RBC Global Asset Management

Economic Compass

ISSUE 37 • JANUARY 2016

GLOBAL PERSPECTIVE FOR INVESTORS

THE FUTURE OF PRODUCTIVITY AND INNOVATION

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The world is embroiled in a crucial debate about the future of productivity. Simply put, is it set to falter, hold steady or instead accelerate (Exhibit 1)? The importance of this question could not be greater since, over the long run, rising productivity and the innovation that drives it are the keys to economic prosperity. Raising the stakes, the economic outlook is already clouded by demographic challenges. The performance of productivity and innovation will thus largely determine whether economic growth is decent or dismal.

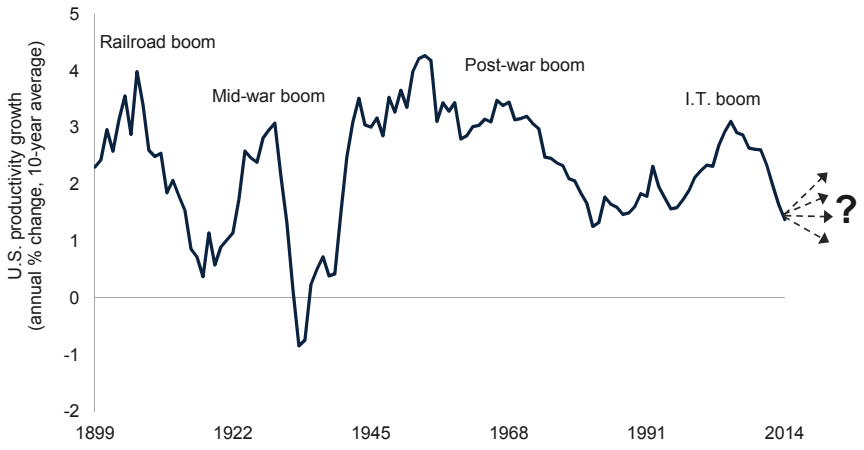
HIGHLIGHTS

- Global productivity growth has slowed since the financial crisis, worrying many.
- Much of this productivity deceleration represents an inevitable slippage after a period of unusually rapid gains. But some also reflects temporary cyclical depressants that have taken hold since the crisis.
- Looking forward, productivity growth should manage a gradual revival as the rate of innovation accelerates across a range of sectors.
- However, unusually fast productivity growth is unlikely given slightly less help from capital investment, labour quality and technological diffusion.
- As part of this exploration, we evaluate new technologies and their potential effects by sector.
- We also consider whether productivity growth is being mismeasured, whether the world is shifting toward a "capital light" economy, and whether there might be significantly more structural unemployment in an increasingly automated world.

There are strong arguments on both sides of the productivity debate. Pessimists dwell on a series of fading one-time productivity dividends that came from urbanization, universal education and the widespread entry of women into the workforce. Similarly, as emerging economies become wealthier and approach the technological frontier, they may find less scope to grow through the absorption of technologies from the developed world.

However, there are no less compelling claims from the optimists. Basic science continues to advance at a heady clip, a raft of new technologies is dramatically disrupting an expanding set of industries, and emerging-market economies should become increasingly capable of driving innovation themselves rather than simply importing it.

Exhibit 1: U.S. productivity waves



Note: Data prior to 1948 is consumption per capita growth; 1948 and later is standard output per hour.
Source: Haver Analytics, R. Shiller, RBC GAM

In weighing the various perspectives (Exhibit 2), we ultimately conclude that the current productivity slowdown is mostly temporary, with additional innovation set to fully compensate for fading tailwinds, weaker technological diffusion and a less forceful contribution from capital deepening and labour quality.

As part of this exploration, we evaluate new technologies and their potential effects by sector. We also consider whether productivity growth is being mismeasured, whether the world is shifting toward a "capital light" economy, and whether there might be significantly higher structural unemployment in an increasingly automated world.

Where productivity growth comes from

The only way to wring ever more out of a fixed amount of human effort is by becoming more productive. Productivity growth is the key to a rising standard of living, robust economic growth and – ultimately – financial-market returns.

Fortunately, there are quite a number of ways to improve productivity (Exhibit 3).

The simplest, most immediate and most predictable means of increasing productivity is to increase a country's or company's capital intensity. That means providing more capital such as machinery, equipment and structures to boost worker output. Over the past 20-plus years, increased capital intensity has generated a whopping 60% of developed-world productivity growth (Exhibit 4).

Another reliable strategy – if less powerful and slower to pay dividends – is to increase the quality of the labour force via education and training. Rising labour quality has historically generated 12% of productivity gains.

Lastly and of crucial importance to productivity growth is the delivery of rising total-factor productivity (TFP). This amounts to finding innovative ways to more efficiently deploy a preset amount of capital and labour. This has officially generated 28% of productivity gains in the modern era, but its true importance is even higher: productivity growth would eventually grind to a complete halt in the absence of new technologies and ideas. Examples of TFP gains help to illustrate its fundamental importance:

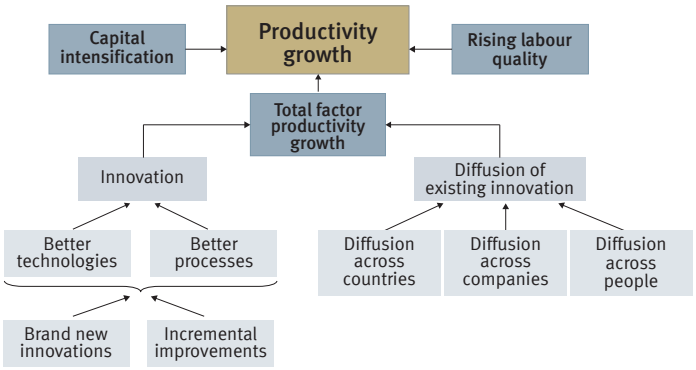
- At its most exciting, TFP can rise due to brand new technologies that propel the economy forward. This is innovation in its purest form, and encompasses the development of inventions both large (electricity, the computer) and small (the paperclip).

Exhibit 2: Productivity pros and cons

Productivity accelerants	Productivity decelerants
Innovation	Fading 20th century tailwinds
	Capital investment
	Labour quality
Eventual end of post-crisis malaise	Tech diffusion
Net effect: normal productivity growth	

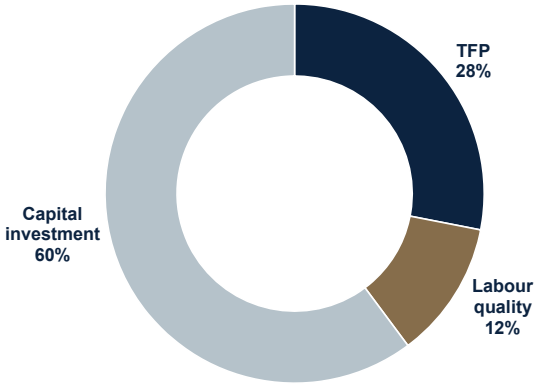
Source: RBC GAM

Exhibit 3: Where does productivity come from?



Source: RBC GAM

Exhibit 4: Historical drivers of developed-world productivity growth



Note: Productivity contribution share for thirteen major developed countries. 3-year moving average between 1992 and 2007. TFP is total-factor productivity. Source: The Conference Board Total Economy Database, Haver Analytics, RBC GAM

- Slightly less exciting but far more common is innovation in the form of incremental technological improvements – the latest computer model, for instance.
- Innovation does not merely occur via the invention of physical things. A better process can be just as important. These improvements can be large (a rejigged supply chain), middling (an improved sequence of tasks on a factory floor) or small (eliminating a bit of wasted fabric).
- Possibly the least acknowledged and yet most important driver of global TFP growth is the diffusion of pre-existing technologies into new parts of the world and more widely across companies. Only a handful of the world's richest nations operate at the technological frontier, meaning that they are reliably developing new technologies. For the rest, their technology improves mainly by absorbing and implementing ideas that have already been invented elsewhere.

Of course, these three types of productivity growth are all fundamentally intertwined. Educated humans invent new technologies, which in turn enable an ever-evolving capital stock.

Recent slowdown

Given the importance of productivity growth, it is distressing that the rate of ascent has tumbled quite abruptly in recent years in both developed and emerging economies. The decline in developed-world productivity growth since the turn of the millennium has been particularly broadly based, with less assistance coming from all three drivers (Exhibit 5).

We take some solace in our assessment that GDP and thus productivity growth may be somewhat underestimated (Appendix A), and also that human well-being may be rising more quickly than even the recalibrated economic figures suggest (Appendix B).

Nevertheless, even factoring in these adjustments, it seems likely that true productivity growth has declined. The next logical question is whether this productivity deceleration is temporary or structural, as that will determine whether households and investors are merely being inconvenienced or permanently damaged.

Temporary influences

There are a number of temporary distortions to productivity growth due to past cyclical tailwinds that have faded, and some newer headwinds that have temporarily strengthened.

Prior temporary tailwinds

Prominently, it is worth acknowledging that productivity growth from the mid-1990s to the mid-2000s was unusually good (Exhibit 6). Thus, a substantial chunk of the subsequent decline in productivity growth is simply a reversion to a more normal trend rate after an unusually strong prior cycle.[1]

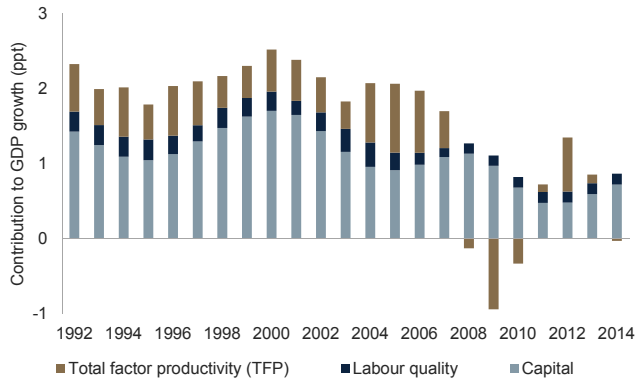
Future temporary headwinds

Meanwhile, the global financial crisis casts a cyclical shadow over productivity growth today. This means that the recent dismal productivity performance is in significant part temporary and should begin to improve as time passes.

Even as risk appetite revives and business investment has picked up, the productivity hangover is likely to persist for

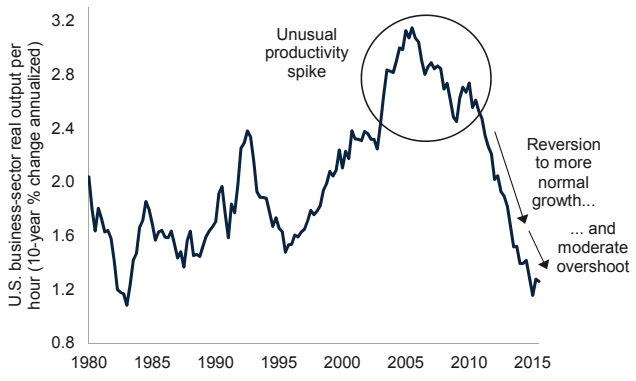
[1]This boom was largely the result of the initial impulse of the information technology revolution, and also partially due to unsustainably fast credit growth and questionable financial sector deregulation.

Exhibit 5: Developed-world productivity slows for multiple reasons



Note: 3-year moving average of contribution to GDP growth of thirteen major developed countries. Source: The Conference Board Total Economy Database, Haver Analytics, RBC GAM

Exhibit 6: U.S. productivity growth was abnormally strong beforehand



Note: Real output per hour of all persons in business sector. Source: BLS, Haver Analytics, RBC GAM

somewhat longer. As the economy undershot its potential for eight years, business investment was persistently weaker than normal. This leaves the capital stock smaller than it would have been – a key determinant for productivity growth. Thus, even as business investment revives and the economy nears its full capacity, the lower level of capital intensity will persist for many years. Furthermore, IMF research finds that a downward shock to capital investment also tends to have a negative effect on the rate of innovation (TFP growth).

