noteholders may have little issue with trust.	Real estate transactions are largely in the public record. But digitization makes it less costly to search records or establish provenance.	We do not see any obvious issues.	Misdirected payments encoded into the blockchain would be hard to correct without an additional offsetting transaction.
Settlements				
Financial assets	High. Much of the delay in settlements results from double- and cross-checking ledgers maintained by the buyer and seller.	In theory, it would be possible to reduce operational risk by eliminating the time delay in settlement.	How anonymous should counterparties be to each other? Likewise, who should have "write" access to the asset's blockchain?	Misdirected payments encoded into the blockchain would be hard to correct without an additional offsetting transaction. This is problematic, given the frequency of delivery instruction errors in some markets. Is it desirable to have

	Acceptance/Trust	Security/Regulation	Privacy	Irreversibility
				a "cure" period, a brief delay in settlement to allow buyers and sellers to correct mistakes before the trade is finalized?
Payments				
Project Jasper	High. Large interbank transfers are limited to central bank deposits among counterparties that presumably share an identifiable encryption code.	High, given the limitation on the ability to transfer money outside the network.	High. As these are interbank payments on a closed system, privacy might not be an issue.	Misdirected payments encoded into the blockchain would be hard to correct without an additional offsetting transaction.

Source: Barclays Research

Potential exists

We think blockchain and distributed ledger technologies hold potential. In our quick survey of potential efficiency gains, we see two general impediments to widespread adoption.

First, what might be technologically possible may not be legally so. Much of the verification and double-checking that now occurs in financial transactions are driven by regulation. Banks and non-bank financial service providers are subject to KYC rules, as well as AML reporting requirements. We have no doubt that technology can greatly simplify these requirements; for example, much like border controls, it is possible to establish trusted counterparties whose transactions and activities are subject to less monitoring and verification. Similarly, as we describe above, it is possible to encode KYC and AML restrictions into the blockchain of the asset, much like a tax lien on a land title.

Second, we suspect that some improvements may be slow to take hold because the existing technology is good enough. As described above, real-time gross settlements for bank payments may be difficult to shift over to blockchain and – at least currently – have little net benefit over the existing technology. And the cost of transitioning may be high relative to the potential savings.

It is not entirely clear what kind of blockchain access should exist for financial assets

Finally, it is not entirely clear what kind of blockchain access should exist for financial assets. In our earlier examples, we assumed that buyers and sellers would enter a matching encrypted code on a permissioned distributed ledger that turns a switch on the asset's blockchained CUSIP. In theory, all investors with write access to the ledger would be able to update the CUSIP chain directly. However, we assume regulators would wish to establish some minimum standards on investors with write access to blockchains. But if the blockchain is publicly viewable, how could it be structured simultaneously to preserve ownership anonymity while allowing the Treasury and other financial market regulators the ability to identify owners and transactions?

Who benefits from the efficiency gains?

Most of the studies of the potential gains from distributed ledger have a similar theme: technology lowers intermediation costs; therefore, consumers benefit. A Bitcoin-based international payments platform eliminates the need for middlemen and correspondent banks while promising (near) immediate settlement. More extreme versions with widespread distributed ledger adoption and smart contracts imagine a completely de-centralized financial marketplace where intermediation costs have been reduced nearly to 0. But this is probably an oversimplification.

Consider the US payment system, which has been the focal point of much of the heated commentary about de-centralization and intermediation costs. Even if US payments become safer and faster through the application of distributed ledger and blockchain, it is unclear

how much the cost of sending and receiving payments will decline. Instead, this would depend on how the organizational structure of the payments system evolves alongside new technology.[20] Three potential market structures could emerge: a dominant operator, a multi-operator or a completely de-centralized platform. These depend on the fixed expense of the new technology and whether, in an industry such as payments, there are economies of scale and network efficiencies.

Will the financial services industry de-concentrate?

It is unclear to what extent the financial services industry will de-centralize, despite stories about the end of traditional banking and the expansion of peer-to-peer lending. While distributed ledger and blockchain may make it easier for smaller firms with cutting-edge technology to become significant financial market disruptors, banking, market-making and other forms of financial intermediation are heavily regulated, so that entry is expensive. Importantly, financial intermediation exhibits significant returns to scale and network efficiency.

New financial technology such as blockchain, distributed ledgers, and smart contracts, have historical parallels. Indeed, advances in computers and telecommunications since the 1970s have tended to favour more centralization in financial services. This has certainly been the case for automatic consumer electronic payments such as direct deposits, mortgages, and other consumer bills. Where once there were several regional platforms processing payments on the Automated Clearing House (ACH) platform, there are now only two left: The Clearing House (TCH) and the Federal Reserve. But electronic payment processing is only one example. Originally, there were several banks that cleared repo transactions, but higher capital and other requirements eventually reduced this number to just one by mid-2016.[21] Our reading of this history suggests that some of the optimism about 'cost-less' cross border payments outside the traditional banking sector may be overstated.

Separately, the application of distributed ledger technology shares some features with 'dematerialization', *ie*, the removal of paper stock and bond certificates. By the late 1960s, increasing financial market activity created an avalanche of circulating paper certificates shuttling between banks and depositories. Not only did this create security risk (no pun intended), but the amount of time it took to move certificates required the New York Stock Exchange to shorten trading hours and close on Wednesday, even with T+5 settlement.[22]

Initially, banks attempted to reduce the volume of circulating paper by immobilizing certificates at a central repository. Ownership changes could be reflected in a book entry ledger without the certificates ever leaving the repository, a pre-computer version of a blockchain without a publicly viewable ledger. Initially, the book entry only modestly reduced the paper avalanche, as the program was voluntary. It was only in 1983 that the NYSE required members to settle securities in book entry form. At about the same time, the Treasury moved its issuance to book entry. That said, even as late as 2012, there were still 1.2m stock and bond certificates sitting in the DTCC's vaults, although down 94% since 2000. Our sense is that removing or reducing the back office costs associated with double-checking ledgers, bookkeeping, and trade verification will be similar to the cost savings associated with dematerialization.

New technology tends either to create a new dominant presence or is quickly co-opted by incumbents

Curiously, despite the technological advances described above, a recent examination of financial intermediation costs reveals surprising stability.[23] Philippon estimates that the unit cost of financial intermediation has been steady at about 2% for 130 years. He suggests there might be three reasons for the stickiness in intermediation costs: barriers to entry, increasing returns to scale, and inefficient regulation (in the form of 'too big to fail', which

[20] See *Faster Payments: Market Structure and Policy Considerations*, A. Rosenbaum, G. Baughman, M. Manuszak, K. Stewart, F. Hayashi, and J. Stavins, Federal Reserve Bank of Boston, September 2017.
[21] Even the Fed's daily reverse repo transactions settle on this platform.
[22] See *A Proposal to Fully De-materialize Physical Securities: Eliminating the Costs and Risks They Incur*, DTCC White Paper, July 2012.
[23] See *The FinTech Opportunity*, T. Philippon, Bank for International Settlements working paper, August 2017.

could act as a *de facto* proxy for counterparty trust). Our sense is that new technology tends either to create a new dominant presence or is quickly co-opted by incumbents.

But if Philippon's numbers are correct, the outlook for lower transaction costs from blockchain and distributed ledger technology is a bit disappointing. After all, if dematerialization, electronic payments, and telecommunication advances such as the phone and Bloomberg have failed to reduce the cost of financial intermediation, what's to say that these new technologies will have any more success?

Of course, it may be the case that crypto adoption is *currently* limited to low-trust environments. But as the technology develops and the sophistication of smart contracts advances, we cannot reject that adoption could spread to developed economies with strong legal frameworks.

Appendix A: A brief lexicon

For a more detailed discussion, please refer to *Fintech primer vol. 3 – Blockchain*, 9 March 2016.

Blockchain: A specific type of ledger in which transactions are recorded in groups or 'blocks' that have been encrypted and linked together. The encryption of new block in the chain uses an identifier uniquely generated from the previous block as an input; in this way, the blocks are 'chained' together. As this is done in a near-unique manner, altering past transactions is extremely difficult and costly.[24]

Distributed ledger: An electronic ledger that is kept in multiple places simultaneously. Because there are multiple copies, a distributed ledger requires a mechanism for keeping all copies of the ledger synchronised and for resolving disputes when copies of the ledger differ from one another.

Public ledgers: The extent to which anyone can read the information recorded in a copy of the distributed ledger. Public ledgers are more resilient because with enough copies in existence, it becomes almost impossible to shut down or permanently lose the ledger. Every transaction is public. To the extent that activity can be linked or tagged to specific owner, this means that ownership is also (potentially) viewable.

Permissioned access: A distributed ledger that only allows specific users to add transactions to the ledger – that is, "write access". By contrast, unpermissioned ledgers allow anyone to add transactions to the record, subject to pre-set rules. Competition between processors to earn a reward for updating the ledger should in theory encourage faster processing at lower cost.

Consensus mechanism: A design feature of unpermissioned distributed ledgers governing the ability to write new information to the ledger. As everyone has the ability to update their copy of the ledger, there needs to be an agreed-upon mechanism to establish a hierarchy for determining the most current version. Consensus mechanisms establish this hierarchy by requiring updaters to solve complicated algorithms: 'proof of work'. Other mechanisms, however, require updaters to establish a 'proof of stake'.

Appendix B: Money: a history

Initially, paper money developed as a receipt from a goldsmith for the deposit of valuables held for safekeeping. People quickly discovered that these paper receipts were much easier for transferring value than moving physical assets in out of the goldsmith's safe. Goldsmiths – and other merchants – quickly discovered that they could issue certificates for more than the value of the metal sitting in their safes; thus, fractional reserve banking was born.

[24] For first generation BC/DLT, which use 'proof-of-work' algorithms, the generation of the nonce is extremely computationally expensive, due to competition to solve increasingly difficult mathematical problems, but newer generations of BC/DLT use 'proof-of-stake' algorithms for verification that reduce the computational (and time) drag, yet, with a distributed ledger, maintain the security of proof-of-work methods.

Individuals began writing their own personal 'notes of hand' (effectively circulating IOUs) as an early form of credit (Figure 17).

Unsurprisingly, this created an environment ripe for forgeries and fraud – the "passing of bad notes". There was no central database of names or signatures of people with a history of passing bad notes. Nor was there a central agency that would vouch for the credit quality and general trustworthiness of the issuer or the solvency of the goldsmith. Henry Fielding's work, like many of his contemporaries, contains numerous references to the circulation of bad paper and the bankruptcies of goldsmith-bankers.

FIGURE 17
Promissory note, 1815

Note: the impressed seal at the left indicates the note was taxed. Source: Abate collection

In Europe, banks with varying levels of government sponsorship began issuing their own convertible paper in the 18th century. Paper notes were exchangeable for a fixed value in specie at the state bank. Over-issuance led to spectacular bubbles and busts in the 1720s, including the Mississippi and South Sea bubbles.

These quasi-private issuers frequently suspended their notes' convertibility. For example, during the Napoleonic Wars, the Bank of England suspended the convertibility of its notes to preserve its holdings of gold. The 'Restriction Period', which began in 1797, only ended in 1821. During this period, a scarcity of silver pushed the Bank of England to issue its own tokens as well as re-coin Spanish pieces (Figure 18).[25] Spanish coins circulated as crowns (5*s*), but their silver content was considerably below that in an English crown.[26]

[25] Minting coins was a sovereign's right, so the Bank of England could only issue 'tokens' in denominations other than those making up royal coinage. See *The Coinage of the British Empire*, H. N. Humphreys, London, 1868
[26] The coins had King of Spain's portrait counterstamped with the King of England's; hence "two crowns not worth a crown". See Figure 18.

FIGURE 18

English 5s countermarked Spanish 8 real coin, 1792

Source: Abate collection

Many crypto enthusiasts are 'hard money' advocates at heart. They note that since the supply of Bitcoin, for example, is fixed, it is not subject to central bank devaluation from over-issuance. However, private money as a substitute for sovereign money is not unique to crypto.

Following its defeat in World War I and its reparation payment requirements under the Versailles Treaty, Germany entered a period of severe hyperinflation. In January 1920, the minimum weekly cost of subsistence for a family of four living in Berlin was 220 Reichsmarks; by mid-November 1923, it was more than RM20 trillion.[27] There are plenty of anecdotes of how families coped with the hyperinflation but one curiosity of corporate behaviour during this period was the issuance of private money to pay employees and suppliers. Railroads[28], banks, coalmines, and even shoe manufacturing companies paid their employees with company script that in some cases could be used in commissaries maintained by the company. Not only could these companies negotiate to buy staples at a discount, but it also meant that workers would not have to cut short their working day in order to spend hours in line at stores and shops to purchase basic necessities (Figure 19).

FIGURE 19

Germany, private issue, notgeld, 1923

Source: Abate collection

[27] See Table 8, *The German Inflation 1914-1923*, C.L. Holtfrerich, deGruyter, 1986.
[28] See"*Das Papiergeld der deutschen Eisenbahnen und der Reichpost*, M. Muller, A. Geiger, Verlag A. Geiger.

'Workmen are given their pay twice a day now – in the morning and in the afternoon, with a recess of a half hour each time so they can rush out and buy things – for if they waited a few hours the value of their money would drop so far that their children would not get half enough food to feel satisfied. Satisfied – not nourished. Satisfied with anything that can be stuffed into their stomachs, not with what the body needs.'[29]

Once the German government established a credibly independent central bank, its currency stabilized,[30] and all this 'worthless paper muck'[31] disappeared in a reverse of Gresham's Law: good (stable value money) drove out the bad. The immediate acceptance of the new *Reichsmark* was supported by its status as legal tender.

Appendix C: Early bubbles

South Seas Company: a public/private monopoly set up in England to trade with South America in 1711. Like the Bank of England at the time, it also traded in government debt. Its directors were involved in insider trading, bribing Parliament, and promising rich returns to shareholders on the potential value of trade with South America. Share prices rapidly inflated, and then collapsed in 1720.

Mississippi Company: a public/private monopoly set up in France to trade with its North American (Mississippi) colonies in 1716. The company gained the right to issue paper currency in return for gold and silver, although these notes were never legal tender. The popularity and excited prospects of profits from North American trade enabled the company (renamed the Compagnie des Indes) to collect indirect taxes, mint coins and eventually restructure French government debt. Over-issuance of paper money and an inability to meet customer's demand for specie led to a run and a swift plunge in its share price.

FIGURE 20
Mississippi bubble note

Source: Abate collection

[29] See *The Black Obelisk*, Erich Maria Remarque, 1957
[30] 'The Ends of Four Big Inflations,' Thomas J. Sargent, *Inflation: Causes and Effects* (NBER 1982), Robert E. Hall, editor (p. 41 - 98).
[31] See *Wolf among Wolves*, Hans Fallada, 1937.

CHAPTER 4

Seeking value in crypto currencies

Joseph Abate
+1 212 412 7459
joseph.abate@barclays.com
BCI, US

Marvin Barth
+44 20 3134 3355
marvin.barth@barclays.com
Barclays, UK

Zoso Davies
+44 20 7773 5815
zoso.davies@barclays.com
Barclays, UK

Tomasz Wieladek
+44 20 3555 2336
tomasz.wieladek@barclays.com
Barclays, UK

Crypto currencies are a new form of 'asset' with no intrinsic value or promised stream of cash flows. As a result, Financial and Economic theory give no guidance for fundamental valuation or expected price behaviour. We attempt to parameterize a ceiling for the potential long-term fundamental value of crypto currencies (in total) based on our analyses of sources and factors of demand. Further, we use a combination of empirical and theoretical modelling of Bitcoin prices to generalise and forecast its price behaviour.

Our primary findings

- **Based on our companion analysis, we estimate that long-term fundamental demand for and value of crypto currencies – as a class – is likely to come from low-trust sectors of the global economy.**
- **Using estimates of money demand for both transactions and wealth storage in these sectors, we estimate – with generous assumptions – that the ceiling for total crypto currency market capitalisation is between $660bn and $780bn. Importantly, these estimates represent an *upper bound for all crypto currencies*, not likely fundamental value and do not apply to any single crypto currency.**
- **For perspective, the upper bound is roughly equivalent to the peak sum of all crypto currencies' market capitalisation in early January 2018.**
- **Using an empirical model of commodity inventory and price behaviour, we decompose weekly Bitcoin price movements into 'supply' and demand contributions, and find that since 2015 both inventory and demand behaviour have been speculative.**
- **We show that speculation in crypto currencies appears to be driven by developed economy purchasers and holders.**
- **Developing a theoretical model of speculative investment in crypto currencies that mimics the epidemiological literature, we show that crypto currency price behaviour is determined by the rate of new entrants ('infections') and the remaining 'susceptible' population.**
- **Survey evidence from developed economies suggests that crypto currency awareness now is nearly universal, that susceptibility to speculative investment is a small share of the population, and that former holders are developing 'immunity' to further investment.**
- **Combined with the results of our theoretical modelling, survey findings suggest that, unlike the peaks in Bitcoin prices in 2011 and 2013, the most recent peak may have been the ultimate top and that speculative interest could decrease from here.**

The novelty and lack of intrinsic value or cash flows of crypto currencies make fundamental analysis difficult

What is Bitcoin's – or any crypto currency's – long-term value? And what caused Bitcoin's exponential price growth in 2017 (and collapse in 2018)? Fundamental analysis of crypto currencies is difficult due to their novelty, as well as lack of intrinsic value or cash flow generation. However, we attempt to establish an upper bound for the long-term fundamental value of total crypto currencies, based on our analysis of the underlying sources of demand; and model the price behaviour of Bitcoin to determine the factors that have led to its recent behaviour.

Subject to caveats, we estimate a maximal upper bound for crypto currency market cap of $780bn, and see signs that recent speculative buying may be nearing an end

Subject to significant assumptions about long-term sources of demand based on our analysis in a companion piece and the existing state of crypto technology, our analysis suggests that the upper bound for the total value of all crypto currencies is between $660bn and $780bn, although the actual value likely is significantly lower. Further, we find that, since 2015, Bitcoin's price has been driven by speculative behaviour, rather than fundamental demand and supply for a commodity. In modelling speculative behaviour, we find that the supply of new entrants to the market is a key driver of price increases and that survey data suggest we may be near the end of that process.

Estimating long-term fundamental value

Companion analysis suggests that long-term demand for and value of crypto currencies will come from low-trust environments

Our analysis of the determinants of fundamental demand for crypto currencies in *Chapter 3 – Crypto technology: A solution still seeking a problem* suggests that it is a mix of speculative (or potentially ideological) interest from developed markets and a desire for security or investment alternatives in low-trust environments. The former source of demand (as we show in our modelling below) likely will prove temporary, and only the latter likely will determine long-term use of and value for crypto currencies. Hence, our estimation of long-term value focuses on the monetary and store of value needs of low-trust sectors of the global economy: weak, underdeveloped states and global criminal enterprise.

Demand in low-trust, low-opportunity economies

A generous definition of low-trust economies yields a total GDP of $11trn

Figure 1 lays out a calculation of the potential demand for currency in low-trust sectors of the global economy. The top portion of the table focuses on weak states with low trust and opportunities. Assuming, generously, that all of the countries in the bottom half of the Legatum Prosperity Index (LPI)[1] – shown to be key relative sources of interest in crypto currencies in *Chapter 3 – Crypto technology: A solution still seeking a problem* – are potentially at risk of complete adoption of crypto currencies, the total GDP of those economies is nearly $11tn.

But accounting for likely government suppression of crypto currencies and internet penetration suggests only $1.5tn of GDP transactions risk replacement with crypto currencies

However, as we note in our companion chapter, governments are unlikely to allow their citizens to shift commerce wholly to alternative currencies as they risk loss of both seigniorage and tax revenue. Accordingly, we narrow the list of countries to those where the sovereign appears weakest, using the bottom third of the Fund for Peace's 'Fragile States Index'[2]; this brings the total GDP down to $3.4tn. However, access to electricity and the internet – prerequisites for electronic payments with crypto currencies – are limited in these economies, so we further reduce by internet penetration rates, taking the total down to $1.5tn. This is our upper-bound estimate of the size of the weak-state, low-trust economy that could adopt crypto currencies.

[1] The Legatum Prosperity Index is a measure of country-level social welfare produced by the Legatum Institute. It measures welfare based on 110 questions divided into eight categories (subindices): Economy, Entrepreneurship and Opportunity, Governance, Education, Health, Safety and Security, Personal Freedoms, and Social Capital, the last being a measure of the 'glue' of society, particularly trust in fellow citizens and institutions.
[2] The Fragile State Index is a quantitative measure of government control over sovereign territories that spans 178 sovereigns and is produced by the Fund for Peace.

We estimate money demand for that annual rate of transactions to be just $323bn

But that is not the same as money demand. To estimate money demand in that portion of the global economy, we multiply the estimated $1.5tn in GDP of the remaining countries by the average ratio of M1/GDP in those fragile, low-trust countries. That yields an estimated demand from these economies for crypto currencies of $323bn. We view this as a likely upper bound, given that even weaker governments likely would be able to enforce at least some use of 'fiat' currency in their economies (at least for tax payments), and lack of payments infrastructure in these economies could force residents to keep a share of their preferred money balances in local currency.

FIGURE 1

Estimation of crypto currency value to low-trust economies

Potential low-trust crypto currency use and market capitalisation, USD, bns		
Weak states with low trust and opportunities		
Negative LPI countries' GDP	10,761	
Share of which 'Fragile'	3,390	
Share of which with internet (47%)	1,542	
x Sample average M1/GDP (0.21)		323
Criminal enterprise		
3.6% of global GDP	2,854	
x Global average M1/GDP (0.31)	889	
x 25% wholesale share		222
Total low trust environments		**545**

Source: Haver Analytics, IMF, ITC, Legatum Prosperity Institute, OAS, RAND, The Fund for Peace, UNODC/World Bank, Barclays Research

Demand in criminal enterprise

Criminal enterprise, worth 3.6% of global GDP likely requires money demand of $889bn

The lower half of Figure 1 adds in the potential crypto currency needs of global criminal enterprise under the same framework. The UN Office of Drugs and Crime and the World Bank jointly estimated that criminal enterprise generates annual proceeds of 3.6% of global GDP or, based on 2017 estimates, $2.9tn. Assuming money demand for criminal enterprise is proportional to the global economy – the average ratio of M1/GDP globally – total money demand from criminal sectors would be $889bn. However, there are indications that most 'retail' criminal transactions involve lower denomination bills.[3] Given potential acceptance and safety issues, as well as processing times (for the current generation of crypto currencies), we assume that most retail transactions will continue to be dominated by small-denomination paper currency.[4]

But not all of that is likely to be through crypto currencies; we estimate $222bn

Thus, crypto currency demand in criminal enterprise likely comes mainly from wholesalers. A RAND Corporation study appears to support this assumption, given its finding that the largest and increasing share of crypto currency transactions in the narcotics trade are wholesale.[5] Both the RAND study and another by the Organization of

[3] For instance, a Reason magazine study with the non-profit Lucy Parsons Labs' study of police seizures in Cook County, Illinois (Chicago) found that of 23,065 seizures of all types (including cars and other property) between 2012 and 2017, the median value was $1,049, roughly 11,000 were for amounts less than $1,000, and nearly 1,500 were for less than $100; see 'Poor Neighborhoods Hit Hardest by Asset Forfeiture in Chicago, Data Shows,' C.J. Ciaramella, *Hit & Run Blog*, Reason, 13 June 2017. Most of the available data and analysis on crypto technologies comes from independent, specialty news services and blogs, hence some caveats are advised.

[4] In any criminal transaction, one runs the risk of robbery, but that risk may be higher if one uses electronic means of payment such as crypto currency: if you pay cash in a 'retail' drug deal, the dealer can only rob you of the cash you are carrying; if paying by Bitcoin on a mobile, the dealer can force you to transfer your entire account value. See 'Bitcoin-Seeking Gangsters Hold Cryptocurrency Trader at Gunpoint in His Own Home,' J.P. Buntinx, *themerkle.com*, 29 January 2018.

[5] 'Internet-facilitated drugs trade, an analysis of the size, scope and the role of the Netherlands,' Kristy Kruithof et alia, *RAND Corporation Research Reports*, 5 August 2016.

American States[6] estimate that wholesale and trafficking account for about 20- 25% of drug revenues. Use of cash in the drug trade likely represents a safe upper bound for broader criminal usage as other studies have found it to have the highest usage of cash among criminal activities.[7] Applying the higher wholesale share of narcotics revenue to the total money demand in criminal enterprise yields an estimated crypto currency demand of $222bn.

Together, this implies an upper bound for transactional demand for crypto currencies of $545bn

This provides an upper bound for total money demand in low-trust portions of the global economy – weak states and criminal enterprise – of $545bn. Again, this likely significantly overstates actual demand based on our generous assumptions, but it provides a potential ceiling on non-sovereign crypto currency market capitalisation.

Demand as illicit store of value

Yet this may undercount illicit demand for a store of wealth

However, the above analysis may neglect potential demand for crypto currencies as an asset, or store of wealth, rather than a medium of exchange, from the same areas of the global economy. The money balance approach used in Figure 1 probably incorporates some asset demand. Roughly $1.25tn of US $100 bills are in circulation and about 65% are estimated to be held outside of the US.[8] Given low levels of merchant acceptance of $100 bills, it is assumed that most is used as a store of wealth. Indeed, there is evidence that demand for $100 bills rises amid global economic turmoil – when transaction demand is falling – supporting the idea that it acts like an asset as well as a medium of exchange.[9] An unknown but assumed large share likely is used in criminal activity or as a store of illicit wealth, as revealed by *single* seizures of $207mn in a Mexican drug bust and $650mn from Uday Hussein's palace during the Iraq War.[10]

Collectively, high-denomination notes of reserve currencies circulating outside of issuer countries is about $1.2tn

Figure 2 shows the total supply of high-denomination notes from the US, euro area, Switzerland, and the UK, circulating outside of their respective borders.[11] These countries' high-denomination notes represent roughly 80% of the seizures of cash suspected in criminal activity.[12] We focus on currency circulating outside of issuing sovereigns' domains for two reasons: 1) research suggests that most home-country large-denomination note use is legitimate;[13] and 2) illicit wealth storage in home-country currency likely reflects home bias in asset preference and, hence, is less likely to be exchanged into crypto currencies, particularly if their volatility remains high.

[6] 'The economics of drug trafficking,' *The drug problem in the Americas: Chapter 4*, Organization of American States.
[7] For instance, the share of cash in drug transactions is estimated at 80%, whereas human trafficking is estimated at 50% and counterfeit goods at just 30%; see 'Making it Harder for the Bad Guys: The Case for Eliminating High Denomination Notes,' Peter Sands, *M-RCBG Associate Working Paper Series, No. 52*, Harvard Kennedy School, February 2016.
[8] Outstanding amount 2017 estimate of Federal Reserve Board of Governors; share abroad estimated in 'Crisis and Calm: Demand for U.S. Currency at Home and Abroad from the Fall of the Berlin Wall to 2011,' Ruth Judson, *International Finance Discussion Papers 1058*, Federal Reserve Board of Governors, November 2012.
[9] See 'Crisis and Calm: Demand for U.S. Currency at Home and Abroad from the Fall of the Berlin Wall to 2011,' Ruth Judson, *International Finance Discussion Papers 1058*, Federal Reserve Board of Governors, November 2012.
[10] 'The $207-million question in Mexico,' Hector Tobar and Carlos Martinez, Los Angeles Times, 17 July 2007; and 'Saddam seized $1bn from central bank,' Alex Spillius, *The Telegraph*, 7 May 2003.
[11] Total circulation of high-denomination notes data are available from the Bank of England, European Central Bank, Federal Reserve, and Swiss National Bank. Proportions circulating abroad are assumed to be 65% of $100 notes, 50% of €500 and €100 notes, 70% of Sfr1,000 notes, and 50% of £50 notes, taken respectively from Judson; 'Estimation of euro currency in circulation outside the euro area,' *External Statistics Division*, ECB, 6 April 2017; 'The use of large denomination banknotes in Switzerland,' Katrin Assenmacher et alia, manuscript, Bundesbank, 24 March 2017; and 'How has cash usage evolved in recent decades? What might drive demand in the future?' *Quarterly Bulletin 2015 Q3*, Bank of England, 15 September 2015.
[12] See 'Making it Harder for the Bad Guys: The Case for Eliminating High Denomination Notes,' Peter Sands, *M-RCBG Associate Working Paper Series, No. 52*, Harvard Kennedy School, February 2016..
[13] Researchers assume that most $100 bills in circulation within the US are not used in criminal enterprise; see 'U.S. Consumers' Holdings and Use of $100 Bills,' Claire Greene and Scott Schuh, *Research Data Reports No. 14-3*, Federal Reserve Bank of Boston, 25 November 2014.

FIGURE 2

Estimated potential value of crypto currencies as an asset

Potential crypto currency use as store of illicit wealth, USD, bns	
$100 notes outside the US	813
€500 and €100 notes outside the euro area	315
Sfr1,000 notes outside of Switzerland	34
£50 notes outside of the UK	11
Total	1,173
Upper bound assumption, 20%	**235**
Lower bound assumption, 10%	**117**

Source: Bank of England, Bundesbank, European Central Bank, Federal Reserve, Swiss National Bank, Barclays Research

We suspect a significant portion of that may double count our estimates of transactional demand for crypto currencies

How much of the roughly $1.2tn in high-denomination bills circulating outside issuing countries would be double counted under our estimation of the monetary needs of criminal enterprise is unknowable. However, two pieces of evidence suggest that the overlap could be substantial. First, 5- 10% of cash seizures suspected as criminal proceeds are in the currencies of the originating or destination countries (other than USD, EUR, GBP, or CHF).[14] Second, high-denomination notes comprise a large share of the outstanding value of currencies of countries counted as 'low-trust' in Figure 1, suggesting that our low-trust environments' calculations already encompass a significant portion of wealth storage.[15]

We also see several reasons why the remainder may not be converted to crypto currencies

Furthermore, we are sceptical that a large share of any remainder would be converted into crypto currencies, for several reasons:

- *Preference for cash*: Despite the growth of crypto currencies – and evidence of their use in crime[16] – average annual growth in demand for $100 bills since the creation of Bitcoin in 2011 is 8.1%, almost double the growth of US nominal GDP, and it accelerated to 8.4% in 2017. Even more clearly, in many developing countries the black market exchange rate premium for $100 bills over lower-denomination USD notes has been measured at 5- 10%, and in Ethiopia it has been measured as high as 20%, suggesting that cash is still king.[17]

- *Low criminal balance/transaction ratio in crypto currency*: Despite the surge in crypto currency usage and values in 2017, estimated holdings of criminal proceeds in crypto currency remain small in absolute value and even smaller relative to estimated criminal transactions. A recent study by the University of Sydney and University of Technology Sydney found that 'approximately one-quarter of bitcoin users and one-half of bitcoin transactions [approximately $72bn per year] are associated with illegal activity.' But, the researchers found the same users collectively hold just $8bn worth of Bitcoin.[18] There is evidence that 'dark web' criminal activity on Bitcoin is shifting to Monero and Zcash to better mask transactions, but these two crypto currencies have total market capitalisations of just $2.7bn and $670mn, respectively.[19]

[14] See 'Making it Harder for the Bad Guys: The Case for Eliminating High Denomination Notes,' Peter Sands, *M-RCBG Associate Working Paper Series, No. 52*, Harvard Kennedy School, February 2016.
[15] See 'Making it Harder for the Bad Guys: The Case for Eliminating High Denomination Notes,' Peter Sands, *M-RCBG Associate Working Paper Series, No. 52*, Harvard Kennedy School, February 2016..
[16] 'Internet-facilitated drugs trade, an analysis of the size, scope and the role of the Netherlands,' Kristy Kruithof et alia, *RAND Corporation Research Reports*, 5 August 2016.
[17] See 'Making it Harder for the Bad Guys: The Case for Eliminating High Denomination Notes,' Peter Sands, *M-RCBG Associate Working Paper Series, No. 52*, Harvard Kennedy School, February 2016..
[18] 'Sex, Drugs, and Bitcoin: How Much Illegal Activity Is Financed Through Cryptocurrencies?' Sean Foley, Jonathan R. Karlsen, and Talis J. Putnins, *SSRN*, 15 January 2018.
[19] See 'Monero, the drug dealer's cryptocurrency of choice, is on fire,' Andy Greenberg, Wired, 25 January 2017; and 'Criminal underworld is dropping bitcoin for other cryptocurrency,' *South China Morning Post*, 2 January 2018.

- *Transformation risks traceability*: Transforming large quantities of cash into crypto currencies requires transforming it into electronic debit-entry money, which is then exchanged for crypto currencies, typically via exchanges. Each of these steps creates a point of traceability by sovereign authorities. Bitcoin and other first-generation crypto currency transactions are themselves increasingly traceable, too.[20] While new crypto currencies with enhanced privacy masking and transaction mixing, such as Monero and Zcash, may solve that problem – though authorities and researchers are working on cracking their algorithms too – criminals still need to exchange criminal proceeds into these currencies, and exchanges increasingly are rejecting suspicious transactions under sovereign pressure.[21]

- *Risk*: Crypto currencies, to date, cannot be considered a safe store of value compared with cash. Crypto currencies have demonstrated extreme volatility since their inception. Bitcoin's 105% annualized daily volatility in the past year was small by comparison with Ripple's 286%, but was still more than 10 times typical exchange rate volatility. Further, theft of Bitcoin through hacking, scams and ransomware has surged.[22]

Among other reasons, estimates of criminal crypto currency holdings to transactions suggest 10% or at most 20% of illicit wealth may be converted

Based on our view that low-trust money demand likely already encompasses significant asset demand for crypto currencies and scepticism regarding the share of cash wealth that is likely to be converted into crypto currencies, we expect only 10- 20% of high-denomination cash wealth will be exchanged in the long run. The lower bound, 10%, is roughly in line with the ratio of estimated criminal Bitcoin holdings to transactions. Generously, we assume that the upper bound is double that share. As shown in Figure 2, these ranges imply long-term demand for crypto currencies as an asset of between $117bn and $235bn.

This implies an upper bound market cap of between $660bn and $780bn

Together with our earlier estimates for potential transaction demand, this suggests that the upper bound for total crypto currency market capitalisation is between $660bn and $780bn. For perspective, the upper end of that range is roughly the peak market capitalisation of all crypto currencies in early January 2018.

Importantly, those values are a generous upper bound, not an estimate of fair value

Two important points are worth emphasising. First, these estimates are upper bounds based on generous assumptions, *not* fair values. Second, the upper bound is for crypto currencies *as a class*, not any particular crypto currency. As we note in *Chapter 3 – Crypto technology: A solution still seeking a problem*, we see a significant likelihood of diffusion of value across a number of crypto currencies, reducing the acceptance and network value of each, and thus potentially reducing further the fundamental market capitalisation value for all collectively.

