THE NEW LONG LIFE

CONTENTS

INTRODUCTION

Human history is an impressive tale of collective achievement. Over thousands of years we have substantially increased our numbers, our lifespan and the resources available to us. We are today far richer and far healthier as a consequence.

Human ingenuity is at the heart of this progress, bringing improvements in knowledge that, embedded in new technologies and education, creates new possibilities and new opportunities. Fire, agriculture, writing, mathematics, the printing press, the steam engine, electricity, penicillin and computers are just some of the innovations that have propelled our standard of living upward.

While human ingenuity has driven these improvements, progress has not always been smooth or swift. Sometimes it is painful, protracted and tumultuous – both for individuals and for society.

Take for example the switch around 10,000 years ago from foraging to farming. In the long run people became richer and healthier, but the transition to the new technologies of farming created a drop in living standards that persisted for centuries. During the UK's Industrial Revolution a similar lag occurred, when living standards failed to improve for many in the first few decades of technological disruption. The human burden wasn't just economic, it was also psychological. As a consequence of industrialisation people relocated away from their families and traditional communities into fast-growing cities, often lacking support and security. They also had to learn new skills, adopt novel roles and identities and often alienating ways of working. For many experiencing this transition, a sense of progress would have felt very distant.

Both these transitions share a common pattern: human ingenuity created technological advances which undermined existing economic and social structures which, in response,

required a different form of human ingenuity – *social ingenuity*. If technological ingenuity creates new possibilities based on new knowledge; then social ingenuity devises ways of living that enable these inventions to improve collectively, and individually, the human lot.

But importantly, social ingenuity does not automatically flow from technological ingenuity. And without social ingenuity, technological ingenuity does not bring unalloyed benefits. That is why the historical pattern of progress and improvement is more evident viewed in retrospect than through the perspective of those experiencing the shift. It is also why periods – when a gap appears between these two types of ingenuity – are characterised by anxiety, transition and social experimentation.

THE FRANKENSTEIN SYNDROME

We are living through a period where the gap between technological and social ingenuity is growing wider. Technological ingenuity is racing ahead, but social ingenuity is lagging and as a result our social forms – the structures and systems that are the context of our lives – have not yet caught up. We might be dazzled by the imminent promise of what technology can achieve, but we are anxious about the social consequences.

In Mary Shelley's novel *Frankenstein*, the creation of Dr Victor Frankenstein rebels and kills his maker. Today there is also a sense of a 'Frankenstein syndrome', fears that our very own human technological triumphs will rise up against us and create not human progress but human misery. In other words, that technological ingenuity is about to manifest itself so powerfully and rapidly it will overwhelm our way of living and we run the risk of losing our jobs, our livelihoods and even our sense of what it is to be human.

Media stories are full of such warnings – '800 million jobs lost globally through automation by 2030',[1] 'more than half of US jobs at risk'.[2] And these fears are not just economic, they are also existential. Stephen Hawking believed: 'The development

of full [Generalised Artificial] intelligence could spell the end of the human race' – a fear shared by figures including Bill Gates and Elon Musk. Shelley's novel is a cautionary tale of human knowledge and ingenuity.

Concerns around human ingenuity are not simply restricted to technology. There is also a profound unease about longevity. During the twentieth century, human ingenuity, through major public health improvements and staggering medical developments, significantly increased the length of life. At the beginning of the century a girl born in the UK could expect a lifespan of around fifty-two years; by the end of the century this had increased to eighty-one years – (and by 2010, eighty-three). By 2050 there will be more than 438 million people in China over the age of sixty-five (that's more than the current population of the US); in Japan 1 in 5 people will be over the age of eighty. But rather than celebrate these extraordinary achievements, the fear is that an aging society will bankrupt countries, destroy pensions, increase health costs and lead inevitably to a weaker economy. We fear human ingenuity and worry that the advancement of knowledge will undermine human life and well-being.