There is a similar cyclical hole in the labour market. Labour quality is unquestionably lower than it otherwise would have been. Many millions of workers were unemployed or underemployed for an unusually long period after the financial crisis. As a result, their existing skills decayed and they failed to acquire new ones. This hole will also take many years to plug.

A further side-effect of the financial crisis is that interest rates have been extraordinarily low for many years. Low interest rates are sometimes thought to gradually unleash two negative influences on productivity growth. First, the marketplace can become cluttered by zombie firms that would have been shuttered in a normal interest-rate environment. Second, and relatedly, low rates reduce the threshold for investing, resulting in projects being pursued that wouldn't be deemed worthwhile under more normal circumstances. Once interest rates normalize, businesses and investors regret these low-yielding projects.

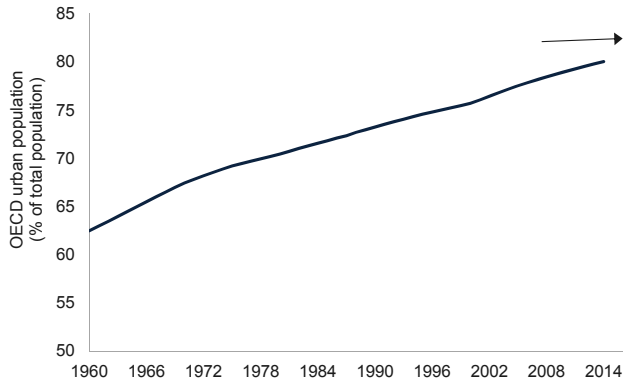
The broad conclusion is that productivity growth enjoyed an unusually strong cyclical upswing through the late 1990s and early 2000s, and so it should not be surprising that this has come to an end. Simultaneously, there are some specific headwinds related to the financial crisis that will linger for several more years, but are not permanent impediments. Thus, the cyclical productivity trend is near its trough and can be expected to improve somewhat over time.

Structural influences

These cyclical observations are promising, but far more important is the question of whether the world's capacity for productivity growth is rising or falling in a structural (i.e. semi-permanent) way.

The U.S. Federal Reserve's (Fed) productivity model argues that we are still in a low productivity regime – in other words, that this is a structural experience rather than merely a cyclical one. That said, the model's definition of "low" versus "high" productivity growth is not entirely in line with our own thinking. Its definition of high is a searing 3.0% productivity growth. We would be delighted with sustainable productivity growth in the range of 1.75% to 2.0%, never mind 3.0%. In fact, the Fed's model predicts precisely this over the next five years.

Exhibit 7: Urbanization continues rising, but nearing its limit?



Source: Haver Analytics, World Bank, RBC GAM

The case for less productivity growth in the future

The standard argument for less productivity growth in the future is that most of the easy pickings that enabled such rapid productivity growth in the past are now becoming scarcer.

Urbanization: The widespread migration from farms to cities has given productivity a critical boost. Each percentage-point increase in the rate of developed-world urbanization adds 0.75% to the level of productivity. In other words, newly urbanized workers are nearly twice as productive as when they were on the farm. In emerging markets like China, the rural-to-urban multiplier is more like three times. However, now that the majority of developed-world citizens live in urban agglomerations, the scope for further support from this trend seems destined to fade in the future (Exhibit 7).[2]

Female employment: The widespread entry of women into the workforce over the past few generations has provided an enormous boost to economic output, and a smaller

[2]Providing a further indignity to overall economic growth, now that the urbanization trend is largely completed in the developed world, one of the realities of a highly urban world is a lower fertility rate. This limits the demographic contribution to economic growth as well.

boost to productivity.[3] But the upward trend in the female employment rate has since halted, meaning this structural tailwind is gone (Exhibit 8).

Education: The quality of the world's human capital has increased enormously for several centuries, starting with an expansion of universal access to education, followed by rising high school graduation rates and lately spiking university attendance. However, it seems obvious that not everyone will have a PhD in 50 years, nor would this even be optimal given that years of potential work must be sacrificed in such a pursuit. Thus, the remarkable rise in education standards will struggle to continue advancing at the same rate into the future.

Longevity: Although longevity continues to rise, the pace is decelerating, and the extra years no longer secure a material increase in workers, productivity or all-around quality of life.

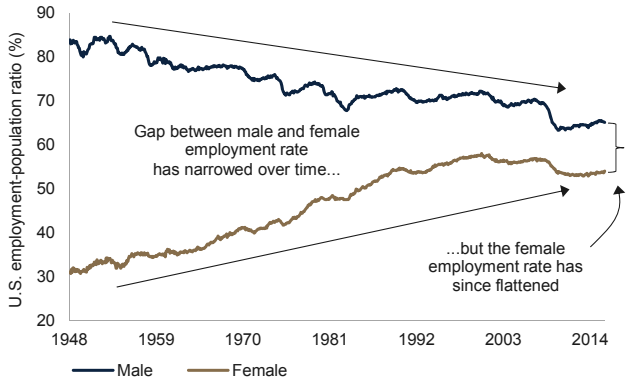
Land: At least in the "New World," land was effectively free in the early stages of colonization, eliminating a key capital cost for businesses. But as the population and economy have grown, the remaining space has become progressively less desirable and more expensive. Companies must now spend far more money on the same underlying capital stock.

Entitlements: Many government entitlements were created on a pay-as-you-go basis with the presumption that steady population growth would continue indefinitely. This assumption has proven incorrect. Now that fertility rates have declined and public-debt levels have risen, these expenses will grow as a share of government revenue, pulling government resources away from more productive ends, such as infrastructure spending or lower tax rates.

A further popular claim is that the past few centuries were blessed by the serendipitous discovery of a raft of profound new technologies, each of which lifted productivity growth materially for several decades. Such "general purpose technologies" include the railroad, electricity, the telephone, mass production, the combustion engine, the corporation, the radio, the air conditioner, plastics and antibiotics. Each had enormous productivity-enhancing effects across a wide swath of human life, and laid the foundation for additional innovations. The presumption is that there will be fewer inventions of this scale in the future.

We cannot deny the tremendous discoveries of the past, but reject the assumption that the future will be any less exciting. For a variety of complicated reasons, the world's capacity

Exhibit 8: Female boost to economic and productivity growth



Source: BLS, Haver Analytics, RBC GAM

for innovation increased dramatically at the onset of the Industrial Revolution. We have not detected any compelling evidence that this remarkable capacity for invention has suddenly been snuffed out. Axiomatically, there should continue to be major new discoveries in the future. We can think of several that are unfolding right now, such as computers, networks and robotics. Others will come as a pleasant surprise, much as the course of prior discoveries was hardly mapped out in advance.

But we get ahead of ourselves. To offer a comprehensive opinion on the outlook for productivity, we must evaluate each of the determinants of productivity highlighted in Exhibit 3 to gauge their adequacy in combatting the loss of structural tailwinds just identified.

Normal current capital contribution

The first and traditionally largest driver of productivity growth is via a rising capital stock. Although the stock of capital is undoubtedly smaller than it would have been without the financial crisis, it has nevertheless managed to roughly keep pace with GDP (Exhibit 9). This argues – theoretically – for a fairly normal contribution to productivity growth, if less than what might have been without the financial crisis.

Sending a positive signal about the next few years, the rate of U.S. private-sector capital investment growth is rising and is actually slightly above normal on an inflation-adjusted basis (Exhibit 10).[4] Technically, this is even more promising than it first seems as the level of capital investment necessary to sustain a fixed level of capital intensity falls with a lower

[3]This has effectively doubled the number of people with a high level of human capital in the economy.

[4]Capital goods prices have generally risen less quickly then other products, making nominal capital investment look paltry even when the volume of new capital purchases is rising.

economic speed limit.[5] Developed world growth rates are lower than before due to deteriorating demographics. Thus, if the current enthusiasm for business investment persists, a notably rising capital intensity is conceivable.

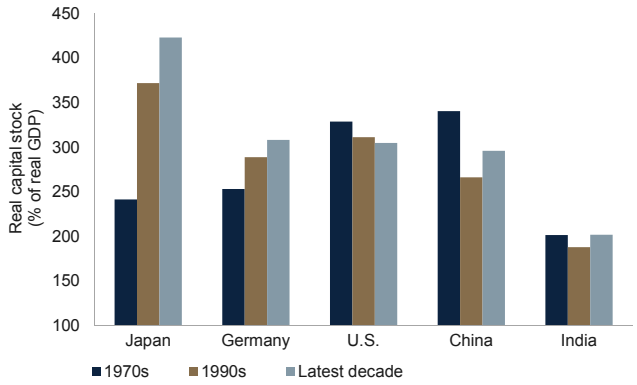
Naysayers like to point out that businesses are currently deploying an unusually small fraction of their profits into capital investment (Exhibit 11). This is true, but largely because profits are unusually high rather than business investment being unusually low. Meanwhile, if firms were to become more enthusiastic about the future – or if the market's preference for dividends and buybacks were to fade – they could easily afford to increase the pace of investment further.

The composition of capital investment has also improved as firms have increasingly tilted their purchases toward especially productivity-enhancing capital such as information and communication technology (ICT) and intellectual property. Intellectual property now represents fully one-quarter of capital investment (Exhibit 12). On the other hand, these types of capital depreciate unusually quickly and so require constant replenishment.

Thus, our initial prognosis is that the current pattern of capital investment is consistent with a slightly larger than normal contribution to productivity growth. But this is not the entirety of the story, as there is considerable debate about whether the changing contours of the economy might make

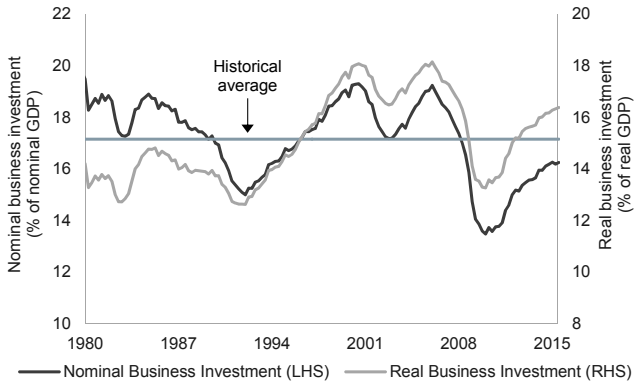
[5]This explains in significant part why China must dedicate so much of its output to capital investment: otherwise, its rapid GDP growth would quickly outstrip its capital stock and limit future economic gains.

Exhibit 9: Capital intensity has held up well to recent crisis



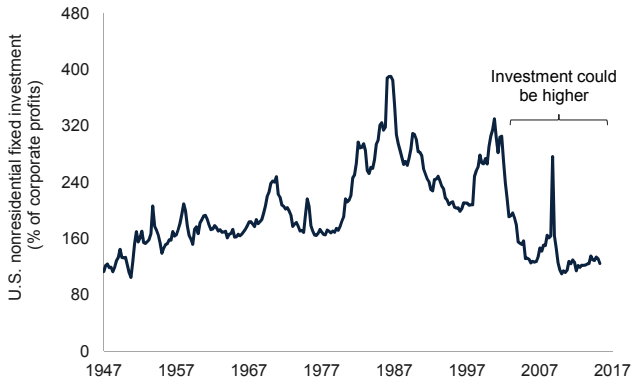
Note: Average real capital stock as % of GDP for the periods indicated. Latest decade from 2002 to 2011. Source: Feenstra, Robert C., Robert Inklaar and Marcel P. Timmer (2015), "The Next Generation of the Penn World Table" forthcoming in American Economic Review, available for download at www.ggdc.net/pwt; RBC GAM

Exhibit 10: Business investment rising again



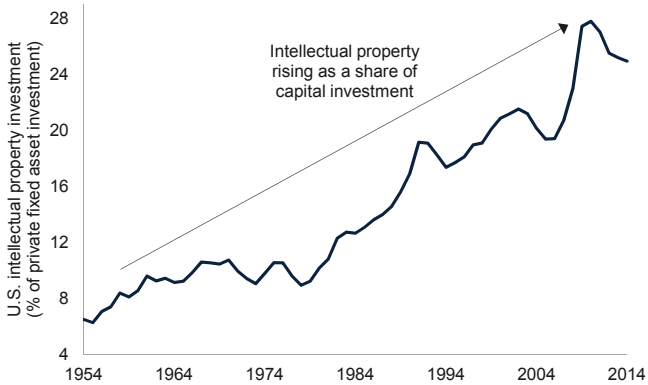
Note: Use of different scales to align historical averages.
Source: BEA, Haver Analytics, RBC GAM

Exhibit 11: U.S. firms allocate less of profits to capex



Source: NBER, BEA, Haver Analytics, RBC GAM

Exhibit 12: Rising intellectual property investment



Note: Nominal fixed asset investment. Source: BEA, Haver Analytics, RBC GAM

capital investment a lower priority for companies in the future.