Modelling Bitcoin price behaviour

We use an empirical and numerical model in combination to capture crypto currency price dynamics

With a ceiling for crypto currencies' potential fundamental long-term value in hand, we use two methods, one empirical and one numerical, to understand and forecast the price behaviour of crypto currencies. We start by testing whether Bitcoin's price and inventory behaviour fit an 'inventory supply' model of commodity behaviour or a model of speculative holdings. We then use those results in a theoretical model of speculative behaviour to determine price dynamics under speculative investment.

[20] 'Criminals Thought Bitcoin Was the Perfect Hiding Place, but They Thought Wrong,' Mike Orcut, *MIT Technology Review*, 11 September 2017.
[21] 'Criminal underworld is dropping bitcoin for other cryptocurrency,' *South China Morning Post*, 2 January 2018.
[22] See 'The Changing Nature of Cryptocrime,' Chainalysis, 18 January 2018.

Digital gold?

Survey and other evidence suggests that developed economy crypto currency demand is speculative

Our analysis in *Chapter 3 – Crypto technology: A solution still seeking a problem* suggests that, unlike in underdeveloped countries, where demand for crypto currencies appears driven by lack of trust and opportunities for wealth storage, speculation is the main driver of demand in advanced economies. Survey evidence appears to strongly support our analysis. Consistent with speculation being a clear motive for holding, despite a Japanese law exempting purchases made in crypto currencies from VAT, only 34% of surveyed owners used Bitcoin for purchases, while 54% held it as a long-term investment and 42% as a short-term investment.[23] A late 2017 survey of US Bitcoin holders undertaken by Lendedu found that just 8% owned it for purchases or payments, while 41% saw it as 'world changing' and 22% viewed it as a long-term investment.[24] The perceived value of crypto currencies by advanced economy investors and whether or not they see crypto currencies as commodities, like gold, or as speculative instruments likely will determine their price dynamics.

We use an empirical model of commodities to test if Bitcoin holders act like it is a commodity or speculative investment

To investigate, we model Bitcoin's past price behaviour as a commodity to determine if 'inventory' holders act as suppliers or speculators, and then develop a theoretical model of speculative behaviour of future price dynamics. Our analysis suggests that while inventory acted as supply in the past, since 2015 it has acted more like speculation. Modelling future behaviour based on speculation suggests that bubbles can have multiple peaks and continue until the supply of new entrants dwindles, as may already be occurring.

Bitcoin holdings can be thought of as 'inventories' in a commodity model

The supply of Bitcoins, like mineral commodities, is created by 'mining', albeit virtually. Because the mining process is algorithmically constrained, supply cannot adjust to demand shocks, just like mineral commodity mining in the short run. But, also like physical commodities, existing Bitcoins can be held in inventory to meet short-run demand shocks. The behaviour of inventory holders amid demand shocks thus determines Bitcoin price dynamics. In the commodity literature, there are two theories of the behaviour of inventory holders.

Commodity inventories typically act as supply: moving opposite to price

One view is that they act as suppliers, basing their expectation of future demand on current prices relative to a notion of fundamental value. This means that when prices are high, inventory holders release supply to meet demand in expectation of lower future prices; when prices are low they reverse course and accumulate inventories in expectation of higher future prices. Under this view, inventory 'supply' moves opposite to prices.

Unless holders are speculating, then holdings move with prices

Another possibility is that inventory holders speculate, or accumulate or release inventories based on their expectation of future prices. If suppliers extrapolate from recent price dynamics, this type of forward-looking expectation can exacerbate price moves in both directions. As prices rise, inventory holders accumulate more in expectation of higher future prices; as prices fall, they shed inventories to avoid selling at expected lower future prices.

We use a VAR model and weekly Bitcoin prices to estimate the contributions to prices from 'supply' and demand

We use a VAR model, a standard approach to study commodity prices, to econometrically examine which of the two inventory behaviours better describes Bitcoin price formation. For this purpose, we need both the price and quantity of Bitcoin supplied. In lieu of inventory data, which is not available, we use Bitcoin transactions as a measure of effective release. We then estimate the model with two lags on monthly data, though similar results are obtained with weekly data. Supply shocks cause transactions and prices to move in opposite directions, while demand shocks push them both in the same direction. We then decompose the deviations from a linear trend into contributions from these two shocks.

[23] See 'Survey Says 88% of Japanese Have Heard of Bitcoin', Kevin Helms, *Bitcoin.com*, 19 November 2017.
[24] See 'Survey: Bitcoin buyers prefer investing in it over using it as a payment method,' Jon Martindale, *Digital Trends*, 17 November 2017.

FIGURE 3
Decomposition of Bitcoin price dynamics into supply and demand shocks

Source: Blockchain.info, Barclays Research

Our analysis suggests that early behaviour was commodity like, but that since 2015, behaviour has been consistent with speculation

The results of our econometric analysis are shown in Figure 3. The light blue line is the contribution of demand to Bitcoin's price, while the dark blue line is the contribution of inventory supplied. Up until 2015, it seems relatively clear that strong demand pushed prices up and was followed by a release of inventories that pushed prices down. Similarly, weak demand yielding falling prices was followed by a supply shock, which pushed them up again. However, since 2015, both supply and demand appear to be pushing prices simultaneously in the *same* direction, suggesting inventory behaviour has become speculative.

Or an 'infectious disease'?

Using our findings, we model speculative investment behaviour similar to propagation of an infectious disease

Taking this a step further, we developed a theoretical model of an asset price with a pool of speculative investors and compared it with actual Bitcoin price behaviour to see what it might imply for the future dynamics. The model has clear parallels with compartmental models of the spread of an infectious disease in epidemiology. Like the infection analogy, the population divides into three groups: 'susceptible' individuals who are vulnerable but not yet infected; 'infected' individuals; and those who are 'immune'. Also like infection, transmission – especially to those with 'fear of missing out' – is by word-of-month, via blogs, news reports and personal anecdotes.

The theoretical model of asset demand assumes a fundamental value, but still exhibits speculative behaviour when that value is unknown

The model assumes a theoretical asset with an unknown long-term fundamental value held by a small, initial share of the population (the 'infected'). The rest of the population is divided into those who are 'susceptible' to speculation in the new asset and those who are 'immune'. Even with an assumed fundamental value, it is possible for frothy price behaviour to develop. Moreover, the asset's bubble can exhibit multiple peaks and reach surprising heights. However, once full adoption is approached, the price decline is sustained and rapid.

The characteristics of our theoretical model are as follows:

- The crypto currency is assumed by all agents to have a long-term fundamental value, but the value is unknown, as is the time until it is reached.
- Initially, only 0.1% of the population holds the asset and is the source of supply. Their willingness to supply (sell) the asset is positively related to past selling (persistence), inversely related to expected future prices (speculative inventory behaviour) and subject to randomly generated shocks.

- New entrants (buyers) are not existing holders and are drawn from the portion of the total population that is susceptible to the 'fear of missing out' speculation. We assume this is 25% based on survey evidence.[25] Their decision to buy the asset is a positive function of previous buyers (persistence), expected future prices (speculation), and randomly generated shocks.
- Some portion of the population is immune and will never buy the asset.
- Expected future prices of both holders and new buyers are a weighted average of the extrapolated exponential trend in recent prices and the most recent price. The weight on the former decreases with time and the weight on the latter increases as it is assumed that prices get closer to the long-term fundamental value as time passes.
- Prices are a function of the ratio of new entrants (buyers) to exits (sellers).

Prices rise rapidly with expectations as new entrants – or 'infected victims' – join, but eventually plateau as awareness – or immunity – expands through the population

Figure 4 plots the simulated results of the model (dark line) versus the actual price history of Bitcoin, both in logarithms. While actual Bitcoin prices have been more volatile, a similar pattern is apparent. As new entrants buy the stimulated asset, its price rises, inducing expectations of further price rises that cause more new entrants and reluctance of existing holders to sell. Word of mouth spreads and creates more new entrants (or 'infections'). As more of the population become asset holders, the share of the population available to become new buyers – the potential 'host' population – falls, while the share of the population that are potential sellers ('recoveries') increases. Eventually, this leads to a plateauing of prices, and progressively, as random shocks to the larger supply population push up the ratio of sellers to buyers (Figure 5), prices begin to fall. That induces speculative selling pressure as price declines are projected forward exponentially. Analogously, this occurs with infectious diseases when the immunity threshold is reached; ie, the point at which a sufficient portion of the population becomes immune such that there are no more secondary infections.

The height of the bubble is randomly generated by shocks, but its peak is driven by the exhaustion of new buyers

The modelling exercise suggests that even if crypto currencies do have fundamental value, they are subject to extreme bubble formation as the population adjusts to their introduction. The height of bubble prices is driven by the pattern of random shocks to entrants and exits, but the conditions that lead to its peak and subsequent decline are clearly apparent: the exhaustion of new buyers.

FIGURE 4

Simulated vs actual Bitcoin prices, log scale

Source: Bloomberg, Barclays Research

FIGURE 5

Ratio of sellers to buyers through time

Source: Barclays Research

[25] See survey data in later section; we use the highest estimate of population share that has invested in Bitcoin among various surveys (South Korea), but lower values yield similar results.

Once exits begin to exceed new buyers, prices begin to fall inexorably

Applying this model to speculative behaviour in crypto currencies, it suggests that once a large enough share of the population susceptible to speculation becomes aware of and holders of crypto currencies, upward pressure on prices stalls. To the extent that holders' attraction to Bitcoin was speculative – as our empirical analysis of historical prices suggests – those holders then become sellers, initiating an accelerating downward spiral. The crucial variables determining when the turn from rising to falling prices occurs, according to our modelling, are the share of the population that are aware of Bitcoin and the share that are willing to invest (or susceptible to 'infection').

Is speculation near its end?

Surveys of Bitcoin awareness suggest that a peak is near: as much as 90% of developed economy residents now are familiar with it, and holding rates are half to a third of peak levels, indicating increasing 'immunity'

What survey evidence we have suggests that this process may be at or near its end, as awareness is nearly universal in developed economies and the share of the population susceptible to speculative investment in most developed economies appears small. A late 2017 survey conducted in South Korea, one of the top centres of Bitcoin trading, found that 90% of Koreans were aware of Bitcoin, and, while 26% had purchased Bitcoin at some point, only 8% were then holders.[26] A November 2017 survey of 10,000 Japanese showed 88% awareness of Bitcoin, but only 4.7% had ever held Bitcoin and only 2.7% were current holders.[27] A late 2016 survey by the Bank of Canada marked Canadians' awareness of Bitcoin at 64%, but ownership at just 2.9%; while a smaller November 2017 survey of Americans placed awareness at 75% and ownership or willingness to own at 10%.[28] Yet these awareness rates likely are out of date; more up-to-date surveys from the UK illustrate that Bitcoin's December 2017 price spike caused a surge in awareness. A D-CYFOR survey in November 2017 found that 80% of UK residents were aware of Bitcoin, but by January 2018, a survey by the same firm pegged awareness at 91%.[29]

Unlike past peaks in Bitcoin prices, the survey evidence, based on our modelling, suggests that the speculative bubble in crypto currencies may have passed its peak

Past peaks in Bitcoin in 2011, early 2013 and late 2013 were followed by collapses in price of 93%, 70% and 86%, respectively, before recovering and advancing to new highs. But in each of those cases, awareness was relatively low and the potential for new entrants consequently was high. The above survey evidence suggests this is no longer the case: 1) most potential 'hosts' (Bitcoin investors) in developed economies already are aware of Bitcoin (have been exposed to the 'virus'); 2) only a small share of developed populations are susceptible to speculation ('infection'); and 3) the falling ratio of current to prior holders suggests a rising 'recovered' share of the population. As a result, we believe the speculative froth phase of crypto currency investment – and perhaps peak prices – may have passed.

[26] See 'Surveys Show South Korea Ahead of Japan and US in Bitcoin Awareness,' Kevin Helms, *Bitcoin.com*, 7 December 2017.
[27] See 'Survey Says 88% of Japanese Have Heard of Bitcoin', Kevin Helms, *Bitcoin.com*, 19 November 2017.
[28] See 'Bitcoin Awareness and Usage in Canada,' Christopher S. Henry & Kim P. Huynh & Gradon Nicholls, *Staff Working Papers* 17-56, Bank of Canada, November 12, 2017; and Ditto Cryptocurrency Public Knowledge Report November 2017
[29] See 'Nearly a third of people think bitcoin will collapse in the next six months,' Courtney Goldsmith, City A.M., 14 November 2017; and 'More than half of people say bitcoin will drop or collapse in six months,' Courtney Goldsmith, City A.M., 26 January 2018.

CHAPTER 5

Artificial Intelligence: A primer

Raimo Lenschow, CFA
+1 212 526 2712
raimo.lenschow@barclays.com
BCI, US

Blayne Curtis
+1 617 342 4101
blayne.curtis@barclays.com
BCI, US

Andrew M. Gardiner, CFA
+44 (0)20 3134 7217
andrew.m.gardiner@
barclays.com
Barclays, UK

In Chapter 1 and Chapter 2 of this year's *Equity Gilt Study*, we have shown how advances in technologies are meaningfully altering macroeconomic metrics such as employment, growth, productivity growth, inflation and wage growth. Much of the excitement about advances in technology stems from the progress made in using Artificial Intelligence (AI) and machine learning for commercial purposes. This report aims to give investors some intuition around the terminology and technology behind AI.[1]

Artificial Intelligence: Untangling the semantics

Simply put, AI is when a machine exhibits human-like intelligence in approaching a problem. Companies have leveraged the technology to create applications that help businesses improve their forecasting, optimize processes, offer new services, and understand their customers better. McKinsey estimates that companies invested between $26bn and $39bn into AI in 2016, and PE and VC financing amounted to an additional $5bn to $8bn. This investment represents a threefold increase from 2013.

The terminology surrounding AI is complex and can be confusing. Common terminology includes machine learning, deep learning, and cognitive systems: semantic confusion arises from the terms being used interchangeably and inconsistently. AI technologies are often used in conjunction with one another, and there is no consensus on how to classify all of the technology that AI encompasses precisely. Figure 1 represents the hierarchy of the different viable artificial intelligence technologies.

FIGURE 1
Artificial Intelligence technology hierarchy

Source: Barclays Research

[1] For a more detailed analysis, please see our reports *A Deep Dive into Artificial Intelligence* and *How Semiconductors Will Enable Artificial Intelligence*.

There are two primary branches of AI technology:

- **Knowledge-based AI:** Such systems access a hard-coded knowledge base and make inferences based on that existing database of knowledge. These systems have applications in natural language processing where the meaning of user inputs is determined by accessing a knowledge base containing information and rules about language. IBM's Watson employs rules-based AI (in addition to other processes) when determining what is being requested of it. Although these systems are currently a viable AI technology, they are rarely used in isolation to create intelligent applications. The vast majority of AI business applications are enabled by machine learning (sometimes in conjunction with knowledge-based systems), and as such machine learning is the focus of this chapter.

- **Machine learning:** This is the branch of AI that aims to understand human intelligence and replicate it in machines through algorithms. Machine learning algorithms learn regularity within data sets and ultimately are able to use what has been learned to deliver insights when processing new data. Machine learning is inductive: the functionality of applications is not explicitly programmed, but is learned through exposure to examples; This is known as the training phase of machine learning. The algorithms must go through the training phase so they can be deployed to make reliable conclusions about data, which is known as the inference phase.

Traditional machine learning

Traditional machine learning consists of algorithms that are constructed in a way that requires just one level of data processing to understand a data set. This differs from deep learning models, which require several more levels of computation. Popular traditional machine learning algorithms include random forests, linear and logistic regression, and decision trees. These methods have had application in areas such as real-time fraud detection and recommendation systems.

Traditional machine learning models can be trained using a straightforward method named 'supervised learning'. Supervised learning can be used to create intelligent applications that are effective in predicting the output that corresponds to input data. In supervised learning, models refine the way they process data by considering the outputs that previous input data have led to in the past. The model must iteratively process a massive amount of example inputs in order to have a high likelihood of predicting new input data's true output.

An early example of a supervised machine learning application is the spam folder. The content of emails is what the algorithm is programmed to analyze. The algorithm predicts if the mail is spam or not, then compares that prediction to the email's true output. If the prediction is incorrect, the parameters of the model will be adjusted so that the next time an email comes through, it will be processed in a slightly different way. As the algorithm is refined through exposure to more examples, it is more likely to predict spam mail accurately. By running example inputs through the supervised learning model, the algorithm is able to construct the relationship that maps input to output. In the spam mail example, what the algorithm is actually learning is the input features that result in a spam output classification. This is the training phase. Once the model has been trained, it can be deployed and make predictions (inferences) about new data.

Deep learning: The next stage

Deep learning is a subfield of machine learning that has been conceptualized since the inception of AI, but has experienced widespread use in enterprise only over the past decade.

Deep learning is able to handle more complicated problems. Data inputted into the algorithm is computed and manipulated several times before producing an output. As a result, the algorithm is able to learn far more about what the data represents than it would be able to with just one level of computation, like in traditional machine learning. Deep learning models are built on an architecture called artificial neural networks (ANN). Neural networks are loosely modelled on the structure of the brain; information is propagated through the neural network similar to how neurons in the brain transmit information. The "deep" aspect of deep learning is referring to the several computational layers between the input and output layer that enable the algorithm to gain greater insight. Neural networks are not effective until they are trained with enormous amounts of data (examples) so they can learn how to interpret the data correctly.

A simple way to think about how a neural network learns to interpret information is to consider how an image classifier, a practical application of deep learning systems, may be structured. An image classifier that is able to distinguish a human face from a cat will have layers that are designed to process specific aspects of the image (this is a simplified explanation). The first hidden layer will detect edges in the image. The next layer is able to take information from the previous layer regarding the edges in the image and do further computation to detect shapes. From there, a third layer would perform further computation to detect specific features that are representative of a human face.

Supervised, unsupervised and reinforcement learning

Deep supervised learning models function by performing computation on input data that delivers insight about what the data represents. The nodes in the first layer of the neural network take in a numerical value from the input layer that is representative of the characteristics of the input's features. Each node is assigned a weighting that dictates the computation the node will perform on its input, and that computation will yield a numerical value. When training the network through supervised learning, the system is able to compare its predicted output with the correct output. When the algorithm does not yield the right output, the model considers how its predicted output differed from the true output and computes an error function for the network. The network then uses that error function to make minor adjustments. Deep supervised learning technologies have tremendous potential in healthcare, particularly in medical imaging. The applications are intended to help radiologists detect diseases faster and more accurately.

Unsupervised deep learning applications are able to analyze large amounts of data, identify relevant features of the data, and cluster the data based on those features. Models are not trained to make predictions about inputs. Instead, they are trained to better understand the underlying structure of inputs and map relationships between them. As such, deep unsupervised learning models are well equipped to handle 'clustering' problems. Companies are able to use unsupervised learning to analyze consumer online behavior data to create customer segments. Typical online behavior that is used to create segments includes number of visits to the web site, duration of visit, time of the day of the visit, number of transactions, and average transaction check. Deep unsupervised learning algorithms are able to extract customer features from their online behavior data in order to group customers to maximize similarity within clusters.

Much of the data that are generated in the world today are unlabeled, and unsupervised learning will be critical in extracting insights from this type of data. Most business applications today utilize supervised learning, not unsupervised learning. The predictive capabilities of supervised learning have been successful at addressing specific problems, but these types of models can be developed only with access to a labelled data set. The hope is that deep learning systems will be able to observe and learn information about the world by processing data on a scale that humans will never be able to.

FIGURE 2
Summary of machine learning algorithms

ML Algorithm	Inputs	Learning Mechanism	Goal	Use Case
Supervised	Labeled Data	Validation	Predict Output	Medical Imaging
Unsupervised	Unlabeled Data	Cluster Analysis	Identify underlying structure	Customer Segmentation
Reinforcement	Information regarding current state	Reward System	Learn optimal series of action	Manufacturing

Source: Barclays Research

Finally, reinforcement learning deals with decision-making algorithms that learn to optimize answers by rewarding or punishing previous outputs. It is similar to supervised learning in that the model receives feedback regarding the action it decided to take. However, the feedback only reports about whether the action was good or bad, and does not inform the algorithm of what the optimal decision is. Deep reinforcement learning has been used to develop robotics technology that has application in manufacturing. Robots are able to remember the optimal series of actions that lead to a desired outcome, and companies have been able to train robots with deep reinforcement learning to automate production processes.

Figure 2 summarizes the different ways to train machine learning algorithms. Each method is able to create intelligent applications by employing different learning techniques on different types of input data. But in general, this exciting new technology ultimately does two things: it makes existing processes more efficient and creates capabilities that were not previously possible.

What is so special about AI?

The advent of neural networks has created a new and unique workload challenge for manufacturers of computer hardware. To understand how systems will develop, we look at the three key challenges posed by AI:

- **Very High Parallelism:** Neural networks are by definition a system of highly interconnected nodes that work in tandem to solve a problem. This translates to a very large number of simultaneous (or parallel) calculations. Not all types of parallel calculating are the same, though, and that may create opportunities for further improvement over existing solutions.
- **Massive Memory Bandwidth:** To support a large amount of parallel processing power, the system must be capable of feeding (and removing) huge amounts of data to (and from) the processor cores to ensure that they are not sitting idle for extended periods.
- **Low Precision, but Wide Dynamic Range:** Deep learning systems need relatively low precision (helps avoid over-fitting), but most existing processors are optimized for the high precision required by HPC (high-performance computing) and other applications (double precision/FP64). Solutions that offer lower precision hardware are emerging, but there is likely room to move further in that direction or even to dynamic precision formats to improve performance further.

Parallelism

In traditional computing implementations, processors and software have been optimized for **serial** computation – that is, problems are solved via a series of instructions performed one after the other. To improve serial performance, coders focus on optimizing software to use fewer instructions and chip designers focus on increasing processor clock speeds (frequency scaling). Rising clock speeds were the primary driver behind PC performance gains essentially from the development of the first PC up until the mid-2000s, as the limits of power consumption/heat dissipation forced chip designers to shift to multi-core

architectures vs. simply making an individual core more and more powerful. This shift has increasingly brought parallel computing into the consumer space, but the concept has been around for years, particularly in high performance computing. In contrast, the basic idea behind parallel computing is breaking a problem down into many component pieces and simultaneously processing each piece (ie, in parallel), and then combining them all at the end to arrive at the answer to the original larger problem. Not all problems are well served by parallel processing – specifically, those that involve long chains of dependencies where each calculation depends on the answer to the prior calculation are very poorly suited to parallelism – but most algorithms offer some opportunity to perform independent calculations simultaneously (hence why multi-core processors have continued to deliver performance improvements to consumer and server products).

Memory bandwidth

In the most basic sense, processors perform simple mathematical operations on data. The data are supplied by either registers (a very small amount of very fast storage that holds data the processor is actually working with at that nanosecond) or by addressable memory that can be shared amongst different programs, procedures, and processors. Memory bandwidth measures the rate at which data can be read from or written to this addressable memory. Why does this matter? Memory bandwidth is critical to overall system performance because a processor can only compute as fast as it can 1) access (read) data it needs to work on; and 2) output (write) that data to some sort of memory so it can move on to the next task.

Precision

While a string of digits can be of any length in standard mathematical notation, in the computing world, memory is limited. This means that one is forced to make choices about precision (how many significant digits) and range (how large or small) when dealing with numbers. One approach would be to figure out a fixed number of digits to the right and left of a decimal point to use when storing each number, but this would be highly inefficient for a physicist dealing with both the speed of light (~300000000.0000000000000 m/s) and Newton's gravitational constant (~000000000.0000000000667 $m^3kg^{-1}s^{-2}$), as it would effectively use a large number of useless bits to store each number. "Floating Point" is the computing world's solution to this issue. In short, it allows a fixed precision and sizable range in an efficient manner through the power of exponents. Each number is represented by a "significand," which contains the number's significant digits and can be thought of as the level of precision, and an "exponent," which specifies where to put the decimal point and can be thought of as a measure of the range across which numbers can be stored. The format is ***significand x base***^{exponent}. Using floating point, the above two examples, can be represented as 3×10^8 m/s and 667×10^{-13} respectively.

By nature, this system creates a trade-off between precision/range and computational performance (eg, more precision requires more bits for each number, which slows down performance). Various workloads skew to one end of the spectrum or the other, with deep learning applications requiring lower precision (helps avoid over-fitting) relative to typical workloads today (HPC typically needs double precision). As a result, many existing processors are configured for more precision than needed in AI applications, which has created an opportunity for dramatic performance improvements simply by allowing for lower precision formats. Going from double precision (64 bit) to single precision (32 bit) should lead to a theoretical doubling of performance, and going to half-precision (16 bit) should lead to a further doubling.

A brief look at the hardware behind AI

The software for machine learning and AI is, of course, only as good as the hardware it runs on. Traditional servers/Central Processing Units (CPUs) are poorly suited to many of the workloads created by deep learning, which drives up cost and reduces performance. Graphics processing units (GPUs) can deliver a significant improvement over CPUs alone, but may not be the optimal solution. Meanwhile, other solutions are emerging to achieve performance gains, such as application-specific integrated circuit (ASIC), application-specific standard parts (ASSPs) and field-programmable gate arrays (FPGAs).

- **CPUs – Jack of All Trades, Master of None:** CPUs are the core processors of virtually all PCs and servers in use today. CPUs deliver enormous flexibility, but have been optimized for serial performance, which leaves them ill suited to the demands of neural networks (particularly Training). That said, their flexibility and dominant market position means they still handle the vast majority of machine learning workloads and their scale may allow them to evolve to better optimize for AI.
- **GPUs – The Reigning Champion (Albeit Kind of by Accident):** GPUs can deliver a substantial performance improvement over CPUs alone, particularly in training, thanks to their high level of single instruction, multiple data (SIMD) parallelism and wide memory bandwidth. However, GPUs were developed for graphics acceleration, not neural networks, and that legacy leaves room for improvement.
- **FPGAs – When You Want Custom Silicon, but Can't Commit:** FPGAs allow the aggregation of a bunch of applications to produce sufficient scale to support leading edge chip design and manufacture. By emulating custom ASICs/ASSPs, FPGAs have the potential to deliver improved cost/performance vs. CPUs and GPUs. However, if AI is as big as many people expect, FPGAs will likely be eclipsed.
- **Custom Silicon – Why Not Just Build a Tool for the Job?** A custom chip is an option for every workload, but the key is to strike a balance between performance/cost and flexibility/scale of the workload. The AI market is still very nascent, but a number of public and private companies have concluded that it will support true dedicated processors designed from the ground up for AI workloads. These products have the potential to improve performance and lower costs meaningfully, but also face a number of hurdles in penetrating an established market.

Figure 3 summarizes the advantages and disadvantages of different types of processors and how suited they are to usage in neural networks and machine learning.

FIGURE 3
Deep Learning / AI Processor Comparison

Processors Type	Advantages	Disadvantages
Traditional CPU	• Existing global computing backbone. Already runs most software in use and most programmers are very familiar with writing code for CPUs • Broad base of server/PC sales means plenty of resources to develop future products	• Relatively power hungry (100W+ / processor) • Limited parallelism (outside of hybrid products like INTC's Xeon Phi) • Relatively expensive ($500+ / CPU)
GPU	• Leading AI-focused product in the market today, good penetration in academia and a growing set of AI programmers comfortable working on GPUs • Broad base of gaming GPU sales means plenty of resources to develop future products • Highly parallel given the right type of structured data (vastly superior to a traditional CPU for training) • Current AI frameworks built around CUDA (favors NVDA) with work just beginning on OpenCL to facilitate other silicon	• Relatively power hungry (200-300W / P100 processor), Inference 50-75W (P4) • Existing products burdened by silicon dedicated to displaying graphics not performing AI tasks • Processor cores must communicate through memory (requires moving data on and off the chip) • Unpredictable or unstructured data limit effective parallelism (this is why GPUs are better at training than inference) • Relatively expensive (hundreds to multiple thousands of $s)
FPGA	• Essentially emulating an ASIC/ASSP, meaning substantial performance gains are possible • Lower power (~25W) for a high-end FPGA • Potentially highly parallel • Potentially integrated/tightly coupled to CPU to support high memory bandwidth • Good early stage development tool, as workloads are still in flux • Highly flexible – can change even intra-cycles	• Product is not optimized for a specific task; has to use standard blocks such as interface and memory • Potentially lots of silicon on the die not dedicated to running AI workload, resulting in higher power consumption and cost • Very little AI-specific software compatibility in existence today, dependent on OpenCL/other open source frameworks gaining widespread adoption • Likely displaced by ASICs over time as workloads crystallize and solutions are optimized • Hard to program, as it involves specifying gate layouts in a chip vs. just knowing a programming language – even with OpenCL support, one still needs to program hardware
ASIC/ASSP (Custom Silicon)	• Optimized for specific tasks and workloads, making this the highest performance, lowest cost, and lowest power consumption solution (potentially by multiple orders of magnitude) • Still flexible enough to handle varying workloads and tasks with a defined boundary • Smaller die sizes allow AI to be deployed in a wider set of devices (eg, drones, cameras, IoT)	• Large burden to create firmware that can support OpenCL and optimize existing frameworks • No existing broad customer base to support development if demand does not materialize • Most development work appears to be happening at smaller startups vs. large established companies with strong industry partnerships • Multiple competing approaches may make it hard for customers to coalesce around a given design

Source: Barclays Research

Summing up

This chapter merely scratches the surface of the technological complexity behind AI. It does not explore the nuances of parallel computing, memory bandwidth considerations, the trade-off between precision and computational performance, or the best software frameworks. All of these are important topics worthy of more discussion and will play a role in determining how successful this technology ultimately is. For a more detailed analysis, please see our recent research reports *A Deep Dive into Artificial Intelligence* and *How Semiconductors Will Enable Artificial Intelligence*.

CHAPTER 6

UK asset returns since 1899

Sreekala Kochugovindan
+44 (0)20 7773 2234
sreekala.kochugovindan@barclays.com
Barclays, UK

We analyse returns on equities, gilts and cash from end-1899 to end-2017. Index-linked gilt returns are available from 1982, while corporate bonds begin in 1999. To deflate the nominal returns, a cost-of-living index is computed using Bank of England inflation data from 1899 to 1914 and the Retail Price Index, calculated by the Office of National Statistics, thereafter.

FIGURE 1
Real investment returns by asset class (% pa)

	2017	10 years	20 years	50 years	118 years*
Equities	8.4	3.2	3.2	5.6	5.1
Long dated Gilts	-1.9	4.0	3.6	3.1	1.3
Corporate bonds	0.7	3.6			
Long dated Index-linked	-1.7	4.0	3.9		
Cash	-3.9	-1.9	0.3	1.2	0.7

Note: * Entire sample. Source: Barclays Research

Figure 1 summarises the real investment returns of each asset class over various time horizons. The first column provides the real returns over one year, the second column real annualised returns over ten years, and so on.

2017 proved to be a strong year for global equity returns as the backdrop of synchronised global growth helped support emerging and developed market stocks. UK equities, however, underperformed their market peers, as Brexit-related uncertainties weighed on performance. The bulk of the annual return for the FTSE 100 and FTSE All-Share came in December following the agreement on the first phase of negotiations, which allowed progress in talks. Whereas in 2016, UK stocks had benefitted from the sharp decline in the currency, in 2017, a partial recovery in sterling weighed on the performance of the globally exposed UK-listed companies, eroding some of the support received from the global growth backdrop. Returns on the more domestically oriented FTSE 250 almost doubled those of the more globally exposed FTSE 100.

Gilt yields were buffeted by the volatility in global fixed income returns as investors shifted their outlook for central bank policy. The first half of the year was characterised by a rally in developed markets as inflation in the US and Europe surprised lower, despite historically low rates of unemployment. However, central bank communication turned hawkish mid-year and the prospect of tighter policy from the BoE, the BoC, the ECB and the Fed gave way to a volatile second half of the year, as investors grappled with signals from data versus central bank communiqués. Long gilts produced a small positive total return of just 2% in nominal terms, compared with 11.5% in 2016. The BoE delivered the first rate hike in over a decade; however, investors initially interpreted the Inflation Report as dovish. Inflation-linked bonds followed with similar returns. Investment grade corporate bonds managed to produce a marginally positive real total return of 0.7%, lower than the previous year (9.5%), in which the initial announcement of the Bank of England's Asset Purchase Programme helped fuel a sharp rally. Corporate credit had a relatively uneventful year as both yields and spreads traded in a tight range, generating carry-like returns from a starting yield of 2.98%. The end of the Bank of England's Corporate Bond Purchase Scheme passed uneventfully and spreads were well supported by the global rally in risk assets.

FIGURE 2
Real investment returns (% pa)

	Equities	Gilts	Index-linked	Cash
1907-17	-3.8	-7.2		-3.8
1917-27	9.1	6.1		5.2
1927-37	6.1	7.3		2.6
1937-47	4.0	1.3		-1.8
1947-57	2.3	-6.2		-2.5
1957-67	11.4	0.8		2.1
1967-77	-0.2	-3.2		-2.5
1977-87	12.0	4.5		3.4
1987-97	10.4	6.9		4.6
1997-07	3.1	3.3	3.7	2.5
2007-17	3.2	4.0	4.0	-1.9

Source: Barclays Research

FIGURE 3
Distribution of real annual equity returns

Source: Barclays Research

FIGURE 4
Distribution of real annual gilt returns

Source: Barclays Research

FIGURE 5
Distribution of real annual cash returns

Source: Barclays Research

FIGURE 6
Maximum and minimum real returns over various periods

Source: Barclays Research

Figure 2 breaks down real asset returns for consecutive ten-year intervals. Gilts have outperformed equities over the past decade, with an average annualised return of 4% since 2007, compared with an equity return of just 3.2%. Cash, on the other hand, has delivered the worst returns since the stagflationary 1970s. Ranking the annual returns and placing them into deciles provides a clearer illustration of their historical significance. The results for 2017 are shown in Figure 7. The equity portfolio is ranked in the fifth-best decile since 1899; linkers and nominal gilts are ranked in the eight and seventh deciles, respectively, a sharp decline in performance compared with last year, when they were in the first and third deciles. Cash returns weakened further, to the ninth decile, as rising inflation eroded real returns.