These concerns about human achievements backfiring are understandable but we believe they are also limiting. Given the historical record, surely there are ways that can be found to ensure that humanity benefits? Shouldn't smart new technologies and longer, healthier lives be considered opportunities and not problems? In the words of Joseph Coughlin, head of AgeLab at Massachusetts Institute of Technology (MIT): 'The greatest achievement in the history of humankind, and all we can say is, is it going to make Medicare go broke? Why don't we take that and create new stories, new rituals and new mythologies for people as they age?'[3]

The challenge is that for these benefits to be really felt, social ingenuity must be as widespread and as profound and innovative as technological ingenuity. That means each of us must be ingenious: be prepared to question norms, create new ways of living, build deeper insights, experiment and explore. And that also means that our institutions – be they

governments, education or corporations – must also rise to the challenge of social ingenuity.

It is this need for social ingenuity that is the fundamental motivation for us writing this book. Our hope is to ignite a conversation about what it is we as humans would like to achieve in response to new technologies and longer lives and how we might seek to flourish in the coming decades. We want to support you as you consider what is likely to happen in the years ahead; to intrigue you about the forms social ingenuity could take; and to provide you with the tools to proactively navigate the transitions and upheavals that we are all experiencing.

SOCIAL PIONEERS

Discussions about how our future will be transformed invariably focus on the phenomena of 'the rise of the robots' and an 'aging society'. What is noticeable about these expressions is how *impersonal* they are. They are about machines or about 'the other'. Yet the human ingenuity required to make these developments work for all of us will be fundamentally *personal.*

That is because the seemingly impersonal aggregate trends of longevity and technology are exerting an enormous impact on what it means to be human. As we will show, they are shaping when and if we marry, the ways we combine family with work and distribute tasks between genders; what we learn, how we learn and who we learn from; how we think of our careers and jobs and piece together our working identity; what we do at each stage of our lives and how we construct a life narrative.

These fundamentals of human life are inevitably changing. The question you face is: What is it you want them to change to?

With millions of others facing the same dilemmas and asking the same questions, this is now becoming fertile ground for social ingenuity. What is clear is the past will not be a good guide to the future. The traditional choices of past generations

are unlikely to be appropriate; and the social structures that traditionally served as the framework for living may no longer be capable of delivering. You will need to both understand these trends and also have the courage and motivation to act on this knowledge. Whatever your age, as longevity and technology place us in novel circumstances, we need to be prepared to experiment as individuals but also collectively as families, as corporations, as educators and as governments.

We must all be prepared to be social pioneers: this is the message at the heart of this book.

EVERYBODIES

We view these changing circumstances through the eyes of a cast of fictional characters – our 'everybodies'. Our hope is that through them you will be able to forge deeper insight into your own life as well as draw connections between broader social trends and your own choices.

Our 'everybodies' are:

Hiroki and Madoka: a young mid-twenties Japanese couple living in the city of Kanazawa who are looking for a new way of living as a couple over a long life but feeling constrained by their parents and societal expectations.

Radhika: a single college graduate in her late twenties working as a professional freelancer in Mumbai. She is enjoying the freedom of the gig economy and has already defied social norms, but realises she has tough choices ahead of her.

Estelle: a thirty-year-old single parent with two children. She works part-time as a cashier in a high-street supermarket chain in London, and in the evenings works in a local nursing home. She would like more regular and stable work.

Tom: a forty-year-old truck driver from Dallas, Texas, who lives with his wife and adult son. He is keeping

abreast of developments in the technology of autonomous vehicles and is wondering what impact this will have on his job.

Ying: a divorced fifty-five-year-old accountant in Sydney, who has just heard that she has lost her job. The work is being automated and her age and length of service make her too expensive to keep on. She needs to work for financial reasons and feels she has many more productive years left in her career.

Clive: a seventy-one-year-old retired engineer living just outside Birmingham in the UK. He retired at sixty-five and is enjoying life with his wife and family, including four grandchildren. He worries about managing his finances in retirement and hopes to re-engage with work as well as his local community.

OUR PROPOSITION

The genesis of this book began with the many conversations we had following the success of our previous work, *The 100-Year Life – Living and Working in an Age of Longevity*. We discovered that whilst people talked about the impact of longer lives, invariably it was the *combination* of technology and longevity that was the source of many questions: as careers lengthened, where would jobs come from? Would robots take away our jobs? What would this mean for careers and the different stages of life? It seemed to us that although we had advanced a more positive agenda around 'aging', there were deep fears and concerns around technology that needed to be addressed. Avoiding the Frankenstein syndrome is hard.