Slightly less capital contribution in the future?

The consensus thinking is that businesses may be starting to transition toward a "capital light" world as new technologies and technology-oriented companies displace their brick-and-mortar ancestors. E-commerce sales are making steady inroads into retail spending, rising from almost nothing in 1999 to 7.4% of sales today, and continue to capture additional market share (Exhibit 13).

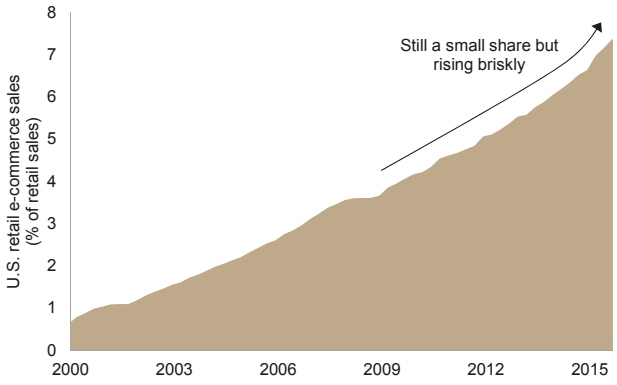
Some also argue that the broader economic shift away from goods and toward services should further decrease capital intensity.

"Capital light" counterpoints

However, we believe the trend toward "capital light" operations will prove much less powerful than imagined:

- Another powerful trend on the upswing – automation – presents precisely the opposite argument: the expected increased usage of robots, machines and software all argue for considerable future capital investments.
- With reference to the shift toward the service sector, a surprising fraction of service industries are in fact very capital intensive – such as rail transportation, telecom and healthcare. This transition does not automatically result in less capital intensity.
- The capital stock has not yet shown any inclination to shrink even as profound new technologies have unfurled over the past 15 years.
- The definition of capital is broader than conventionally imagined, as it includes forms of intellectual property such as software, research & development and patents. The acquisition of such soft capital should accelerate given the anticipated technological focus. Meanwhile, these new kinds of capital are particularly good at driving productivity gains.
- Even in a world of online sales that decimates physical storefronts, keep in mind that the sale of goods demands an enhanced wholesaling infrastructure (larger, more sophisticated warehouses) and obliges far more transportation capital as products are shipped directly to homes rather than en masse to stores. These will provide a material offset to reduced storefronts.
- While e-commerce sales should continue to expand their market share for decades to come and may ultimately capture the bulk of all retail spending, it is not reasonable to assume that store-based transactions will vanish altogether. There are inherent limits to how much can be purchased online given the value that some place in the social and experiential aspects of shopping, personalized expert advice from salesclerks and the ability to physically evaluate a product before purchase.[6]
- As this disruption to "old economy" companies occurs, a fierce battle is erupting over who will capture the market share that is suddenly up for grabs. This competition may manifest in the form of accelerating investment and corporate acquisitions (another form of capital investment).
- Related to this, while a handful of sectors – most notably social networks and search engines – are enjoying greater barriers to entry thanks to unstoppable network effects,[7] the bulk of sectors – such as media, entertainment and trade – are experiencing reduced barriers to entry. The enhanced competition that results may create a sort of arms race that incents additional capital investment.

Exhibit 13: U.S. consumers embrace retail e-commerce



Source: U.S. Census Bureau, Haver Analytics, RBC GAM

Return on capital

Framed slightly differently, so long as a healthy return on capital persists, why would companies stop investing in capital? The current U.S. return on capital is actually unusually high, suggesting that the substantial technological changes already under way have yet to seriously undermine

[6]Offering free returns for delivered products is not the same, as it is a hassle to repackage and return them.

[7]Absent significant differentiation, no one will join a new social network unless all of their friends are already there, making it an almost impossible task to compete with successful incumbents.

the value of investing in capital (Exhibit 14).[8] Companies are still well incented to invest.

Even if the demand for capital ebbs slightly in the future – theoretically exerting a downward force on the marginal return on capital – keep in mind that the dissaving that accompanies an aging population should reduce the supply of investible funds in parallel (Exhibit 15). These two forces should roughly neutralize each other, leaving the ultimate return on capital essentially unchanged.

As such, we walk away with the impression that while "capital light" expectations are not entirely an illusion, the effect may not be nearly as strong as most expect. Thus, we budget for a bit less productivity help from capital investment, but only a bit.

Labour quality contribution

As discussed earlier, labour quality has been an important driver to productivity growth for centuries. There are legitimate fears that this upward trend could be coming to an end. We share this concern for the developed world, but should note that there are several countervailing factors from a global perspective:

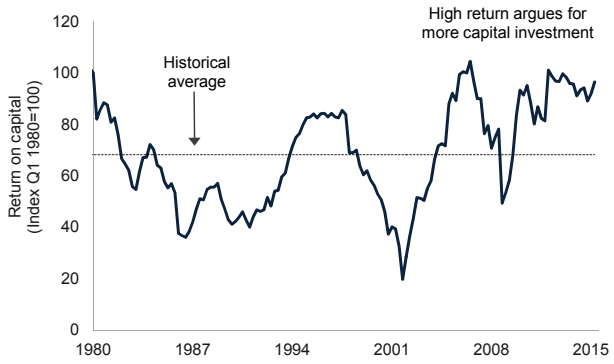
- Actual measures of global education continue to rise without any apparent sign of deceleration. In fact, if anything, there has been a slight acceleration (Exhibit 16). Much of this success comes from emerging-market nations.
- The "Flynn effect" of rising IQ scores from generation to generation – theoretically independent of education – continues to add to labour quality in a somewhat mysterious way, possibly related to rising levels of stimulation in the world and/or improving nutrition standards.
- Labour quality may also be able to continue rising in a more unorthodox fashion as increased flexible work arrangements save commuting time, reduce stress and allow for a more efficient distribution of work across the day.[9] Similarly, increasingly diverse workforces may unleash positive social dynamics with favourable consequences for productivity.

Overall, we conservatively presume that labour quality will provide slightly less help than in the past to productivity growth, but it may not fade as much as many imagine.

[8]Of course, there is a slight circularity to this argument given that this measure is calculated as profits as a percentage of the corporate capital stock, such that a marginal decline in capital actually increases the return on capital, at least initially.

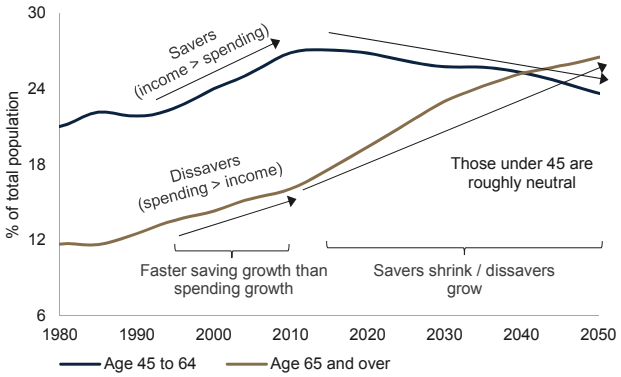
[9] Of course, these advantages must be contrasted against potential disadvantages, such as reduced communication across teams and the scope for distraction at home.

Exhibit 14: High return on capital is good sign for future growth



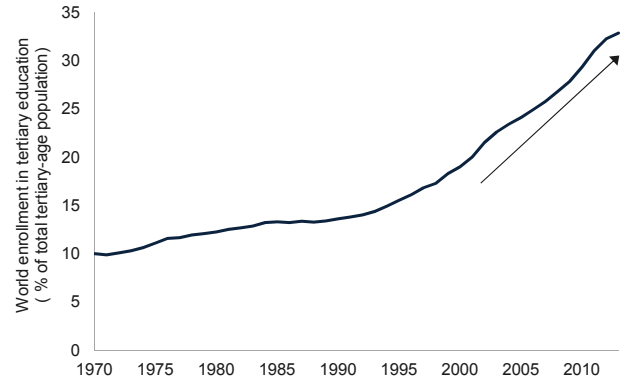
Source: BEA, Haver Analytics, RBC GAM

Exhibit 15: Dissaving could keep return on capital from falling



Note: Population of developed countries. Source: United Nations, Haver Analytics, RBC GAM

Exhibit 16: Education quality not done rising



Note: Tertiary education includes all post-secondary education, including but not limited to universities. Total school-age population is the total population of the five-year age group following on from secondary school leaving. Source: World Bank, Haver Analytics, RBC GAM

Technological contribution

With the prospect of slightly less support from both capital intensification and labour-quality growth over the long run, any hope of achieving a normal rate of productivity growth lies in the hands of TFP growth, and whether it can revive after having shrunk to virtually nothing in recent years (refer back to Exhibit 5 for developed economies and forward to Exhibit 18 for emerging economies).

We believe there could be less technological diffusion in the future, but more outright technological innovation (Exhibit 17). On the aggregate, the latter should outweigh the former.

Less technological diffusion

A key driver of worldwide productivity over the last century was the better diffusion of technology from rich nations to poor ones. This enhanced flow occurred for a number of reasons. Extreme differences in technological advancement created the opportunity. Rising trade, direct investment flows and a global diaspora then brought the technological advancements to poor nations. Finally, many poor countries proved increasingly capable of absorbing and re-deploying these technologies when they encountered them.[10]

Whereas technological diffusion has generated just 20% of TFP growth for rich nations, it has provided a remarkable 60% of the gain for poorer nations.

In the future, we suspect technological diffusion will weaken slightly, for the following reasons:

- Between nations, income inequality has been declining. Similarly, countries are becoming increasingly homogenous in terms of their education levels, business activities, cultures and tastes. No longer do the shopping malls of foreign countries reveal a kaleidoscope of unfamiliar products. They all look and operate in an increasingly similar fashion, meaning less remaining room for the diffusion of unfamiliar technologies from one nation to the next.
- As emerging-market nations become wealthier, they are naturally approaching the technological frontier. This reduces the scope for further technological absorption. Indeed, emerging-market TFP growth has plummeted (Exhibit 18). Recall that 60% of this has traditionally come from technological diffusion.
- Trade and foreign direct investment are acknowledged to be key drivers of technological diffusion. We believe the pace of globalization is slowing in a structural way, which may interfere with this process.[11]
- Some companies on the bleeding edge of technology have stopped securing patents for their findings to avoid allowing competitors to see the exact specifications of their new inventions.[12] This may limit cross-firm diffusion.

To be fair, it is hardly a one-way street of declining technology diffusion. The internet makes the spread of basic knowledge and technologies much easier. In addition, immigrants regularly take technological know-how back to their country of origin. Finally, decent labour-market mobility allows for the

Exhibit 17: Tech diffusion vs. tech innovation

	Tech diffusion	Tech innovation
Current:	20 % Developed; 60% Emerging	80 % Developed; 40% Emerging
Expected change:	↓ Less tech diffusion from rich nations as EM become richer	↑ More tech innovation from EM as they approach tech frontier
Future:	Less	More

Source: RBC GAM

Exhibit 18: EM productivity growth slows for one key reason

Note: 3-year moving average of contribution to GDP growth of six major EM countries. Source: The Conference Board Total Economy Database, Haver Analytics, RBC GAM

[10]Countries were more capable of absorbing foreign technologies due to greater economic flexibility that rewarded ideas more generally.