FIGURE 7

2017 performance ranked by decile (1899-2017)

	Decile
Equities	5
Gilts	7
Index-linked	8
Cash	9

Note: Deciles ranking: 1 signifies the best 10% of the history, 10 the worst 10%. Index-linked returns since 1982.
Source: Barclays Research

Figures 3-5 illustrate the distribution of returns over the past 118 years. They show that equity returns have the widest dispersion, followed by gilts then cash. The observed distributions are in accordance with financial theory; from an *ex ante* perspective, we would apply the highest risk premium to equities, given their perpetual nature and our uncertainty about growth in corporate profits and changes in the rate of inflation. For gilts, the uncertainty with respect to inflation remains, but the risk from the perspective of coupon and principal is reduced, given their government guarantee. Over the past 30 years, the dispersion of annual gilt returns has widened significantly. In the 1970s and 1980s, an unexpected increase in the inflation rate led to significant negative real returns, while in the 1990s, an unanticipated fall in inflation, in conjunction with lower government deficits, facilitated above-average real returns. The cash return index has the lowest dispersion. In recent decades, the real returns to cash have been relatively stable, with the move towards inflation-targeting by the Bank of England stabilising the short-term real interest rate.

Performance over time

Having analysed annual real returns since 1899, we now examine returns over various holding periods. Figure 6 compares annualised returns when the holding period is extended to 5, 10 or 20 years and beyond.

The most striking feature of Figure 6 is the change in the volatility of returns as the investments are held for longer periods. The variance of equity returns falls significantly relative to the other assets as the holding period is extended. When equities are held for as long as 20 years, the minimum return is actually greater than for either gilts or cash. However, as discussed in past issues of this study, we do not believe that this fall in volatility should be interpreted as an indication of mean reversion in the returns. The series used comprise rolling returns; hence, there is an overlap in the data. For example, in the ten-year holding period, nine of the annual returns will be the same in any consecutive period; thus, the observations cannot be considered to be independently drawn.

Figure 8 illustrates the performance of equities against gilts and cash for various holding periods. The first column shows that over a holding period of two years, equities outperformed cash in 80 out of 117 years; thus, the sample-based probability of equity outperformance is 68%. Extending the holding period to ten years, this rises to 91%.

FIGURE 8
Equity performance

	Number of consecutive years				
	2	3	4	5	10
Outperform cash	80	82	84	86	99
Underperform cash	37	34	31	28	10
Total number of years	117	116	115	114	109
Probability of equity outperformance	68%	71%	73%	75%	91%
Outperform gilts	80	86	86	83	84
Underperform gilts	37	30	29	31	25
Total number of years	117	116	115	114	109
Probability of equity outperformance	68%	74%	75%	73%	77%

Source: Barclays Research

The importance of reinvestment

Figures 10 and 11 show how reinvestment of income affects the performance of the various asset classes. Figure 10 shows £100 invested at the end of 1899 without reinvesting income; the second is with reinvestment. One hundred pounds invested in equities at the end of 1899 would be worth just £203 in real terms without the reinvestment of dividend income; however, with reinvestment, the portfolio would have grown to £34,758. The effect on the gilt portfolio is smaller in absolute terms, but the ratio of the reinvested to non-reinvested portfolio is over 600 in real terms.

FIGURE 9
Five-year average dividend growth rates

Source: Barclays Research

FIGURE 10
Today's value of £100 invested at the end of 1899 without reinvesting income, £

	Nominal	Real
Equities	17,444.08	203.71
Gilts	62.90	0.73

Source: Barclays Research

FIGURE 11
Today's value of £100 invested at the end of 1899, income reinvested gross, £

	Nominal	Real
Equities	2,976,377.61	34,758.11
Gilts	41,451.00	484.06
Cash	20,630.55	240.92

Source: Barclays Research

Turning to the dividend growth ratio, the FTSE All-Share dividend rose 12.8% in 2017, the fastest pace since 2011. Figure 9 shows that the five-year average growth rate picked up in 2010 following the steady declines of recent years after corporates began cutting dividends in 2008. In 1997-2001, dividend income fell a cumulative 15% as companies cut dividends on the basis that funds would be put to better use by corporates than by shareholders. In the wake of the dotcom crash, investors actively sought income-yielding stocks as a way to lower risk.

Figures 12 and 13 illustrate the time series of price indices and total return indices for equities, gilts and cash over the entire series. These returns are in nominal terms and are shown with the use of a logarithmic scale.

FIGURE 12

Barclays price indices – Nominal terms reinvested

Source: Barclays Research

FIGURE 13

Barclays total return indices – Nominal terms, gross income reinvested

Source: Barclays Research

FIGURE 14

Today's value of £100 invested at the end of 1945 without reinvesting income, £

	Nominal	Real
Equities	10,933	288
Gilts	69	1.81

Source: Barclays Research

FIGURE 15

Today's value of £100 invested at the end of 1945, gross income reinvested, £

	Nominal	Real
Equities	238,690.07	6,294.26
Gilts	8,900.82	234.71
Cash	6,317.81	166.60

Source: Barclays Research

FIGURE 16

Today's value of £100 invested at the end of 1990, gross income reinvested, £

	Nominal	Real
Equities	997	466
Gilts	875	409
Index-linked gilts	690	322
Treasury bills	303	142

Source: Barclays Research

CHAPTER 7

US asset returns since 1925

Sreekala Kochugovindan
+44 (0)20 7773 2234
sreekala.kochugovindan@
barclays.com
Barclays, UK

We analyse returns on equities, government bonds, and cash with a total sample of 92 annual return observations. The construction of the series is explained in more detail in Chapter 8 ("Barclays Indices"). Corporate bond performance is captured using the Bloomberg Barclays Investment Grade Corporate Long Index, which incorporates bonds with a maturity of 10 years or more. The Bloomberg Barclays US Inflation Linked 15-year Plus Index is used to represent the performance of TIPS. The nominal return series are deflated by the change in the consumer price index, which is calculated by the Bureau of Labor Statistics. The first holding period covered in this analysis is calendar year 1926, representing money invested at the end of 1925 and its value at the end of 1926.

FIGURE 1
Real investment returns (% pa)

	2017	10 years	20 years	50 years	92 years*
Equities	18.2	6.0	5.0	5.6	6.7
20y Government Bond	4.1	4.5	4.5	3.6	2.6
TIPS (15y plus)	7.2	4.0			
Long Corporate Bond	9.8	6.1	4.8		
Cash	-1.3	-1.3	-0.26	0.7	0.4

Note: * Entire sample. Source: Centre for Research into Security Prices (CRSP), Barclays Research

Figure 1 provides real annualised returns over various time horizons. US equities posted a strong performance, benefitting from a range of domestic drivers, as well as the broader global growth backdrop. Expectations of US tax reform, deregulation and higher infrastructure spending all provided a bullish backdrop. The strong growth picture reinforced this as a tight labour market and improved corporate earnings also provided support despite the more hawkish Fed and some residual concerns regarding the late stage of the business cycle and elevated valuations.

US bond markets were characterised by a curve flattening trend. The first half of the year featured a rally driven by inflation surprising lower, despite the historically low levels of unemployment. During the second half, the curve flattened further as the short end was directly affected by monetary tightening, and long-end Treasuries rallied. Long TIPS rallied along with long-end nominals and benefited from the rebound in energy prices. Corporate bonds also performed well as spreads tightened in line with the global rally in risk assets.

FIGURE 2

Real investment returns (% pa)

	Equities	20y Government Bond	Long Corporate Bond	Cash
1927-37	0.5	6.0		3.2
1937-47	5.0	-1.5		-4.5
1947-57	12.8	-0.1		-0.3
1957-67	11.5	-0.4		1.3
1967-77	-2.8	-1.0		-0.4
1977-87	8.2	3.0		2.7
1987-97	13.4	7.3	7.4	1.9
1997-2007	4.0	4.4	3.6	0.8
2007-2017	6.0	4.5	6.1	-1.3

Source: CRSP, Barclays Research

Equities and corporate bonds had a strong decade. A total real return of 6% is close to the long-run average performance since 1925. Equities' best years occurred in the immediate aftermath of World War II and the late 1980-90s. Bonds have enjoyed decent performance over the past four decades relative to those preceding, largely as a result of continued disinflation since the late 1970s. Figure 2 highlights that the interwar decade of 1927-37 was also positive for government bonds.

Figure 3 ranks the relative performance of 2017 returns by deciles to provide a clearer indication of their historical significance. The US equity ranking has risen from the sixth decile in 2016 to the fourth decile in 2017. Bonds rose from the seventh to the fifth decile in 2017. Cash returns remained weak, with negative real returns placing them in the eighth decile.

FIGURE 3

Comparison of 2017 real returns with historical performance ranked by decile

	Decile
Equities	4
20y Govt Bond	5
Cash	8

Note: Deciles ranking - 1 signifies the best 10% of the history, 10 the worst 10%. Source: CRSP, Barclays Research

Figures 4-6 plot the sample distributions with identical maximum and minimum categories across each. These charts are useful in allowing readers to appreciate the volatility of each asset class while gaining an understanding of the distribution of the annual return observations. Clearly, cash exhibits the lowest volatility of each asset class overall, with bonds next and equities having the highest dispersion of returns.

FIGURE 4
Distribution of real annual cash returns (%)

Source: CRSP, Barclays Research

FIGURE 5
Distribution of real annual bond returns (%)

Source: CRSP, Barclays Research

FIGURE 6
Distribution of real annual equity returns (%)

Source: CRSP, Barclays Research

FIGURE 7
Maximum and minimum real returns over different periods

Source: CRSP, Barclays Research

Figure 7 illustrates the extremes of the return distribution for various holding periods. The volatility of equities over very short horizons is clearly demonstrated in the maximum and minimum distribution of one-year returns. As we extend the holding period, the distribution begins to narrow. Over the past 90 years, the worst average annualised 20-year return for equities was 0.9%, while the best was 13%. However, this is not to say that it is impossible to lose money by holding equities over a 20-year period, as the analysis is conducted on an ex-post basis. The figure merely highlights that such an occurrence seems unlikely, given equities' performance over the past 90 years.

In addition, over the long term, we would expect the ex-ante equity risk premium to provide a cushion against uncertainty. Bonds and cash have experienced negative returns over 20-year investment horizons, reflecting unexpected jumps in inflation at various points in the past century.

Figure 8 plots the US equity risk premium and shows that the 10-year annualised excess return of equities over bonds has picked up over the past year.

FIGURE 8

Equity-risk premium – Excess return of equities relative to bonds (10y annualised)

Source: CRSP, Barclays Research

The importance of reinvestment

Figures 11 and 12 show the importance of reinvestment of income in the form of dividends on equity investments and coupons on government bonds.

FIGURE 9

Value of $100 invested at the end of 1925 without reinvesting income

	Nominal	Real
Equities	17,946	1,303
20y Govt Bonds	135	10

Source: CRSP, Barclays Research

FIGURE 10

Value of $100 invested at the end of 1925 with income reinvested gross

	Nominal	Real
Equities	546,032	39,647
20y Govt Bonds	14,288	1,037
Cash	2,063	150

Source: CRSP, Barclays Research

FIGURE 11

Barclays US price indices in nominal terms

Source: CRSP, Barclays Research

FIGURE 12

Barclays US total return indices in nominal terms with gross income reinvested

Source: CRSP, Barclays Research

CHAPTER 8

Barclays indices

Sreekala Kochugovindan
+44 (0)20 7773 2234
sreekala.kochugovindan@
barclays.com
Barclays, UK

We calculate three indices showing: 1) changes in the capital value of each asset class; 2) changes to income from these investments; and 3) a combined measure of the overall return, on the assumption that all income is reinvested. Additional series allow for the effects of inflation. The data for cash include building society deposit rates and Treasury bills. The series on index-linked securities is based at December 1982 and the corporate bond index starts at the end of 1990.

Barclays Equity Index

The Barclays Equity Index is designed to give as accurate a measure as possible of the performance of a representative portfolio of equities. Three main types of index can be used. The FT Index, which for years was the most widely used in the UK, is geometric, meaning that the price changes of the 30 shares it comprises are multiplied together to produce the change in the index. We believe that this is a fair basis for indicating short-term market behaviour, but that over long periods it imparts a downward bias. The second type of index uses the Dow formula, in which the prices of a number of shares are added together. This does not have the distorting effect of a geometric index, but the weighting of the various shares is arbitrary and varies with changes in capitalisation.

We think the most accurate and representative indices are arithmetic and weighted by the number of shares in issue by each company. These indices include virtually all of the large quoted companies; thus, we believe they accurately reflect the behaviour of an equity market. The Standard & Poor's indices are of this type and date back to the 1920s. The FT Actuaries Indices, introduced in the 1960s, were the first of this type in the UK. Subsequently, a number of weighted arithmetic international indices, such as those calculated by Morgan Stanley Capital International and Datastream, have been introduced. More recently, the FTSE 100 Index, which uses the same construction, but incorporates only the 100 leading shares, has been introduced and, generally, is now used as the main market indicator because it is calculated on a real-time basis throughout the day.

The Barclays Equity Index, which is used in this study, is a weighted arithmetic index and is available for the period since 1899, with a dividend yield and an income index. The original Barclays Equity Index, used in editions of this study until 1999, was first calculated retrospectively in 1956 and included 30 shares chosen because of their similarities to the FT 30 Index, which covers 1935-62. For the 2000 edition of this study, we compiled a new index for 1899-1935, based on the 30 largest shares by market capitalisation in each year. From 1962, the Barclays Equity Index is based on the FTSE Actuaries All-Share Index, because with its broader coverage, it gives a more accurate picture of market movements. The indices are calculated only annually, at year-end.

The equity returns between 1899 and 1935 are therefore calculated from a new Equity Index, consisting of the 30 largest shares by market capitalisation in each year; between 1935 and 1962, they are calculated from the FT 30 Index, and from 1962 onward, they are derived from the FTSE Actuaries All-Share Index.

FIGURE 1
Equity Index constituents

Constituents at December 1899	Constituents at December 1934	Constituents at December 1962
De Beers Consolidated Mines	Woolworth Ltd	Associated Portland Cement
Rio Tinto Ltd	Imperial Chemical Industries	Bass Mitchells & Butlers
Armstrong Whitworth	Shell' Transport & Trading Ltd	British Motor
Consolidated Gold Fields	Courtaulds Ltd	Coats Patons
London and County Bank	Royal Insurance Co	Cory (William)
London City & Midland Bank Ltd	Barclay & Company	Courtaulds
Lloyds Bank Ltd	Lloyds Bank	Distillers
London & Westminster Bank Ltd	Prudential Assurance Co Ltd	Dunlop
Vickers, Sons & Maxim Ltd	Westminster Bank Ltd	EMI
Imperial Ottoman Bank	Midland Bank Ltd	Fine Spinners & Doublers
Parrs Bank Ltd	London & Lancashire Fire Ins. Co	General Electric
Royal Insurance Co	North British & Mercantile In. Co Ltd	Guest Keen
Tharsis Sulphur & Copper Ltd	Reckitt & Sons Ltd	Hawker Siddeley
Great Northern of Copenhagen	County of London Electric Supply Co	House of Fraser
Simmer & Jack PropietaryMines Ltd	Unilever Ltd	ICI
North British & Mercantile Insurance	Tate & Lyle Ltd	Imperial Tobacco
Consett Iron Ltd	Alliance Assurance Company	International Stores
Eastern Extension Australasia * China Ltd	Boots Pure Drug Co Ltd	Leyland Motors
Nobel Dynamite TstLtd	Pearl Assurance Co	London Brick
Mysore Gold Mining Ltd	Marks & Spencer Ltd	Murex
Exploration Co	Cory (WM.) & Son	P&O Steam Navigation
Alliance Assurance Co	National Bank Of Egypt	Rolls-Royce
Aerated Bread Ltd	Consolidated Gold Fields Of South Africa	Swan Hunter
Howard & Bullough Ltd	Bass, Ratcliff & Gretton Ltd	Tate & Lyle
Sun Insurance Office	GeduldProp Mines Ltd	Tube Investments
New JagersfonteinMining & Expl Ltd	Sun Insurance Office	Turner & Newall
Champion Reef Gold Mining	Bank Of Australasia	United Steel
National Telephone Ltd	British South Africa Co	Vickers
Northern Assurance	Chartered Bank Of India, Australia & China	WatneyMann
Phoenix Assurance Co	North Eastern Elec Supply Co	Woolworth

Source: Barclays Research

The Equity Index is a weighted arithmetic average. In it, the weights of the 30 constituent companies for each year are proportional to their market capitalisation at the beginning of the year. Each year, a fund was constructed. The number of shares in the fund for each company was calculated so that its market value at the beginning of the year was equal to its index weighting. The value of the fund was calculated annually at the end of the year.

For 1899-1962, the Equity Income Index is based on the Barclays Equity Fund. The Income Index relates to the dividend income actually received in the 12 months prior to the date of the index. It is calculated by totalling the dividends paid on the shares in the fund. We believe that it is the only published index based on actual income receipts.

From 1963, the Income Index is derived from the yield on the FTSE All-Share Index. Despite a minimal discontinuity in the yield, in our view, this is the most representative method of evaluating equity performance over the period. The dividend yield is quoted net from 1998, with non-taxpayers no longer able to reclaim ACT.

Barclays Gilt Index

The Gilt Index measures the performance of long-dated gilts. From 1899 to 1962, the index is based on the prices of undated British funds. During this period, the undated stocks were a major part of the gilt market, but over the years, the effect of high interest rates on their prices, together with the growing number of conventional long-dated issues, meant that undated stocks became less and less representative of the market as a whole.

Since 1962, the Barclays Gilt Index has been based on a portfolio of long-dated stocks, selected on 1 January each year. The portfolio is chosen to represent as closely as possible a 20-year security on a par yield and contains a weighted combination of four long-dated stocks with a mean life of 20½ years (so that the average life of the stocks for the year in which they are in the portfolio is 20 years). The combination and weightings of the four stocks are chosen to have the minimum possible deviation from a par yield. Small issues (less than £1bn) are excluded, and in any year, none of the four stocks has been allocated a weight of more than 40%, or less than 5% of the index.

During the late 1980s, there was a steady contraction in the number of issues that satisfied the criteria for inclusion in the Gilt Index. As a result of the lack of issues of new long-dated stocks and the fall in the remaining life of existing stocks, the universe of eligible stocks narrowed sharply. By the end of 1989, there were four stocks with a life of more than 20 years, and only two of these were over £1bn nominal.

Thus, from the beginning of 1990, the index has been constructed to represent a portfolio of 15-year par yielding gilts.

Barclays Inflation-linked Index

The index-linked market has now been established for almost four decades and is capitalised at £661bn (compared with the £1.4trn capitalisation of the conventional market). The index has been constructed to mirror as closely as possible the rules of the conventional gilt index. An average life of 20 years was used up until 1990, and 15 years thereafter. Again, stocks have been chosen to be as close to par as possible, although of course in this case, par means "indexed par".

Barclays Corporate Bond Index

The UK corporate bond market has expanded markedly since the beginning of 1999. The index and returns are based on the Bloomberg Barclays Sterling Aggregate Corporate Index. Clearly, we are unable to select individual stocks for this index in the way we do for the gilt indices because such a small sample cannot be representative of the market.

Barclays Building Society Fund

In previous editions of this study, we included indices of the value of £100 invested in a building society at the end of 1945. We originally used the average interest rate on an ordinary share account. In the mid-1980s, many building societies introduced new tiered interest rate accounts, which provided a higher rate of interest while still allowing instant access. In response, we have been tracking both types of account, but as time progressed, the old style "ordinary share accounts" became less and less representative and by the mid-1990s had been completely superseded by the new accounts. From 1986, the Barclays Index follows the Halifax Liquid Gold Account (formerly called the Halifax Instant Xtra) as a representative of the newer tiered interest rate-style accounts. The Halifax is no longer a building society, having converted to a bank, so from 1998, we follow the Nationwide Invest Direct Account. This is the closest equivalent account offered by the Nationwide Building Society (which is now the largest remaining building society in the UK); the difference is that it is operated by post. We consider this type of postal account to be more representative of building society returns than the branch-operated passbook accounts, which are more in the nature of a cash-based transaction account.

US asset returns

Analysis on the US indices used in this study is calculated (or Derived) based on data from Database Name ©201712 Centre for Research in Security Prices (CRSP®) at the University of Chicago Booth School of Business (2017 being the year the database was published). The value-weighted equity index covers all common stocks trading on the New York, Nasdaq, and Arca Stock Exchanges, excluding ADRs. For the bond index, the CRSP has used software that selects the bond that is closest to a 20-year bond in each month. The CRSP employs the same methodology to create the 30-day T-bill series.

Total returns

In this study, we show the performance of representative investments in UK equities and long gilts, with additional analysis of equivalent US returns in both monetary and real (inflation adjusted) terms. The total returns to the investor, however, also include the income on the investment. This is important throughout the study for comparability between asset classes. For example, when constructing an index for a cash investment such as the UK Treasury Bill Index, the £100 invested at the end of 1899 grew to approximately £104 by the end of the following year. This full amount is reinvested, and by the end of 1920, the value of this investment had grown to about £190. In contrast, equity and bond market returns can be split into two components: capital appreciation and dividend income. The most commonly quoted stock market indices usually include only the capital component of the return. To calculate returns on a comparable basis, we need to include the returns obtained by reinvesting this income. This is particularly important in looking at bonds where the scope for capital appreciation is small, so almost all of the return will be from income. In this study, total returns are calculated assuming income is reinvested at the end of the year.

Taxation

The total return to an investor depends crucially on the tax regime. The largest long-term investors in the British equity and gilt markets are pension funds and similar institutions that (until the abolition of the advance corporation tax (ACT) credit) have not suffered tax on their income or capital; our main tables therefore make no allowance for tax until 1998, which was the first full year that non-taxpayers were unable to reclaim the ACT credit. This effectively reduced the dividend yield to non-taxpayers and is reflected in our main tables and gross total return series.

The personal investor must suffer tax. The net return to a building society account is straightforward to compute. However, changes in the tax regime in recent years make the net return to equity and gilt investment less straightforward to calculate on a consistent basis. For example, the change to total return taxation for gilts means that it is inappropriate to calculate a net total return on the basis of taxing income alone. Thus, returns are quoted gross throughout, but for reference we also quote basic tax rates.

Arithmetic and geometric averages

Our analysis of past data usually relies on calculations of the geometric mean for each series. Arithmetic averages can provide a misleading picture. For example, suppose equities rose from a base of 100 to 200 over one year and then fell back to 100 over the next. The return for year one would have been 100% and for year two minus 50%. The arithmetic average return would be 25%, even though equities are actually unchanged in value over the two years.

The geometric average return in this example would be zero. This method of calculation is therefore preferable. Over long periods, the geometric average for total returns is the rate at which a sum invested at the beginning of the period will grow by the end of the period,

assuming all income is reinvested. The calculation of geometric averages depends only on the initial and final values for the investment, not particular values at any other point in time.

For periods of one year, arithmetic and geometric averages will be the same. But over longer periods, the geometric average is always less than the arithmetic average, except when all the individual yearly returns are the same. For the mathematically minded, the geometric return is approximately equal to the arithmetic return minus one-half the variance of the arithmetic return.

Although geometric returns are appropriate to analyse the past, arithmetic returns should be used to provide forecasts. Arithmetic averages provide the better unbiased estimator of returns (for a statistical proof of this, see Ian Cooper's paper *Arithmetic vs Geometric Premium: setting discount rates for capital budgeting calculations*, IFA Working Paper 174-93, April 1993).

Capital value indices

The indices in Figure 2 show the nominal capital value of £100 invested in equities and gilts at the end of 1899. The chart also plots the Barclays Cost of Living Index. Note how the equity index has correlated with increases in the cost of living versus a similar investment in gilts. The index values at the end of 2017 were 17,444 for equities, 62.9 for gilts, and 8563 for the cost of living.

We then show the same capital indices adjusted for the increase in the cost of living since 1899. Figure 3 shows the end-2017 real equity price index at 204 with the real gilt price index at 0.73.

Total return indices

The next two charts show the nominal and real value of the equity, gilt and cash funds with gross income received reinvested at the end of each year since 1899. Figure 4 shows that the nominal worth of £100 invested in equities at the end of 1899 was £2,976,378. The same investment in gilts was worth £41,451 and in T-Bills £20,631. When adjusted for inflation, the equity fund is worth £34,758, the gilt £484, and the cash fund £241.

FIGURE 2

Barclays price indices in nominal terms

Source: Barclays Research

FIGURE 3

Barclays price indices in real terms

Source: Barclays Research

FIGURE 4

Barclays total return indices in nominal terms with gross income reinvested

Source: Barclays Research

FIGURE 5

Barclays total return indices in real terms with gross income reinvested

Source: Barclays Research

FIGURE 6
Barclays UK Cost of Living Index

Year	December (1899=100)	Change % In year	Change % 5y average	Year	December	Change % In year	Change % 5y average
1900	103.3	3.3		1940	216.9	12.7	5.8
1901	103.3	0.0		1941	223.6	3.1	5.9
1902	106.7	3.2		1942	222.5	-0.5	4.6
1903	106.7	0.0		1943	221.4	-0.5	5.0
1904	106.7	0.0	1.3	1944	223.6	1.0	3.0
1905	106.7	0.0	0.6	1945	225.8	1.0	0.8
1906	100.0	-6.2	-0.7	1946	226.9	0.5	0.3
1907	110.0	10.0	0.6	1947	234.2	3.2	1.0
1908	113.3	3.0	1.2	1948	245.7	4.9	2.1
1909	113.3	0.0	1.2	1949	254.3	3.5	2.6
1910	113.3	0.0	1.2	1950	262.4	3.2	3.0
1911	116.7	2.9	3.1	1951	294.0	12.0	5.3
1912	120.0	2.9	1.8	1952	312.7	6.3	6.0
1913	120.0	0.0	1.1	1953	316.0	1.1	5.2
1914	120.0	0.0	1.1	1954	328.5	4.0	5.3
1915	148.3	23.6	5.5	1955	347.7	5.8	5.8
1916	175.8	18.5	8.6	1956	358.3	3.0	4.0
1917	212.5	20.9	12.1	1957	374.9	4.6	3.7
1918	244.7	15.2	15.3	1958	381.8	1.8	3.9
1919	250.3	2.3	15.8	1959	381.8	0.0	3.1
1920	299.2	19.6	15.1	1960	388.7	1.8	2.3
1921	221.4	-26.0	4.7	1961	405.7	4.4	2.5
1922	200.2	-9.5	-1.2	1962	416.5	2.6	2.1
1923	196.9	-1.7	-4.3	1963	424.2	1.9	2.1
1924	201.3	2.3	-4.3	1964	444.6	4.8	3.1
1925	196.9	-2.2	-8.0	1965	464.5	4.5	3.6
1926	199.1	1.1	-2.1	1966	481.6	3.7	3.5
1927	188.0	-5.6	-1.3	1967	493.4	2.5	3.4
1928	186.9	-0.6	-1.0	1968	522.7	5.9	4.3
1929	185.8	-0.6	-1.6	1969	547.1	4.7	4.2
1930	172.4	-7.2	-2.6	1970	590.3	7.9	4.9
1931	164.6	-4.5	-3.7	1971	643.6	9.0	6.0
1932	159.1	-3.4	-3.3	1972	692.9	7.7	7.0
1933	159.1	0.0	-3.2	1973	766.2	10.6	7.9
1934	160.2	0.7	-2.9	1974	912.8	19.1	10.8
1935	163.5	2.1	-1.1	1975	1140.0	24.9	14.1
1936	168.0	2.7	0.4	1976	1311.8	15.1	15.3
1937	178.0	6.0	2.3	1977	1471.1	12.1	16.3
1938	173.5	-2.5	1.8	1978	1594.4	8.4	15.8
1939	192.4	10.9	3.7	1979	1869.3	17.2	15.4

Year	December (1899=100)	Change % In year	Change % 5y average	Year	December	Change % In year	Change % 5y average
1980	2151.9	15.1	13.5	**2000**	5302.3	2.9	2.7
1981	2411.2	12.0	12.9	**2001**	5339.2	0.7	2.3
1982	2541.6	5.4	11.6	**2002**	5496.3	2.9	2.2
1983	2676.7	5.3	10.9	**2003**	5650.2	2.8	2.2
1984	2799.3	4.6	8.4	**2004**	5847.3	3.5	2.6
1985	2958.5	5.7	6.6	**2005**	5976.6	2.2	2.4
1986	3068.6	3.7	4.9	**2006**	6241.4	4.4	3.2
1987	3182.0	3.7	4.6	**2007**	6493.9	4.0	3.4
1988	3397.6	6.8	4.9	**2008**	6555.5	0.9	3.0
1989	3659.5	7.7	5.5	**2009**	6712.5	2.4	2.8
1990	4001.4	9.3	6.2	**2010**	7032.8	4.8	3.3
1991	4180.0	4.5	6.4	**2011**	7371.5	4.8	3.4
1992	4287.8	2.6	6.1	**2012**	7599.3	3.1	3.2
1993	4369.3	1.9	5.2	**2013**	7802.6	2.7	3.5
1994	4495.6	2.9	4.2	**2014**	7928.8	1.6	3.4
1995	4640.3	3.2	3.0	**2015**	8024.3	1.2	2.7
1996	4754.2	2.5	2.6	**2016**	8224.4	2.5	2.2
1997	4926.6	3.6	2.8	**2017**	8563.1	4.1	2.4
1998	5062.1	2.8	3.0				
1999	5151.4	1.8	2.8				

Source: Barclays Research

FIGURE 7
Barclays UK Equity Index

Year	Equity Price Index December		Equity Income Index December		Income yield %	Equity Price Index adjusted for cost of living		Equity Income Index adjusted for cost of living	
1899	100					100			
1900	108	+8.3%	100		6.3	105	+4.8%	100	
1901	100	-7.9%	69	-30.6%	4.8	97	-7.9%	69	-30.6%
1902	101	+1.3%	80	+15.6%	5.4	95	-1.9%	78	+11.9%
1903	98	-2.7%	66	-17.3%	4.6	92	-2.7%	64	-17.3%
1904	106	+8.0%	62	-6.1%	4.0	100	+8.0%	60	-6.1%
1905	105	-0.7%	71	+13.7%	4.6	99	-0.7%	69	+13.7%
1906	112	+6.1%	77	+8.5%	4.7	112	+13.2%	79	+15.7%
1907	107	-4.7%	79	+2.9%	5.1	97	-13.3%	74	-6.4%
1908	108	+1.3%	57	-27.4%	3.6	95	-1.7%	52	-29.5%
1909	115	+6.3%	73	+26.5%	4.3	101	+6.3%	66	+26.5%
1910	112	-2.1%	69	-4.5%	4.2	99	-2.1%	63	-4.5%
1911	109	-2.9%	71	+2.1%	4.4	94	-5.7%	63	-0.8%
1912	108	-1.4%	69	-3.2%	4.4	90	-4.2%	59	-5.8%
1913	100	-7.1%	57	-16.5%	3.9	83	-7.1%	49	-16.5%
1914	96	-4.4%	57	+0.1%	4.1	80	-4.4%	49	+0.1%
1915	96	0.0%	36	-37.8%	2.6	64	-19.1%	25	-49.7%
1916	89	-6.8%	67	+88.2%	5.2	51	-21.4%	39	+58.8%
1917	93	+4.2%	66	-2.2%	4.8	44	-13.8%	32	-19.1%
1918	108	+16.3%	63	-3.6%	4.0	44	+1.0%	27	-16.3%
1919	116	+7.7%	34	-47.0%	2.0	46	+5.3%	14	-48.2%
1920	86	-25.6%	77	+128.9%	6.1	29	-37.8%	26	+91.4%
1921	80	-7.1%	79	+2.7%	6.7	36	+25.5%	37	+38.8%
1922	96	+19.8%	73	-7.9%	5.2	48	+32.5%	37	+1.8%
1923	92	-4.0%	72	-0.8%	5.3	47	-2.4%	38	+0.9%
1924	106	+15.3%	67	-7.5%	4.3	53	+12.8%	34	-9.5%
1925	117	+9.9%	73	+10.3%	4.3	59	+12.4%	39	+12.7%
1926	119	+1.8%	83	+12.5%	4.8	60	+0.7%	43	+11.2%
1927	124	+4.0%	76	-8.2%	4.2	66	+10.1%	42	-2.8%
1928	139	+12.2%	79	+3.9%	3.9	74	+12.9%	44	+4.5%
1929	113	-19.1%	90	+14.9%	5.5	61	-18.6%	50	+15.6%
1930	102	-9.2%	80	-11.0%	5.4	59	-2.1%	48	-4.2%
1931	77	-24.3%	65	-18.7%	5.8	47	-20.8%	41	-14.8%
1932	99	+27.9%	64	-2.4%	4.4	62	+32.4%	41	+1.0%
1933	119	+20.6%	60	-5.6%	3.5	75	+20.6%	39	-5.6%
1934	131	+9.8%	70	+15.7%	3.6	82	+9.0%	45	+14.9%
1935	144	+9.9%	78	+11.5%	3.7	88	+7.7%	49	+9.2%
1936	166	+15.1%	82	+5.8%	3.4	99	+12.1%	51	+3.0%
1937	138	-16.7%	93	+12.7%	4.6	78	-21.4%	54	+6.4%
1938	118	-14.9%	94	+1.8%	5.5	68	-12.7%	56	+4.4%
1939	114	-3.1%	90	-4.8%	5.4	59	-12.6%	48	-14.2%
1940	102	-10.2%	94	+4.8%	6.3	47	-20.3%	45	-7.1%
1941	119	+16.8%	91	-3.6%	5.2	53	+13.3%	42	-6.5%