Our hope is that our combined perspectives of an economist and a psychologist will provide a breadth of insight needed to more fully explore the interactions between technology and longevity and the social ingenuity required to ensure humanity can flourish. In Part I: Human Questions, we explore the interaction between technology and longevity by examining the staggering recent achievements in Artificial Intelligence (AI) and

robotics, considering the trends in life expectancy and health and then reviewing how society is aging. We use our everybodies as a lens to imagine the questions these developments trigger and the set of choices they create. These achievements impact significantly on how we construct ways of living that enable human flourishing. In other words, they are a profound invitation to social ingenuity.

The crucial question though is social ingenuity for what purpose? Clearly the overarching aim is to achieve human flourishing. But how do we design new social forms? and on what basis will these social forms be judged? Economic prosperity has to be a part, and we must think about how we can build the resources to finance a good life. However, any positive social reform should fundamentally be capable of delivering on deeper aspects of what it means to be human: to support the development of a cohesive and positive human narrative; to enable people to explore, to experiment and to learn; and to build and sustain relationships with others. These three principles of Narrate, Explore and Relate form the basis for the analysis laid out in Part II: Human Ingenuity, which outlines the steps each of us needs to take to adjust to this new long life.

As we outline in Part II, there is much that you as a social pioneer can achieve on your own. Yet the choices you face and the decisions you make are embedded in a wider context of partnerships and interactions. This holds especially true for your interactions with educational institutions, companies and governments. In order for everyone to flourish there needs to be significant institutional change, and in Part III: Human Society, we lay out the deep-seated changes that need to occur to our economic and social system. There is an immense pressure for change, an agenda that is becoming clearer, and a profound need for both individual and collective action.

PART ONE

HUMAN QUESTIONS

1

HUMAN PROGRESS

Whether it's using a wheel or boiling a kettle, across history humans have used technology to make their lives easier. For each generation the word 'technology' is assigned to unfamiliar new developments – those they imagine will usher in a new age.[1] Today we use it most often in connection with computers which, powered by a quartet of 'laws', are seeing their abilities transformed.

CREATING EXTRAORDINARY TECHNOLOGY

In 1965 the co-founder of Intel, Gordon Moore, conjectured that computing power[2] would double every eighteen months. This observation, 'Moore's Law', has proved to be remarkably accurate and with this dramatic increase in power has come a host of innovations, including autonomous vehicles. If this exponential growth holds, then in the next three years the computational power of autonomous vehicles will rise a further fourfold – making today's versions look rudimentary and limited.

It seems that the world around us is on the verge of being transformed by machines that are improving at a staggering rate. But will Moore's Law continue? The technological challenge is increasing the number of processing units on a chip, which are now so small that the limits of nanotechnology are being reached, threatening a slowdown in the rate of increase. Some experts are forecasting that Moore's Law will even come to an end within the next five years.

The irony is that even as growth in computing power is feared to be slowing, belief in the technological power of AI and

robotics has sped up. Parallel technological developments are exploiting the gains Moore's Law has already achieved and it is the combined impact of these new technologies that will reshape the economy, the work you do and how you live your life.

One of these complementary technologies is the size of the bandwidth through which information can be distributed. The American technologist George Gilder predicts that bandwidth will grow at least three times the pace of computing power. This 'Gilder's Law' implies that if computing power doubles every eighteen months, then bandwidth doubles every six months. The result has been an explosive growth in Internet traffic. By 2018 this was estimated at 1.8 zettabytes[3] – substantially more than all the words humans have written in their entire history.

When bandwidth grows, so the numbers of network connections increases. As Robert Metcalfe, the inventor of the Ethernet, observed in 'Metcalfe's Law', the value of a network rises in proportion to the *square* of connected users. That means if the number of connected users doubles, the value of the network rises more than fourfold. This explains the astonishing expansion of Facebook and YouTube – the bigger the network, the more attractive it becomes to new users.

What supercharges this growth even further is an observation by Hal Varian, chief economist at Google.[4] 'Varian's Law' explains how the sheer breadth of freely available existing technologies creates the possibilities of valuable combinations of existing ideas. For instance, driverless cars in some sense require no new technologies but just 'mash-ups' of existing technologies such as 'GPS, Wi-Fi, advanced sensors, anti-lock brakes, automatic transmission, traction and stability control, adaptive cruise control, lane control, and mapping software'.[5] The more such technologies exist, the wider the variety of mash-ups available to exploit, and the more valuable the combinations – and, as a consequence, the more rapidly entrepreneurs will seek to bring them to market.