[11]Trade flows are already weak. While FDI flows are still strong, companies seem decreasingly willing to effectively give away their technological secrets to partners in foreign countries.

[12]On the other hand, cyberattacks and open-source software are laying bare technologies that might otherwise have gone unshared.

diffusion of knowledge technologies across firms – another important channel.

Despite these counterpoints, we believe the balance of evidence favours an interpretation of slightly less technological diffusion at the global level.

More innovation

This takes us to the crux of the productivity debate: will the rate of innovation rise or fall in the future? With plenty of caveats, we are more inclined toward the optimistic argument.

Leading indicators

Before we evaluate the promise of specific new technologies, let us consider the signals being sent more broadly. There are quite a number of positive ones:

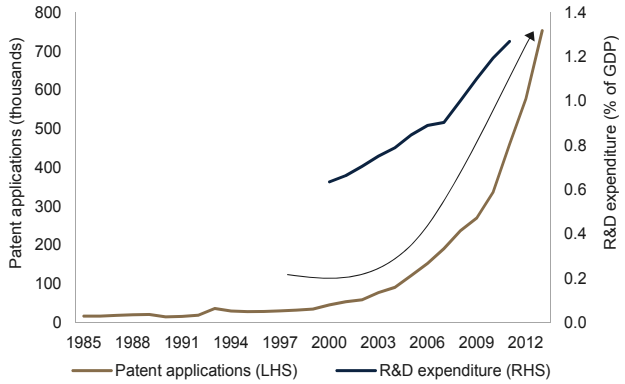
- The fundamental creativity and inquisitiveness of humans is not obviously impaired, nor have all the mysteries been solved in basic science. Many fields are just scraping the surface. Every new scientific or technological solution surfaces new burning questions.
- Existing "general purpose technologies" – revolutions like the computer and the network – continue to play out, as we discuss in more detail later. Historically, monumental achievements like these take decades to be fully absorbed into productivity figures, and they enable other technological improvements on their backs (Exhibit 19). These technologies can continue to pay dividends.
- There are fewer barriers to innovation today than ever: basic knowledge is available to anyone on the internet; many sectors are now ripe for disruption by startups; the venture capital industry continues to expand and improve; off-the-shelf tools now exist to start a sizeable business almost overnight via plug-and-play solutions such as selling on Amazon, advertising on Google and storing data in the cloud; and large companies are keen to pay up for good ideas by bolting on small acquisitions.
- Although emerging-market nations may find there are fewer foreign technologies they do not already possess than in the past, they should be theoretically better at generating their own technological innovations now that they are nearing the technological frontier. This is evident in the data, with emerging-market R&D spending and patent applications both increasing sharply (Exhibit 20). As a result, the pool of prospective innovators has effectively expanded from less than a billion people in the developed world to many billions around the world.

Exhibit 19: The long road to productivity gains

	Basic research	Disruptive innovation	Deployment
TIMING:	Years/ Decades	Years	Decades
EXCITEMENT:	Unexciting	Exciting	Less exciting
ECONOMIC VALUE:	No benefit	Small benefit	Maximum benefit

Source: Carlota Perez, Technological University of Tallinn, RBC GAM

Exhibit 20: Middle-income country innovation on the rise



Note: Patent applications and R&D expenditures of middle income countries.
Source: World Bank, Haver Analytics, RBC GAM

- Meanwhile, developed-world R&D is also rising. U.S. inflation-adjusted R&D has recently accelerated out of a flat decade and is now at its highest share of GDP on record (Exhibit 21). R&D spending tends to lead productivity growth by several years.
- The time between technological discoveries and commercialization, while still long, may be shrinking (Exhibit 22). This allows future technologies to map much more quickly onto productivity.

Admittedly, there are also a few unpromising signals, though we believe they are trumped by the prior factors:

- One clever strategy for divining the financial market's own opinion on the expected degree of innovation is to look at the gap between the price-to-earnings ratio of the tech sector and that of the overall stock market. This reveals a pretty low premium, and so fails to identify an expected surge (Exhibit 23).

- Historically, a great deal of innovation comes from "creative destruction," whereby new technologies and firms outright replace old ones. However, the turnover of businesses has actually been falling for quite some time (Exhibit 24).

New technologies

We now turn to our crystal ball to evaluate the key new technology buckets likely to drive productivity growth over the next few decades (Exhibit 25).

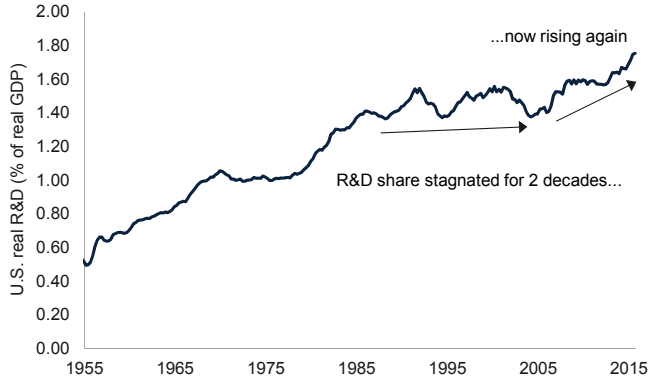
In so doing, Amara's Law is worth heeding: "we tend to overestimate the effect of a new technology in the short run and underestimate the effect in the long run." Thus, we should withhold judgement even as some of these technologies get off to a slow start.

Let us also acknowledge that the yardstick for technological improvement is constantly changing. Once upon a time, a key test was how quickly one could get from London to New York. Humankind has failed to advance at all in this regard in recent decades. However, one can now instantaneously obtain all of the information from the libraries of London in a split second, and speak face-to-face with someone there via video conference. Technological advancements do not always come in a linear fashion, but they do still come.

Computers

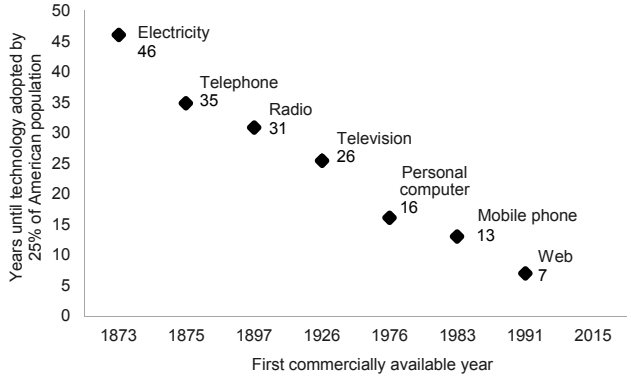
Computers are an indisputable "general purpose technology" given their widespread application. They have now been permeating developed economies for the better part of 50 years, and have had a profound effect on society and productivity. The current level of data processing and analysis was not remotely possible when performed manually by humans.

Exhibit 21: R&D is rising and leads productivity



Source: Haver Analytics, RBC GAM

Exhibit 22: The pace of technological adoption may be accelerating

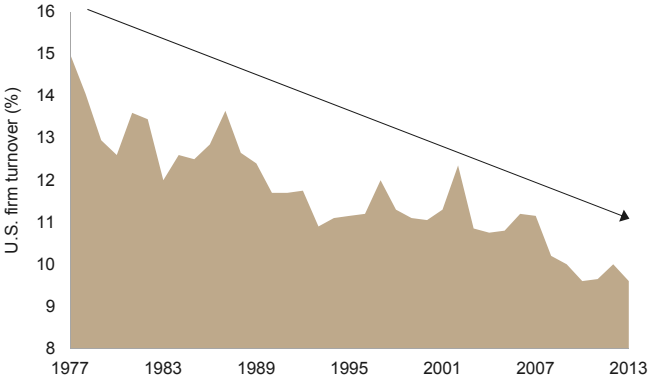


Source: BofA Merrill Lynch, Ray Kurzweil, Singularity.com, RBC GAM

Exhibit 23: Markets not pricing in a sudden surge of innovation

Source: Bloomberg, RBC GAM

Exhibit 24: Firm turnover declining steadily



Note: Turnover defined as fraction of outstanding firms created or closed in a year. Source: U.S. Census Bureau, RBC GAM

Exhibit 25: Evaluating new technologies

Category	Technology	Development stage	Importance	Productivity growth impact
Computers	Calculation	Late	High	Accelerate
	Pattern recognition	Mid	High	Accelerate
	Artificial intelligence	Early	High	Accelerate
Networks	Internet	Late	High	Accelerate
	Email	Late	High	Sustain
	Video conferencing	Mid	Low	Decelerate
	Mobile	Mid	High	Accelerate
	Virtual reality	Early	Low	Decelerate
Robots	Precision	Late	High	Sustain
	Manipulation	Mid	High	Accelerate
	Miniaturization	Mid	Medium	Decelerate
	Social intelligence	Early	Low	Accelerate
	Task flexibility	Early	Medium	Accelerate
Transportation	Driverless car	Mid	High	Sustain
	Driverless trucks	Mid	Medium	Sustain
	Drones	Mid	High	Accelerate
Materials	New composites	Early	Medium	Decelerate
Energy	Shale oil & gas	Late	Low	Sustain
	Wind	Mid	Medium	Sustain
	Solar	Mid	High	Sustain
	Biofuels	Early	Medium	Sustain
	Batteries	Early	High	Accelerate
Food	Farm analytics	Mid	Medium	Sustain
	Genetic engineering	Early	Medium	Sustain
Health	Drug development	Late	High	Sustain
	Health tracking & diagnosis	Mid	High	Sustain
	Robotic surgery	Mid	Low	Sustain
	Synthetic biology	Early	High	Accelerate
	Big data analytics	Early	Medium	Sustain
Customization	Custom manufacturing	Mid	Medium	Accelerate
	Niche targeting	Mid	High	Accelerate
	3D printing	Early	Medium	Accelerate
NET EFFECT:				**MODERATE ACCELERATION**

Note: A decelerating impact on productivity growth means the new technology will still add to productivity, but won't provide as much upward momentum as prior technologies in the space did. Source: RBC GAM

Perhaps the most important question for the future is whether the boost to productivity growth from computers may now be starting to fade after many decades of support. After all, some of the most elemental uses for computers – performing calculations, for example – have already been widely deployed.

We reject this concern. Computer processing power continues to rise at a remarkable clip,[13] sophisticated analysis and pattern recognition is at best in the middle of its development arc[14] and artificial intelligence applications remain at a very early stage of development. As such, computers should remain a productivity accelerant for the foreseeable future.

Networks

Built atop a backbone of computers, network technology has advanced rapidly in recent decades, and the transmission of information electronically represents another general-purpose technology that will pay dividends for decades and is already enabling additional innovations that sit on top of it.

Some argue that the provision of Internet access to homes is a far less monumental development than the arrival of other general-purpose technologies like electricity or plumbing. Perhaps this is true from a casual, day-to-day perspective.

But the ability to obtain virtually any information (and, increasingly, products) over the internet – from libraries' worth of books to entertainment to a local restaurant review to a competitive price for a product – remains an enormous leap beyond the glacial advances of knowledge transmission over the past century, and is arguably on par with the invention of the printing press and the diffusion of widespread literacy. Decision-making is now much more informed.

The significance of smartphones is debatable. In a sense they are just smaller computers, and as such welcome but unrevolutionary from a productivity standpoint. However, their mobility is important for location-specific applications such as navigation, and in many emerging economies they provide the only form of computing power and Internet access. This is truly revolutionary. Going forward, the smartphone offers tantalizing potential as it is better integrated into education, healthcare, banking, agriculture and elsewhere.