Year	Equity Price Index December		Equity Income Index December		Income yield %	Equity Price Index adjusted for cost of living		Equity Income Index adjusted for cost of living	
1942	135	+12.9%	86	-4.5%	4.4	61	+13.4%	40	-4.0%
1943	144	+7.1%	86	-0.2%	4.1	65	+7.7%	40	+0.3%
1944	156	+8.3%	87	+0.4%	3.8	70	+7.3%	40	-0.6%
1945	160	+2.0%	88	+2.0%	3.8	71	+1.0%	40	+1.0%
1946	182	+13.9%	93	+4.9%	3.5	80	+13.3%	42	+4.4%
1947	170	-6.3%	107	+15.1%	4.3	73	-9.2%	47	+11.6%
1948	157	-7.7%	98	-7.7%	4.3	64	-12.1%	41	-12.1%
1949	141	-10.3%	103	+4.4%	5.0	55	-13.3%	42	+0.8%
1950	149	+5.6%	109	+5.6%	5.0	57	+2.3%	43	+2.3%
1951	153	+3.0%	121	+11.2%	5.4	52	-8.1%	42	-0.7%
1952	144	-5.9%	128	+6.3%	6.1	46	-11.5%	42	-0.0%
1953	170	+17.8%	134	+4.3%	5.4	54	+16.6%	44	+3.2%
1954	242	+42.4%	155	+16.0%	4.4	74	+36.9%	49	+11.6%
1955	256	+5.8%	179	+15.4%	4.8	74	-0.0%	53	+9.1%
1956	220	-13.9%	183	+2.2%	5.7	62	-16.5%	53	-0.8%
1957	205	-7.0%	188	+2.8%	6.3	55	-11.1%	52	-1.7%
1958	289	+41.1%	202	+7.5%	4.8	76	+38.5%	55	+5.5%
1959	432	+49.5%	227	+12.1%	3.6	113	+49.5%	61	+12.1%
1960	421	-2.6%	276	+21.7%	4.5	108	-4.4%	73	+19.5%
1961	409	-3.0%	286	+3.5%	4.8	101	-7.0%	73	-0.8%
1962	391	-4.4%	285	-0.4%	5.0	94	-6.9%	71	-3.0%
1963	450	+15.2%	266	-6.5%	4.1	106	+13.1%	65	-8.2%
1964	405	-10.0%	303	+13.7%	5.1	91	-14.2%	70	+8.5%
1965	428	+5.9%	326	+7.7%	5.2	92	+1.3%	73	+3.1%
1966	389	-9.3%	328	+0.5%	5.8	81	-12.5%	70	-3.1%
1967	500	+28.7%	319	-2.5%	4.4	101	+25.6%	67	-4.8%
1968	718	+43.5%	339	+6.1%	3.2	137	+35.4%	67	+0.2%
1969	609	-15.2%	342	+0.8%	3.9	111	-19.0%	65	-3.7%
1970	563	-7.5%	360	+5.5%	4.4	95	-14.3%	63	-2.3%
1971	799	+41.9%	379	+5.1%	3.3	124	+30.2%	61	-3.6%
1972	901	+12.8%	414	+9.3%	3.2	130	+4.8%	62	+1.6%
1973	619	-31.4%	430	+3.9%	4.8	81	-37.9%	58	-6.0%
1974	276	-55.3%	472	+9.6%	11.7	30	-62.5%	53	-8.0%
1975	653	+136.3%	521	+10.4%	5.5	57	+89.2%	47	-11.6%
1976	628	-3.9%	588	+12.8%	6.4	48	-16.5%	46	-2.0%
1977	886	+41.2%	682	+16.1%	5.3	60	+25.9%	48	+3.5%
1978	910	+2.7%	768	+12.6%	5.8	57	-5.3%	50	+3.9%
1979	949	+4.3%	951	+23.8%	6.9	51	-11.0%	53	+5.6%
1980	1206	+27.1%	1073	+12.8%	6.1	56	+10.4%	52	-2.0%
1981	1294	+7.2%	1111	+3.5%	5.9	54	-4.3%	48	-7.6%
1982	1579	+22.1%	1211	+9.0%	5.3	62	+15.8%	49	+3.4%
1983	1944	+23.1%	1309	+8.1%	4.6	73	+16.9%	51	+2.7%
1984	2450	+26.0%	1578	+20.6%	4.4	88	+20.5%	58	+15.3%
1985	2822	+15.2%	1781	+12.8%	4.3	95	+9.0%	62	+6.8%
1986	3452	+22.3%	2033	+14.1%	4.0	112	+17.9%	68	+10.0%
1987	3596	+4.2%	2264	+11.4%	4.3	113	+0.4%	74	+7.4%

Year	Equity Price Index December		Equity Income Index December		Income yield %	Equity Price Index adjusted for cost of living		Equity Income Index adjusted for cost of living	
1988	3829	+6.5%	2628	+16.1%	4.7	113	-0.3%	80	+8.7%
1989	4978	+30.0%	3076	+17.0%	4.2	136	+20.7%	87	+8.7%
1990	4265	-14.3%	3401	+10.5%	5.5	107	-21.6%	88	+1.1%
1991	4907	+15.1%	3591	+5.6%	5.0	117	+10.1%	89	+1.1%
1992	5635	+14.8%	3573	-0.5%	4.4	131	+11.9%	86	-3.0%
1993	6951	+23.3%	3414	-4.4%	3.4	159	+21.0%	81	-6.2%
1994	6286	-9.6%	3684	+7.9%	4.0	140	-12.1%	85	+4.9%
1995	7450	+18.5%	4127	+12.0%	3.8	161	+14.8%	92	+8.5%
1996	8320	+11.7%	4536	+9.9%	3.7	175	+9.0%	99	+7.3%
1997	9962	+19.7%	4690	+3.4%	3.2	202	+15.5%	98	-0.2%
1998	11048	+10.9%	4026	-14.2%	2.5	218	+7.9%	82	-16.5%
1999	13396	+21.2%	4140	+2.8%	2.1	260	+19.1%	83	+1.0%
2000	12329	-8.0%	4007	-3.2%	2.2	233	-10.6%	78	-5.9%
2001	10428	-15.4%	3998	-0.2%	2.6	195	-16.0%	77	-0.9%
2002	7825	-25.0%	4049	+1.3%	3.6	142	-27.1%	76	-1.6%
2003	9121	+16.6%	4121	+1.8%	3.1	161	+13.4%	75	-1.0%
2004	9961	+9.2%	4428	+7.5%	3.1	170	+5.5%	78	+3.8%
2005	11764	+18.1%	5058	+14.2%	3.0	197	+15.5%	87	+11.8%
2006	13311	+13.2%	5549	+9.7%	2.9	213	+8.3%	92	+5.0%
2007	13580	+2.0%	5978	+7.7%	3.0	209	-1.9%	95	+3.5%
2008	9129	-32.8%	5974	-0.1%	4.5	139	-33.4%	94	-1.0%
2009	11407	+25.0%	5321	-10.9%	3.2	170	+22.0%	82	-13.0%
2010	12655	+10.9%	5331	+0.2%	2.9	180	+5.9%	78	-4.4%
2011	11808	-6.7%	6059	+13.6%	3.5	160	-11.0%	85	+8.4%
2012	12782	+8.2%	6651	+9.8%	3.6	168	+5.0%	90	+6.5%
2013	14915	+16.7%	7131	+7.2%	3.3	191	+13.6%	94	+4.4%
2014	14597	-2.1%	7170	+0.6%	3.4	184	-3.7%	93	-1.0%
2015	14231	-2.5%	7675	+7.0%	3.7	177	-3.7%	99	+5.8%
2016	16004	+12.5%	8095	+5.5%	3.5	195	+9.7%	102	+2.9%
2017	17444	+9.0%	9128	+12.8%	3.6	204	+4.7%	110	+8.3%

Source: Barclays Research

FIGURE 8
Barclays UK Gilt Index

Year	Gilt Price Index December		Yield %	Gilt Price Index adjusted for cost of living	
1899	100.0			100.0	
1900	98.4	-1.6%	2.8	95.2	-4.8%
1901	94.6	-3.8%	2.9	91.5	-3.8%
1902	93.7	-0.9%	3.0	87.8	-4.0%
1903	88.3	-5.8%	2.9	82.8	-5.8%
1904	89.4	+1.2%	2.8	83.8	+1.2%
1905	90.1	+0.8%	2.8	84.4	+0.8%
1906	86.6	-3.8%	2.9	86.6	+2.6%
1907	84.1	-2.9%	3.0	76.5	-11.7%
1908	84.6	+0.6%	3.0	74.7	-2.4%
1909	83.6	-1.3%	3.0	73.7	-1.3%
1910	80.0	-4.3%	3.1	70.6	-4.3%
1911	77.7	-2.8%	3.2	66.6	-5.6%
1912	75.8	-2.4%	3.3	63.2	-5.1%
1913	72.3	-4.7%	3.5	60.2	-4.7%
1914	73.0	+1.0%	3.4	60.9	+1.0%
1915	73.0	0.0	3.4	49.2	-19.1%
1916	55.7	-23.8%	4.5	31.7	-35.7%
1917	54.9	-1.4%	4.6	25.8	-18.4%
1918	59.4	+8.3%	4.2	24.3	-6.0%
1919	51.9	-12.7%	4.8	20.7	-14.6%
1920	45.6	-12.1%	5.5	15.2	-26.5%
1921	50.6	+11.1%	4.9	22.9	+50.2%
1922	56.2	+10.9%	4.4	28.1	+22.6%
1923	56.1	-0.2%	4.5	28.5	+1.5%
1924	57.7	+2.9%	4.3	28.6	+0.6%
1925	55.4	-3.9%	4.5	28.1	-1.7%
1926	54.5	-1.6%	4.6	27.4	-2.7%
1927	55.9	+2.6%	4.5	29.8	+8.7%
1928	56.7	+1.3%	4.4	30.3	+1.9%
1929	53.3	-6.0%	4.7	28.7	-5.4%
1930	57.8	+8.5%	4.3	33.5	+16.9%
1931	55.0	-4.7%	4.5	33.4	-0.2%
1932	74.7	+35.6%	3.3	46.9	+40.4%
1933	74.6	-0.1%	3.3	46.9	-0.1%
1934	92.8	+24.4%	2.7	57.9	+23.5%
1935	87.4	-5.8%	2.9	53.4	-7.8%
1936	85.1	-2.6%	2.9	50.7	-5.2%
1937	74.8	-12.2%	3.3	42.0	-17.1%
1938	70.7	-5.4%	3.5	40.8	-3.0%
1939	68.9	-2.6%	3.6	35.8	-12.2%
1940	77.4	+12.3%	3.2	35.7	-0.3%
1941	83.1	+7.4%	3.0	37.2	+4.2%
1942	82.9	-0.3%	3.0	37.2	+0.2%
1943	80.0	-3.4%	3.1	36.1	-3.0%

Year	Gilt Price Index December		Yield %	Gilt Price Index adjusted for cost of living	
1944	82.1	+2.6%	3.0	36.7	+1.6%
1945	91.8	+11.8%	2.7	40.6	+10.7%
1946	99.2	+8.0%	2.5	43.7	+7.5%
1947	82.5	-16.8%	3.0	35.2	-19.4%
1948	80.6	-2.3%	3.1	32.8	-6.9%
1949	70.9	-12.0%	3.5	27.9	-15.0%
1950	71.3	+0.5%	3.5	27.2	-2.6%
1951	61.9	-13.1%	4.0	21.1	-22.4%
1952	59.0	-4.8%	4.2	18.9	-10.5%
1953	64.7	+9.7%	3.9	20.5	+8.5%
1954	66.1	+2.2%	3.8	20.1	-1.7%
1955	56.9	-13.8%	4.4	16.4	-18.6%
1956	52.7	-7.5%	4.7	14.7	-10.2%
1957	46.9	-10.9%	5.3	12.5	-14.9%
1958	52.4	+11.7%	4.8	13.7	+9.6%
1959	50.4	-3.9%	5.0	13.2	-3.9%
1960	44.3	-11.9%	5.6	11.4	-13.5%
1961	38.3	-13.7%	6.5	9.4	-17.3%
1962	45.3	+18.3%	5.4	10.9	+15.3%
1963	44.5	-1.7%	5.5	10.5	-3.5%
1964	41.0	-7.9%	6.1	9.2	-12.1%
1965	40.3	-1.7%	6.2	8.7	-6.0%
1966	39.5	-2.1%	6.4	8.2	-5.5%
1967	37.9	-4.1%	6.9	7.7	-6.4%
1968	34.4	-9.3%	7.6	6.6	-14.4%
1969	31.7	-7.6%	8.5	5.8	-11.7%
1970	30.1	-5.2%	9.3	5.1	-12.2%
1971	35.4	+17.6%	8.3	5.5	+7.8%
1972	31.0	-12.3%	9.6	4.5	-18.5%
1973	25.3	-18.6%	11.9	3.3	-26.4%
1974	18.3	-27.5%	17.0	2.0	-39.2%
1975	21.8	+19.2%	14.8	1.9	-4.6%
1976	21.6	-1.1%	15.0	1.6	-14.0%
1977	28.2	+30.6%	10.9	1.9	+16.4%
1978	24.4	-13.3%	13.2	1.5	-20.0%
1979	22.2	-9.2%	14.7	1.2	-22.6%
1980	23.5	+6.2%	13.9	1.1	-7.8%
1981	20.7	-12.1%	15.8	0.9	-21.6%
1982	28.2	+36.2%	11.1	1.1	+29.2%
1983	29.5	+4.9%	10.5	1.1	-0.4%
1984	28.5	-3.4%	10.6	1.0	-7.7%
1985	28.7	+0.4%	10.5	1.0	-5.0%
1986	28.8	+0.4%	10.5	0.9	-3.2%
1987	30.6	+6.2%	9.5	1.0	+2.4%
1988	30.6	+0.0%	9.3	0.9	-6.3%
1989	29.4	-3.7%	10.0	0.8	-10.6%

Year	Gilt Price Index December		Yield %	Gilt Price Index adjusted for cost of living	
1990	28.1	-4.5%	10.6	0.7	-12.7%
1991	30.4	+8.0%	9.8	0.7	+3.4%
1992	33.0	+8.7%	8.7	0.8	+6.0%
1993	39.4	+19.3%	6.4	0.9	+17.1%
1994	32.2	-18.1%	8.6	0.7	-20.4%
1995	35.5	+10.3%	7.6	0.8	+6.8%
1996	35.7	+0.6%	7.6	0.8	-1.8%
1997	40.0	+11.8%	6.3	0.8	+7.9%
1998	47.4	+18.6%	4.4	0.9	+15.4%
1999	43.4	-8.4%	5.3	0.8	-10.0%
2000	45.2	+4.0%	4.7	0.9	+1.0%
2001	43.4	-3.8%	5.0	0.8	-4.5%
2002	45.5	+4.8%	4.4	0.8	+1.8%
2003	44.1	-3.2%	4.7	0.8	-5.8%
2004	45.2	+2.5%	4.5	0.8	-1.0%
2005	47.0	+3.9%	4.1	0.8	+1.7%
2006	44.8	-4.6%	4.7	0.7	-8.6%
2007	45.1	+0.6%	4.5	0.7	-3.3%
2008	48.8	+8.3%	3.4	0.7	+7.3%
2009	46.4	-5.0%	4.2	0.7	-7.3%
2010	48.7	+5.0%	3.6	0.7	+0.3%
2011	57.2	+17.4%	2.4	0.8	+12.0%
2012	57.9	+1.3%	2.2	0.8	-1.7%
2013	51.8	-10.6%	3.3	0.7	-12.9%
2014	59.3	+14.4%	2.1	0.7	+12.6%
2015	57.6	-2.8%	2.3	0.7	-4.0%
2016	62.8	+9.0%	1.2	0.8	+6.3%
2017	62.9	+0.2%	1.2	0.7	-3.8%

Source: Barclays Research

FIGURE 9
Barclays UK Treasury Bill Index

Year	Treasury Bill Index December		Treasury Bill Index adjusted for cost of living	
1899	100		100	
1900	104	+4.0%	101	+0.6%
1901	107	+2.5%	103	+2.5%
1902	110	+3.0%	103	-0.3%
1903	114	+3.4%	106	+3.4%
1904	117	+2.9%	110	+2.9%
1905	119	+2.2%	112	+2.2%
1906	123	+3.0%	123	+9.9%
1907	128	+3.8%	116	-5.7%
1908	130	+2.2%	115	-0.8%
1909	133	+2.1%	118	+2.1%
1910	137	+3.1%	121	+3.1%
1911	141	+2.8%	121	-0.1%
1912	144	+2.0%	120	-0.8%
1913	148	+3.0%	124	+3.0%
1914	153	+3.0%	127	+3.0%
1915	158	+3.0%	106	-16.6%
1916	162	+3.0%	92	-13.1%
1917	167	+3.0%	79	-14.7%
1918	172	+3.0%	70	-10.5%
1919	179	+3.6%	71	+1.3%
1920	190	+6.5%	64	-11.0%
1921	199	+4.7%	90	+41.5%
1922	204	+2.6%	102	+13.4%
1923	210	+2.7%	107	+4.4%
1924	217	+3.5%	108	+1.2%
1925	226	+4.2%	115	+6.6%
1926	237	+4.6%	119	+3.5%
1927	247	+4.4%	131	+10.5%
1928	257	+4.3%	138	+4.9%
1929	271	+5.4%	146	+6.1%
1930	278	+2.5%	161	+10.5%
1931	289	+3.7%	175	+8.6%
1932	293	+1.5%	184	+5.0%
1933	295	+0.6%	185	+0.6%
1934	297	+0.7%	185	+0.0%
1935	298	+0.5%	182	-1.5%
1936	300	+0.6%	179	-2.1%
1937	302	+0.6%	170	-5.1%
1938	304	+0.6%	175	+3.2%
1939	308	+1.3%	160	-8.6%
1940	311	+1.0%	143	-10.4%
1941	314	+1.0%	140	-2.0%
1942	317	+2.0%	143	+1.5%
1943	320	+1.0%	145	+1.5%

Year	Treasury Bill Index December		Treasury Bill Index adjusted for cost of living	
1944	324	+1.0%	145	+0.0%
1945	327	+0.9%	145	-0.1%
1946	328	+0.5%	145	+0.0%
1947	330	+0.5%	141	-2.6%
1948	332	+0.5%	135	-4.2%
1949	333	+0.5%	131	-2.9%
1950	335	+0.5%	128	-2.6%
1951	337	+0.5%	115	-10.3%
1952	344	+2.1%	110	-4.0%
1953	352	+2.4%	111	+1.3%
1954	359	+1.9%	109	-2.0%
1955	371	+3.5%	107	-2.2%
1956	390	+5.0%	109	+1.9%
1957	409	+5.0%	109	+0.4%
1958	430	+5.1%	113	+3.2%
1959	445	+3.4%	117	+3.4%
1960	467	+5.0%	120	+3.2%
1961	491	+5.1%	121	+0.7%
1962	513	+4.5%	123	+1.8%
1963	533	+3.8%	126	+1.9%
1964	556	+4.4%	125	-0.4%
1965	591	+6.3%	127	+1.7%
1966	627	+6.1%	130	+2.4%
1967	664	+5.9%	135	+3.4%
1968	714	+7.4%	137	+1.4%
1969	770	+7.9%	141	+3.1%
1970	828	+7.5%	140	-0.4%
1971	879	+6.2%	137	-2.6%
1972	927	+5.4%	134	-2.1%
1973	1010	+9.0%	132	-1.4%
1974	1137	+12.6%	125	-5.5%
1975	1259	+10.8%	110	-11.3%
1976	1402	+11.3%	107	-3.2%
1977	1534	+9.4%	104	-2.4%
1978	1658	+8.1%	104	-0.3%
1979	1881	+13.5%	101	-3.2%
1980	2204	+17.2%	102	+1.8%
1981	2507	+13.8%	104	+1.5%
1982	2817	+12.4%	111	+6.6%
1983	3103	+10.1%	116	+4.6%
1984	3399	+9.5%	121	+4.8%
1985	3803	+11.9%	129	+5.8%
1986	4219	+10.9%	137	+7.0%
1987	4624	+9.6%	145	+5.7%
1988	5133	+11.0%	151	+4.0%
1989	5880	+14.6%	161	+6.4%

Year	Treasury Bill Index December		Treasury Bill Index adjusted for cost of living	
1990	6812	+15.9%	170	+6.0%
1991	7602	+11.6%	182	+6.8%
1992	8322	+9.5%	194	+6.7%
1993	8810	+5.9%	202	+3.9%
1994	9286	+5.4%	207	+2.4%
1995	9911	+6.7%	214	+3.4%
1996	10522	+6.2%	221	+3.6%
1997	11246	+6.9%	228	+3.1%
1998	12137	+7.9%	240	+5.0%
1999	12805	+5.5%	249	+3.7%
2000	13601	+6.2%	257	+3.2%
2001	14349	+5.5%	269	+4.8%
2002	14939	+4.1%	272	+1.1%
2003	15500	+3.8%	274	+0.9%
2004	16211	+4.6%	277	+1.1%
2005	17022	+5.0%	285	+2.7%
2006	17856	+4.9%	286	+0.4%
2007	18903	+5.9%	291	+1.8%
2008	19891	+5.2%	303	+4.2%
2009	20026	+0.7%	298	-1.7%
2010	20124	+0.5%	286	-4.1%
2011	20226	+0.5%	274	-4.1%
2012	20292	+0.3%	267	-2.7%
2013	20362	+0.3%	261	-2.3%
2014	20442	+0.4%	258	-1.2%
2015	20534	+0.4%	256	-0.7%
2016	20612	+0.4%	251	-2.1%
2017	20631	+0.1%	241	-3.9%

Source: Barclays Research

FIGURE 10

Barclays UK Index-linked Gilt Index

Year	Index-linked Gilt Price Index December		Real yield %	Money yield %	Index-linked Gilt Price Index adjusted for cost of living	
1982	100		2.7	8.3	100	
1983	98.1	-1.9%	3.2	8.7	93.2	-6.8%
1984	101.6	+3.6%	3.3	8.1	92.3	-1.0%
1985	98.5	-3.1%	3.9	9.8	84.6	-8.3%
1986	101.4	+3.0%	4.1	7.9	84.0	-0.7%
1987	105.1	+3.6%	4.0	7.9	84.0	-0.1%
1988	116.0	+10.4%	3.8	10.8	86.8	+3.3%
1989	129.1	+11.3%	3.5	11.5	89.7	+3.3%
1990	130.8	+1.3%	4.0	13.8	83.1	-7.4%
1991	133.2	+1.8%	4.5	9.2	81.0	-2.5%
1992	151.1	+13.4%	3.9	6.6	89.6	+10.6%
1993	177.1	+17.2%	2.9	4.9	103.0	+15.0%
1994	158.3	-10.6%	4.0	7.0	89.5	-13.1%
1995	171.1	+8.1%	3.6	6.9	93.7	+4.7%
1996	176.2	+3.0%	3.6	6.1	94.2	+0.5%
1997	193.4	+9.8%	3.1	6.9	99.8	+5.9%
1998	227.4	+17.6%	2.0	4.8	114.2	+14.4%
1999	233.7	+2.8%	2.2	4.0	115.3	+1.0%
2000	235.4	+0.8%	2.3	5.3	112.9	-2.1%
2001	227.7	-3.3%	2.7	3.4	108.4	-4.0%
2002	240.7	+5.7%	2.1	5.1	111.3	+2.7%
2003	251.9	+4.7%	1.7	4.5	113.3	+1.8%
2004	267.6	+6.3%	1.7	5.3	116.3	+2.7%
2005	286.7	+7.1%	1.5	3.8	121.9	+4.8%
2006	287.0	+0.1%	1.6	6.0	116.9	-4.1%
2007	297.9	+3.8%	1.4	5.5	116.6	-0.3%
2008	290.3	-2.5%	1.4	2.3	112.5	-3.5%
2009	302.5	+4.2%	0.8	3.2	114.5	+1.8%
2010	328.3	+8.5%	0.4	5.2	118.6	+3.6%
2011	369.5	+12.5%	-0.5	4.2	127.4	+7.4%
2012	363.6	-1.6%	-0.5	2.6	121.6	-4.5%
2013	355.7	-2.2%	-0.2	2.5	115.9	-4.7%
2014	409.6	+15.2%	-0.8	0.8	131.3	+13.3%
2015	400.1	-2.3%	-0.6	0.6	126.7	-3.5%
2016	476.8	+19.2%	-1.8	0.7	147.3	+16.3%
2017	468.0	-1.8%	-1.8	2.3	138.9	-5.7%

Source: Barclays Research

FIGURE 11

Barclays UK equity, gilt, and Treasury bill funds

	Equities				Gilts				Treasury bills			
Year	Value of fund December £		Adjusted for cost of living		Value of fund December £		Adjusted for cost of living		Value of fund December £		Adjusted for cost of living	
1945	100		100		100		100		100		100	
1946	118	+17.9%	117	+17.3%	111	+10.7%	110	+10.2%	101	+0.5%	100	+0.0%
1947	115	-2.3%	111	-5.3%	95	-14.3%	92	-16.9%	101	+0.5%	97	-2.6%
1948	111	-3.8%	102	-8.3%	96	+0.7%	88	-4.0%	102	+0.5%	93	-4.2%
1949	104	-5.8%	93	-8.9%	87	-8.9%	77	-12.0%	102	+0.5%	91	-2.9%
1950	116	+10.9%	100	+7.4%	91	+4.0%	78	+0.8%	103	+0.5%	88	-2.6%
1951	126	+8.5%	97	-3.1%	82	-9.6%	63	-19.3%	103	+0.5%	79	-10.3%
1952	126	-0.1%	91	-6.1%	81	-0.8%	59	-6.7%	105	+2.1%	76	-4.0%
1953	156	+24.2%	111	+22.9%	93	+14.0%	66	+12.8%	108	+2.4%	77	+1.3%
1954	232	+48.6%	159	+42.9%	98	+6.1%	67	+2.0%	110	+1.9%	75	-2.0%
1955	257	+10.9%	167	+4.8%	88	-10.1%	57	-15.0%	114	+3.5%	74	-2.2%
1956	234	-9.0%	147	-11.7%	85	-3.2%	54	-6.0%	119	+5.0%	75	+1.9%
1957	231	-1.1%	139	-5.5%	80	-6.2%	48	-10.4%	125	+5.0%	75	+0.4%
1958	342	+47.9%	202	+45.2%	94	+17.0%	55	+14.9%	132	+5.1%	78	+3.2%
1959	529	+54.8%	313	+54.8%	95	+0.9%	56	+0.9%	136	+3.4%	81	+3.4%
1960	539	+1.8%	313	-0.1%	88	-7.0%	51	-8.7%	143	+5.0%	83	+3.2%
1961	548	+1.7%	305	-2.5%	81	-8.1%	45	-11.9%	150	+5.1%	84	+0.7%
1962	550	+0.4%	298	-2.2%	101	+24.7%	55	+21.5%	157	+4.5%	85	+1.8%
1963	659	+19.9%	351	+17.7%	105	+3.7%	56	+1.8%	163	+3.8%	87	+1.9%
1964	623	-5.4%	317	-9.8%	102	-2.3%	52	-6.7%	170	+4.4%	87	-0.4%
1965	694	+11.4%	337	+6.6%	107	+4.4%	52	-0.1%	181	+6.3%	88	+1.7%
1966	666	-4.0%	312	-7.4%	111	+4.2%	52	+0.5%	192	+6.1%	90	+2.4%
1967	895	+34.3%	410	+31.1%	114	+2.6%	52	+0.1%	203	+5.9%	93	+3.4%
1968	1326	+48.1%	573	+39.8%	111	-2.4%	48	-7.8%	219	+7.4%	94	+1.4%
1969	1168	-11.9%	482	-15.9%	112	+0.2%	46	-4.2%	236	+7.9%	97	+3.1%
1970	1127	-3.5%	431	-10.5%	116	+3.6%	44	-4.0%	253	+7.5%	97	-0.4%
1971	1652	+46.5%	579	+34.4%	147	+27.3%	52	+16.8%	269	+6.2%	94	-2.6%
1972	1922	+16.4%	626	+8.1%	142	-3.8%	46	-10.7%	284	+5.4%	92	-2.1%
1973	1382	-28.1%	407	-35.0%	129	-8.9%	38	-17.6%	309	+9.0%	91	-1.4%
1974	690	-50.1%	171	-58.1%	109	-15.2%	27	-28.8%	348	+12.6%	86	-5.5%
1975	1719	+149.3%	341	+99.6%	150	+36.8%	30	+9.5%	386	+10.8%	76	-11.3%
1976	1759	+2.3%	303	-11.1%	170	+13.7%	29	-1.1%	429	+11.3%	74	-3.2%
1977	2614	+48.6%	401	+32.5%	247	+44.8%	38	+29.1%	470	+9.4%	72	-2.4%
1978	2839	+8.6%	402	+0.2%	242	-1.8%	34	-9.4%	508	+8.1%	72	-0.3%
1979	3165	+11.5%	382	-4.9%	252	+4.1%	30	-11.2%	576	+13.5%	70	-3.2%
1980	4268	+34.8%	448	+17.1%	305	+20.9%	32	+5.0%	675	+17.2%	71	+1.8%
1981	4846	+13.6%	454	+1.3%	310	+1.8%	29	-9.2%	768	+13.8%	72	+1.5%
1982	6227	+28.5%	553	+21.9%	469	+51.3%	42	+43.6%	863	+12.4%	77	+6.6%
1983	8019	+28.8%	676	+22.3%	544	+15.9%	46	+10.0%	950	+10.1%	80	+4.6%
1984	10552	+31.6%	851	+25.8%	581	+6.8%	47	+2.1%	1041	+9.6%	84	+4.8%
1985	12680	+20.2%	968	+13.7%	644	+11.0%	49	+5.0%	1165	+11.9%	89	+5.8%
1986	16139	+27.3%	1188	+22.7%	715	+11.0%	53	+7.0%	1292	+10.9%	95	+7.0%
1987	17536	+8.7%	1244	+4.8%	831	+16.3%	59	+12.1%	1416	+9.6%	100	+5.7%

Year	Equities				Gilts				Treasury bills			
	Value of fund December £		Adjusted for cost of living		Value of fund December £		Adjusted for cost of living		Value of fund December £		Adjusted for cost of living	
1988	19552	+11.5%	1299	+4.4%	909	+9.4%	60	+2.4%	1572	+11.0%	104	+4.0%
1989	26498	+35.5%	1635	+25.8%	963	+5.9%	59	-1.7%	1801	+14.6%	111	+6.4%
1990	23947	-9.6%	1351	-17.4%	1017	+5.6%	57	-3.4%	2086	+15.9%	118	+6.0%
1991	28936	+20.8%	1563	+15.7%	1209	+18.9%	65	+13.8%	2328	+11.6%	126	+6.8%
1992	34672	+19.8%	1826	+16.8%	1432	+18.4%	75	+15.4%	2549	+9.5%	134	+6.7%
1993	44207	+27.5%	2285	+25.1%	1844	+28.8%	95	+26.4%	2698	+5.9%	139	+3.9%
1994	41590	-5.9%	2089	-8.6%	1635	-11.3%	82	-13.8%	2844	+5.4%	143	+2.4%
1995	51163	+23.0%	2490	+19.2%	1945	+19.0%	95	+15.3%	3035	+6.7%	148	+3.4%
1996	59275	+15.9%	2815	+13.1%	2095	+7.7%	100	+5.1%	3222	+6.2%	153	+3.6%
1997	73263	+23.6%	3358	+19.3%	2503	+19.4%	115	+15.3%	3444	+6.9%	158	+3.1%
1998	83284	+13.7%	3715	+10.6%	3129	+25.0%	140	+21.7%	3717	+7.9%	166	+5.0%
1999	103120	+23.8%	4520	+21.7%	3018	-3.5%	132	-5.2%	3921	+5.5%	172	+3.7%
2000	97023	-5.9%	4132	-8.6%	3296	+9.2%	140	+6.1%	4165	+6.2%	177	+3.2%
2001	84226	-13.2%	3562	-13.8%	3340	+1.3%	141	+0.6%	4394	+5.5%	186	+4.8%
2002	65440	-22.3%	2689	-24.5%	3668	+9.8%	151	+6.7%	4575	+4.1%	188	+1.1%
2003	78643	+20.2%	3143	+16.9%	3725	+1.6%	149	-1.2%	4747	+3.8%	190	+0.9%
2004	88508	+12.5%	3418	+8.8%	3994	+7.2%	154	+3.6%	4964	+4.6%	192	+1.1%
2005	107609	+21.6%	4066	+18.9%	4329	+8.4%	164	+6.0%	5213	+5.0%	197	+2.7%
2006	125243	+16.4%	4531	+11.4%	4323	-0.1%	156	-4.4%	5468	+4.9%	198	+0.4%
2007	131639	+5.1%	4577	+1.0%	4550	+5.2%	158	+1.2%	5789	+5.9%	201	+1.8%
2008	92460	-29.8%	3185	-30.4%	5135	+12.9%	177	+11.8%	6091	+5.2%	210	+4.2%
2009	119238	+29.0%	4011	+25.9%	5087	-1.0%	171	-3.3%	6133	+0.7%	206	-1.7%
2010	136107	+14.1%	4370	+8.9%	5565	+9.4%	179	+4.4%	6163	+0.5%	198	-4.1%
2011	131469	-3.4%	4027	-7.8%	6755	+21.4%	207	+15.8%	6194	+0.5%	190	-4.1%
2012	147384	+12.1%	4379	+8.7%	7078	+4.8%	210	+1.6%	6214	+0.3%	185	-2.7%
2013	177620	+20.5%	5140	+17.4%	6569	-7.2%	190	-9.6%	6235	+0.3%	180	-2.3%
2014	179695	+1.2%	5118	-0.4%	7773	+18.3%	221	+16.4%	6260	+0.4%	178	-1.2%
2015	181676	+1.1%	5113	-0.1%	7815	+0.5%	220	-0.6%	6288	+0.4%	177	-0.7%
2016	211392	+16.4%	5804	+13.5%	8711	+11.5%	239	+8.7%	6312	+0.4%	173	-2.1%
2017	238690	+12.9%	6294	+8.4%	8901	+2.2%	235	-1.9%	6318	+0.1%	167	-3.9%

Note: Original Investment of £100 December 1945, gross income reinvested.
Source: Barclays Research

FIGURE 12

Barclays UK Treasury bills and Building Society accounts

Year	Treasury bills annual return %	Building Society acc. annual rate of interest	Basic rate income tax calendar year average	Year	Treasury bills annual return %	Building Society acc. annual rate of interest	Basic rate income tax calendar year average
1946	0.51	6.51	46.25	1986	10.95	10.55	29.26
1947	0.51	6.36	45.00	1987	9.58	9.66	27.50
1948	0.51	6.36	45.00	1988	11.01	8.26	25.50
1949	0.52	6.36	45.00	1989	14.55	10.71	25.00
1950	0.52	6.36	45.00	1990	15.86	12.04	25.00
1951	0.52	4.82	46.88	1991	11.59	9.32	25.00
1952	2.09	4.65	47.50	1992	9.47	9.59	24.68
1953	2.36	4.60	45.62	1993	5.86	4.12	24.50
1954	1.89	4.55	45.00	1994	5.40	3.69	20.00
1955	3.50	4.69	43.12	1995	6.74	3.93	20.00
1956	5.02	5.44	42.50	1996	6.16	2.61	20.00
1957	5.01	6.09	42.50	1997	6.88	3.06	20.00
1958	5.11	6.09	42.50	1998	7.92	7.06	20.00
1959	3.42	5.59	39.69	1999	5.51	5.11	23.00
1960	5.04	5.52	38.75	2000	6.22	5.50	22.00
1961	5.14	5.81	38.75	2001	5.50	4.70	22.00
1962	4.46	6.12	38.75	2002	4.12	3.40	22.00
1963	3.80	5.81	38.75	2003	3.75	3.33	22.00
1964	4.40	5.71	38.75	2004	4.59	4.21	22.00
1965	6.29	6.50	40.62	2005	5.00	3.95	22.00
1966	6.12	6.81	41.25	2006	4.90	4.36	22.00
1967	5.90	7.23	41.25	2007	5.87	4.77	22.00
1968	7.43	7.52	41.25	2008	5.23	0.85	20.00
1969	7.93	8.29	41.25	2009	0.68	0.25	20.00
1970	7.45	8.51	41.25	2010	0.49	0.20	20.00
1971	6.18	8.25	39.38	2011	0.51	0.20	20.00
1972	5.42	8.16	38.75	2012	0.33	0.20	20.00
1973	9.01	9.70	32.19	2013	0.34	0.20	20.00
1974	12.56	11.07	32.25	2014	0.39	0.25	20.00
1975	10.75	11.01	34.50	2015	0.45	0.25	20.00
1976	11.34	10.65	35.00	2016	0.38	0.10	20.00
1977	9.44	10.65	34.25	2017	0.09	0.10	20.00
1978	8.06	9.42	33.25				
1979	13.45	12.22	30.75				
1980	17.17	15.00	30.00				
1981	13.76	12.94	30.00				
1982	12.38	12.19	30.00				
1983	10.14	9.64	30.00				
1984	9.55	9.99	30.00				
1985	11.87	10.81	30.00				

Note: 1. Annual returns on Treasury bills are based on four consecutive investments in 91-day bills. 2. The building society rate of interest above is gross of tax.
Source: Barclays Research

FIGURE 13
Barclays Index-linked funds

	Index-linked gilts			
	Value of fund December £		Adjusted for cost of living	
1982	100		100	
1983	101	+0.8%	96	-4.3%
1984	107	+6.6%	98	+1.9%
1985	107	-0.2%	92	-5.5%
1986	114	+6.1%	94	+2.3%
1987	122	+6.9%	97	+3.1%
1988	138	+13.7%	103	+6.5%
1989	158	+14.5%	110	+6.3%
1990	165	+4.4%	105	-4.5%
1991	174	+5.2%	106	+0.7%
1992	204	+17.1%	121	+14.1%
1993	247	+21.1%	144	+18.9%
1994	227	-7.9%	128	-10.5%
1995	254	+12.0%	139	+8.5%
1996	271	+6.5%	145	+4.0%
1997	307	+13.4%	158	+9.4%
1998	369	+20.3%	186	+17.1%
1999	388	+5.0%	191	+3.2%
2000	400	+3.1%	192	+0.1%
2001	396	-0.9%	189	-1.6%
2002	428	+8.2%	198	+5.1%
2003	457	+6.8%	206	+3.9%
2004	497	+8.6%	216	+4.9%
2005	542	+9.1%	231	+6.7%
2006	554	+2.3%	226	-2.1%
2007	585	+5.5%	229	+1.4%
2008	578	-1.2%	224	-2.1%
2009	610	+5.6%	231	+3.1%
2010	673	+10.3%	243	+5.3%
2011	808	+19.9%	278	+14.4%
2012	834	+3.3%	279	+0.2%
2013	824	-1.3%	268	-3.9%
2014	954	+15.9%	306	+14.0%
2015	933	-2.2%	296	-3.4%
2016	1115	+19.5%	345	+16.6%
2017	1141	+2.3%	339	-1.7%

Source: Barclays Research

FIGURE 14

Barclays US Equity Index

Year	Equity Price Index December		Equity Income Index December		Income yield %	Equity Price Index adjusted for cost of living		Equity Income Index adjusted for cost of living	
1925	100					100			
1926	104	+4.3%	100		5.3	105	+5.5%	100	
1927	132	+26.6%	119	+19.0%	5.0	137	+29.6%	122	+21.7%
1928	177	+33.7%	132	+11.3%	4.2	185	+35.3%	137	+12.7%
1929	144	-18.2%	98	-26.3%	3.8	150	-18.7%	101	-26.7%
1930	98	-32.1%	80	-17.7%	4.6	109	-27.5%	88	-12.1%
1931	51	-47.7%	54	-32.6%	5.9	63	-42.3%	66	-25.7%
1932	44	-14.1%	55	+1.7%	7.0	60	-4.2%	74	+13.3%
1933	66	+50.9%	53	-4.4%	4.4	90	+49.8%	71	-5.1%
1934	66	-1.0%	50	-5.7%	4.2	88	-2.4%	66	-7.1%
1935	92	+39.6%	71	+42.2%	4.3	119	+35.6%	91	+38.1%
1936	116	+26.7%	95	+34.1%	4.5	149	+24.9%	120	+32.2%
1937	72	-38.1%	69	-27.4%	5.3	90	-39.8%	85	-29.4%
1938	89	+23.0%	70	+1.6%	4.4	113	+26.5%	88	+4.5%
1939	86	-2.9%	75	+7.1%	4.8	110	-2.9%	95	+7.1%
1940	75	-12.8%	79	+5.7%	5.9	95	-13.4%	99	+5.0%
1941	63	-16.1%	81	+1.9%	7.1	73	-23.7%	92	-7.3%
1942	69	+9.1%	87	+8.3%	7.1	73	+0.0%	91	-0.7%
1943	84	+21.6%	80	-8.6%	5.3	86	+18.1%	81	-11.2%
1944	96	+15.5%	90	+12.7%	5.2	97	+12.9%	89	+10.2%
1945	129	+33.5%	98	+9.0%	4.2	127	+30.6%	95	+6.6%
1946	116	-10.2%	86	-12.6%	4.1	96	-24.0%	71	-26.0%
1947	113	-2.3%	115	+34.5%	5.7	87	-10.2%	87	+23.6%
1948	108	-4.1%	125	+8.1%	6.4	81	-6.9%	92	+5.0%
1949	122	+12.1%	156	+25.6%	7.2	92	+14.5%	117	+28.2%
1950	148	+21.7%	194	+24.3%	7.3	106	+14.9%	138	+17.3%
1951	169	+14.3%	178	-8.3%	5.9	114	+7.8%	119	-13.5%
1952	182	+7.4%	182	+2.2%	5.6	122	+6.6%	121	+1.4%
1953	173	-5.0%	175	-3.8%	5.7	115	-5.7%	115	-4.5%
1954	247	+43.4%	225	+28.5%	5.1	166	+44.4%	149	+29.4%
1955	298	+20.4%	228	+1.1%	4.3	199	+20.0%	150	+0.7%
1956	311	+4.4%	225	-1.4%	4.0	202	+1.3%	144	-4.2%
1957	267	-14.1%	205	-8.6%	4.3	168	-16.5%	128	-11.2%
1958	372	+39.3%	270	+31.6%	4.0	231	+36.9%	165	+29.3%
1959	406	+9.1%	240	-11.1%	3.3	247	+7.2%	145	-12.6%
1960	397	-2.2%	251	+4.5%	3.5	238	-3.5%	149	+3.1%
1961	490	+23.3%	266	+5.9%	3.0	292	+22.5%	157	+5.2%
1962	425	-13.3%	262	-1.3%	3.4	250	-14.4%	153	-2.6%
1963	497	+17.1%	291	+11.0%	3.3	288	+15.2%	167	+9.2%
1964	561	+12.8%	310	+6.6%	3.1	322	+11.8%	176	+5.5%
1965	623	+11.0%	343	+10.6%	3.1	350	+8.9%	191	+8.5%
1966	550	-11.7%	327	-4.7%	3.3	299	-14.6%	176	-7.9%
1967	686	+24.7%	381	+16.5%	3.1	362	+21.0%	199	+13.0%
1968	761	+10.9%	404	+6.1%	3.0	384	+5.9%	201	+1.3%
1969	658	-13.5%	361	-10.5%	3.1	312	-18.6%	170	-15.8%
1970	636	-3.4%	413	+14.4%	3.6	286	-8.5%	184	+8.4%

Year	Equity Price Index December		Equity Income Index December		Income yield %	Equity Price Index adjusted for cost of living		Equity Income Index adjusted for cost of living	
1971	717	+12.8%	389	-5.9%	3.0	312	+9.2%	167	-8.9%
1972	819	+14.3%	405	+4.0%	2.8	345	+10.5%	168	+0.6%
1973	646	-21.2%	344	-15.0%	3.0	250	-27.5%	132	-21.8%
1974	445	-31.1%	348	+1.1%	4.4	154	-38.6%	119	-10.0%
1975	587	+31.8%	453	+30.3%	4.3	189	+23.3%	145	+21.9%
1976	715	+21.9%	515	+13.7%	4.0	220	+16.3%	157	+8.4%
1977	663	-7.3%	553	+7.3%	4.6	191	-13.1%	158	+0.5%
1978	685	+3.3%	629	+13.8%	5.1	181	-5.3%	164	+4.4%
1979	810	+18.3%	764	+21.4%	5.3	189	+4.4%	176	+7.2%
1980	1030	+27.1%	910	+19.1%	4.9	214	+13.0%	187	+5.9%
1981	944	-8.4%	804	-11.7%	4.7	180	-15.9%	151	-18.9%
1982	1078	+14.2%	1059	+31.7%	5.5	198	+10.0%	192	+26.9%
1983	1271	+17.9%	936	-11.6%	4.1	225	+13.6%	163	-14.9%
1984	1257	-1.1%	985	+5.3%	4.4	214	-4.9%	166	+1.3%
1985	1589	+26.5%	1141	+15.8%	4.0	260	+21.8%	185	+11.6%
1986	1777	+11.8%	1096	-3.9%	3.4	288	+10.6%	175	-5.0%
1987	1753	-1.4%	1012	-7.6%	3.2	272	-5.5%	155	-11.6%
1988	1980	+13.0%	1452	+43.5%	4.1	294	+8.2%	213	+37.4%
1989	2456	+24.0%	1594	+9.8%	3.6	349	+18.5%	224	+4.9%
1990	2225	-9.4%	1454	-8.8%	3.6	298	-14.6%	192	-14.0%
1991	2885	+29.6%	1640	+12.8%	3.2	374	+25.8%	210	+9.4%
1992	3061	+6.1%	1533	-6.5%	2.8	386	+3.1%	191	-9.2%
1993	3330	+8.8%	1547	+0.9%	2.6	409	+5.9%	188	-1.8%
1994	3221	-3.3%	1502	-2.9%	2.6	385	-5.8%	178	-5.4%
1995	4269	+32.5%	1876	+24.9%	2.4	498	+29.2%	216	+21.8%
1996	5070	+18.8%	1877	+0.0%	2.1	572	+14.9%	209	-3.2%
1997	6499	+28.2%	2011	+7.2%	1.7	721	+26.0%	221	+5.4%
1998	7831	+20.5%	2082	+3.5%	1.5	855	+18.6%	225	+1.9%
1999	9683	+23.6%	2308	+10.9%	1.3	1030	+20.4%	243	+8.0%
2000	8507	-12.1%	1687	-26.9%	1.1	875	-15.0%	172	-29.3%
2001	7448	-12.4%	1779	+5.4%	1.3	755	-13.8%	178	+3.8%
2002	5802	-22.1%	1660	-6.7%	1.6	574	-23.9%	162	-8.8%
2003	7588	+30.8%	2511	+51.3%	1.8	737	+28.4%	241	+48.5%
2004	8410	+10.8%	2970	+18.3%	2.0	791	+7.3%	276	+14.6%
2005	8863	+5.4%	2930	-1.4%	1.8	806	+1.9%	264	-4.6%
2006	10108	+14.0%	3474	+18.6%	1.9	897	+11.2%	305	+15.6%
2007	10638	+5.3%	3674	+5.7%	1.9	907	+1.1%	310	+1.6%
2008	6420	-39.7%	2639	-28.2%	2.3	547	-39.7%	222	-28.2%
2009	8223	+28.1%	3767	+42.8%	2.6	682	+24.7%	309	+39.0%
2010	9476	+15.2%	3692	-2.0%	2.2	774	+13.5%	298	-3.4%
2011	9181	-3.1%	3438	-6.9%	2.1	728	-5.9%	270	-9.6%
2012	10368	+12.9%	4719	+37.3%	2.5	808	+11.0%	364	+34.9%
2013	13238	+27.7%	5233	+10.9%	2.2	1017	+25.8%	397	+9.2%
2014	14328	+8.2%	5443	+4.0%	2.1	1092	+7.4%	410	+3.2%
2015	13785	-3.8%	5396	-0.9%	2.2	1043	-4.5%	404	-1.6%
2016	15185	+10.2%	6301	+16.8%	2.3	1126	+7.9%	462	+14.4%
2017	17946	+18.2%	6785	+7.7%	2.1	1303	+15.7%	487	+5.5%

Source: CRSP, Barclays Research

FIGURE 15
Barclays US Bond Index

Year	Bond Price Index December		Yield %	Bond Price Index adjusted for cost of living	
1925	100			100	
1926	104	+3.9%	3.5	105	+5.1%
1927	110	+5.4%	3.2	113	+7.8%
1928	106	-3.1%	3.4	111	-2.0%
1929	106	-0.2%	3.4	110	-0.8%
1930	107	+1.3%	3.3	119	+8.2%
1931	98	-8.5%	4.1	120	+0.9%
1932	111	+12.9%	3.2	151	+25.8%
1933	107	-3.1%	3.4	146	-3.9%
1934	115	+6.8%	2.9	153	+5.2%
1935	117	+2.1%	2.8	152	-0.8%
1936	122	+4.6%	2.6	157	+3.1%
1937	119	-2.5%	2.7	148	-5.2%
1938	123	+2.8%	2.5	157	+5.8%
1939	127	+3.5%	2.3	163	+3.5%
1940	132	+3.8%	1.9	167	+3.0%
1941	131	-1.0%	2.0	151	-10.0%
1942	131	+0.7%	2.4	139	-7.6%
1943	131	-0.4%	2.5	135	-3.3%
1944	131	+0.3%	2.4	132	-1.9%
1945	142	+8.1%	2.0	140	+5.8%
1946	139	-2.4%	2.1	115	-17.4%
1947	132	-4.9%	2.4	101	-12.6%
1948	133	+0.9%	2.4	99	-2.0%
1949	138	+4.0%	2.1	105	+6.2%
1950	135	-2.3%	2.2	97	-7.8%
1951	127	-6.3%	2.7	86	-11.6%
1952	125	-1.4%	2.8	84	-2.1%
1953	126	+0.9%	2.7	84	+0.2%
1954	131	+4.1%	2.6	88	+4.9%
1955	126	-3.6%	3.0	84	-4.0%
1956	115	-9.1%	3.4	75	-11.7%
1957	120	+4.7%	3.2	76	+1.8%
1958	110	-8.4%	3.8	68	-10.0%
1959	103	-6.4%	4.4	63	-8.0%
1960	112	+9.0%	3.8	68	+7.5%
1961	109	-3.4%	4.0	65	-4.0%
1962	113	+4.0%	3.8	67	+2.6%
1963	108	-4.3%	4.1	63	-5.8%
1964	109	+0.4%	4.1	62	-0.6%
1965	104	-3.9%	4.4	59	-5.7%
1966	104	+0.0%	4.5	57	-3.3%
1967	94	-9.9%	5.2	50	-12.6%
1968	89	-14.9%	5.7	45	-21.1%
1969	79	-11.1%	6.6	37	-16.3%
1970	85	+7.0%	6.2	38	+1.4%

Year	Bond Price Index December		Yield %	Bond Price Index adjusted for cost of living	
1971	95	+12.2%	4.5	41	+8.6%
1972	96	+1.3%	4.5	40	-2.1%
1973	88	-8.8%	7.1	34	-16.1%
1974	84	-3.8%	7.7	29	-14.4%
1975	83	-1.7%	7.7	27	-8.0%
1976	91	+9.8%	6.9	28	+4.7%
1977	86	-6.0%	7.5	25	-11.9%
1978	77	-10.3%	8.8	20	-17.7%
1979	69	-10.0%	9.9	16	-20.5%
1980	60	-13.3%	11.6	12	-22.9%
1981	53	-11.5%	13.7	10	-18.7%
1982	65	+23.3%	10.5	12	+18.8%
1983	59	-9.4%	11.6	10	-12.7%
1984	61	+2.5%	11.3	10	-1.4%
1985	72	+18.7%	9.3	12	+14.3%
1986	84	+16.1%	7.6	14	+14.8%
1987	75	-11.0%	8.8	12	-14.8%
1988	74	-0.6%	8.8	11	-4.8%
1989	81	+9.5%	7.9	12	+4.6%
1990	79	-2.8%	8.2	11	-8.4%
1991	86	+9.1%	7.3	11	+5.9%
1992	86	-0.3%	7.3	11	-3.1%
1993	93	+8.8%	6.4	11	+5.9%
1994	80	-14.3%	7.9	10	-16.5%
1995	97	+21.1%	5.9	11	+18.1%
1996	90	-7.0%	6.6	10	-10.0%
1997	97	+7.7%	5.9	11	+5.9%
1998	103	+6.1%	5.3	11	+4.4%
1999	88	-14.5%	6.7	9	-16.8%
2000	100	+13.3%	5.5	10	+9.6%
2001	98	-2.1%	5.7	10	-3.6%
2002	108	+10.5%	4.8	11	+7.9%
2003	105	-2.9%	5.0	10	-4.7%
2004	107	+2.4%	4.8	10	-0.8%
2005	110	+2.2%	4.6	10	-1.2%
2006	105	-4.1%	4.8	9	-6.5%
2007	109	+4.1%	4.5	9	-0.0%
2008	131	+19.8%	3.1	11	+19.7%
2009	107	-17.9%	4.5	9	-20.1%
2010	113	+4.8%	4.1	9	+3.3%
2011	137	+21.7%	2.5	11	+18.2%
2012	138	+0.4%	2.7	11	-1.3%
2013	116	-15.4%	3.7	9	-16.7%
2014	140	+20.2%	2.4	11	+19.3%
2015	134	-4.0%	2.7	10	-4.7%
2016	132	-1.9%	2.8	10	-3.9%
2017	135	+2.7%	2.6	10	+0.6%

Source: CRSP, Barclays Research

FIGURE 16
Barclays US Treasury Bill Index

Year	Treasury Bill Index December		Treasury Bill Index adjusted for cost of living	
1925	100		100	
1926	103	+3.2%	104	+4.4%
1927	106	+3.1%	110	+5.5%
1928	110	+3.8%	116	+5.0%
1929	116	+4.7%	120	+4.1%
1930	118	+2.3%	132	+9.3%
1931	120	+1.0%	147	+11.4%
1932	121	+0.8%	165	+12.3%
1933	121	+0.3%	164	-0.5%
1934	121	+0.2%	162	-1.3%
1935	121	+0.2%	157	-2.7%
1936	122	+0.2%	155	-1.3%
1937	122	+0.3%	152	-2.5%
1938	122	+0.0%	156	+2.9%
1939	122	+0.0%	156	+0.0%
1940	122	-0.1%	155	-0.8%
1941	122	+0.0%	141	-9.0%
1942	122	+0.3%	130	-8.0%
1943	123	+0.3%	126	-2.5%
1944	123	+0.3%	124	-1.9%
1945	124	+0.3%	121	-1.9%
1946	124	+0.4%	103	-15.1%
1947	125	+0.5%	95	-7.7%
1948	126	+1.0%	93	-2.0%
1949	127	+1.1%	96	+3.2%
1950	129	+1.2%	92	-4.5%
1951	131	+1.5%	88	-4.3%
1952	133	+1.6%	89	+0.9%
1953	135	+1.8%	90	+1.0%
1954	136	+0.9%	91	+1.6%
1955	138	+1.6%	92	+1.2%
1956	142	+2.4%	92	-0.5%
1957	146	+3.1%	92	+0.2%
1958	148	+1.4%	92	-0.3%
1959	152	+2.8%	93	+1.1%
1960	156	+2.6%	94	+1.2%
1961	160	+2.2%	95	+1.5%
1962	164	+2.7%	97	+1.4%
1963	169	+3.2%	98	+1.5%
1964	175	+3.5%	101	+2.5%
1965	182	+4.0%	103	+2.0%
1966	191	+4.7%	104	+1.2%
1967	199	+4.1%	105	+1.1%
1968	209	+9.7%	105	+0.5%
1969	223	+6.6%	106	+0.4%
1970	237	+6.4%	107	+0.8%

Year	Treasury Bill Index December		Treasury Bill Index adjusted for cost of living	
1971	247	+4.3%	108	+1.0%
1972	257	+3.9%	108	+0.5%
1973	275	+7.1%	107	-1.5%
1974	297	+8.1%	103	-3.8%
1975	315	+5.8%	101	-1.0%
1976	331	+5.2%	102	+0.3%
1977	348	+5.2%	100	-1.5%
1978	373	+7.3%	99	-1.6%
1979	413	+10.7%	96	-2.3%
1980	461	+11.5%	96	-0.9%
1981	529	+14.9%	101	+5.4%
1982	586	+10.7%	107	+6.6%
1983	638	+8.8%	113	+4.9%
1984	701	+10.0%	119	+5.8%
1985	755	+7.7%	124	+3.7%
1986	801	+6.1%	130	+4.9%
1987	844	+5.4%	131	+0.9%
1988	897	+6.3%	133	+1.8%
1989	971	+8.2%	138	+3.4%
1990	1045	+7.7%	140	+1.5%
1991	1103	+5.5%	143	+2.4%
1992	1141	+3.4%	144	+0.5%
1993	1174	+2.9%	144	+0.1%
1994	1219	+3.9%	146	+1.2%
1995	1287	+5.5%	150	+2.9%
1996	1353	+5.1%	153	+1.8%
1997	1422	+5.1%	158	+3.3%
1998	1490	+4.8%	163	+3.1%
1999	1557	+4.6%	166	+1.8%
2000	1647	+5.8%	169	+2.3%
2001	1709	+3.8%	173	+2.2%
2002	1737	+1.6%	172	-0.7%
2003	1755	+1.0%	170	-0.8%
2004	1776	+1.2%	167	-2.0%
2005	1829	+3.0%	166	-0.4%
2006	1916	+4.8%	170	+2.2%
2007	2006	+4.7%	171	+0.6%
2008	2035	+1.5%	173	+1.4%
2009	2037	+0.1%	169	-2.6%
2010	2040	+0.1%	167	-1.4%
2011	2041	+0.04%	162	-2.8%
2012	2042	+0.06%	159	-1.7%
2013	2042	+0.03%	157	-1.5%
2014	2043	+0.02%	156	-0.7%
2015	2043	+0.01%	155	-0.7%
2016	2047	+0.19%	152	-1.8%
2017	2063	+0.79%	150	-1.3%

Source: CRSP, Barclays Research

CHAPTER 9

Total investment returns

Sreekala Kochugovindan
+44 (0)20 7773 2234
sreekala.kochugovindan@barclays.com
Barclays, UK

Our final chapter presents a series of tables showing the performance of equity and fixed-interest investments over any period of years since December 1899.

The first section reviews the performance of each asset class, taking inflation into account, since December 1960. On each page, we provide two tables illustrating the same information in alternative forms. The first table shows the average annual real rate of return; the second shows the real value of a portfolio at the end of each year, which includes reinvested income. This section provides data on equities and gilts, with dividend income reinvested gross. Finally, we provide figures for Treasury bills and building society shares.

The final pullout section provides the annual real rate of return on UK and US equities and bonds (with reinvestment of income for each year since 1899 for the UK and since 1925 for the US). There is also a table showing the real capital value of equities for the UK. The sources for all data in this chapter are the Bloomberg Barclays indices, as outlined in Chapter 8.

1960-2017

- Equities – income gross
- Gilts – income gross
- Treasury Bills – income gross
- Building Society Shares – income gross
- Index-linked gilts

UK: 1899-2017
US: 1925-2017

- UK and US real bond returns – income gross
- UK and US real equities returns – income gross
- UK Equities – real capital value

Real return on equities – Gross income re-invested

Average Annual Real Rate of Return

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	(2.5)																																																									
1962	(2.4)	(2.2)																																																									
1963	3.9	7.3	17.7																																																								
1964	0.3	1.3	3.0	(9.8)																																																							
1965	1.5	2.6	4.2	(1.9)	6.6																																																						
1966	(0.0)	0.5	1.2	(3.8)	(0.7)	(7.4)																																																					
1967	3.9	5.0	6.6	3.9	9.0	10.2	31.1																																																			
1968	7.8	9.4	11.5	10.3	16.0	19.3	35.4	39.8																																																		
1969	4.9	5.9	7.1	5.4	8.8	9.3	15.5	8.5	(15.9)																																																
1970	3.3	3.9	4.7	3.0	5.3	5.0	8.4	1.7	(13.2)	(10.5)																																															
1971	5.8	6.6	7.7	6.5	9.0	9.4	13.2	9.1	0.4	9.7	34.4																																														
1972	6.0	6.8	7.7	6.7	8.9	9.2	12.3	8.9	2.3	9.1	20.5	8.1																																														
1973	2.1	2.4	2.9	1.5	2.8	2.4	3.9	(0.1)	(6.6)	(4.1)	(1.9)	(16.2)	(35.0)																																														
1974	(4.2)	(4.4)	(4.5)	(6.3)	(6.0)	(7.3)	(7.3)	(11.8)	(18.3)	(18.7)	(20.7)	(33.5)	(47.8)	(58.1)																																														
1975	0.6	0.8	1.0	(0.2)	0.7	0.1	1.0	(2.3)	(7.2)	(5.6)	(4.6)	(12.4)	(18.4)	(8.6)	99.6																																													
1976	(0.2)	(0.0)	0.1	(1.1)	(0.4)	(1.0)	(0.3)	(3.3)	(7.7)	(6.4)	(5.7)	(12.2)	(16.6)	(9.4)	33.2	(11.1)																																													
1977	1.5	1.7	2.0	1.0	1.8	1.5	2.3	(0.2)	(3.9)	(2.3)	(1.0)	(5.9)	(8.5)	(0.4)	33.0	8.5	32.5																																												
1978	1.4	1.6	1.9	0.9	1.7	1.4	2.1	(0.2)	(3.5)	(2.0)	(0.9)	(5.1)	(7.1)	(0.3)	23.9	5.7	15.2	0.2																																											
1979	1.1	1.3	1.5	0.5	1.3	0.9	1.6	(0.6)	(3.6)	(2.3)	(1.3)	(5.1)	(6.8)	(1.1)	17.5	2.9	8.1	(2.4)	(4.9)																																										
1980	1.8	2.0	2.3	1.4	2.2	1.9	2.6	0.7	(2.0)	(0.7)	0.4	(2.8)	(4.1)	1.4	17.4	5.6	10.3	3.7	5.5	17.1																																										
1981	1.8	2.0	2.2	1.4	2.1	1.9	2.5	0.7	(1.8)	(0.5)	0.5	(2.4)	(3.5)	1.4	15.0	4.9	8.4	3.1	4.1	8.9	1.3																																									
1982	2.6	2.9	3.1	2.4	3.2	3.0	3.6	2.0	(0.2)	1.1	2.1	(0.4)	(1.2)	3.5	15.8	7.2	10.6	6.6	8.3	13.1	11.1	21.9																																								
1983	3.4	3.7	4.0	3.3	4.1	3.9	4.6	3.2	1.1	2.5	3.5	1.3	0.7	5.2	16.5	9.0	12.2	9.1	11.0	15.3	14.7	22.1	22.3																																							
1984	4.3	4.6	4.9	4.3	5.1	5.0	5.7	4.4	2.5	3.9	5.0	3.0	2.6	6.9	17.4	10.7	13.8	11.3	13.3	17.4	17.4	23.3	24.0	25.8																																						
1985	4.6	4.9	5.3	4.7	5.5	5.4	6.1	4.9	3.1	4.5	5.5	3.7	3.4	7.5	17.1	11.0	13.8	11.6	13.4	16.7	16.7	20.8	20.5	19.6	13.7																																					
1986	5.3	5.6	5.9	5.4	6.2	6.2	6.9	5.8	4.1	5.4	6.5	4.9	4.7	8.6	17.5	12.0	14.6	12.8	14.5	17.6	17.7	21.2	21.0	20.6	18.1	22.7																																				
1987	5.2	5.6	5.9	5.4	6.1	6.1	6.8	5.7	4.2	5.4	6.4	4.9	4.7	8.3	16.5	11.4	13.7	12.0	13.4	15.9	15.7	18.3	17.6	16.5	13.5	13.4	4.8																																		
			5.2	5.5	5.8	5.4	6.1	6.0	6.7	5.7	4.2	5.4	6.3	4.9	4.7	8.0	15.6	10.9	12.9	11.3	12.4	14.6	14.2	16.2	15.3	13.9	11.2	10.3	4.6	4.4																														
			5.9	6.2	6.5	6.1	6.8	6.8	7.5	6.5	5.1	6.3	7.3	5.9	5.8	9.1	16.3	11.9	13.9	12.4	13.6	15.6	15.5	17.4	16.7	15.8	13.9	14.0	11.2	14.6	25.8																												
			5.0	5.3	5.5	5.1	5.7	5.7	6.3	5.3	4.0	5.0	5.9	4.6	4.4	7.3	13.8	9.6	11.3	9.8	10.6	12.2	11.7	12.9	11.8	10.4	8.0	6.9	3.3	2.8	2.0	(17.4)																										
			5.3	5.6	5.9	5.5	6.1	6.1	6.7	5.7	4.5	5.5	6.3	5.1	4.9	7.8	13.9	10.0	11.6	10.2	11.0	12.4	12.0	13.2	12.2	11.0	9.1	8.3	5.6	5.9	6.4	(2.2)	15.7																								
			5.7	5.9	6.2	5.9	6.5	6.5	7.0	6.2	5.0	6.0	6.8	5.6	5.5	8.2	14.1	10.4	11.9	10.6	11.4	12.8	12.4	13.5	12.7	11.7	10.0	9.5	7.4	8.0	8.9	3.7	16.2	16.8																								
			6.2	6.5	6.8	6.4	7.1	7.1	7.6	6.8	5.7	6.7	7.5	6.4	6.4	9.0	14.6	11.2	12.6	11.5	12.3	13.6	13.4	14.4	13.8	12.9	11.6	11.3	9.8	10.7	11.9	8.7	19.1	20.9	25.1																						
			5.7	6.0	6.3	5.9	6.5	6.5	7.0	6.2	5.1	6.0	6.8	5.7	5.6	8.1	13.3	10.0	11.3	10.2	10.8	12.0	11.6	12.5	11.7	10.8	9.4	8.9	7.3	7.7	8.2	5.0	11.5	10.1	7.0	(8.6)																				
			6.1	6.4	6.6	6.3	6.9	6.9	7.4	6.7	5.6	6.5	7.3	6.3	6.2	8.6	13.6	10.5	11.7	10.7	11.3	12.4	12.1	12.9	12.3	11.5	10.2	9.9	8.6	9.1	9.7	7.3	13.0	12.3	10.9	4.4	19.2																		
			6.3	6.6	6.8	6.5	7.1	7.1	7.6	6.9	5.9	6.8	7.5	6.5	6.5	8.8	13.6	10.6	11.8	10.8	11.4	12.5	12.2	12.9	12.3	11.6	10.5	10.2	9.0	9.5	10.1	8.1	13.0	12.5	11.4	7.2	16.1	13.1																		
			6.6	6.9	7.2	6.9	7.4	7.4	8.0	7.3	6.3	7.2	7.9	7.0	6.9	9.2	13.8	11.0	12.1	11.2	11.8	12.8	12.6	13.3	12.8	12.1	11.1	10.9	9.9	10.4	11.1	9.4	13.9	13.6	13.0	10.1	17.1	16.1	19.3																
			6.7	7.0	7.3	7.0	7.5	7.5	8.0	7.4	6.4	7.3	8.0	7.1	7.1	9.2	13.7	10.9	12.1	11.2	11.8	12.7	12.5	13.2	12.6	12.0	11.1	10.9	10.0	10.5	11.1	9.5	13.5	13.2	12.6	10.2	15.5	14.3	14.9	10.6														
			7.1	7.4	7.6	7.4	7.9	7.9	8.4	7.8	6.9	7.7	8.4	7.6	7.6	9.7	14.0	11.4	12.5	11.6	12.2	13.1	12.9	13.6	13.2	12.6	11.8	11.6	10.8	11.3	12.0	10.7	14.4	14.2	13.8	12.0	16.7	16.1	17.1	16.0	21.7												
			6.7	6.9	7.2	6.9	7.4	7.4	7.9	7.3	6.4	7.2	7.8	7.0	7.0	9.0	13.0	10.5	11.5	10.7	11.2	12.0	11.8	12.3	11.8	11.2	10.4	10.2	9.3	9.7	10.1	8.8	11.8	11.4	10.7	8.8	12.0	10.7	10.1	7.2	5.5	(8.6)											
			6.1	6.3	6.6	6.3	6.8	6.8	7.2	6.6	5.7	6.5	7.0	6.2	6.2	8.1	11.9	9.4	10.4	9.5	9.9	10.7	10.4	10.9	10.3	9.7	8.8	8.5	7.6	7.8	8.1	6.7	9.2	8.6	7.7	5.7	7.9	6.2	4.8	1.5	(1.4)	(11.2)	(13.8)										
			5.3	5.5	5.7	5.4	5.8	5.8	6.2	5.5	4.7	5.3	5.9	5.1	5.0	6.7	10.3	8.0	8.8	7.9	8.2	8.8	8.5	8.8	8.2	7.5	6.6	6.2	5.2	5.3	5.3	3.9	5.9	5.1	3.9	1.8	3.2	1.1	(0.8)	(4.3)	(7.8)	(15.9)	(19.3)	(24.5)									
			5.5	5.7	5.9	5.6	6.1	6.0	6.4	5.8	5.0	5.7	6.2	5.4	5.3	7.0	10.6	8.3	9.1	8.2	8.6	9.2	8.8	9.2	8.6	8.0	7.1	6.8	5.9	6.0	6.1	4.8	6.7	6.0	5.1	3.2	4.6	3.0	1.6	(1.1)	(3.3)	(8.7)	(8.7)	(6.1)	16.9								
			5.6	5.8	6.0	5.7	6.1	6.1	6.5	5.9	5.1	5.8	6.3	5.5	5.4	7.1	10.5	8.3	9.0	8.3	8.6	9.2	8.8	9.2	8.6	8.0	7.2	6.9	6.0	6.1	6.2	5.0	6.9	6.2	5.4	3.7	5.0	3.6	2.5	0.3	(1.4)	(5.4)	(4.6)	(1.4)	12.8	8.8							
			5.9	6.1	6.3	6.0	6.4	6.4	6.8	6.2	5.4	6.1	6.6	5.9	5.8	7.5	10.8	8.6	9.4	8.6	8.9	9.5	9.2	9.6	9.1	8.5	7.7	7.4	6.7	6.8	6.9	5.9	7.6	7.1	6.4	4.9	6.2	5.0	4.2	2.4	1.3	(1.8)	(0.3)	3.4	14.8	13.7	18.9						
			6.0	6.2	6.4	6.1	6.5	6.5	6.9	6.4	5.6	6.2	6.8	6.1	6.0	7.6	10.8	8.7	9.4	8.7	9.0	9.6	9.3	9.6	9.2	8.6	7.9	7.6	6.9	7.0	7.2	6.2	7.9	7.4	6.7	5.4	6.7	5.6	4.9	3.4	2.5	0.0	1.5	4.9	13.9	13.0	15.1	11.4					
			5.9	6.1	6.3	6.0	6.4	6.4	6.8	6.2	5.5	6.1	6.6	5.9	5.8	7.4	10.5	8.5	9.2	8.5	8.7	9.3	9.0	9.3	8.8	8.3	7.6	7.3	6.6	6.7	6.9	5.9	7.4	6.9	6.3	5.1	6.2	5.2	4.5	3.1	2.3	0.2	1.5	4.3	11.2	9.9	10.2	6.1	1.0				
			5.0	5.1	5.3	5.0	5.4	5.4	5.7	5.1	4.4	5.0	5.4	4.7	4.6	6.1	9.0	7.0	7.6	6.9	7.1	7.6	7.3	7.5	7.0	6.4	5.7	5.3	4.6	4.6	4.6	3.6	4.9	4.3	3.5	2.2	3.1	1.9	1.0	(0.5)	(1.5)	(3.8)	(3.2)	(1.6)	2.9	0.3	(1.8)	(7.8)	(16.2)	(30.4)			
			5.3	5.5	5.7	5.4	5.8	5.8	6.1	5.6	4.9	5.4	5.9	5.2	5.1	6.6	9.4	7.5	8.1	7.5	7.7	8.1	7.9	8.1	7.6	7.1	6.4	6.1	5.4	5.5	5.5	4.6	5.9	5.4	4.7	3.6	4.4	3.5	2.8	1.5	0.7	(1.2)	(0.3)	1.5	5.9	4.1	3.3	(0.3)	(4.0)	(6.4)	25.9		
			5.4	5.6	5.8	5.5	5.9	5.9	6.2	5.7	5.0	5.5	6.0	5.3	5.2	6.6	9.4	7.6	8.2	7.5	7.7	8.2	7.9	8.1	7.7	7.2	6.5	6.2	5.6	5.6	5.7	4.8	6.0	5.6	5.0	3.9	4.7	3.8	3.2	2.0	1.4	(0.3)	0.6	2.3	6.3	4.8	4.2	1.5	(0.9)	(1.5)	17.1	8.9	
			5.1	5.3	5.5	5.2	5.6	5.5	5.8	5.3	4.6	5.2	5.6	5.0	4.9	6.2	8.9	7.1	7.7	7.0	7.2	7.6	7.3	7.5	7.1	6.6	5.9	5.6	5.0	5.0	5.0	4.2	5.3	4.8	4.3	3.2	3.9	3.1	2.4	1.3	0.6	(1.0)	(0.2)	1.2	4.6	3.1	2.4	(0.2)	(2.3)	(3.2)	8.1	0.2	(7.8)
			5.2	5.4	5.5	5.3	5.6	5.6	5.9	5.4	4.7	5.3	5.7	5.1	5.0	6.3	8.9	7.1	7.7	7.1	7.3	7.7	7.4	7.6	7.1	6.7	6.0	5.8	5.1	5.2	5.2	4.4	5.5	5.0	4.5	3.5	4.2	3.4	2.8	1.8	1.2	(0.2)	0.5	1.9	5.0	3.8	3.1	1.1	(0.6)	(0.9)	8.3	3.0	0.1	8.7
			5.4	5.6	5.7	5.5	5.9	5.8	6.1	5.7	5.0	5.5	5.9	5.3	5.3	6.5	9.1	7.4	8.0	7.3	7.6	7.9	7.7	7.9	7.5	7.0	6.4	6.1	5.6	5.6	5.7	4.9	6.0	5.6	5.1	4.1	4.9	4.1	3.6	2.7	2.2	0.9	1.7	3.1	6.1	5.0	4.6	3.0	1.8	2.0	10.0	6.4	5.6	13.0	17.4	
			5.3	5.5	5.6	5.4	5.7	5.7	6.0	5.5	4.9	5.4	5.8	5.2	5.1	6.4	8.9	7.2	7.7	7.1	7.3	7.7	7.4	7.6	7.2	6.7	6.2	5.9	5.4	5.4	5.4	4.7	5.7	5.3	4.8	3.9	4.6	3.9	3.4	2.5	2.0	0.8	1.5	2.8	5.5	4.5	4.1	2.6	1.5	1.6	8.2	5.0	4.0	8.3	8.1	(0.4)	
			5.2	5.4	5.5	5.3	5.6	5.6	5.9	5.4	4.8	5.3	5.6	5.1	5.0	6.2	8.6	7.0	7.5	6.9	7.1	7.5	7.2	7.4	7.0	6.5	6.0	5.7	5.2	5.2	5.2	4.5	5.5	5.1	4.6	3.7	4.4	3.7	3.2	2.4	1.9	0.8	1.4	2.6	5.1	4.1	3.7	2.3	1.4	1.4	7.0	4.1	3.2	6.1	5.3	(0.3)	(0.1)	
			5.4	5.5	5.7	5.4	5.8	5.7	6.0	5.6	4.9	5.4	5.8	5.3	5.2	6.4	8.8	7.2	7.7	7.1	7.3	7.6	7.4	7.6	7.2	6.7	6.2	5.9	5.4	5.5	5.5	4.8	5.8	5.4	4.9	4.1	4.8	4.1	3.7	2.9	2.5	1.5	2.1	3.3	5.7	4.8	4.5	3.3	2.5	2.7	7.8	5.4	4.8	7.6	7.3	4.1	6.5	13.5	
			5.4	5.6	5.7	5.5	5.8	5.8	6.1	5.6	5.0	5.5	5.9	5.3	5.3	6.4	8.8	7.2	7.7	7.1	7.3	7.6	7.4	7.6	7.2	6.8	6.3	6.0	5.5	5.6	5.6	4.9	5.9	5.5	5.1	4.3	4.9	4.3	3.9	3.2	2.8	1.9	2.5	3.6	5.8	5.1	4.8	3.7	3.0	3.2	7.9	5.8	5.4	7.7	7.5	5.2	7.1	11.0	8.4