The so-called "internet of things," in which even small objects connect to the network, will be a boon for logistics, permitting even more efficient just-in-time inventory systems and automatic product replenishment.

On the other hand, the specific ability to communicate more easily with others – via email or video conferencing, say – seems less revolutionary. To be sure, these continue to advance productivity, but they are less foundational than the development of the telephone or the telegraph before it, inventions that first made distant communication possible in something approximating real time.

Robots

Much as computers took several decades to fully permeate society, increasingly sophisticated robotic technology now exists and is becoming more relevant. Defined simply, robots are computers plus a physical presence that interacts with the world. Robots are another "general purpose technology" in the sense that they can be deployed for a wide range of purposes, most obviously in manufacturing, but also in transportation and areas as far afield as personal care.

Robotic efficiency is now improving by about 5% per year thanks to a mix of improved brains, better brawn and greater flexibility, while costs are falling by 2% to 3% annually.[15] Relative to humans, whose real wages are rising roughly in line with their productivity, this amounts to a robot-human cost tradeoff that favours robots by an additional 7% to 8% per year. We discuss the outlook for automation and its potentially profoundly negative implications for employment in Appendix D.

The scope for further automation via robots depends on the industry. Car manufacturing is already 80% automated, whereas many other manufacturing sectors are still very low in their degree of automation and thus ripe for change. The initial slow uptake is in many cases due to greater product customization or rapidly changing specs that have historically hindered robots. But this may cease to be such an impediment in the future, and robot sales are now rising by almost 30% per year.

Robots are already quite adept at tasks demanding strength, endurance and precision. The main advances going forward relate to manipulation (being more dexterous), perception (having a better awareness of the world around them) and

[13] In line with Moore's Law of processing power doubling every two years, and also because computer algorithms have been rapidly improving (with quantum computing nearing viability).

[14] Some strategies such as machine learning have the potential to be especially potent.

[15] From Bank of America Merrill Lynch, "Robot Revolution", November 3rd, 2015.

task flexibility (being able to do more than one thing). More distant is a material improvement in goal-setting (identifying what needs to be done in a complex environment) and social intelligence (engaging with humans and human emotions in a pleasant, responsive and ultimately useful way).

Transportation

The remainder of the technologies we discuss are important but not quite general-purpose technologies. As such, they can help productivity growth but are unlikely to sustain it for decades, or to unleash significant additional efficiencies in their wake.

As noted earlier, it is tempting to imagine that transportation technology has stagnated for many years. Superficially, it has, in that airplanes are no faster than they were decades ago and cars are stuck in more gridlock than ever. However, tempering this initial dour interpretation, a flight is now much cheaper than in decades past, healthier (there's no smoking on board), there are far more flights to choose from and planes are much safer. These are all forms of improved quality and thus productivity. Meanwhile, car quality has increased substantially in the sense of being safer, more reliable and less polluting.

Without question, the most important new technology in the transportation space – and arguably the most exciting development in all of technology to the lay person – is the expected arrival of the driverless car. This achievement is of course a manifestation of other more basic revolutions in computing, networks and robotics.

Google has long had several autonomous cars patrolling Mountain View, California, with millions of miles on their collective odometers. Traditional car companies have begun testing their own technologies. Other tech firms, including Apple, Uber and Tesla, have also entered the driverless-car race.

There are two drastically different approaches being taken. The first strategy is to build a fully-automated self-driving vehicle from scratch, a path that Google is pursuing with particular enthusiasm. The alternate strategy is to incrementally increase the automated features of present-day cars until they eventually cease to require human assistance. Traditional car companies have been inching along this second route for decades, starting long ago with cruise control and proceeding much more recently to automated parallel parking, automatic emergency stopping and improved sensors that warn of nearby danger. Tesla's latest cars can now navigate autonomously within a lane, remaining below the speed limit and at a safe distance to the car in front of them. They can also safely switch lanes when instructed to do so by the driver.

While these advances are impressive, most estimates put a fully driverless car at five to 15 years into the future. For all of its much-ballyhooed miles, the Google car still cannot handle unfamiliar roads very well, or adverse weather at all. Chaotic traffic situations are a challenge. These are difficult nuts to crack.

That said, once the technology is available, it could spread surprisingly quickly. The main challenge for self-driving cars is in honing algorithms, not the quality of the hardware. This is important, as software can be updated for vehicles already on the road, with Tesla's automated features rolling out practically overnight to existing drivers. The incremental improvement strategy has another huge advantage: car companies can monitor how their technology is working in millions of vehicles and use that copious flow of information to refine future generations of the technology. As things stand now, Google is stuck processing data from a few dozen vehicles.

Driverless cars may unleash a variety of fascinating productivity-enhancing changes on the world:

- Commuting times and traffic could be substantially lessened by vehicles taking the best possible route, reducing the gap between cars, driving at an efficient and steady clip, and via the use of coordinated convoys.[16]
- Alternately, it could become more practical to live a greater distance from work, providing more affordable housing options or a more desirable setting for families.
- Reduced traffic fatalities will prevent the loss of many workers in the prime of their lives.
- Additional leisure time while traveling by car.
- Greater transportation freedom for children and non-driving seniors.
- Parking could be relegated away from prime real estate, freeing up central land for more productive uses.

Despite these very real implications, the feverish excitement over the driverless car may be somewhat overdone. The traffic potential is real, but to the extent that it increases people's tolerance for driving (and appetite for distant homes), the result may just be additional distance covered per vehicle and thus the same old traffic snarls. The additional leisure for the average person may also be less exciting than it first seems. Keep in mind that three out of

[16] Coordinated convoys would also allow better cooperation with smart traffic signals.

the four people in a car already enjoy this "leisure," and generally do not revel in book reading, sleeping or work-related tasks. Limited mobility within the vehicle and motion sickness will remain key impediments.

The right way to frame this technology is in the context of whether it is more revolutionary than past transportation breakthroughs. The answer is almost certainly "no." The invention of the railroad radically altered the ability of goods and people to travel long distances. The invention of the car gave unprecedented freedom to individuals and enabled the creation of suburbs. In contrast, the self-driving car is nice and represents an important contribution to the advancement of transportation technologies, but may not outright accelerate it.

Drone technology is a related transportation innovation. It may yet enable the near-instantaneous delivery of goods as per the vision of retailer Amazon, but this isn't obviously a huge leap forward from the one-day service offered by traditional package delivery companies, and there are many safety and practical considerations that have yet to be solved. From a policing and (especially) military perspective, on the other hand, the applications for drones seem highly significant. This technology could increasingly redirect military personnel into other more productive pursuits.

Materials

There continues to be steady progress in the materials science space, with the development of new composites and the recent manufacturing of graphene – an incredibly strong and light carbon substance that is beginning to find a market. Incremental progress continues on many fronts in the search for materials exhibiting unusual strength, conductivity and/or flexibility.

However, compared to the groundbreaking materials science advances of the 20th century – with the invention of plastics at the top of the list – our sense is that new materials technologies are providing less support to productivity growth than in the past.

Energy

Energy technologies are becoming increasingly interesting, with recent innovations set to drive productivity growth in the sector at least as quickly as prior innovations did over the last century.

In the oil and gas space, shale technologies continue to advance particularly quickly, possibly even spurred on by the oil shock. The technology still has ample opportunity to spread more broadly outside of the U.S.

Meanwhile, renewable energy technologies – most obviously wind and solar – continue to advance. Solar in particular has sustained a rapid rate of productivity growth, and appears set to be cost-competitive with oil within a few years.

The knock on alternative energy is that it is unreliable given the fickle nature of the sun and the wind. But when solar and wind technologies are paired with further advances in battery technology, this could provide a tipping point for alternative energy production.[17] Improved storage technologies – if possible on a grand scale[18] – would also materially reduce the need for the excess capacity on the electrical grid that is only required on the hottest few days of the year. As such, we view battery technologies as highly significant, and with the potential to accelerate productivity.

Emerging markets stand to gain in particular from the interplay of alternative energies and battery technologies, as alternative energy sources can be deployed in a localized way without massive infrastructure investment.

Lastly, biofuels continue to hold promise as the search continues for genetically engineered organisms that might eventually produce fuel with little waste. Such technological pursuits are still in the early stages.

Food

Food productivity has increased to an incredible degree over the past few centuries. We believe farm yields can continue to rise at a similar rate.

The strategy is no longer primarily about mechanization since farms are now highly mechanized and have only limited reliance on humans. The new opportunity is in optimizing farming practices and improving the quality of produce.

Farm analytics seem to be advancing quite quickly as more rigorous record-keeping, better and more sensors, pattern recognition technologies, drones and driverless tractors combine to ensure that crops are farmed in the most effective way possible.

Similarly, the genetic engineering of crops is still in its very early stages. Much as corn began its domestication journey 10,000 years ago as a tiny ear with rock-hard kernels before ending up today as a juicy product that is 40 times larger, there remains ample room for improvement right across the spectrum of foods with regard to their ease of growth, disease resistance, nutrition and environmental footprint.

[17] Incidentally, improved battery technologies are also a key enabler for widespread adoption of the electric car.

[18] Conceivably, electric cars could provide this large-scale storage capacity.

Health

Health improvements have been enormous over the past century, thanks to a mixture of better medical practices, better diets, better living conditions and improved drugs. Alas, the rate of drug development seems to have slowed for infectious diseases, but it remains normal for other afflictions.

Elsewhere, the gains and prospective gains are quite impressive. We see important developments in health tracking and diagnosis. The former is aided by a myriad of increasingly sophisticated labs-on-a-chip, genetic tests, electronic recordkeeping and personal health-measurement devices. Better diagnostics are largely the result of more informed patients thanks to the internet, and more up-to-date doctors due to online medical journals. Artificial-intelligence software is also becoming better at interpreting symptoms and asking the right questions. Robotic surgery continues to progress, with machines assisting in tasks for which precision is key.

Synthetic biology – manipulation of the genetic code – still holds a great deal of promise: basically, fixing problems in the genetic code or creating new organs in a lab. "Big data" analytics will likely help in identifying the relevant genes.

Analytics will also be key in processing the rising tide of information coming from personal health trackers into a usable form so as to identify the specific health risks of individuals, and also to reach broad epidemiological conclusions for the benefits of humankind.

Customization

This category is a grab-bag for technologies that allow for ever-more customized experiences and products. To the extent that these better meet their buyers' needs, they represent an increase in effective quality and thus productivity.

Custom manufacturing is already reasonably well advanced. The interplay of the Internet, more sophisticated robotics and superior supply-chain management has allowed for the blossoming of mini-industries around customized machine parts, personalized running shoes, book-form family photo albums and even self-published novels. 3D printing is still in its early stages, but promises to make some of this much easier.[19]

[19] 3D printing should also allow the creation of more sophisticated products not currently possible with standard molding techniques, and stronger, lighter structures. Waste is also reduced. Applications have even started to include components for the human body.

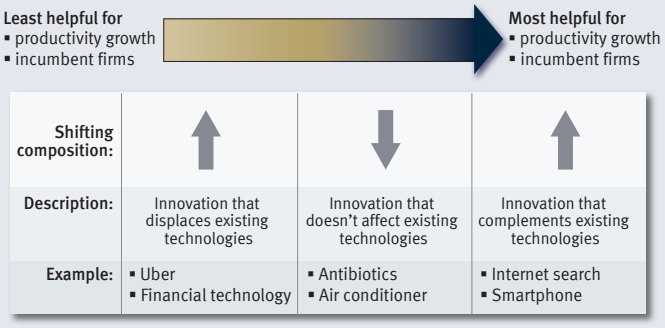
TEXTBOX A: THE VARIED IMPACT OF TECH CHANGE

In fairness, not all technological breakthroughs have the same effect on productivity (Exhibit 26):

- The best type of new technologies enhance the utility of existing technologies. Examples include Internet search engines and the smartphone, both of which have greatly extended the value of the Internet. The good news is that we are seeing more of this sort of technology.
- The least helpful type (though still, to be clear, a positive for productivity growth) are innovations that displace existing technologies. Examples include Uber's potential replacement of taxis or financial technologies that might displace banks. The less positive news is that we are seeing more of this displacing type of innovation.
- Finally, we are seeing fewer innovations of the sort that neither displace nor enhance existing technologies. Examples include the invention of antibiotics or the air conditioner.