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the annual rate of return is calculated. Reading the top figure in each column diagonally down the table gives the real rate of return in each year since 1960. The table can be used to see the real rate of return over any period; thus a purchase made at the end of 1960 would have lost 2.5% (allowing for reinvestment of income) in one year but over the first three years (up to the end of 1963) would have given an average annual real return of 3.9%. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real Value of £100 Invested

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	97
1962	95	98
1963	112	115	118
1964	101	104	106	90
1965	108	111	113	96	107
1966	100	102	105	89	99	93
1967	131	134	137	117	129	121	131
1968	183	188	192	163	181	170	183	140
1969	154	158	162	137	152	143	154	118	84
1970	138	141	145	123	136	128	138	105	75	89
1971	185	190	194	165	183	172	185	141	101	120	134
1972	200	205	210	179	198	186	201	153	109	130	145	108
1973	130	134	137	116	129	121	130	99	71	85	94	70	65
1974	55	56	57	49	54	51	55	42	30	35	40	29	27	42
1975	109	112	114	97	108	101	109	83	59	71	79	59	54	84	200
1976	97	99	102	86	96	90	97	74	53	63	70	52	48	74	177	89
1977	128	132	135	114	127	119	128	98	70	83	93	69	64	98	235	118	133
1978	128	132	135	115	127	119	129	98	70	83	93	69	64	99	236	118	133	100
1979	122	125	128	109	121	113	122	93	67	79	89	66	61	94	224	112	126	95	95
1980	143	147	150	128	141	133	143	109	78	93	104	77	71	110	262	132	148	112	111	117
1981	145	149	152	129	143	134	145	111	79	94	105	78	72	111	266	133	150	113	113	119	101
1982	177	181	186	158	175	164	177	135	97	115	128	95	88	136	324	162	183	138	138	145	124	122
1983	216	222	227	193	214	200	217	165	118	140	157	117	108	166	396	199	223	169	168	177	151	149	122
1984	272	279	286	243	269	252	272	208	149	177	197	147	136	209	499	250	281	212	212	223	190	188	154	126
1985	309	317	325	276	306	287	310	236	169	201	224	167	154	238	567	284	320	241	241	253	216	213	175	143	114
1986	380	390	398	339	375	352	380	290	207	246	275	205	190	292	696	349	392	296	295	311	265	262	215	176	140	123
1987	398	408	417	355	393	369	398	304	217	258	289	215	199	305	729	365	411	310	310	325	278	274	225	184	146	129	105
1988	415	426	436	370	411	385	416	317	227	270	301	224	207	319	762	382	429	324	323	340	290	286	235	192	153	134	109	104
1989	523	536	549	466	517	485	523	399	286	339	379	282	261	401	958	480	540	408	407	428	365	360	296	242	192	169	138	131	126
1990	432	443	453	385	427	400	433	330	236	280	313	233	216	332	792	397	446	337	336	353	302	298	244	200	159	140	114	109	104	83
1991	500	513	524	446	494	463	500	382	273	324	363	270	250	384	916	459	516	390	389	409	349	344	283	231	184	162	132	126	120	96	116
1992	584	599	613	521	577	541	584	446	319	379	423	315	291	448	1070	536	603	455	454	478	408	402	330	270	215	189	154	147	141	112	135	117
1993	730	749	766	651	722	677	731	558	399	474	530	394	365	561	1339	671	755	569	568	597	510	503	413	338	268	236	192	184	176	140	169	146	125
1994	668	685	701	596	660	619	669	510	365	434	485	361	333	513	1224	613	690	521	520	546	467	460	378	309	245	216	176	168	161	128	155	134	114	91
1995	796	817	835	710	787	738	797	608	435	517	577	430	397	611	1459	731	822	621	619	651	556	549	450	368	292	257	210	200	192	152	184	159	136	109	119
1996	900	923	944	803	889	834	901	687	492	584	653	486	449	691	1650	827	930	702	700	736	629	620	509	416	331	291	237	226	217	172	208	180	154	123	135	113
1997	1073	1101	1126	957	1061	995	1075	820	586	697	779	579	536	824	1968	986	1109	837	835	878	750	740	607	496	394	347	283	270	258	205	248	215	184	147	161	135	119
1998	1187	1218	1246	1059	1174	1101	1189	907	649	771	862	641	593	912	2177	1091	1227	926	924	972	830	819	672	549	436	384	313	299	286	227	275	238	203	163	178	149	132	111
1999	1445	1482	1516	1289	1428	1340	1447	1104	789	938	1048	780	722	1110	2649	1327	1493	1127	1124	1182	1009	996	817	668	531	467	381	363	348	276	334	289	248	198	216	182	161	135	122
2000	1321	1355	1386	1178	1305	1224	1323	1009	722	858	958	713	660	1014	2422	1213	1365	1030	1028	1081	923	910	747	611	485	427	348	332	318	253	306	264	226	181	198	166	147	123	111	91
2001	1138	1168	1195	1016	1125	1056	1140	870	622	739	826	615	569	874	2088	1046	1177	888	886	932	795	785	644	527	418	368	300	286	274	218	264	228	195	156	171	143	127	106	96	79	86
2002	859	882	902	766	849	797	861	656	470	558	624	464	429	660	1576	790	888	670	669	703	600	592	486	397	316	278	226	216	207	164	199	172	147	118	129	108	95	80	72	59	65	75
2003	1005	1031	1054	896	993	931	1006	767	549	652	729	542	502	771	1842	923	1038	783	782	822	702	693	568	465	369	325	265	253	242	192	233	201	172	138	150	126	112	94	85	70	76	88	117
2004	1092	1121	1147	974	1080	1013	1094	835	597	709	793	590	546	839	2003	1004	1129	852	850	894	763	753	618	505	402	353	288	275	263	209	253	219	187	150	164	137	121	102	92	76	83	96	127	109
2005	1299	1333	1364	1159	1284	1205	1301	993	710	844	943	702	649	998	2383	1194	1343	1013	1011	1063	908	896	735	601	478	420	342	327	313	249	301	260	223	178	195	163	144	121	109	90	98	114	151	129	119
2006	1448	1486	1520	1292	1432	1343	1450	1106	791	940	1051	782	723	1112	2656	1331	1497	1129	1127	1185	1012	998	819	670	532	468	382	364	349	277	335	290	248	198	217	182	161	135	122	100	110	127	169	144	133	111
2007	1463	1501	1536	1305	1446	1356	1465	1118	799	950	1062	790	731	1124	2683	1344	1512	1141	1139	1197	1022	1009	827	677	538	473	385	368	352	280	339	293	251	200	219	184	163	136	123	101	111	129	170	146	134	113	101
2008	1018	1045	1068	908	1006	944	1019	778	556	661	739	550	508	782	1867	935	1052	794	792	833	711	702	576	471	374	329	268	256	245	195	236	204	174	139	152	128	113	95	86	70	77	89	118	101	93	78	70	70
2009	1282	1316	1346	1144	1267	1189	1284	979	700	832	930	692	640	985	2351	1178	1325	1000	998	1049	896	884	725	593	471	414	338	322	309	245	297	257	220	176	192	161	142	119	108	89	97	113	149	128	117	99	89	88	126
2010	1397	1433	1466	1246	1381	1295	1399	1067	763	907	1014	754	698	1073	2561	1283	1444	1089	1087	1143	976	963	790	646	513	452	368	351	336	267	323	280	239	191	209	176	155	130	118	97	106	123	163	139	128	107	96	95	137	109
2011	1287	1321	1351	1148	1272	1193	1289	983	703	836	934	695	643	989	2360	1183	1330	1004	1002	1053	899	887	728	595	473	416	339	324	310	246	298	258	221	176	193	162	143	120	108	89	97	113	150	128	118	99	89	88	126	100	92
2012	1400	1436	1469	1249	1384	1298	1402	1069	765	909	1016	756	699	1075	2567	1286	1447	1091	1089	1145	978	965	792	647	514	453	369	352	337	268	324	280	240	192	210	176	156	130	118	97	106	123	163	139	128	108	97	96	138	109	100	109
2013	1643	1686	1724	1465	1624	1523	1645	1255	898	1067	1192	887	821	1262	3013	1510	1698	1281	1279	1344	1148	1133	929	760	604	531	433	413	396	314	380	329	282	225	246	206	183	153	138	114	124	144	191	164	150	126	113	112	161	128	118	128	117
2014	1636	1678	1717	1459	1617	1517	1638	1250	894	1062	1187	883	817	1256	2999	1503	1690	1275	1273	1338	1143	1128	925	757	601	529	431	411	393	313	378	327	280	224	245	206	182	152	138	113	124	144	190	163	150	126	113	112	161	128	117	127	117	100
2015	1634	1677	1715	1458	1615	1515	1636	1248	893	1061	1186	882	816	1255	2996	1501	1689	1274	1272	1337	1142	1127	924	756	601	528	430	411	393	313	378	327	280	224	245	205	182	152	138	113	124	144	190	163	150	126	113	112	161	127	117	127	117	99	100
2016	1855	1904	1947	1655	1834	1720	1858	1417	1014	1205	1346	1002	927	1425	3402	1704	1917	1447	1444	1518	1296	1279	1049	858	682	600	489	466	447	355	429	371	318	254	278	233	206	173	156	128	140	163	216	185	170	143	128	127	182	145	133	144	133	113	113	114
2017	2012	2064	2112	1794	1989	1865	2015	1537	1099	1306	1460	1086	1005	1545	3689	1848	2079	1569	1566	1646	1406	1387	1138	930	739	650	530	506	484	385	466	403	345	276	301	253	224	187	169	139	152	177	234	200	184	155	139	138	198	157	144	156	144	122	123	123	108

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the change in real value is calculated. Reading the top figure in each column diagonally down the table gives the growth in each year since 1960. The table can be used to see the real growth over any period; thus an investment of £100 made at the end of 1960 would have fallen to £97 (allowing for reinvestment of income and the effect of inflation) in one year but after three years (up to the end of 1963) would have reached £112 in real terms. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real return on gilts – Gross income re-invested

Average Annual Real Rate of Return

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	(11.9)
1962	3.5	21.5
1963	2.9	11.2	1.8
1964	0.4	4.9	(2.6)	(6.7)
1965	0.3	3.6	(1.8)	(3.5)	(0.1)
1966	0.3	3.0	(1.2)	(2.2)	0.2	0.5
1967	0.3	2.5	(0.9)	(1.6)	0.2	0.3	0.1
1968	(0.8)	0.9	(2.1)	(2.9)	(1.9)	(2.5)	(4.0)	(7.8)
1969	(1.1)	0.3	(2.4)	(3.1)	(2.4)	(2.9)	(4.0)	(6.1)	(4.2)
1970	(1.4)	(0.2)	(2.6)	(3.2)	(2.6)	(3.1)	(4.0)	(5.4)	(4.1)	(4.0)
1971	0.1	1.4	(0.6)	(0.9)	(0.1)	(0.1)	(0.2)	(0.3)	2.4	5.9	16.8
1972	(0.9)	0.2	(1.7)	(2.1)	(1.5)	(1.7)	(2.0)	(2.4)	(1.0)	0.0	2.1	(10.7)
1973	(2.3)	(1.4)	(3.3)	(3.7)	(3.4)	(3.8)	(4.4)	(5.1)	(4.6)	(4.7)	(4.9)	(14.2)	(17.6)
1974	(4.4)	(3.8)	(5.7)	(6.4)	(6.3)	(7.0)	(7.9)	(9.0)	(9.1)	(10.1)	(11.6)	(19.4)	(23.4)	(28.8)
1975	(3.6)	(2.9)	(4.6)	(5.1)	(5.0)	(5.4)	(6.1)	(6.8)	(6.7)	(7.1)	(7.7)	(13.0)	(13.7)	(11.7)	9.5
1976	(3.4)	(2.8)	(4.4)	(4.8)	(4.7)	(5.1)	(5.6)	(6.2)	(6.0)	(6.3)	(6.6)	(10.7)	(10.7)	(8.3)	4.1	(1.1)
1977	(1.8)	(1.1)	(2.4)	(2.7)	(2.4)	(2.6)	(2.9)	(3.2)	(2.6)	(2.4)	(2.2)	(5.1)	(3.9)	(0.1)	11.8	13.0	29.1
1978	(2.2)	(1.6)	(2.9)	(3.2)	(2.9)	(3.1)	(3.4)	(3.8)	(3.3)	(3.2)	(3.1)	(5.7)	(4.8)	(2.1)	6.1	5.0	8.1	(9.4)
1979	(2.7)	(2.2)	(3.4)	(3.7)	(3.5)	(3.7)	(4.1)	(4.4)	(4.1)	(4.1)	(4.1)	(6.4)	(5.8)	(3.6)	2.4	0.7	1.3	(10.3)	(11.2)
1980	(2.3)	(1.8)	(2.9)	(3.2)	(3.0)	(3.2)	(3.4)	(3.7)	(3.4)	(3.3)	(3.2)	(5.2)	(4.5)	(2.5)	2.8	1.5	2.2	(5.5)	(3.4)	5.0
1981	(2.7)	(2.2)	(3.3)	(3.6)	(3.4)	(3.6)	(3.8)	(4.1)	(3.8)	(3.8)	(3.8)	(5.6)	(5.0)	(3.3)	1.0	(0.4)	(0.2)	(6.4)	(5.4)	(2.3)	(9.2)
1982	(0.9)	(0.4)	(1.4)	(1.5)	(1.2)	(1.3)	(1.4)	(1.5)	(1.0)	(0.8)	(0.5)	(1.9)	(1.0)	1.0	5.5	5.0	6.0	1.9	5.0	11.1	14.2	43.6
1983	(0.5)	0.1	(0.8)	(1.0)	(0.7)	(0.7)	(0.8)	(0.8)	(0.3)	(0.0)	0.3	(1.0)	(0.1)	1.9	6.0	5.6	6.6	3.2	6.0	10.8	12.8	25.7	10.0
1984	(0.4)	0.2	(0.7)	(0.8)	(0.5)	(0.5)	(0.6)	(0.6)	(0.2)	0.1	0.4	(0.8)	0.1	1.9	5.6	5.2	6.0	3.1	5.3	9.0	10.0	17.3	6.0	2.1
1985	(0.2)	0.4	(0.5)	(0.6)	(0.3)	(0.3)	(0.3)	(0.3)	0.1	0.4	0.7	(0.4)	0.5	2.2	5.6	5.2	5.9	3.3	5.3	8.3	9.0	14.1	5.7	3.6	5.0
1986	0.1	0.6	(0.2)	(0.3)	0.1	0.1	0.0	0.0	0.5	0.8	1.1	0.1	0.9	2.5	5.7	5.3	6.0	3.7	5.5	8.1	8.7	12.6	6.0	4.7	6.0	7.0
1987	0.5	1.0	0.3	0.2	0.6	0.6	0.6	0.6	1.1	1.4	1.7	0.8	1.6	3.2	6.2	5.9	6.6	4.5	6.2	8.6	9.1	12.5	7.2	6.5	8.0	9.5	12.1
1988	0.6	1.1	0.4	0.3	0.6	0.7	0.7	0.7	1.1	1.4	1.7	0.9	1.7	3.1	5.9	5.6	6.2	4.3	5.8	7.9	8.3	11.0	6.4	5.7	6.6	7.1	7.2	2.4
1989	0.5	1.0	0.3	0.2	0.5	0.6	0.6	0.6	1.0	1.3	1.6	0.8	1.5	2.8	5.4	5.1	5.6	3.8	5.1	6.9	7.1	9.4	5.2	4.4	4.9	4.8	4.2	0.4	(1.7)
1990	0.4	0.8	0.2	0.1	0.4	0.4	0.4	0.4	0.8	1.0	1.3	0.6	1.2	2.5	4.8	4.5	4.9	3.3	4.4	5.9	6.0	7.9	4.1	3.3	3.4	3.1	2.2	(0.9)	(2.5)	(3.4)
1991	0.8	1.2	0.6	0.6	0.8	0.9	0.9	0.9	1.3	1.6	1.9	1.2	1.8	3.1	5.3	5.1	5.5	4.0	5.1	6.6	6.7	8.4	5.1	4.5	4.9	4.8	4.4	2.6	2.6	4.8	13.8
1992	1.2	1.7	1.1	1.0	1.3	1.4	1.4	1.5	1.9	2.2	2.5	1.8	2.5	3.7	5.9	5.6	6.1	4.7	5.8	7.2	7.4	9.1	6.1	5.7	6.1	6.3	6.2	5.0	5.7	8.3	14.6	15.4
1993	1.9	2.4	1.8	1.8	2.1	2.2	2.3	2.3	2.8	3.1	3.4	2.8	3.5	4.7	6.8	6.7	7.2	5.9	7.1	8.5	8.8	10.4	7.8	7.6	8.2	8.6	8.9	8.3	9.5	12.5	18.4	20.8	26.4
1994	1.4	1.8	1.3	1.3	1.5	1.6	1.6	1.7	2.1	2.3	2.6	2.0	2.7	3.7	5.7	5.5	5.9	4.7	5.6	6.8	7.0	8.3	5.8	5.4	5.8	5.9	5.7	4.8	5.2	6.7	9.4	7.9	4.4	(13.8)
1995	1.8	2.2	1.7	1.7	2.0	2.0	2.1	2.1	2.5	2.8	3.1	2.6	3.2	4.2	6.1	6.0	6.4	5.2	6.2	7.4	7.5	8.8	6.5	6.2	6.6	6.8	6.7	6.1	6.6	8.1	10.5	9.7	7.9	(0.3)	15.3
1996	1.9	2.3	1.8	1.8	2.1	2.1	2.2	2.2	2.6	2.9	3.2	2.7	3.3	4.3	6.1	5.9	6.3	5.2	6.1	7.2	7.4	8.6	6.4	6.1	6.5	6.6	6.6	6.0	6.4	7.6	9.6	8.8	7.2	1.5	10.1	5.1
1997	2.2	2.6	2.1	2.1	2.4	2.5	2.6	2.7	3.0	3.3	3.6	3.1	3.7	4.7	6.5	6.3	6.7	5.7	6.6	7.7	7.8	9.0	7.0	6.8	7.1	7.3	7.3	6.9	7.4	8.6	10.4	9.8	8.8	4.7	11.8	10.1	15.3
1998	2.7	3.1	2.6	2.7	2.9	3.0	3.1	3.2	3.6	3.9	4.2	3.7	4.3	5.3	7.1	7.0	7.4	6.4	7.3	8.3	8.5	9.7	7.8	7.7	8.1	8.4	8.5	8.1	8.7	10.0	11.7	11.5	10.8	7.9	14.2	13.8	18.4	21.7
1999	2.5	2.9	2.4	2.4	2.7	2.8	2.9	2.9	3.3	3.6	3.8	3.4	4.0	4.9	6.6	6.4	6.8	5.9	6.6	7.6	7.8	8.8	7.0	6.8	7.2	7.3	7.4	7.0	7.4	8.3	9.7	9.2	8.4	5.6	10.0	8.7	9.9	7.4	(5.2)
2000	2.6	3.0	2.5	2.5	2.8	2.9	3.0	3.0	3.4	3.7	3.9	3.5	4.1	5.0	6.5	6.4	6.7	5.9	6.6	7.6	7.7	8.6	7.0	6.8	7.1	7.2	7.3	6.9	7.3	8.1	9.4	8.9	8.1	5.7	9.3	8.2	9.0	7.0	0.3	6.1
2001	2.5	2.9	2.5	2.5	2.7	2.8	2.9	3.0	3.3	3.6	3.8	3.4	3.9	4.8	6.3	6.2	6.5	5.6	6.4	7.2	7.3	8.2	6.6	6.5	6.7	6.8	6.8	6.4	6.8	7.5	8.5	8.0	7.2	5.0	8.1	6.9	7.3	5.3	0.4	3.3	0.6
2002	2.6	3.0	2.6	2.6	2.8	2.9	3.0	3.1	3.4	3.7	3.9	3.5	4.0	4.9	6.3	6.2	6.5	5.7	6.4	7.2	7.3	8.2	6.6	6.5	6.7	6.8	6.8	6.5	6.7	7.4	8.4	7.9	7.2	5.2	7.9	6.9	7.2	5.6	1.9	4.4	3.6	6.7
2003	2.5	2.9	2.5	2.5	2.7	2.8	2.9	3.0	3.3	3.5	3.7	3.4	3.8	4.7	6.1	5.9	6.2	5.4	6.1	6.8	6.9	7.7	6.3	6.1	6.3	6.3	6.3	6.0	6.2	6.8	7.6	7.1	6.4	4.6	6.8	5.8	5.9	4.4	1.3	3.0	2.0	2.7	(1.2)
2004	2.5	2.9	2.5	2.5	2.8	2.8	2.9	3.0	3.3	3.5	3.7	3.4	3.8	4.6	6.0	5.9	6.1	5.3	6.0	6.7	6.8	7.5	6.1	5.9	6.1	6.2	6.2	5.8	6.0	6.6	7.3	6.8	6.1	4.5	6.5	5.6	5.6	4.3	1.7	3.1	2.4	3.0	1.2	3.6
2005	2.6	3.0	2.6	2.6	2.8	2.9	3.0	3.0	3.4	3.6	3.8	3.4	3.9	4.7	6.0	5.9	6.1	5.4	6.0	6.7	6.7	7.5	6.1	6.0	6.1	6.2	6.2	5.8	6.0	6.5	7.2	6.8	6.1	4.6	6.5	5.6	5.7	4.5	2.3	3.6	3.1	3.7	2.8	4.8	6.0
2006	2.5	2.8	2.4	2.4	2.7	2.7	2.8	2.9	3.1	3.4	3.6	3.2	3.7	4.4	5.6	5.5	5.7	5.0	5.6	6.3	6.3	7.0	5.7	5.5	5.6	5.7	5.6	5.3	5.4	5.9	6.5	6.0	5.4	3.9	5.5	4.7	4.6	3.5	1.4	2.4	1.8	2.1	0.9	1.7	0.7	(4.4)
2007	2.4	2.8	2.4	2.4	2.6	2.7	2.7	2.8	3.1	3.3	3.5	3.2	3.6	4.3	5.5	5.4	5.6	4.9	5.4	6.1	6.1	6.7	5.5	5.3	5.4	5.5	5.4	5.1	5.2	5.6	6.1	5.7	5.1	3.7	5.2	4.4	4.3	3.3	1.4	2.3	1.7	1.9	1.0	1.5	0.9	(1.7)	1.2
2008	2.6	3.0	2.6	2.6	2.8	2.9	2.9	3.0	3.3	3.5	3.7	3.4	3.8	4.5	5.7	5.6	5.8	5.1	5.6	6.3	6.3	6.9	5.7	5.5	5.7	5.7	5.7	5.4	5.5	5.9	6.5	6.0	5.5	4.2	5.6	4.9	4.9	4.0	2.4	3.3	2.9	3.3	2.7	3.5	3.5	2.6	6.4	11.8
2009	2.5	2.8	2.5	2.5	2.7	2.7	2.8	2.9	3.1	3.3	3.5	3.2	3.6	4.3	5.4	5.3	5.5	4.8	5.3	5.9	6.0	6.5	5.4	5.2	5.3	5.3	5.3	5.0	5.1	5.4	5.9	5.5	4.9	3.7	5.0	4.3	4.3	3.4	1.9	2.6	2.2	2.4	1.8	2.3	2.1	1.1	3.0	4.0	(3.3)
2010	2.5	2.9	2.5	2.5	2.7	2.8	2.8	2.9	3.2	3.4	3.6	3.2	3.6	4.3	5.4	5.3	5.5	4.8	5.3	5.9	5.9	6.5	5.3	5.2	5.3	5.3	5.2	4.9	5.1	5.4	5.8	5.4	4.9	3.8	5.0	4.3	4.3	3.5	2.1	2.8	2.4	2.6	2.2	2.6	2.5	1.8	3.4	4.1	0.5	4.4
2011	2.8	3.1	2.8	2.8	3.0	3.1	3.1	3.2	3.4	3.6	3.8	3.5	3.9	4.6	5.7	5.5	5.7	5.1	5.6	6.2	6.2	6.8	5.7	5.5	5.7	5.7	5.6	5.4	5.5	5.8	6.3	5.9	5.5	4.4	5.6	5.0	5.0	4.3	3.1	3.8	3.6	3.9	3.6	4.2	4.3	4.0	5.8	6.9	5.4	10.0	15.8
2012	2.8	3.1	2.7	2.7	3.0	3.0	3.1	3.1	3.4	3.6	3.8	3.5	3.9	4.5	5.5	5.4	5.6	5.0	5.5	6.0	6.1	6.6	5.5	5.4	5.5	5.5	5.5	5.2	5.3	5.6	6.1	5.7	5.3	4.3	5.4	4.8	4.8	4.1	3.0	3.6	3.4	3.7	3.4	3.9	4.0	3.7	5.1	5.9	4.4	7.1	8.5	1.6
2013	2.5	2.8	2.5	2.5	2.7	2.7	2.8	2.8	3.1	3.3	3.4	3.1	3.5	4.1	5.1	5.0	5.2	4.6	5.0	5.5	5.6	6.0	5.0	4.9	4.9	4.9	4.9	4.6	4.7	5.0	5.3	5.0	4.5	3.5	4.5	3.9	3.9	3.2	2.1	2.6	2.4	2.5	2.1	2.5	2.4	1.9	2.8	3.1	1.5	2.7	2.1	(4.2)	(9.6)
2014	2.7	3.0	2.7	2.7	2.9	3.0	3.1	3.1	3.4	3.5	3.7	3.4	3.8	4.4	5.4	5.3	5.5	4.9	5.3	5.8	5.9	6.3	5.4	5.2	5.3	5.3	5.3	5.0	5.1	5.4	5.8	5.4	5.0	4.1	5.1	4.6	4.5	3.9	2.9	3.5	3.3	3.5	3.3	3.7	3.7	3.4	4.4	4.9	3.8	5.3	5.5	2.3	2.6	16.4
2015	2.7	3.0	2.7	2.7	2.9	2.9	3.0	3.0	3.3	3.5	3.6	3.3	3.7	4.3	5.2	5.1	5.3	4.7	5.2	5.6	5.7	6.1	5.2	5.0	5.1	5.1	5.1	4.8	4.9	5.2	5.5	5.2	4.8	3.9	4.8	4.3	4.3	3.7	2.7	3.2	3.0	3.2	3.0	3.3	3.3	3.0	3.9	4.2	3.2	4.3	4.2	1.5	1.5	7.6	(0.6)
2016	2.8	3.1	2.8	2.8	3.0	3.0	3.1	3.2	3.4	3.6	3.7	3.5	3.8	4.4	5.3	5.2	5.4	4.8	5.2	5.7	5.7	6.2	5.3	5.1	5.2	5.2	5.2	4.9	5.0	5.3	5.6	5.3	4.9	4.1	5.0	4.5	4.5	3.9	3.0	3.5	3.4	3.6	3.4	3.7	3.7	3.5	4.3	4.7	3.8	4.9	5.0	2.9	3.3	8.0	3.9	8.7
2017	2.7	3.0	2.7	2.7	2.9	2.9	3.0	3.1	3.3	3.4	3.6	3.3	3.7	4.2	5.2	5.0	5.2	4.7	5.1	5.5	5.5	6.0	5.1	4.9	5.0	5.0	4.9	4.7	4.8	5.0	5.4	5.0	4.6	3.8	4.7	4.2	4.2	3.6	2.8	3.2	3.1	3.2	3.0	3.3	3.3	3.1	3.8	4.0	3.2	4.0	4.0	2.1	2.2	5.4	2.0	3.3	(1.9)

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the annual rate of return is calculated. Reading the top figure in each column diagonally down the table gives the real rate of return in each year since 1960. The table can be used to see the real rate of return over any period; thus a purchase made at the end of 1960 would have lost 11.9% (allowing for reinvestment of income) in one year but over the first three years (up to the end of 1963) would have given an average annual real return of 2.9%. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real Value of £100 Invested

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR

	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	88
1962	107	121
1963	109	124	102
1964	102	115	95	93
1965	101	115	95	93	100
1966	102	116	95	94	100	101
1967	102	116	95	94	100	101	100
1968	94	107	88	86	93	93	92	92
1969	90	102	84	83	89	89	88	88	96
1970	87	98	81	79	85	85	85	85	92	96
1971	101	115	94	93	99	100	99	99	107	112	117
1972	90	102	84	83	89	89	88	88	96	100	104	89
1973	74	84	69	68	73	73	73	73	79	83	86	74	82
1974	53	60	49	49	52	52	52	52	56	59	61	52	59	71
1975	58	66	54	53	57	57	57	57	62	64	67	57	64	78	110
1976	57	65	54	53	56	56	56	56	61	64	66	57	63	77	108	99
1977	74	84	69	68	73	73	73	72	79	82	86	73	82	100	140	128	129
1978	67	76	63	61	66	66	66	66	71	74	77	66	74	90	127	116	117	91
1979	59	68	56	55	59	59	58	58	63	66	69	59	66	80	112	103	104	80	89
1980	62	71	58	57	61	62	61	61	66	69	72	62	69	84	118	108	109	84	93	105
1981	57	64	53	52	56	56	56	56	60	63	66	56	63	76	107	98	99	77	85	95	91
1982	81	92	76	75	80	80	80	80	87	90	94	81	90	110	154	141	142	110	122	137	130	144
1983	90	102	84	82	88	88	88	88	95	99	104	89	99	121	169	155	156	121	134	151	143	158	110
1984	92	104	86	84	90	90	90	90	97	102	106	91	101	123	173	158	160	124	137	154	147	161	112	102
1985	96	109	90	88	95	95	94	94	102	107	111	95	107	129	182	166	168	130	143	162	154	169	118	107	105
1986	103	117	96	94	101	101	101	101	109	114	119	102	114	138	194	177	179	139	153	173	165	181	126	115	112	107
1987	115	131	108	106	113	114	113	113	123	128	133	114	128	155	218	199	201	156	172	194	185	203	142	129	126	120	112
1988	118	134	110	108	116	116	116	116	126	131	137	117	131	159	223	204	206	160	176	199	189	208	145	132	129	123	115	102
1989	116	132	109	107	114	114	114	114	123	129	134	115	129	156	220	200	203	157	173	195	186	205	143	130	127	121	113	101	98
1990	112	127	105	103	110	111	110	110	119	125	130	111	124	151	212	194	196	152	167	189	180	198	138	125	123	117	109	97	95	97
1991	128	145	119	117	126	126	125	125	136	142	148	126	142	172	241	220	223	173	191	215	204	225	157	142	139	133	124	111	108	110	114
1992	147	167	138	135	145	145	144	144	157	164	170	146	163	198	279	254	257	199	220	248	236	260	181	164	161	153	143	128	125	127	131	115
1993	186	211	174	171	183	184	183	182	198	207	215	184	206	251	352	321	325	252	278	313	298	328	229	208	203	194	181	162	158	160	166	146	126
1994	161	182	150	147	158	158	157	157	171	178	186	159	178	216	303	277	280	217	240	270	257	283	197	179	175	167	156	139	136	138	143	126	109	86
1995	185	210	173	170	182	182	181	181	197	205	214	183	205	249	350	319	323	250	276	311	296	326	227	206	202	193	180	160	157	159	165	145	126	99	115
1996	195	221	182	179	191	192	191	191	207	216	225	193	216	262	368	336	340	263	290	327	311	343	239	217	213	202	189	169	165	167	173	152	132	104	121	105
1997	224	255	210	206	221	221	220	220	238	249	259	222	248	302	424	387	391	303	335	377	359	395	275	250	245	233	218	194	190	193	200	176	152	120	140	121	115
1998	273	310	255	250	268	269	267	267	290	303	315	270	302	367	516	471	476	369	407	459	437	481	335	304	298	284	265	237	231	235	243	214	185	146	170	147	140	122
1999	259	294	242	237	254	255	254	253	275	287	299	256	287	348	489	446	451	350	386	435	414	456	317	288	282	269	251	224	219	223	230	202	175	139	161	140	133	115	95
2000	274	311	256	252	270	270	269	269	292	305	317	272	304	369	519	473	479	371	410	461	439	483	337	306	300	285	267	238	232	236	245	215	186	147	171	148	141	122	101	106
2001	276	314	258	253	272	272	271	270	293	306	319	273	306	371	522	476	482	373	412	464	442	487	339	308	302	287	269	239	234	238	246	216	187	148	172	149	142	123	101	107	101
2002	295	334	275	270	290	290	289	289	313	327	341	292	326	396	557	508	514	398	440	495	471	519	362	329	322	306	287	255	249	254	263	231	200	158	183	159	151	131	108	114	107	107
2003	291	330	272	267	286	287	285	285	309	323	336	288	322	391	550	502	508	393	434	489	466	513	357	325	318	303	283	252	246	251	259	228	197	156	181	157	150	130	107	113	106	105	99
2004	301	342	282	277	297	297	296	295	320	335	349	298	334	405	570	520	526	407	450	507	482	531	370	336	329	314	293	261	255	260	269	236	205	162	188	163	155	134	111	117	110	109	102	104
2005	320	363	299	293	315	315	313	313	340	355	370	316	354	430	604	552	558	432	477	537	512	563	392	357	349	333	311	277	271	275	285	250	217	172	199	173	164	143	117	124	117	116	109	110	106
2006	306	347	286	281	301	301	300	299	325	339	353	303	339	411	578	527	534	413	456	514	489	539	375	341	334	318	297	265	259	263	272	239	207	164	190	165	157	136	112	118	111	111	104	105	101	96
2007	309	351	289	284	304	305	303	303	329	343	357	306	343	416	584	534	540	418	462	520	495	545	380	345	338	322	301	268	262	266	276	242	210	166	193	167	159	138	113	120	113	112	105	106	103	97	101
2008	346	393	323	317	340	341	339	339	367	384	400	342	383	465	653	597	604	467	516	581	553	609	424	386	378	360	336	300	293	298	308	271	235	186	215	187	178	154	127	134	126	125	117	119	115	108	113	112
2009	335	380	313	307	329	330	328	328	355	371	387	331	371	450	632	577	584	452	499	562	535	589	411	373	365	348	325	290	283	288	298	262	227	180	208	181	172	149	123	129	122	121	114	115	111	105	109	108	97
2010	349	397	326	321	344	344	342	342	371	388	404	346	387	470	660	603	610	472	521	587	559	615	429	390	382	363	340	303	296	301	311	274	237	187	218	189	180	156	128	135	127	126	119	120	116	109	114	113	101	104
2011	405	459	378	371	398	399	397	396	430	449	468	400	448	544	764	698	706	547	604	680	647	713	496	451	442	421	393	351	342	348	360	317	274	217	252	219	208	180	148	156	147	146	137	139	134	127	132	131	117	121	116
2012	411	467	384	377	405	405	403	403	437	456	475	407	456	553	777	709	718	556	614	691	658	724	505	459	449	428	400	357	348	354	366	322	279	221	256	222	211	183	151	159	150	149	140	141	136	129	134	133	119	123	118	102
2013	372	422	347	341	366	366	364	364	395	412	430	368	412	500	702	641	649	502	555	625	595	655	456	415	406	387	361	322	315	320	331	291	252	199	231	201	191	166	136	144	135	135	126	128	123	116	122	120	107	111	106	92	90
2014	433	491	404	397	426	426	424	424	460	480	500	428	479	582	818	747	755	585	646	727	692	762	531	483	473	450	421	375	366	373	386	339	294	232	270	234	222	193	159	167	158	157	147	149	144	135	142	140	125	129	124	107	105	116
2015	430	488	402	395	423	424	421	421	457	477	497	425	476	578	812	742	750	581	642	723	688	758	528	480	470	447	418	373	364	370	383	337	292	231	268	232	221	192	158	166	157	156	146	148	143	134	141	139	124	129	123	106	105	116	99
2016	468	531	437	429	460	461	458	458	497	519	540	463	518	629	883	807	816	632	698	786	748	824	574	522	511	486	455	405	396	402	417	366	317	251	291	253	240	208	171	181	170	169	159	161	155	146	153	151	135	140	134	116	114	126	108	109
2017	459	521	429	421	452	452	450	449	488	509	530	454	508	617	867	792	801	620	685	771	734	808	563	512	501	477	446	398	388	395	409	359	311	246	286	248	236	205	168	177	167	166	156	158	152	144	150	148	133	137	131	113	112	123	106	107	98

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the change in real value is calculated. Reading the top figure in each column diagonally down the table gives the growth in each year since 1960. The table can be used to see the real growth over any period; thus an investment of £100 made at the end of 1960 would have fallen to £88 (allowing for reinvestment of income and the effect of inflation) in one year but after three years (up to the end of 1963) would have reached £109 in real terms. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real return on Treasury bills – Gross income re-invested

Average Annual Real Rate of Return

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	0.7
1962	1.3	1.8
1963	1.5	1.8	1.9
1964	1.0	1.1	0.8	(0.4)
1965	1.1	1.2	1.1	0.7	1.7
1966	1.3	1.5	1.4	1.2	2.0	2.4
1967	1.6	1.8	1.8	1.8	2.5	2.9	3.4
1968	1.6	1.7	1.7	1.7	2.2	2.4	2.4	1.4
1969	1.8	1.9	1.9	1.9	2.4	2.6	2.6	2.3	3.1
1970	1.6	1.6	1.6	1.6	1.9	2.0	1.9	1.4	1.3	(0.4)
1971	1.2	1.2	1.1	1.1	1.3	1.2	0.9	0.4	0.0	(1.5)	(2.6)
1972	0.9	0.9	0.8	0.7	0.8	0.7	0.4	(0.1)	(0.5)	(1.7)	(2.3)	(2.1)
1973	0.7	0.7	0.6	0.5	0.6	0.4	0.2	(0.4)	(0.7)	(1.6)	(2.0)	(1.7)	(1.4)
1974	0.3	0.2	0.1	(0.1)	(0.0)	(0.2)	(0.6)	(1.1)	(1.5)	(2.4)	(2.9)	(3.0)	(3.5)	(5.5)
1975	(0.6)	(0.7)	(0.8)	(1.1)	(1.1)	(1.4)	(1.8)	(2.4)	(3.0)	(4.0)	(4.7)	(5.2)	(6.2)	(8.5)	(11.3)
1976	(0.7)	(0.8)	(1.0)	(1.2)	(1.3)	(1.6)	(2.0)	(2.5)	(3.0)	(3.9)	(4.4)	(4.8)	(5.4)	(6.8)	(7.4)	(3.2)
1977	(0.8)	(0.9)	(1.1)	(1.3)	(1.4)	(1.6)	(2.0)	(2.5)	(2.9)	(3.7)	(4.1)	(4.4)	(4.8)	(5.7)	(5.7)	(2.8)	(2.4)
1978	(0.8)	(0.9)	(1.1)	(1.3)	(1.3)	(1.5)	(1.9)	(2.3)	(2.7)	(3.3)	(3.7)	(3.8)	(4.1)	(4.6)	(4.4)	(2.0)	(1.4)	(0.3)
1979	(0.9)	(1.0)	(1.2)	(1.4)	(1.4)	(1.7)	(2.0)	(2.4)	(2.7)	(3.3)	(3.6)	(3.7)	(4.0)	(4.4)	(4.2)	(2.3)	(2.0)	(1.8)	(3.2)
1980	(0.8)	(0.9)	(1.0)	(1.2)	(1.2)	(1.4)	(1.7)	(2.1)	(2.4)	(2.9)	(3.1)	(3.1)	(3.3)	(3.5)	(3.2)	(1.5)	(1.1)	(0.6)	(0.8)	1.8
1981	(0.7)	(0.8)	(0.9)	(1.0)	(1.1)	(1.3)	(1.5)	(1.8)	(2.1)	(2.5)	(2.7)	(2.7)	(2.8)	(2.9)	(2.5)	(1.0)	(0.5)	(0.1)	(0.0)	1.7	1.5
1982	(0.4)	(0.4)	(0.5)	(0.7)	(0.7)	(0.8)	(1.0)	(1.3)	(1.5)	(1.8)	(1.9)	(1.9)	(1.9)	(1.9)	(1.4)	0.1	0.6	1.2	1.6	3.3	4.0	6.6
1983	(0.2)	(0.2)	(0.3)	(0.4)	(0.4)	(0.5)	(0.7)	(0.9)	(1.1)	(1.4)	(1.5)	(1.4)	(1.3)	(1.3)	(0.8)	0.6	1.2	1.8	2.2	3.6	4.2	5.6	4.6
1984	0.0	0.0	(0.1)	(0.2)	(0.1)	(0.2)	(0.4)	(0.6)	(0.7)	(1.0)	(1.0)	(0.9)	(0.8)	(0.7)	(0.3)	1.1	1.6	2.2	2.6	3.8	4.4	5.3	4.7	4.8
1985	0.3	0.2	0.2	0.1	0.1	0.0	(0.1)	(0.3)	(0.4)	(0.6)	(0.6)	(0.4)	(0.3)	(0.2)	0.3	1.5	2.1	2.6	3.1	4.2	4.7	5.4	5.1	5.3	5.8
1986	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.1	0.0	(0.1)	(0.1)	0.0	0.2	0.3	0.8	2.0	2.6	3.1	3.6	4.6	5.0	5.7	5.5	5.9	6.4	7.0
1987	0.7	0.7	0.7	0.6	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.4	0.6	0.7	1.2	2.3	2.8	3.4	3.8	4.7	5.1	5.7	5.6	5.8	6.2	6.3	5.7
1988	0.8	0.8	0.8	0.7	0.8	0.7	0.7	0.5	0.5	0.4	0.4	0.6	0.8	0.9	1.4	2.4	2.9	3.4	3.8	4.6	5.0	5.5	5.3	5.4	5.6	5.5	4.8	4.0
1989	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.9	1.1	1.2	1.7	2.7	3.2	3.7	4.0	4.8	5.1	5.6	5.4	5.6	5.8	5.7	5.3	5.2	6.4
1990	1.2	1.2	1.2	1.1	1.2	1.2	1.1	1.0	1.0	0.9	1.0	1.2	1.4	1.5	2.0	2.9	3.4	3.8	4.2	4.9	5.2	5.6	5.5	5.6	5.8	5.8	5.5	5.4	6.2	6.0
1991	1.3	1.4	1.4	1.3	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.4	1.6	1.8	2.3	3.2	3.6	4.1	4.4	5.1	5.4	5.8	5.7	5.8	5.9	6.0	5.8	5.8	6.4	6.4	6.8
1992	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.5	1.5	1.4	1.5	1.7	1.9	2.1	2.5	3.4	3.8	4.2	4.6	5.2	5.5	5.8	5.8	5.9	6.0	6.1	5.9	6.0	6.5	6.5	6.8	6.7
1993	1.6	1.6	1.6	1.6	1.7	1.7	1.6	1.6	1.6	1.5	1.6	1.8	2.0	2.1	2.6	3.4	3.8	4.2	4.5	5.1	5.3	5.7	5.6	5.7	5.8	5.8	5.6	5.6	5.9	5.8	5.8	5.3	3.9
1994	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.6	1.6	1.5	1.6	1.8	2.0	2.2	2.6	3.3	3.7	4.1	4.4	4.9	5.1	5.4	5.3	5.4	5.5	5.4	5.2	5.2	5.4	5.2	5.0	4.3	3.2	2.4
1995	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.6	1.7	1.9	2.1	2.2	2.6	3.4	3.7	4.1	4.3	4.8	5.0	5.3	5.2	5.2	5.3	5.2	5.0	4.9	5.1	4.9	4.6	4.1	3.2	2.9	3.4
1996	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.7	1.7	1.7	1.8	2.0	2.1	2.3	2.6	3.4	3.7	4.0	4.3	4.7	4.9	5.2	5.1	5.1	5.1	5.1	4.9	4.8	4.9	4.7	4.5	4.0	3.3	3.2	3.5	3.6
1997	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.8	2.0	2.2	2.3	2.7	3.4	3.7	4.0	4.2	4.7	4.8	5.0	4.9	5.0	5.0	4.9	4.7	4.6	4.7	4.5	4.3	3.9	3.3	3.2	3.4	3.4	3.1
1998	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.1	2.3	2.4	2.8	3.4	3.7	4.0	4.3	4.7	4.8	5.0	4.9	5.0	5.0	4.9	4.7	4.7	4.7	4.5	4.4	4.0	3.6	3.5	3.8	3.9	4.1	5.0
1999	1.9	1.9	1.9	1.9	2.0	2.0	2.0	1.9	2.0	1.9	2.0	2.2	2.3	2.5	2.8	3.4	3.7	4.0	4.2	4.6	4.8	5.0	4.9	4.9	4.9	4.8	4.7	4.6	4.6	4.5	4.3	4.0	3.6	3.5	3.8	3.9	3.9	4.4	3.7
2000	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.4	2.5	2.8	3.4	3.7	4.0	4.2	4.6	4.7	4.9	4.8	4.8	4.8	4.7	4.6	4.5	4.5	4.3	4.2	3.9	3.5	3.5	3.7	3.7	3.8	4.0	3.4	3.2
2001	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.0	2.1	2.3	2.4	2.6	2.9	3.5	3.8	4.0	4.2	4.6	4.7	4.9	4.8	4.8	4.8	4.7	4.6	4.5	4.5	4.4	4.2	4.0	3.7	3.7	3.8	3.9	4.0	4.2	3.9	4.0	4.8
2002	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.0	2.0	2.0	2.1	2.2	2.4	2.5	2.8	3.4	3.7	3.9	4.1	4.4	4.5	4.7	4.6	4.6	4.6	4.5	4.4	4.3	4.3	4.1	4.0	3.7	3.4	3.4	3.5	3.5	3.5	3.6	3.2	3.0	2.9	1.1
2003	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.2	2.3	2.5	2.8	3.3	3.6	3.8	4.0	4.3	4.4	4.5	4.4	4.4	4.4	4.3	4.1	4.1	4.1	3.9	3.7	3.5	3.2	3.1	3.2	3.2	3.1	3.1	2.7	2.5	2.3	1.0	0.9
2004	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.3	2.4	2.7	3.2	3.5	3.7	3.8	4.1	4.2	4.4	4.3	4.2	4.2	4.1	4.0	3.9	3.9	3.7	3.5	3.3	3.0	2.9	3.0	2.9	2.9	2.8	2.5	2.2	2.0	1.0	1.0	1.1
2005	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.3	2.4	2.7	3.2	3.4	3.7	3.8	4.1	4.2	4.3	4.2	4.2	4.1	4.1	3.9	3.8	3.8	3.6	3.5	3.3	3.0	2.9	3.0	2.9	2.8	2.8	2.5	2.3	2.1	1.5	1.6	1.9	2.7
2006	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	1.9	2.0	2.1	2.3	2.4	2.6	3.1	3.3	3.5	3.7	3.9	4.0	4.1	4.0	4.0	4.0	3.9	3.7	3.6	3.6	3.5	3.3	3.1	2.8	2.7	2.8	2.7	2.6	2.5	2.2	2.0	1.8	1.3	1.3	1.4	1.6	0.4
2007	1.9	1.9	1.9	1.9	2.0	2.0	2.0	1.9	2.0	1.9	2.0	2.1	2.2	2.4	2.6	3.1	3.3	3.5	3.6	3.9	3.9	4.0	3.9	3.9	3.9	3.8	3.6	3.5	3.5	3.4	3.2	3.0	2.7	2.7	2.7	2.6	2.5	2.5	2.2	2.0	1.8	1.3	1.4	1.5	1.6	1.1	1.8
2008	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.2	2.3	2.4	2.7	3.1	3.3	3.5	3.6	3.9	4.0	4.0	3.9	3.9	3.9	3.8	3.7	3.6	3.5	3.4	3.3	3.1	2.8	2.8	2.8	2.7	2.7	2.6	2.4	2.2	2.1	1.7	1.9	2.0	2.3	2.1	3.0	4.2
2009	1.9	1.9	1.9	1.9	1.9	2.0	1.9	1.9	1.9	1.9	2.0	2.1	2.2	2.3	2.5	3.0	3.2	3.3	3.5	3.7	3.8	3.8	3.7	3.7	3.7	3.6	3.4	3.3	3.3	3.1	3.0	2.8	2.6	2.5	2.5	2.4	2.3	2.3	2.0	1.8	1.7	1.3	1.3	1.4	1.5	1.2	1.4	1.2	(1.7)
2010	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.7	1.8	1.9	2.0	2.1	2.3	2.8	2.9	3.1	3.2	3.4	3.5	3.6	3.4	3.4	3.4	3.3	3.1	3.0	2.9	2.8	2.6	2.4	2.2	2.1	2.1	2.0	1.9	1.8	1.5	1.3	1.1	0.7	0.6	0.6	0.5	0.1	0.0	(0.6)	(2.9)	(4.1)
2011	1.6	1.6	1.6	1.6	1.7	1.7	1.7	1.6	1.6	1.6	1.7	1.8	1.9	1.9	2.2	2.6	2.7	2.9	3.0	3.2	3.2	3.3	3.2	3.1	3.1	3.0	2.8	2.7	2.6	2.5	2.3	2.1	1.8	1.7	1.7	1.6	1.4	1.3	1.0	0.8	0.6	0.2	0.1	0.0	(0.1)	(0.6)	(0.8)	(1.5)	(3.3)	(4.1)	(4.1)
2012	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.6	1.7	1.8	2.0	2.4	2.6	2.7	2.8	3.0	3.0	3.1	3.0	2.9	2.9	2.7	2.6	2.5	2.4	2.2	2.1	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.8	0.6	0.3	(0.1)	(0.2)	(0.3)	(0.5)	(0.9)	(1.1)	(1.7)	(3.1)	(3.6)	(3.4)	(2.7)
2013	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.5	1.6	1.6	1.7	1.9	2.3	2.4	2.6	2.7	2.8	2.9	2.9	2.8	2.7	2.7	2.6	2.4	2.3	2.2	2.0	1.9	1.7	1.4	1.3	1.2	1.1	1.0	0.8	0.6	0.3	0.1	(0.2)	(0.4)	(0.5)	(0.7)	(1.1)	(1.3)	(1.8)	(3.0)	(3.3)	(3.0)	(2.5)	(2.3)
2014	1.4	1.4	1.4	1.4	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.6	1.6	1.8	2.2	2.3	2.5	2.6	2.7	2.8	2.8	2.7	2.6	2.5	2.4	2.3	2.1	2.1	1.9	1.7	1.5	1.3	1.2	1.1	1.0	0.9	0.7	0.5	0.2	0.0	(0.3)	(0.4)	(0.6)	(0.7)	(1.1)	(1.3)	(1.7)	(2.7)	(2.9)	(2.6)	(2.1)	(1.7)	(1.2)
2015	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.4	1.5	1.6	1.8	2.1	2.3	2.4	2.5	2.6	2.7	2.7	2.6	2.5	2.4	2.3	2.2	2.0	2.0	1.8	1.6	1.4	1.2	1.1	1.0	0.9	0.8	0.6	0.4	0.2	(0.0)	(0.3)	(0.5)	(0.6)	(0.7)	(1.1)	(1.2)	(1.6)	(2.4)	(2.5)	(2.2)	(1.7)	(1.4)	(1.0)	(0.7)
2016	1.3	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.2	1.3	1.4	1.4	1.5	1.7	2.0	2.2	2.3	2.3	2.5	2.5	2.5	2.4	2.4	2.3	2.2	2.0	1.9	1.8	1.7	1.5	1.3	1.1	1.0	0.9	0.8	0.6	0.5	0.2	0.0	(0.1)	(0.5)	(0.6)	(0.7)	(0.8)	(1.2)	(1.3)	(1.6)	(2.4)	(2.5)	(2.2)	(1.8)	(1.6)	(1.3)	(1.4)	(2.1)
2017	1.2	1.2	1.2	1.2	1.3	1.2	1.2	1.2	1.2	1.1	1.2	1.2	1.3	1.4	1.5	1.9	2.0	2.1	2.2	2.3	2.3	2.4	2.2	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.3	1.1	0.9	0.7	0.7	0.5	0.4	0.3	0.0	(0.2)	(0.4)	(0.7)	(0.8)	(0.9)	(1.1)	(1.4)	(1.5)	(1.9)	(2.5)	(2.6)	(2.4)	(2.1)	(2.0)	(2.0)	(2.2)	(3.0)	(3.9)

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the annual rate of return is calculated. Reading the top figure in each column diagonally down the table gives the real rate of return in each year since 1960. The table can be used to see the real rate of return over any period; thus a purchase made at the end of 1963 would have lost 0.4% (allowing for reinvestment of income) in one year but over the first three years (up to the end of 1966) would have given an average annual real return of 1.2%. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real Value of £100 Invested

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	101
1962	103	102
1963	104	104	102
1964	104	103	102	100
1965	106	105	103	101	102
1966	108	108	106	104	104	102
1967	112	111	109	107	108	106	103
1968	114	113	111	109	109	107	105	101
1969	117	116	114	112	113	111	108	105	103
1970	117	116	114	112	112	110	108	104	103	100
1971	114	113	111	109	109	107	105	101	100	97	97
1972	111	110	109	106	107	105	103	99	98	95	95	98
1973	110	109	107	105	105	104	101	98	97	94	94	97	99
1974	104	103	101	99	100	98	96	92	91	88	89	91	93	94
1975	92	91	90	88	88	87	85	82	81	78	79	81	83	84	89
1976	89	88	87	85	85	84	82	79	78	76	76	78	80	81	86	97
1977	87	86	85	83	83	82	80	77	76	74	74	76	78	79	84	94	98
1978	86	86	84	83	83	82	80	77	76	74	74	76	78	79	83	94	97	100
1979	84	83	82	80	80	79	77	75	74	71	72	74	75	76	81	91	94	96	97
1980	85	85	83	82	82	80	79	76	75	73	73	75	77	78	82	93	96	98	98	102
1981	86	86	84	83	83	82	80	77	76	74	74	76	78	79	83	94	97	100	100	103	102
1982	92	92	90	88	89	87	85	82	81	79	79	81	83	84	89	100	104	106	107	110	108	107
1983	96	96	94	92	93	91	89	86	85	82	83	85	87	88	93	105	108	111	111	115	113	111	105
1984	101	100	99	97	97	95	93	90	89	86	87	89	91	92	98	110	114	116	117	121	119	117	110	105
1985	107	106	104	102	103	101	99	95	94	91	92	94	96	98	103	116	120	123	124	128	126	124	116	111	106
1986	114	114	112	109	110	108	106	102	101	98	98	101	103	104	110	124	129	132	132	137	134	132	124	119	113	107
1987	121	120	118	116	116	114	112	108	106	103	104	106	109	110	117	132	136	139	140	144	142	140	131	125	120	113	106
1988	126	125	123	120	121	119	116	112	111	107	108	111	113	115	121	137	141	145	145	150	148	145	136	130	124	118	110	104
1989	134	133	130	128	128	126	123	119	118	114	115	118	120	122	129	145	150	154	155	160	157	155	145	139	132	125	117	111	106
1990	142	141	138	136	136	134	131	126	125	121	121	125	127	129	137	154	159	163	164	169	166	164	154	147	140	132	124	117	113	106
1991	151	150	148	145	145	143	140	135	133	129	130	133	136	138	146	165	170	174	175	181	178	175	164	157	150	141	132	125	120	113	107
1992	161	160	157	155	155	152	149	144	142	138	138	142	145	147	156	176	182	186	187	193	190	187	175	167	160	151	141	134	128	121	114	107
1993	168	166	164	161	161	158	155	150	148	143	144	148	151	153	162	183	189	193	194	200	197	194	182	174	166	157	147	139	133	125	118	111	104
1994	172	171	168	164	165	162	159	153	151	147	147	151	154	157	166	187	193	198	199	205	202	199	186	178	170	161	150	142	137	129	121	114	106	102
1995	178	176	173	170	171	168	164	159	156	152	152	156	160	162	171	193	200	205	205	212	209	205	193	184	176	166	155	147	141	133	125	117	110	106	103
1996	184	183	180	176	177	174	170	164	162	157	158	162	166	168	178	200	207	212	213	220	216	213	200	191	182	172	161	152	146	138	130	122	114	110	107	104
1997	190	188	185	182	182	179	175	170	167	162	163	167	171	173	183	207	214	219	220	227	223	220	206	197	188	178	166	157	151	142	134	126	118	113	111	107	103
1998	199	198	195	191	192	188	184	178	176	170	171	176	179	182	192	217	224	230	231	238	234	231	216	207	197	187	174	165	159	149	141	132	124	119	116	112	108	105
1999	207	205	202	198	199	195	191	185	182	177	177	182	186	189	200	225	233	238	239	247	243	239	224	214	205	193	181	171	165	155	146	137	128	123	120	116	112	109	104
2000	213	212	208	204	205	202	197	190	188	182	183	188	192	195	206	232	240	246	247	255	250	247	231	221	211	200	187	177	170	160	151	141	132	127	124	120	116	112	107	103
2001	224	222	218	214	215	211	206	200	197	191	192	197	201	204	216	243	251	258	258	267	262	258	242	232	221	209	195	185	178	167	158	148	138	133	130	126	121	118	112	108	105
2002	226	224	221	216	217	214	209	202	199	193	194	199	203	206	218	246	254	261	261	270	265	261	245	234	224	211	198	187	180	169	160	149	140	135	132	127	123	119	113	109	106	101
2003	228	227	223	218	219	216	211	204	201	195	196	201	205	208	220	248	257	263	264	273	268	264	247	237	226	213	200	189	182	171	161	151	141	136	133	128	124	120	114	110	107	102	101
2004	231	229	225	221	222	218	213	206	203	197	198	203	207	210	223	251	259	266	267	276	271	267	250	239	228	216	202	191	184	173	163	152	143	137	134	130	125	121	116	112	108	103	102	101
2005	237	235	231	227	228	224	219	212	209	202	203	209	213	216	229	258	267	273	274	283	278	274	257	246	235	222	207	196	189	177	167	157	147	141	138	133	129	125	119	115	111	106	105	104	103
2006	238	236	232	228	229	225	220	212	210	203	204	210	214	217	230	259	268	274	275	284	279	275	258	247	236	223	208	197	189	178	168	157	147	142	139	134	129	125	119	115	112	106	105	104	103	100
2007	242	240	236	232	233	229	223	216	213	207	208	213	218	221	234	264	272	279	280	289	284	280	263	251	240	226	212	200	193	181	171	160	150	144	141	136	132	128	121	117	113	108	107	106	105	102	102
2008	252	251	246	242	243	238	233	225	222	216	216	222	227	230	244	275	284	291	292	302	296	292	274	262	250	236	221	209	201	189	178	167	156	150	147	142	137	133	127	122	118	113	112	111	109	107	106	104
2009	248	246	242	238	238	234	229	222	218	212	213	218	223	226	240	270	279	286	287	297	291	287	269	257	246	232	217	205	197	186	175	164	154	148	144	140	135	131	124	120	116	111	110	109	108	105	104	102	98
2010	238	236	232	228	229	225	220	213	210	203	204	210	214	217	230	259	268	274	275	284	279	275	258	247	236	223	208	197	189	178	168	157	147	142	139	134	129	125	119	115	112	106	105	104	103	100	100	98	94	96
2011	228	227	223	218	219	216	211	204	201	195	196	201	205	208	220	248	257	263	264	273	268	264	248	237	226	213	200	189	182	171	161	151	141	136	133	128	124	120	114	110	107	102	101	100	99	96	96	94	90	92	96
2012	222	220	217	213	213	210	205	198	196	190	190	196	200	203	214	242	250	256	257	265	261	257	241	230	220	208	194	184	177	166	157	147	138	132	129	125	121	117	111	107	104	99	98	97	96	94	93	92	88	90	93	97
2013	217	215	212	208	209	205	200	194	191	185	186	191	195	198	210	236	244	250	251	259	255	251	235	225	215	203	190	180	173	162	153	143	134	129	126	122	118	114	109	105	102	97	96	95	94	92	91	90	86	87	91	95	98
2014	214	213	209	205	206	203	198	191	189	183	184	189	193	196	207	233	241	247	248	256	252	248	233	222	212	201	188	177	171	160	151	142	133	128	125	121	116	113	108	104	101	96	95	94	93	91	90	89	85	86	90	94	97	99
2015	213	211	208	204	205	201	196	190	187	182	182	187	191	194	205	232	239	245	246	254	250	246	231	221	211	199	186	176	169	159	150	141	132	127	124	120	116	112	107	103	100	95	94	93	92	90	89	88	84	86	89	93	96	98	99
2016	208	207	203	200	200	197	192	186	184	178	179	184	187	190	201	227	235	240	241	249	245	241	226	216	206	195	182	172	166	156	147	138	129	124	121	117	113	110	105	101	98	93	92	91	90	88	88	86	83	84	88	91	94	96	97	98
2017	200	199	195	192	193	189	185	179	176	171	172	176	180	183	193	218	225	231	232	239	235	232	217	208	198	187	175	166	159	150	142	132	124	119	117	113	109	106	100	97	94	90	89	88	87	85	84	83	79	81	84	88	90	92	93	94	96

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the change in real value is calculated. Reading the top figure in each column diagonally down the table gives the growth in each year since 1960. The table can be used to see the real growth over any period; thus an investment of £100 made at the end of 1978 would have fallen to £97 (allowing for reinvestment of income and the effect of inflation) in one year but after four years (up to the end of 1982) would have reached £107 in real terms. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real return on building society account – Gross income re-invested