On balance, the first two of these forces largely neutralize one another, leaving a fairly normal mapping of innovation onto aggregate productivity growth.

Exhibit 26: Innovation types



Source: RBC GAM

Lastly, the realm of "niche targeting" has exploded thanks to the internet, allowing individuals to organize and find like-minded communities that simply weren't practical given the geographic constraints of the past. This has led to a boom in practically every kind of hobby, a golden age of entertainment choices, more specialized education degrees, and even (theoretically) better marriage matches![20] From a business perspective, companies can much more easily identify and target prospective customers, and can also afford to produce highly-specialized products that were not previously practical.

New technology implications

Our conclusion – assisted by a brief aside into the different styles of innovation in Textbox A – is that the rate of technological innovation should be somewhat faster than normal in the future. The key supports for this argument are the still-accelerating benefits from general-purpose technologies such as computers and networks, the emergence of robotic technologies, and important upticks in energy and customization. We discuss the sector-specific implications of these new technologies in Appendix C. One slight tempering factor from the perspective of overall productivity growth is that the rapid advance of new technologies can actually cause the value of existing capital and labour to depreciate more quickly.

Other productivity considerations

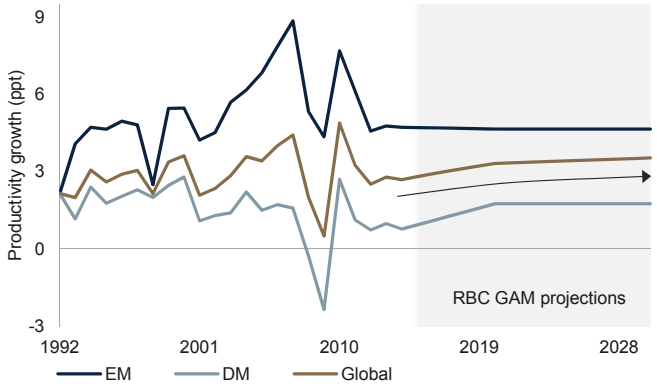
Finally, we step back from specific technologies to consider additional productivity-relevant developments. Broadly, we find there to be slightly more negative ancillary influences than positive ones, though it is hardly a one-sided affair and the collective drag should be insufficient to interfere with our overarching conclusion of a normalization of productivity growth.

Positive forces

We start with the positive forces. First, many national governments are responding to the post-crisis economic malaise and now beginning to deliver productivity-enhancing structural reforms such as reducing the rigidity of their labour markets, cutting red tape, and allowing financial markets (and indeed market forces more generally) to operate more freely. A significant swath of emerging-market countries, Japan and peripheral Europe are implementing this strategy.

Second, it is worth remembering that many of the productivity tailwinds that are sputtering in the developed world are still blowing freely for emerging economies. These include the rapid pace of urbanization, rising female employment, improving education levels and rising human longevity. Furthermore, these countries can still expect to benefit from falling corruption and better infrastructure over time.

Exhibit 27: EM compositional effect keeps global productivity rising



Note: Productivity growth includes capital, labour quality and total factor productivity growth. Global is an aggregate of six EM countries and thirteen major developed countries. RBC GAM estimates used in projections for 2015 and beyond. Source: Feenstra, Inklaar and Timmer (2015), "The Next Generation of the Penn World Table" forthcoming in American Economic Review, available for download at www.ggdc.net/pwt, The Conference Board Total Economy Database, RBC GAM

Third, and continuing with the emerging-market theme, there is a favourable compositional effect at work. Emerging economies represent an ever-rising share of global output, and their rate of productivity growth is faster than that of developed nations. This allows global productivity growth to – in principle – accelerate even if national-level productivity growth remains unchanged (Exhibit 27).

Fourth, across the long arc of history there is tentative evidence of a "challenge-response mechanism" that surfaces during periods of weak population growth whereby productivity growth ticks higher in a compensatory manner. The poor demographic outlook for the next few decades could yet unleash this force.[21]

Fifth, a reduction of "too-big-to-fail" subsidies for financial institutions has resulted in lower relative profitability for banks and other financial companies, impacting worker compensation. If this trend persists, it might improve the distribution of talent across a wide range of sectors, improving overall productivity growth.

[20] The internet permits the vetting of a far larger swath of people for dating purposes, theoretically improving the quality of marriage matches, and thus happiness.

[21] The causality is not entirely understood, but an inadequate labour supply could stoke the embers of innovation to increase the output of the existing workforce.

Negative forces

However, there are also a number of ancillary negative forces to consider on productivity.

First is demographics. An aging population generally increases skill levels in the workforce since older employees, particularly white-collar workers, are materially more experienced and knowledgeable than their younger counterparts. We calculate that this structurally adds around 0.2 percentage point per year to U.S. productivity growth. However, we cannot simply append this to our productivity-growth forecast because the benefit of a rising workforce age was even greater over the past few decades. Thus, this is a tailwind, but a fading one.

Second, and continuing with the demographic theme, there are clear productivity negatives associated with an aging population. One is that while experience levels rise, the rate of innovation plummets for workers past middle age. Another is that governments are forced to expand their entitlement spending, foregoing other more productivity-enhancing purposes.

Third, and in direct opposition to the hope of additional structural reforms, there has been a worrying trend toward more populist governments in the developed world – ones that are less rather than more inclined to implement productivity-enhancing reforms.

Fourth, the world is transitioning from U.S. hegemony to a multi-polar world given China's economic ascendance. Historically, multi-polar environments have been associated with less globalization, and by extension less economic growth and smaller productivity gains.

Fifth, rising inequality is known to limit productivity growth as it constitutes a less efficient allocation of resources. While it is important to allow market forces and meritocracy to operate at a fundamental level, it is equally undeniable that the poor have a higher marginal propensity to consume their money, derive a larger benefit from each additional dollar of income and enjoy superior returns to education and health spending. Productivity suffers when the distribution becomes too lop-sided.

Sixth, the prospect of further climate change is a notable negative for productivity growth, with a two degree Celsius increase in global temperatures expected to subtract around 4% from global productivity.

Seventh, because monetary policy and fiscal policy have both been significantly stretched by the most recent crisis, there will be diminished policy recourse in any future downturn. Thus, economic downturns could be more frequent and/or deeper in the future.

Outlook

The outlook for productivity is hugely important, both in its role as the central enabler of rising financial well-being and in the context of deteriorating demographics as the only means of avoiding economic stagnation.

Our forecast is as follows. Over the next few years, productivity growth should remain underwhelming as the cyclical depressants of the financial crisis continue to play out.

However, over the long term, we see no reason why productivity growth cannot revert to a normal rate. The yoke of cyclical depressants should fade with time. Granted, capital investment and labour quality are likely to provide slightly less help than normal, and the diffusion of existing technologies around the world may even fade to some extent. But we see considerable potential in a raft of powerful new technologies, and so believe that innovation – helped by a rising contribution from emerging economies – should accelerate in the future. This latter force should roughly offset the drags from capital and labour quality, permitting a return in both the developed and emerging world to the sort of productivity gains that prevailed prior to the distortions of the past decade.

For the developed world, this should amount to around 1.75% productivity growth per year (Exhibit 28). For emerging economies, we figure this should average 4.65% (Exhibit 29). Naturally, the actual experience will vary significantly over time and by country, and emerging-market productivity growth should ebb over the long run as these nations become wealthier.

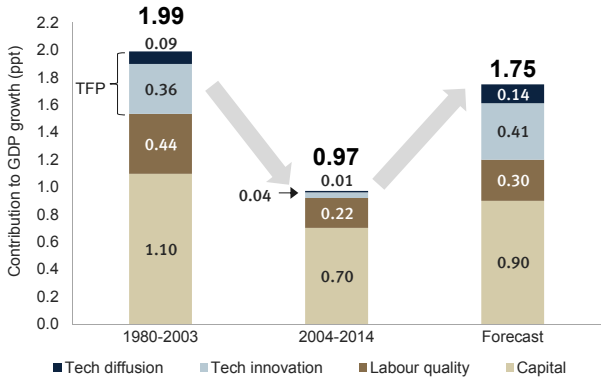
For businesses and investors, this relatively optimistic conclusion is a relief. Yes, investment returns could be somewhat lower in the future for demographic reasons, but the core foundation of corporate growth – businesses building a better mousetrap and finding new markets – should remain active.

That said, from the perspective of individual businesses, the future is still fraught with risk. Technology is radically

changing how many economic sectors operate. Myriad existing businesses will be disrupted by new entrants. The scalability of new business models is such that economies are now increasingly oriented toward winner-take-all outcomes, with the implication that picking the right company will be crucial.

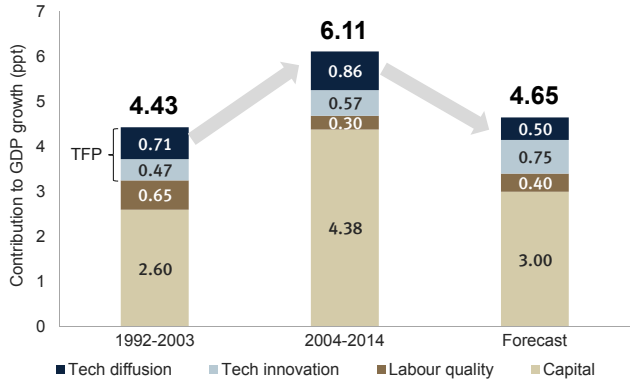
For people, further productivity growth is good in the sense of potentially raising real wages and the standard of living, but it is a significant threat over the longer run if automation eventually translates into mass unemployment, as discussed in Appendix D. It will be up to voters (and human nature) as to whether this is allowed to happen, and whether the end result is utopia or dystopia.

Exhibit 28: Developed nation productivity growth should revive



Note: Contribution to GDP growth of thirteen major developed countries. Total factor productivity (TFP) is separated into innovation and diffusion of technology. Forecast based on RBC GAM estimates. Source: Feenstra, Inklaar and Timmer (2015), "The Next Generation of the Penn World Table" forthcoming in American Economic Review, available for download at www.ggdc.net/pwt, The Conference Board Total Economy Database, RBC GAM

Exhibit 29: Emerging markets: tech innovation to ramp up



Note: Contribution to GDP growth of six EM countries. Total factor productivity (TFP) is separated into innovation and diffusion of technology. Forecast based on RBC GAM estimates. Source: Feenstra, Inklaar and Timmer (2015), "The Next Generation of the Penn World Table" forthcoming in American Economic Review, available for download at www.ggdc.net/pwt,The Conference Board Total Economy Database, RBC GAM

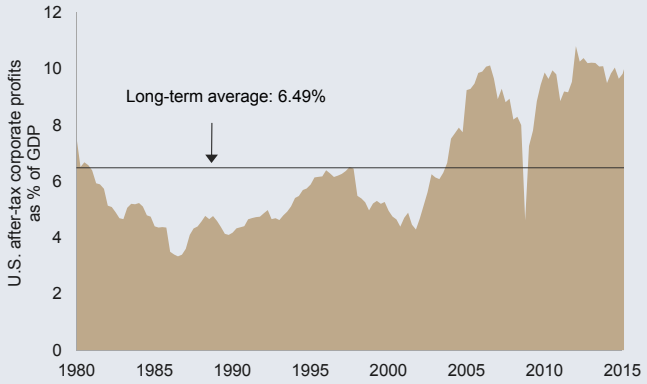
APPENDIX A
GDP DISTORTIONS

Official GDP figures simply do not capture several types of economic activity, collectively entitled "the underground economy." At the extreme end of lawlessness, the official numbers fail to capture such activities as illegal drug manufacturing and dealing, prostitution and illegal gambling. Also excluded are less malignant but nevertheless illegal businesses engaged in tax avoidance, such the proverbial plumber paid mainly in cash and waiters who do not report their tips. There are then rather more benign cash-only "businesses" such as babysitting and lemonade stands. None of these is captured in GDP, and the omissions across the OECD are thought to average about 16% of economic output, and significantly more for emerging economies.

Depending upon how broad a net one wishes to cast, one could further add the perfectly legal economic output generated via unpaid household production: your own cooking, cleaning, child care, housework and gardening. The value of this output is no less significant when generated personally rather than outsourced to paid help. The collective value of unpaid household production is regularly pegged at another 10% to 15% of GDP in the U.S.

While these observations coherently argue that the aggregate level of human output is at least 26% higher than officially reported, the interpretation is slightly different when the focus is shifted from the level of output to the rate of growth. This is because the underground economy and unpaid household production have both been declining as a share of GDP for decades. Thus, a proper accounting of these excluded sectors actually subtracts 0.2 percentage point per year from properly measured GDP growth, rather than adding to it. Of course, we care about productivity for the purposes of this report. The interpretation there is positive, but only very slightly. Because the unreported economic output tends to be materially less productive than official output, a declining underground economy means that a proper accounting of productivity growth has been as much as 0.1 percentage point faster per year than the official estimate over the past several decades.

Exhibit A: U.S. after-tax corporate profits at record high



Source: Haver Analytics, RBC GAM

Fortunately, this muted finding is not the end of the story. There are a number of other arguments as to why true productivity growth is likely faster than the official figures:

- Surging corporate profit growth has easily outpaced economic growth over the decades (Exhibit A).[1] This offers a hint (but nothing more) that official GDP and productivity growth may have been undercounted in recent years.
- The service sector is becoming substantially more important over time, and is notoriously difficult to measure. How does one even begin to measure the economic output of a bank, for instance, let alone the government? Statistical techniques adapt to changing conditions with a lag, leaving elements of the service sector perpetually under-measured.
- Repeated studies have found that the official inflation figures overestimate true inflation in large part by failing to incorporate the deflationary effects of new technologies sufficiently quickly into the price basket. Because productivity growth is derived from real GDP, and real GDP comes from nominal GDP less inflation, any overestimate of inflation is also an underestimate of productivity growth.
- On a related front, statisticians still fail to fully capture the rising quality of technological products. An hour of internet usage today offers a much higher quality of service than it did in the past. The bandwidth is higher, the total data downloaded will almost certainly be higher,

[1] As a counterpoint, revenue growth has not outpaced GDP growth, rendering a somewhat murky interpretation.

and the range of online content is exponentially greater. These are unrecorded productivity gains.

- Every year seems to bring an ever greater kaleidoscope of products to choose from, and a greater variety of ways to consume it. This better selection increases the odds of finding just the right product. Being able to consume your favourite TV show or film with the click of a button is surely worth something, even if just in the sense of leisure more productively spent.
- Prices regularly fail to capture the full economic value of a product. Theoretically, people don't bother to buy something unless it is worth more to them than the asking price. This unrecorded "consumer surplus" is often small, but sometimes it can be profound. The surplus has arguably grown in recent years as the "economy of free" – a myriad of free or nearly free services – have cropped up on the Internet, ranging from Wikipedia to online news to social networks. These free services clearly have a value greater than zero, and so productivity gains are not fully captured. Even where ads or fees create an implicit cost for the user, it is usually well below the consumer surplus. Various studies calculate that the consumer surplus from information technology has grown to over US$100 billion per year in the U.S., or at least 0.5% of GDP. Others conclude that productivity growth may now be as much as 0.2 percentage point per year faster than the official numbers show.
- Productivity figures capture process improvements more easily than product innovation. It is easy to observe that a factory is now producing more goods without changing the number of machines or workers. It is much harder to determine how much productivity has risen when a factory switches from an old product to a brand new product. Some believe product innovation has accelerated over the past few decades, meaning productivity figures may be underestimated.

APPENDIX B
WELL-BEING

GDP and productivity, even when properly measured, are not perfect arbiters of our well-being. They fail to reflect the impact of debt, the environment, inequality, leisure time, health and personal safety.

Debt: Global indebtedness rose markedly for several decades, halting its upward ascent only recently. The acquisition of this debt permitted a temporary boost to GDP that, if anything, damaged well-being given the need to eventually pay the money back.

Environment: Environmental destruction is not captured directly by GDP, but certainly matters to well-being. Water and air pollution has declined precipitously in the developed world for decades, but carbon emissions are becoming an ever-more-pressing problem. It is more uniformly negative for emerging economies. These collectively leave a mixed interpretation, but ultimately a slightly negative one.

Inequality: A country's well-being would hardly be the same if all of the money were in one person's hands. Thus, the degree of inequality matters. The increased inequality visible within countries in recent decades argues that well-being has not kept pace with GDP, particularly since the poor generally enjoy a higher return on each dollar deployed into health and education. However, the assessment becomes less negative when contemplated from an international perspective, as inequality has actually declined between countries. Sharply declining poverty rates in middle-income and low-income countries demonstrate that even modest income gains can sharply reduce poverty rates (Exhibit B).

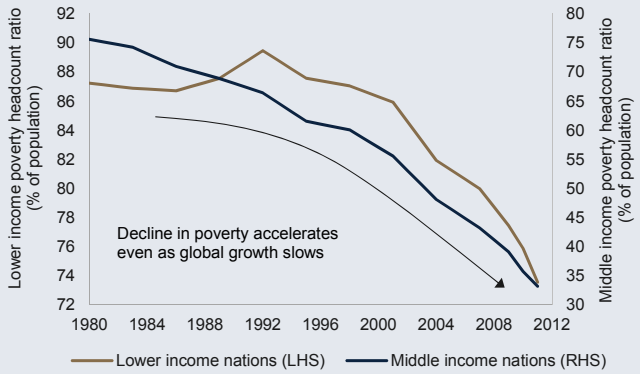
Leisure: A large fraction of leisure goes uncounted in GDP, yet provides enormous benefit to well-being. Surely there is value in time spent not working, be it lazing around or engaging in hobbies. As the world's population ages, the retired fraction of the population will continue to grow. Society as a whole is set to experience a marked increase in leisure (Exhibit C), even if the prophecies of Appendix D do not come true.

Health: Although median real income levels have stagnated in the developed world for several decades, health outcomes have generally improved. Longevity continues to rise. Even in the poorest of developing economies, infant-mortality rates have enjoyed a significant decline despite underwhelming economic growth. These are hugely important welfare gains that are not fully captured in GDP.

Safety: Despite perceptions to the contrary due to blanket media coverage, the developed world is a much safer place than it was a few decades ago. Rates of violent crimes are almost universally down.

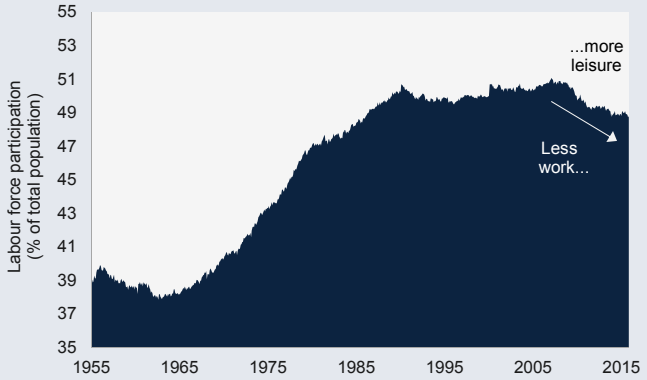
When we assess these collectively, we find one factor (debt) that argues well-being is rising less quickly than GDP, two (environment and inequality) that make a mixed but ultimately negative assessment, one (leisure) that makes a weak positive argument, and two that reach a clearly positive conclusion (health and safety). Thus, we conclude that well-being may be rising slightly more quickly than even properly measured productivity figures would suggest.

Exhibit B: Well-being is likely improving faster than GDP



Note: Poverty threshold is set at $3.10 a day based on 2011 PPP.
Source: Haver Analytics, RBC GAM

Exhibit C: Structurally less work = more leisure



Source: Haver Analytics, RBC GAM

APPENDIX C
TECH CHANGE AT THE INDUSTRY LEVEL

Technological change has already had a revolutionary effect on the retail sector, displacing book stores and record shops, and increasingly biting into other retail categories (Exhibit D). This process has ample room to continue given that just 7% of retail sales are conducted online. Fundamentally, the allure of e-commerce is that it enables much greater transparency, providing buyers with the opportunity to secure the cheapest price and offering a better sense of quality via user and expert reviews.

The media and entertainment sectors have been substantially undercut by free competition, the rise of citizen journalism and pirating. Going forward, a large swath of the service sector suddenly seems similarly ripe for disruptive technological change.

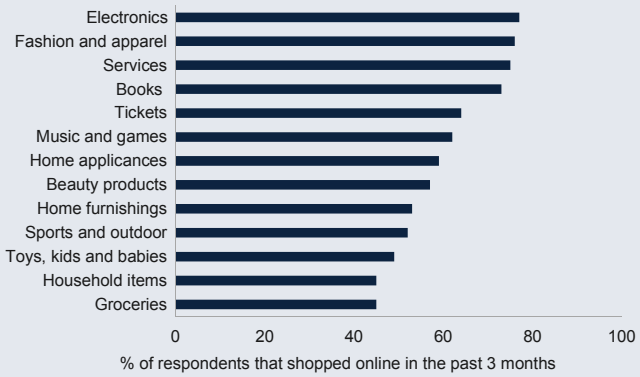
Manufacturing may also evolve quite quickly, if more due to robots and automation than the Internet and algorithms that threaten other sectors.

Several additional themes warrant exploration. A winner-take-all economy seems to be forming, at both the worker and corporate levels. While the forces of creative destruction have always pushed out tired old companies in favour of innovative new ones, it seems that a multitude of old firms are being replaced by only a handful of new ones. The arrival of Amazon in the retail space is a good example, and illustrates the incredible scalability of the new breed of businesses. For investors, this means it isn't enough to invest in the right sector – they must also identify precisely the right company within it.

Within sectors, the declining power of "brand" – as consumers are able to more easily vet actual quality rather than rely on a company's reputation as a proxy – is a significant disruption.

Disintermediation – removing the middle man from transactions – is another theme. For books and many types of merchandise, this effectively means buying straight from the wholesaler online, without the need for physical shops. Do-it-yourself online property listing will reduce the need and/or pricing power of real estate agents. LinkedIn and a variety of job-listing sites reduce reliance on traditional head hunters. With peer-to-peer lending, people can lend and borrow directly from one another, without the involvement of a bank. The list goes on.

Exhibit D: E-commerce is becoming more pervasive



Note: % is the global average of the U.S., U.K., Germany, Japan, India, Brazil, Russia, China, South Africa and Nigeria. Source: A.T. Kearney Connected Consumer Study, RBC GAM

A final theme is the "sharing economy", which captures the idea of renting goods and services rather than buying them outright. Burgeoning examples abound. Apartments can be rented out on a short-term basis via services like Airbnb, or for a longer period via other services. Cars (and drivers) are effectively rented via Uber. It is becoming more common to rent luxury goods rather than pay an enormous amount for something that might be worn only a few times. Depending on how the self-driving car evolves, one line of thought is that there could be a wholesale shift from vehicle ownership to renting once transportation can be summoned for any purpose and duration with the click of a button. Fundamentally, why own rather than rent a lawn mower or a tool when it is only used for a few hours a year? At the most existential level, it is possible to "rent" a worker for a specific task via a variety of websites. Most of these pursuits were not practical before the Internet made matching transaction partners so easy. These are all opportunities for people and entrepreneurs, but challenges for existing companies in each sector.