Average Annual Real Rate of Return

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	1.4
1962	2.4	3.4
1963	2.9	3.6	3.9
1964	2.4	2.7	2.4	0.9
1965	2.3	2.5	2.2	1.4	1.9
1966	2.4	2.6	2.4	1.9	2.5	3.0
1967	2.7	3.0	2.9	2.6	3.2	3.8	4.7
1968	2.6	2.7	2.6	2.4	2.8	3.1	3.1	1.5
1969	2.7	2.8	2.8	2.6	2.9	3.2	3.2	2.5	3.5
1970	2.5	2.6	2.5	2.3	2.5	2.6	2.5	1.8	2.0	0.6
1971	2.2	2.2	2.1	1.9	2.0	2.1	1.9	1.2	1.1	(0.1)	(0.7)
1972	2.0	2.1	2.0	1.7	1.8	1.8	1.6	1.0	0.9	0.1	(0.1)	0.5
1973	1.8	1.8	1.7	1.5	1.6	1.5	1.3	0.7	0.6	(0.1)	(0.3)	(0.2)	(0.8)
1974	1.2	1.1	1.0	0.7	0.7	0.6	0.2	(0.4)	(0.7)	(1.5)	(2.0)	(2.4)	(3.8)	(6.8)
1975	0.3	0.2	(0.0)	(0.3)	(0.4)	(0.7)	(1.1)	(1.8)	(2.2)	(3.2)	(3.9)	(4.7)	(6.3)	(9.0)	(11.1)
1976	0.0	(0.1)	(0.3)	(0.6)	(0.7)	(1.0)	(1.4)	(2.0)	(2.4)	(3.3)	(3.9)	(4.5)	(5.7)	(7.3)	(7.6)	(3.8)
1977	(0.0)	(0.1)	(0.4)	(0.7)	(0.8)	(1.0)	(1.4)	(1.9)	(2.3)	(3.0)	(3.5)	(4.0)	(4.8)	(5.8)	(5.5)	(2.6)	(1.3)
1978	0.0	(0.1)	(0.3)	(0.6)	(0.7)	(0.9)	(1.2)	(1.7)	(2.0)	(2.6)	(3.0)	(3.3)	(3.9)	(4.5)	(3.9)	(1.4)	(0.2)	1.0
1979	(0.2)	(0.3)	(0.5)	(0.8)	(0.9)	(1.1)	(1.4)	(1.9)	(2.2)	(2.8)	(3.1)	(3.4)	(4.0)	(4.5)	(4.0)	(2.1)	(1.6)	(1.7)	(4.3)
1980	(0.2)	(0.3)	(0.5)	(0.8)	(0.9)	(1.0)	(1.3)	(1.8)	(2.0)	(2.5)	(2.8)	(3.1)	(3.5)	(3.9)	(3.4)	(1.7)	(1.2)	(1.2)	(2.2)	(0.1)
1981	(0.2)	(0.2)	(0.4)	(0.7)	(0.8)	(0.9)	(1.2)	(1.6)	(1.8)	(2.2)	(2.5)	(2.7)	(3.0)	(3.3)	(2.8)	(1.3)	(0.8)	(0.7)	(1.2)	0.3	0.8
1982	0.1	0.1	(0.1)	(0.3)	(0.4)	(0.5)	(0.7)	(1.1)	(1.3)	(1.6)	(1.8)	(1.9)	(2.1)	(2.3)	(1.7)	(0.3)	0.4	0.7	0.6	2.3	3.6	6.4
1983	0.3	0.2	0.1	(0.1)	(0.1)	(0.3)	(0.4)	(0.8)	(0.9)	(1.2)	(1.3)	(1.4)	(1.6)	(1.6)	(1.1)	0.3	0.9	1.3	1.3	2.8	3.8	5.3	4.1
1984	0.5	0.5	0.3	0.2	0.1	0.0	(0.1)	(0.4)	(0.5)	(0.8)	(0.9)	(0.9)	(1.0)	(1.0)	(0.4)	0.8	1.4	1.8	2.0	3.2	4.1	5.2	4.6	5.2
1985	0.7	0.6	0.5	0.4	0.3	0.3	0.1	(0.1)	(0.2)	(0.5)	(0.5)	(0.5)	(0.6)	(0.6)	0.0	1.2	1.8	2.2	2.4	3.5	4.3	5.1	4.7	5.0	4.8
1986	0.9	0.9	0.8	0.6	0.6	0.6	0.4	0.2	0.1	(0.1)	(0.1)	(0.0)	(0.1)	(0.0)	0.6	1.7	2.3	2.7	2.9	3.9	4.6	5.4	5.2	5.5	5.7	6.6
1987	1.1	1.0	1.0	0.8	0.8	0.8	0.7	0.5	0.4	0.3	0.2	0.3	0.3	0.4	0.9	2.0	2.6	3.0	3.2	4.2	4.8	5.5	5.3	5.6	5.7	6.2	5.7
1988	1.1	1.1	1.0	0.9	0.9	0.8	0.7	0.5	0.5	0.3	0.3	0.4	0.4	0.4	1.0	2.0	2.5	2.8	3.0	3.9	4.4	4.9	4.6	4.7	4.6	4.5	3.5	1.4
1989	1.1	1.1	1.0	0.9	0.9	0.9	0.8	0.6	0.6	0.4	0.4	0.5	0.5	0.6	1.1	2.0	2.5	2.8	3.0	3.7	4.2	4.6	4.4	4.4	4.3	4.1	3.3	2.1	2.8
1990	1.2	1.2	1.1	1.0	1.0	1.0	0.9	0.7	0.7	0.5	0.5	0.6	0.6	0.7	1.2	2.1	2.5	2.8	2.9	3.6	4.0	4.4	4.1	4.1	4.0	3.8	3.1	2.2	2.6	2.5
1991	1.3	1.3	1.2	1.1	1.1	1.1	1.0	0.9	0.8	0.7	0.7	0.8	0.8	0.9	1.4	2.2	2.6	2.9	3.1	3.7	4.1	4.4	4.2	4.2	4.1	3.9	3.4	2.8	3.3	3.6	4.6
1992	1.5	1.5	1.4	1.3	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.7	2.5	2.9	3.2	3.3	4.0	4.3	4.6	4.4	4.5	4.4	4.3	4.0	3.6	4.2	4.6	5.7	6.8
1993	1.5	1.5	1.4	1.3	1.4	1.3	1.3	1.1	1.1	1.0	1.0	1.1	1.2	1.3	1.7	2.5	2.9	3.1	3.3	3.8	4.1	4.4	4.2	4.2	4.1	4.1	3.7	3.4	3.8	4.0	4.5	4.5	2.2
1994	1.5	1.5	1.4	1.3	1.3	1.3	1.3	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.7	2.4	2.7	3.0	3.1	3.6	3.9	4.1	3.9	3.9	3.8	3.7	3.3	3.0	3.3	3.4	3.6	3.2	1.5	0.8
1995	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.6	2.3	2.6	2.9	3.0	3.4	3.7	3.9	3.7	3.7	3.5	3.4	3.0	2.7	2.9	2.9	3.0	2.6	1.2	0.7	0.7
1996	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.5	2.2	2.5	2.7	2.8	3.2	3.4	3.6	3.4	3.4	3.2	3.1	2.7	2.4	2.5	2.5	2.5	2.1	0.9	0.5	0.4	0.2
1997	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.0	1.0	0.9	0.9	1.0	1.0	1.1	1.5	2.1	2.4	2.5	2.6	3.0	3.2	3.4	3.2	3.1	2.9	2.8	2.4	2.1	2.2	2.1	2.1	1.7	0.6	0.3	0.1	(0.2)	(0.5)
1998	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.6	2.2	2.4	2.6	2.7	3.1	3.3	3.4	3.2	3.2	3.0	2.9	2.6	2.3	2.4	2.4	2.3	2.0	1.2	1.0	1.1	1.2	1.8	4.2
1999	1.5	1.5	1.4	1.3	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.2	1.2	1.3	1.6	2.2	2.5	2.6	2.7	3.1	3.3	3.4	3.2	3.2	3.0	2.9	2.6	2.4	2.5	2.4	2.4	2.2	1.5	1.4	1.5	1.8	2.3	3.7	3.3
2000	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.7	2.2	2.5	2.6	2.7	3.1	3.2	3.4	3.2	3.1	3.0	2.9	2.6	2.4	2.5	2.4	2.4	2.2	1.6	1.6	1.7	1.9	2.3	3.3	2.9	2.5
2001	1.6	1.6	1.5	1.4	1.5	1.4	1.4	1.3	1.3	1.2	1.3	1.3	1.4	1.4	1.8	2.3	2.5	2.7	2.8	3.1	3.3	3.4	3.2	3.2	3.1	3.0	2.7	2.5	2.6	2.6	2.6	2.4	1.9	1.9	2.0	2.2	2.7	3.5	3.3	3.2	4.0
2002	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.7	2.2	2.5	2.6	2.7	3.0	3.1	3.2	3.1	3.0	2.9	2.8	2.6	2.4	2.4	2.4	2.4	2.2	1.8	1.7	1.8	2.0	2.3	2.9	2.5	2.3	2.2	0.4
2003	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.7	2.2	2.4	2.5	2.6	2.9	3.0	3.1	3.0	2.9	2.8	2.7	2.5	2.2	2.3	2.3	2.3	2.1	1.6	1.6	1.7	1.8	2.0	2.5	2.1	1.8	1.6	0.5	0.5
2004	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.6	2.1	2.3	2.5	2.5	2.8	2.9	3.0	2.9	2.8	2.7	2.6	2.4	2.2	2.2	2.2	2.1	2.0	1.6	1.5	1.6	1.7	1.9	2.2	1.9	1.6	1.4	0.6	0.6	0.7
2005	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.6	2.1	2.3	2.4	2.5	2.8	2.9	3.0	2.8	2.8	2.6	2.5	2.3	2.1	2.2	2.1	2.1	1.9	1.6	1.5	1.6	1.7	1.8	2.2	1.9	1.6	1.5	0.8	1.0	1.2	1.7
2006	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.6	2.0	2.2	2.3	2.4	2.6	2.8	2.8	2.7	2.6	2.5	2.4	2.2	2.0	2.1	2.0	2.0	1.8	1.5	1.4	1.4	1.5	1.7	1.9	1.6	1.4	1.2	0.7	0.7	0.8	0.8	(0.1)
2007	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.2	1.2	1.2	1.3	1.6	2.0	2.2	2.3	2.3	2.6	2.7	2.8	2.6	2.5	2.4	2.3	2.1	1.9	2.0	1.9	1.9	1.7	1.4	1.3	1.4	1.4	1.6	1.8	1.5	1.3	1.1	0.7	0.7	0.8	0.8	0.3	0.7
2008	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.2	1.2	1.3	1.5	1.9	2.1	2.2	2.3	2.5	2.6	2.6	2.5	2.4	2.3	2.2	2.0	1.9	1.9	1.8	1.8	1.6	1.3	1.3	1.3	1.3	1.4	1.6	1.4	1.1	1.0	0.6	0.6	0.6	0.6	0.2	0.3	(0.1)
2009	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.1	1.1	1.2	1.4	1.8	2.0	2.1	2.1	2.3	2.4	2.5	2.3	2.3	2.1	2.0	1.8	1.7	1.7	1.6	1.6	1.4	1.1	1.0	1.1	1.1	1.2	1.3	1.0	0.8	0.6	0.2	0.2	0.1	0.0	(0.4)	(0.5)	(1.1)	(2.1)
2010	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	1.0	1.0	1.2	1.6	1.8	1.9	1.9	2.1	2.2	2.2	2.1	2.0	1.9	1.8	1.6	1.4	1.4	1.3	1.3	1.1	0.8	0.7	0.7	0.7	0.7	0.8	0.6	0.3	0.1	(0.3)	(0.4)	(0.5)	(0.7)	(1.2)	(1.5)	(2.2)	(3.2)	(4.4)
2011	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.9	1.1	1.4	1.6	1.7	1.7	1.9	2.0	2.0	1.9	1.8	1.6	1.5	1.3	1.1	1.1	1.1	1.0	0.8	0.5	0.4	0.4	0.4	0.4	0.5	0.2	(0.1)	(0.3)	(0.7)	(0.8)	(1.0)	(1.3)	(1.7)	(2.1)	(2.8)	(3.6)	(4.4)	(4.4)
2012	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.8	1.0	1.3	1.5	1.5	1.6	1.8	1.8	1.8	1.7	1.6	1.5	1.4	1.2	1.0	1.0	0.9	0.8	0.6	0.3	0.2	0.2	0.2	0.2	0.2	(0.0)	(0.3)	(0.5)	(0.9)	(1.0)	(1.2)	(1.5)	(1.9)	(2.2)	(2.8)	(3.4)	(3.9)	(3.6)	(2.8)
2013	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.9	1.2	1.4	1.4	1.5	1.6	1.7	1.7	1.6	1.5	1.3	1.2	1.0	0.9	0.8	0.8	0.7	0.5	0.2	0.1	0.1	0.0	0.0	0.1	(0.2)	(0.4)	(0.7)	(1.0)	(1.2)	(1.3)	(1.6)	(2.0)	(2.2)	(2.7)	(3.2)	(3.5)	(3.2)	(2.6)	(2.4)
2014	0.9	0.9	0.9	0.8	0.8	0.8	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.8	1.2	1.3	1.4	1.4	1.5	1.6	1.6	1.5	1.4	1.3	1.1	0.9	0.8	0.7	0.7	0.6	0.4	0.1	0.0	0.0	(0.0)	(0.0)	(0.0)	(0.3)	(0.5)	(0.7)	(1.1)	(1.2)	(1.3)	(1.5)	(1.9)	(2.1)	(2.5)	(2.9)	(3.1)	(2.7)	(2.2)	(1.9)	(1.3)
2015	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.6	0.6	0.5	0.5	0.6	0.6	0.6	0.8	1.1	1.2	1.3	1.3	1.5	1.5	1.5	1.4	1.3	1.2	1.1	0.9	0.7	0.7	0.6	0.5	0.4	0.1	(0.0)	(0.0)	(0.1)	(0.1)	(0.1)	(0.3)	(0.5)	(0.7)	(1.1)	(1.2)	(1.3)	(1.5)	(1.8)	(2.0)	(2.3)	(2.6)	(2.7)	(2.4)	(1.9)	(1.6)	(1.1)	(0.9)
2016	0.8	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.7	1.0	1.1	1.2	1.2	1.4	1.4	1.4	1.3	1.2	1.1	1.0	0.8	0.6	0.6	0.5	0.4	0.3	(0.0)	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)	(0.4)	(0.6)	(0.8)	(1.1)	(1.3)	(1.4)	(1.6)	(1.8)	(2.0)	(2.3)	(2.6)	(2.7)	(2.4)	(2.0)	(1.8)	(1.5)	(1.6)	(2.3)
2017	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.1	1.0	0.9	0.8	0.6	0.5	0.4	0.3	0.3	0.1	(0.2)	(0.3)	(0.3)	(0.4)	(0.4)	(0.4)	(0.6)	(0.8)	(1.0)	(1.3)	(1.4)	(1.6)	(1.7)	(2.0)	(2.2)	(2.5)	(2.7)	(2.8)	(2.6)	(2.3)	(2.2)	(2.1)	(2.4)	(3.1)	(3.9)

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the annual rate of return is calculated. Reading the top figure in each column diagonally down the table gives the real rate of return in each year since 1960. The table can be used to see the real rate of return over any period; thus a purchase made at the end of 1960 would have grown by 1.4% (allowing for reinvestment of income) in one year but over the first three years (up to the end of 1963) would have given an average annual real return of 2.9%. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real Value of £100 Invested

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1961	101
1962	105	103
1963	109	107	104
1964	110	108	105	101
1965	112	110	107	103	102
1966	115	114	110	106	105	103
1967	121	119	115	111	110	108	105
1968	123	121	117	113	112	109	106	101
1969	127	125	121	116	115	113	110	105	103
1970	127	126	122	117	116	114	111	106	104	101
1971	127	125	121	116	115	113	110	105	103	100	99
1972	127	125	121	117	116	114	110	105	104	100	100	100
1973	126	124	120	116	115	113	109	105	103	100	99	100	99
1974	118	116	112	108	107	105	102	97	96	93	92	93	92	93
1975	105	103	100	96	95	93	91	87	85	82	82	83	82	83	89
1976	101	99	96	92	92	90	87	83	82	79	79	79	79	80	85	96
1977	99	98	95	91	90	89	86	82	81	78	78	78	78	79	84	95	99
1978	100	99	96	92	91	89	87	83	82	79	79	79	79	79	85	96	100	101
1979	96	95	91	88	87	86	83	79	78	76	75	76	75	76	81	92	95	97	96
1980	96	94	91	88	87	86	83	79	78	76	75	76	75	76	81	92	95	97	96	100
1981	97	95	92	89	88	86	84	80	79	76	76	76	76	76	82	92	96	97	96	101	101
1982	103	101	98	94	94	92	89	85	84	81	81	81	81	81	87	98	102	104	103	107	107	106
1983	107	105	102	98	97	96	93	89	87	84	84	84	84	85	91	102	106	108	107	112	112	111	104
1984	112	111	107	103	102	100	98	93	92	89	88	89	88	89	96	108	112	113	112	117	117	117	109	105
1985	118	116	112	108	107	105	102	98	96	93	92	93	93	93	100	113	117	119	118	123	123	122	115	110	105
1986	126	124	120	115	114	112	109	104	103	99	99	99	99	100	107	120	125	127	126	131	131	130	122	118	112	107
1987	133	131	127	122	121	119	115	110	108	105	104	105	105	105	113	127	132	134	133	139	139	138	129	124	118	113	106
1988	135	133	129	124	123	120	117	112	110	106	106	106	106	107	115	129	134	136	135	141	141	140	131	126	120	114	107	101
1989	138	137	132	127	126	124	120	115	113	109	109	109	109	110	118	132	138	140	138	144	145	144	135	130	123	117	110	104	103
1990	142	140	135	130	129	127	123	118	116	112	111	112	112	112	121	136	141	143	142	148	148	147	138	133	126	120	113	107	105	102
1991	149	146	142	136	135	133	129	123	121	117	116	117	117	118	126	142	148	150	148	155	155	154	145	139	132	126	118	112	110	107	105
1992	159	156	151	146	144	142	138	131	129	125	124	125	125	126	135	152	158	160	158	166	166	164	154	148	141	135	126	119	118	115	112	107
1993	162	160	155	149	148	145	141	134	132	128	127	128	127	128	138	155	161	163	162	169	169	168	158	152	144	137	129	122	120	117	114	109	102
1994	163	161	156	150	149	146	142	135	133	129	128	129	128	129	139	156	163	165	163	170	171	169	159	153	145	139	130	123	121	118	115	110	103	101
1995	164	162	157	151	150	147	143	136	134	130	129	130	129	130	140	157	164	166	164	172	172	170	160	154	146	139	131	124	122	119	116	111	104	101	101
1996	165	162	157	151	150	147	143	136	134	130	129	130	130	131	140	158	164	166	165	172	172	171	160	154	146	140	131	124	122	119	116	111	104	102	101	100
1997	164	162	156	150	149	146	142	136	134	129	129	129	129	130	139	157	163	165	164	171	171	170	160	153	146	139	130	123	122	118	115	110	103	101	100	100	99
1998	171	168	163	157	155	152	148	141	139	135	134	135	134	135	145	163	170	172	170	178	178	177	166	160	152	145	136	128	127	123	120	115	108	105	104	104	104	104
1999	176	174	168	162	161	157	153	146	144	139	138	139	139	140	150	169	175	178	176	184	184	183	172	165	157	150	140	133	131	127	124	119	111	109	108	107	107	108	103
2000	181	178	172	166	165	161	157	150	148	143	142	143	142	143	154	173	180	182	180	189	189	187	176	169	161	153	144	136	134	130	127	122	114	111	111	110	110	110	106	102
2001	188	185	179	173	171	168	163	156	153	148	147	148	148	149	160	180	187	189	188	196	196	195	183	176	167	159	150	141	139	136	132	127	118	116	115	114	114	115	110	107	104
2002	189	186	180	173	172	169	164	156	154	149	148	149	148	150	160	181	188	190	188	197	197	196	184	176	168	160	150	142	140	136	133	127	119	116	116	115	115	115	111	107	104	100
2003	190	187	181	174	173	169	164	157	155	150	149	150	149	150	161	181	189	191	189	198	198	197	185	177	169	161	151	143	141	137	134	128	120	117	116	115	115	116	111	108	105	101	101
2004	191	188	182	175	174	171	166	158	156	151	150	151	150	151	162	183	190	193	191	199	200	198	186	179	170	162	152	144	142	138	135	129	120	118	117	116	116	117	112	108	106	102	101	101
2005	194	192	185	178	177	174	168	161	159	153	152	154	153	154	165	186	193	196	194	203	203	201	189	182	173	165	155	146	144	140	137	131	122	120	119	118	118	119	114	110	108	103	103	102	102
2006	194	191	185	178	177	173	168	161	158	153	152	153	153	154	165	186	193	196	194	203	203	201	189	182	173	165	154	146	144	140	137	131	122	120	119	118	118	119	114	110	107	103	103	102	102	100
2007	195	193	187	180	178	175	170	162	160	154	153	154	154	155	166	187	194	197	195	204	204	203	190	183	174	166	156	147	145	141	138	132	123	121	120	119	119	119	115	111	108	104	104	103	102	101	101
2008	195	193	186	179	178	174	169	162	159	154	153	154	154	155	166	187	194	197	195	204	204	202	190	183	174	166	155	147	145	141	138	132	123	120	120	119	119	119	114	111	108	104	103	103	102	101	101	100
2009	191	189	182	176	174	171	166	158	156	151	150	151	150	152	163	183	190	193	191	200	200	198	186	179	170	162	152	144	142	138	135	129	121	118	117	116	116	117	112	108	106	102	101	101	100	98	98	98	98
2010	183	180	174	168	166	163	159	151	149	144	143	144	144	145	155	175	182	184	183	191	191	189	178	171	163	155	146	138	136	132	129	123	115	113	112	111	111	112	107	104	101	97	97	96	96	94	94	94	94	96
2011	175	172	167	161	159	156	152	145	143	138	137	138	137	139	149	167	174	176	175	182	183	181	170	163	155	148	139	132	130	126	123	118	110	108	107	106	106	107	102	99	97	93	93	92	92	90	90	89	90	91	96
2012	170	168	162	156	155	152	147	141	139	134	133	134	134	135	144	163	169	171	170	177	177	176	165	159	151	144	135	128	126	123	120	114	107	105	104	103	103	104	100	96	94	90	90	90	89	87	88	87	87	89	93	97
2013	166	164	158	152	151	148	144	137	135	131	130	131	130	131	141	159	165	167	166	173	173	172	161	155	147	141	132	125	123	120	117	112	105	102	102	101	101	101	97	94	92	88	88	87	87	85	85	85	85	87	91	95	98
2014	164	161	156	150	149	146	142	136	134	129	128	129	129	130	139	156	163	165	163	171	171	170	159	153	145	139	130	123	121	118	115	110	103	101	100	99	99	100	96	93	91	87	87	86	86	84	84	84	84	86	89	94	96	99
2015	162	160	155	149	148	145	141	134	132	128	127	128	127	128	138	155	161	163	162	169	169	168	158	152	144	137	129	122	120	117	114	109	102	100	99	99	98	99	95	92	90	86	86	85	85	83	83	83	83	85	89	93	95	98	99
2016	158	156	151	145	144	141	137	131	129	125	124	125	124	125	135	151	157	160	158	165	165	164	154	148	141	134	126	119	117	114	112	107	100	98	97	96	96	97	93	90	88	84	84	83	83	81	82	81	81	83	87	91	93	95	97	98
2017	152	150	145	140	139	136	132	126	124	120	119	120	120	121	129	146	151	153	152	159	159	158	148	142	135	129	121	114	113	110	107	102	96	94	93	93	92	93	89	86	84	81	81	80	80	78	78	78	78	80	83	87	90	92	93	94	96

The dates along the top (and bottom) are those on which each portfolio starts. Those down the side are the dates to which the change in real value is calculated. Reading the top figure in each column diagonally down the table gives the growth in each year since 1960. The table can be used to see the real growth over any period; thus an investment of £100 made at the end of 1960 would have grown to £101 (allowing for reinvestment of income and the effect of inflation) in one year but after three years (up to the end of 1963) would have reached £109 in real terms. Each figure on the bottom line of the table shows the real growth up to December 2017 from the year shown below the figure.

Real return on index-linked gilts

Average Annual Real Rate of Return

GROSS INCOME RE-INVESTED

INVESTMENT TO END YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1983	(4.3)																																		
1984	(1.2)	1.9																																	
1985	(2.7)	(1.9)	(5.5)																																
1986	(1.5)	(0.5)	(1.7)	2.3																															
1987	(0.6)	0.4	(0.1)	2.7	3.1																														
1988	0.6	1.6	1.5	3.9	4.8	6.5																													
1989	1.4	2.3	2.4	4.5	5.3	6.4	6.3																												
1990	0.6	1.3	1.2	2.7	2.7	2.6	0.8	(4.5)																											
1991	0.6	1.3	1.2	2.3	2.3	2.2	0.7	(1.9)	0.7																										
1992	1.9	2.6	2.7	3.9	4.2	4.4	3.9	3.2	7.2	14.1																									
1993	3.3	4.1	4.4	5.7	6.2	6.7	6.8	6.9	11.0	16.5	18.9																								
1994	2.1	2.7	2.8	3.8	3.9	4.1	3.7	3.1	5.2	6.7	3.1	(10.5)																							
1995	2.6	3.2	3.3	4.2	4.4	4.6	4.3	4.0	5.8	7.1	4.9	(1.5)	8.5																						
1996	2.7	3.2	3.3	4.2	4.4	4.5	4.3	4.0	5.5	6.5	4.6	0.3	6.2	4.0																					
1997	3.1	3.7	3.8	4.6	4.8	5.0	4.8	4.7	6.0	7.0	5.6	2.5	7.3	6.7	9.4																				
1998	3.9	4.5	4.7	5.5	5.8	6.1	6.0	6.0	7.4	8.3	7.4	5.3	9.6	10.0	13.2	17.1																			
1999	3.9	4.4	4.6	5.4	5.6	5.8	5.7	5.7	6.9	7.7	6.8	4.9	8.3	8.3	9.7	9.9	3.2																		
2000	3.7	4.2	4.3	5.0	5.2	5.4	5.3	5.2	6.2	6.8	5.9	4.2	6.9	6.6	7.2	6.5	1.6	0.1																	
2001	3.4	3.8	4.0	4.6	4.7	4.8	4.7	4.6	5.5	5.9	5.1	3.5	5.6	5.2	5.4	4.4	0.5	(0.7)	(1.6)																
2002	3.5	3.9	4.0	4.6	4.7	4.9	4.7	4.6	5.4	5.9	5.1	3.6	5.6	5.2	5.4	4.6	1.7	1.2	1.7	5.1															
2003	3.5	3.9	4.0	4.6	4.7	4.8	4.7	4.6	5.3	5.7	5.0	3.7	5.4	5.0	5.1	4.4	2.1	1.8	2.4	4.5	3.9														
2004	3.6	4.0	4.1	4.6	4.7	4.8	4.7	4.6	5.3	5.6	5.0	3.8	5.3	5.0	5.1	4.5	2.6	2.4	3.0	4.6	4.4	4.9													
2005	3.7	4.1	4.2	4.7	4.8	4.9	4.8	4.7	5.4	5.7	5.1	4.0	5.5	5.2	5.3	4.8	3.2	3.2	3.8	5.2	5.2	5.8	6.7												
2006	3.5	3.8	3.9	4.4	4.5	4.5	4.4	4.3	4.9	5.2	4.6	3.5	4.8	4.5	4.5	4.0	2.5	2.4	2.8	3.7	3.3	3.1	2.2	(2.1)											
2007	3.4	3.7	3.8	4.2	4.3	4.4	4.3	4.2	4.7	4.9	4.4	3.4	4.5	4.2	4.3	3.7	2.4	2.3	2.6	3.3	2.9	2.7	2.0	(0.3)	1.4										
2008	3.2	3.5	3.5	3.9	4.0	4.1	3.9	3.8	4.3	4.5	3.9	3.0	4.1	3.7	3.7	3.2	1.9	1.8	2.0	2.5	2.1	1.7	0.9	(0.9)	(0.4)	(2.1)									
2009	3.2	3.4	3.5	3.9	4.0	4.0	3.9	3.8	4.2	4.4	3.9	3.0	4.0	3.7	3.7	3.2	2.0	1.9	2.1	2.6	2.2	2.0	1.4	0.1	0.8	0.5	3.1								
2010	3.2	3.5	3.6	4.0	4.0	4.1	4.0	3.9	4.3	4.5	4.0	3.2	4.1	3.8	3.8	3.4	2.3	2.2	2.4	2.9	2.6	2.4	2.0	1.1	1.9	2.1	4.2	5.3							
2011	3.6	3.9	4.0	4.3	4.4	4.5	4.4	4.3	4.8	5.0	4.5	3.8	4.7	4.4	4.5	4.1	3.2	3.2	3.5	4.0	3.9	3.9	3.7	3.2	4.3	5.0	7.5	9.8	14.4						
2012	3.5	3.8	3.8	4.2	4.3	4.3	4.2	4.1	4.5	4.7	4.3	3.6	4.4	4.2	4.2	3.8	3.0	2.9	3.2	3.6	3.5	3.4	3.3	2.8	3.6	4.0	5.6	6.5	7.1	0.2					
2013	3.2	3.5	3.5	3.9	3.9	4.0	3.9	3.8	4.2	4.3	3.9	3.2	4.0	3.7	3.7	3.3	2.5	2.4	2.6	3.0	2.8	2.7	2.4	1.9	2.5	2.7	3.7	3.8	3.3	(1.8)	(3.9)				
2014	3.6	3.8	3.9	4.2	4.3	4.3	4.3	4.2	4.6	4.7	4.3	3.7	4.4	4.2	4.2	3.9	3.2	3.2	3.4	3.8	3.7	3.7	3.5	3.2	3.9	4.2	5.3	5.8	5.9	3.2	4.7	14.0			
2015	3.3	3.6	3.6	4.0	4.0	4.1	4.0	3.9	4.2	4.4	4.0	3.3	4.1	3.8	3.8	3.5	2.8	2.8	2.9	3.3	3.1	3.1	2.9	2.5	3.0	3.2	4.0	4.2	4.0	1.5	1.9	5.0	(3.4)		
2016	3.7	4.0	4.0	4.3	4.4	4.5	4.4	4.3	4.7	4.8	4.5	3.9	4.6	4.4	4.4	4.2	3.5	3.5	3.7	4.1	4.0	4.0	4.0	3.7	4.3	4.6	5.5	5.9	6.0	4.4	5.4	8.7	6.1	16.6	
2017	3.5	3.8	3.8	4.2	4.2	4.2	4.2	4.1	4.4	4.6	4.2	3.6	4.3	4.1	4.1	3.9	3.2	3.2	3.4	3.7	3.6	3.6	3.5	3.3	3.8	4.0	4.7	4.9	4.8	3.3	3.9	6.0	3.4	7.0	(1.7)

Real Value of £100 Invested

GROSS INCOME RE-INVESTED

INVESTMENT TO END YEAR	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1983	96
1984	98	102
1985	92	96	94
1986	94	98	97	102
1987	97	102	100	105	103
1988	103	108	106	112	110	106
1989	110	115	113	119	117	113	106
1990	105	110	108	114	111	108	102	95
1991	106	111	108	115	112	109	102	96	101
1992	121	126	124	131	128	124	117	110	115	114
1993	144	150	147	156	152	148	139	130	137	136	119
1994	128	134	132	139	136	132	124	117	122	121	106	89
1995	139	146	143	151	148	143	135	127	133	132	115	97	108
1996	145	151	148	157	154	149	140	132	138	137	120	101	113	104
1997	158	166	162	172	168	163	153	144	151	150	131	110	123	114	109
1998	186	194	190	201	197	191	179	169	177	175	154	129	144	133	128	117
1999	191	200	196	208	203	197	185	174	182	181	158	133	149	137	132	121	103
2000	192	200	196	208	203	197	185	174	182	181	159	133	149	138	132	121	103	100
2001	189	197	193	205	200	194	182	171	179	178	156	131	147	135	130	119	102	99	98
2002	198	207	203	215	210	204	191	180	189	187	164	138	154	142	137	125	107	104	103	105
2003	206	215	211	223	218	212	199	187	196	194	170	143	160	148	142	130	111	108	107	109	104
2004	216	226	221	234	229	222	209	196	206	204	179	150	168	155	149	136	116	113	113	115	109	105
2005	231	241	236	250	244	237	223	210	219	218	191	161	179	165	159	145	124	120	120	122	116	112	107
2006	226	236	231	245	239	232	218	205	215	213	187	157	176	162	156	142	122	118	118	120	114	110	105	98
2007	229	239	235	248	243	236	221	208	218	216	190	160	178	164	158	144	123	120	119	121	116	111	106	99	101
2008	224	234	230	243	238	231	217	204	213	212	186	156	175	161	155	141	121	117	117	119	113	109	104	97	99	98
2009	231	241	237	251	245	238	223	210	220	218	191	161	180	166	160	146	125	121	121	123	117	112	107	100	102	101	103
2010	243	254	249	264	258	250	235	221	232	230	202	170	190	175	168	154	131	127	127	129	123	118	113	106	108	106	109	105
2011	278	291	285	302	295	287	269	253	265	263	231	194	217	200	192	176	150	146	145	148	141	135	129	121	123	122	124	121	114
2012	279	292	286	303	296	287	270	254	266	264	231	194	217	200	193	176	150	146	146	148	141	136	129	121	124	122	124	121	115	100
2013	268	280	275	291	285	276	259	244	255	254	222	187	209	193	185	169	145	140	140	142	135	130	124	116	119	117	120	116	110	96	96
2014	306	320	314	332	324	315	296	278	291	289	253	213	238	220	211	193	165	160	160	162	154	149	142	133	136	134	136	132	126	110	110	114
2015	296	309	303	321	314	304	286	269	281	279	245	206	230	212	204	187	159	155	154	157	149	144	137	128	131	129	132	128	121	106	106	110	97
2016	345	360	353	374	365	355	333	313	328	326	285	240	268	247	238	217	186	180	180	183	174	167	160	149	153	151	154	149	142	124	123	128	113	117
2017	339	354	347	368	359	349	327	308	322	320	280	236	264	243	234	214	183	177	177	180	171	165	157	147	150	148	151	147	139	122	121	126	111	115	98

UK real return on equities - gross income re-invested

(annual average rates of return between year ends)

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR

| | 1899 | 1900 | 1901 | 1902 | 1903 | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | INVESTMENT TO END YEAR |
|---|---|---

UK real capital value of equities

(annual average rates of return between year-ends)

HOW TO USE TABLES OF RETURNS

The dates along the top (and bottom) are those on which each portfolio starts; those down the side are the dates to which the annual rate of return is calculated. Thus the figure at the bottom right hand corner - 105 - shows that the real capital value of a portfolio bought at the end of December 2016 and held for one year to December 2017 was £105.

Each figure on the bottom line of the table shows the real capital value of £100 up to the end of December 2017 from the year shown below the figure. The first figure is 204, showing that the accumulated capital value of £100 for the whole period since 1899 is £204.

The top figure in each column is the capital value in the first year, so that reading diagonally down the table gives the capital value in each year since 1899. The table can be used to see the cumulative capital growth over any period; thus a £100 investment made at the end of 1900 would have fallen to £92 in one year but, over the first five years (up to the end of 1905), would have climbed back up to £94, £6 below the original investment

UK real return on gilts - gross income re-invested

(annual average rates of return between year ends)

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR

| | 1899 | 1900 | 1901 | 1902 | 1903 | 1904 | 1905 | 1906 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---

US real return on equities - gross income re-invested

(annual average rates of return between year ends)

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR

| | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---

US real return on bonds - gross income re-invested

(annual average rates of return between year ends)

INVESTMENT FROM END YEAR

INVESTMENT TO END YEAR

| | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
|---|---|---

Analyst Certification
We, Jeffrey Meli, Ajay Rajadhyaksha, Aroop Chatterjee, Christian Keller, Tomasz Wieladek, Iaroslav Shelepko, Blayne Curtis, Andrew M. Gardiner, CFA, Raimo Lenschow, CFA, Sreekala Kochugovindan, Joseph Abate, Marvin Barth and Zoso Davies, hereby certify (1) that the views expressed in this research report accurately reflect our personal views about any or all of the subject securities or issuers referred to in this research report and (2) no part of our compensation was, is or will be directly or indirectly related to the specific recommendations or views expressed in this research report.

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