Exhibit E reviews the constellation of changes afoot in a wide range of sectors.

Exhibit E: Tech change at the industry level

Sector	Change	Size of sector pivot	Effect on incumbents	Opportunity
Retail	Internet shopping increases transparency of prices and quality; provides new competition; offers scope for niche products; sharing economy	Massive	Displaces many incumbents; empties malls; lowers margins	Scalability and network effects create only a few big winners; others must focus on niche success
News	Many new online media sources; new advertising methods; rising variety of content; niche targeting; low price or cost-free	Massive	Displaces many incumbents; drastically lower margins	Provide specialized content (niche subject matter or geography)
Entertainment	Streaming of entertainment; rising content quality; niche targeting; new pricing models; self-publishing; pirating	Massive	Displaces many incumbents; eventually more profits to go around	Spectacle of live theatre/concerts; streaming business; online ticket sales; niche focus
Advertising	Online advertising captures market share, allows incredible targeting	Massive	Google has stranglehold on online advertising; incumbents are left with rest	Online advertising; niche advertising
Military	Drone technology; cyber warfare; self-navigating vehicles	Massive	May revolutionize warfare	Rapid change in military expenditures
Transportation services	Demand-sensitive ride-hailing pricing, better quality assurance; self-driving car; self-driving transport truck; package delivery	Massive	Displacement of taxi medallion owners; eventual displacement of taxi drivers and truck drivers	Fractured industry to become more concentrated; package delivery
Information technology	I.T. driving productivity gains; entering many other sectors	Massive	Big opportunity, but smaller nimble firms also threaten when network effects/scalability have not locked down category	Continue disrupting other sectors
Education	Improved testing; improved teacher analytics; Internet and video conferencing should allow all to be taught by best teacher & curriculum – improves quality and offers incredible scalability	Massive	Price increases to slow; brand name quality premium to persist, lower prestige schools to struggle	Invest in technologies that improve quality of testing, student/teacher analytics, scalable education solutions
Manufacturing	Automation to continue reducing costs and lowering reliance on labour	Massive	Cost savings; developed-world manufacturers compete more equally with emerging markets	Invest in robotics; developed-world manufacturing
Health	Self-diagnosis on internet; robo-surgeries; lab-on-a-chip; health tracking; computer diagnosis; electronic record-keeping; synthetic biology; analytics	Moderate	Incumbents to be more reliant on acquisitions of new medicines from smaller firms	New, smaller companies to generate many of the new technologies and drugs
Motor vehicles	New competitors (tech + Tesla); electric car; self-driving car; sharing economy; possible undercutting of dealer model	Moderate	Incumbents can survive but there might be reduced to mere assembler for tech firms	Keep pace with tech innovation in sector; disruption to dealer sales model
Finance	Non-banks skirt regulations; robo-lending; ETFs; online functionality; peer-to-peer lending; new payment systems; big data; open source; heavier capital requirements; tighter bank regulations	Moderate	Sector function essentially unchanged, but with new technologies to improve/speed processes, new profitability headwinds	New entrants provide real competition in wealth management and payments; but banks have trust of clients and will largely acquire new technologies
Energy	New types of oil and gas production; rapid tech improvement in renewables; electric car; battery technologies	Moderate	Traditional energy production still cost effective; but electric car threatens type of energy needs	Further investment needed in renewables, battery tech; potentially new pricing model
Law	Low-cost plain-vanilla law services; AI assistance in research	Moderate	Displaces small law firms; AI helps sophisticated firms	Low cost plain vanilla law services
Utilities	Low oil and gas prices; renewables boom; improving battery technology; electric car	Minimal	Lower peak demand for power with better battery tech; modest threat from non-utility grid-connected renewables; but opportunity with electric car	Expand renewables and natural gas; invest in battery tech; electric charging stations
Telecom	Smartphone revolution; increased data usage; less voice usage; lower voice prices	Minimal	Incumbents largely remain, with shift in sources of profitability	Focus on data; further EM growth
Hospitality	Peer-to-peer property rentals; sharing economy	Minimal	Does not seriously displace hotels; potentially greater restaurant demand	Restaurants and hotels seem durable amid tech change

Source: RBC GAM

APPENDIX D
AUTOMATION AND EMPLOYMENT

A perpetual fear associated with technological change – the so-called "Luddite fallacy" – is that it will result in massive job losses as machines replace people. Fortunately, this fear has repeatedly gone unrealized. Increased farm mechanization and efficiency has undeniably displaced millions of agricultural workers (Exhibit F), yet unemployment failed to rise as other sectors happily absorbed the excess labour.

Manufacturing employment has suffered in more recent decades, but once again there has been no material surge in unemployment as these workers were absorbed elsewhere.

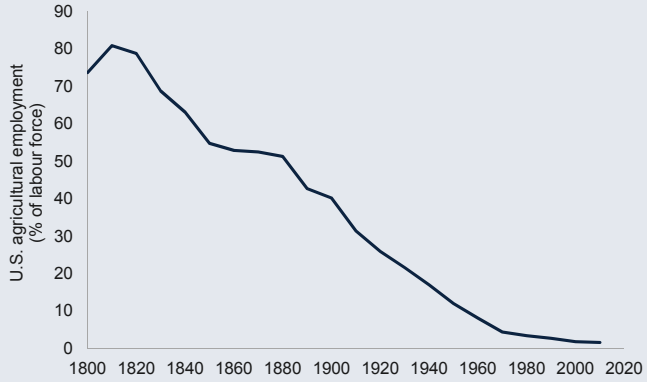
However, the story may not end in quite so cozy a fashion. The world is now changing in rapid and unprecedented ways. The long-derided threat of technology-induced job losses on an economy-wide scale may actually be on the cusp of coming true. The correct analogy may not be the successful repurposing of farm workers but the absolute obsolescence of workhorses after the introduction of motor vehicles in the early 20th century.

One initial symptom of a profound shift is that real wages have now been underperforming productivity growth for some time. The gains are accruing disproportionately to the owners of capital, and less so to the operators of capital. Some estimates attribute as much as half of the wage underperformance to the effects of technology.

Automation is still in a nascent state, and seems capable of stretching significantly further. Robots and computers can already perform many tasks at a higher level than people, and their capabilities continue to grow by leaps and bounds (Exhibit G). At the same time, robot costs are falling. Human abilities, in comparison, are relatively static. As noted earlier, robot cost-competitiveness is outpacing humans by an additional 7% to 8% each year.

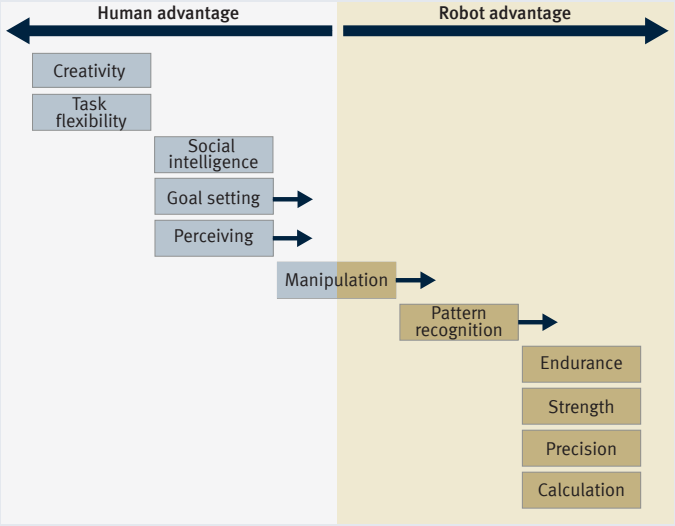
It is one thing when robots can perform a few tasks better than people, but something very different when they start to do many things better – and more cheaply. The next set of technological advances seem set to bleed into occupations that were previously shielded from these forces, such as clerks, cashiers, truck and taxi drivers, warehouse workers and soldiers. Given all of this, it does not require a great leap of the imagination to arrive at projections of large scale job losses. A widely-cited

Exhibit F: Falling U.S. farm employment did not spur mass unemployment



Source: NBER, Federal Reserve Bank of St. Louis

Exhibit G: Humans versus robots



Note: Arrows indicate shifting relative advantage. Source: RBC GAM

Oxford University study estimates that 47% of U.S. jobs are at a high risk of being automated away within the next 20 years (Exhibit H). This risk may take longer to manifest in emerging economies, but is ultimately no less significant.

Let us be clear, however, that unemployment rates would not rise as high as 50% even if half of all existing jobs were destroyed since there are always new sectors being formed with their own labour needs.

Moreover, many jobs should prove resistant to automation given the requirement of task flexibility – for instance, a waiter must be able to make a personalized recommendation, take an order, deliver the food, open a wine bottle, replenish the bread, mop up the spilled soup and make change.

Humans are also still materially more creative than robots, have a higher social intelligence and are far better at goal setting. As a NASA report once famously quipped, "man is the lowest-cost, 150-pound, nonlinear, all-purpose computer system which can be mass-produced by unskilled labor."

But even with all of these qualifiers, it still seems quite possible that widespread job destruction will eventually result from this automation trend.[1] Providing an indirect confirmation of this assessment, the majority of the companies floating to the top of this new technological world do not have large staffs.

Businesses may view this automation trend as a source of profit growth for now, but they risk eventually running out of customers. As such, automation and the potential for widespread job losses presents a challenge to all parties.

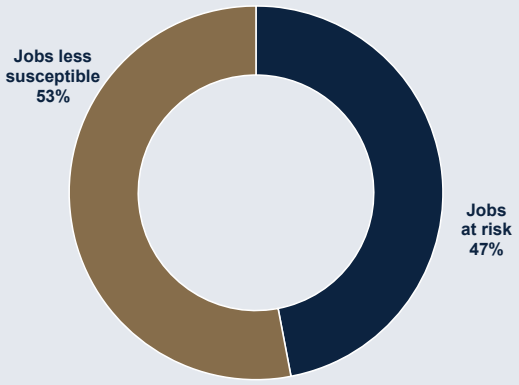
Policy remedies

What can be done? Unlike horses, people vote, and in extreme scenarios, they revolt. It is therefore unlikely that an underclass of mass unemployed will be allowed to rot. Society will have to (try to) do something about it.

While many approaches may be taken, the most obvious and conventional strategy is large-scale government redistribution of money to the structurally unemployed, financed via substantially higher taxes on the owners of capital who benefit from automation, and perhaps also in the form of higher taxes on high-income workers who benefit from their collaboration with machines.[2]

Another potential policy strategy would be to pursue large-scale "make work" projects, be they infrastructure-oriented or government-funded services (more social workers, street cleaners, park gardeners and tourist greeters).

Exhibit H: Almost half of U.S. employment may be replaced by machines



Note: Jobs at risk are U.S. jobs that the authors expect could be automated over the next 20 years. Source: Frey and Osborne (2013). "The Future of Employment: How Susceptible Are Jobs to Computerisation?", Oxford Martin School Working Paper, RBC GAM

Further strategies might include banning technologies that prove particularly disruptive to employment – though this is a slippery slope and without question productivity-deterring – or incenting the development of technologies that support workers rather than replace them.

Optimistically, human ingenuity may yet find a creative solution that we cannot yet fathom.

Scenarios

The best-case scenario in an automated future is a world that has managed to largely shed the drudgery of work, permitting more leisure time, a greater focus on family and friends, and enabling a world of hobbyists, artists, philosophers and inventors, free to pursue their passions.

In contrast, there are two very bad scenarios. The first is a world that proves incapable of rescuing the structurally unemployed, resulting in an irreparable fracture to society and widespread poverty. The second is a world in which financial transfers prevent destitution, but decay, delinquency and malaise nevertheless set in without the structure and purpose of work.

[1] Furthermore, wage rigidities – the difficulty companies have in reducing worker wages – may result in greater unemployment when a lower wage might otherwise have enabled workers to remain competitive with machines.

[2] This might hurt productivity growth given the disincentive of higher taxes on productive investments.

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