It is this combination of the underlying technological capabilities described in Moore's, Gilder's, Metcalfe's and

Varian's laws that is bringing about the unprecedented and accelerating developments in robotics and Artificial Intelligence. The result isn't just new products, but also new ways of operating, the emergence of new sectors of the economy and shifts in value, and a dramatic change in the nature of the jobs that are available.

Will machines take our jobs?

Tom drives a truck in Texas and is hearing more about autonomous vehicles. He knows something about them and has even seen them on occasion moving around the streets where he lives. During his working life he has already experienced major changes to the navigation, tracking and fuel efficiency systems of the trucks he drives – but this time it feels different. He is aware of the investments being made by leading technology companies such as Alphabet, and automotive companies like BMW and Tesla, and ride share companies such as Uber. By October 2018, Alphabet's self-driving car Waymo had already racked up more than 10 million miles of driving on public roads.

Tom's home state of Texas is one of twenty-two US states that have already embraced regulations which allow autonomous driving test runs as a precursor to possible full-scale adoption. It seems to him more a matter of *when* and not *if* autonomous vehicles will become mainstream. He has also read the early press releases from the investors in autonomous vehicles; these claim that compared to humans, autonomous vehicles are more reliable, less error prone and have no need of a break. When drivers' pay and benefits account for nearly 40 per cent of shipping companies' costs, the economic incentives behind autonomous vehicles are obvious. There are also broader social benefits: in the US, over 4,000 people are killed each year in crashes involving trucks.

All of this makes Tom nervous about the future of his job – along with many of the estimated 4 million people in the US who work as drivers. With some studies suggesting full automation will reduce employment in this sector by two-thirds,[6]

Tom's worry about his job seems reasonable.

Many others, like Tom, are becoming aware of the impact of robots on their job. The word 'robot' was first introduced in Karel Capek's 1920 science fiction play *R.U.R*. The origins are from the Czech word *robota* – meaning forced labour or drudgery. Consistent with this original definition, robots are adept at taking on repetitive and dull tasks. Today more than 2 million robots operate around the world, mostly in manufacturing, with the highest concentration in South Korea where there are fifty robots for every thousand people. This concentration will rise even further with entrepreneur Elon Musk anticipating 'the alien dreadnought' factory, a production line with no people. As he explains, 'you can't have people in the production line, otherwise you drop to people speed'.[7]

Improvements in the technological quality of robots and further declines in their price will inevitably lead to robots replacing workers beyond the manufacturing sector. In the service sector you may already have met 'Pepper', the diminutive childlike machines that Softbank introduced in 2014 in its Tokyo branches. Across the city, Pepper is used as a receptionist or greeter in a range of banks and offices, welcoming customers and providing basic information about services. The robot reduces employment costs and frees up the sales team to have longer and more focused conversations with their customers.

The range of possible service-sector applications is vast. Henn-na hotel in Japan describes itself as a robot hotel, with a head robot chef (Andrew) that specialises in making *okonomiyaki* (Japanese omelette) and others which check guests into the hotel and help with their luggage.[8] Meanwhile in California, 'Sally' is a robot that makes salads; 'Flippy' is a robot that flips burgers; 'Botlr' works in hotels providing extra towels and toiletries; while Italian firm Makr Shakr is developing a robot bartender. Technology's ceaseless march to solve humanity's problems even led Domino's in 2016 to provide the first drone-delivered pizza in New Zealand – a peri-peri chicken and cranberry pizza delivered to a couple in Whangaparaoa, New Zealand.

You can certainly expect to be served by a robot – will you also be cared for by one?[9] By 2030 the likelihood is that you will, and in countries such as Japan, with declining and aging populations, robots will provide that extra pair of hands that family and friends can't. You can also expect to find robots in your home, taking care of basic tasks like vacuuming, paying bills, and automatically ordering your daily needs from food to medicine.

What qualifications will be needed to safeguard careers?

For much of history, human ingenuity created tools that augmented and substituted *physical power* – the stone axe, the wheel, the spinning jenny. Using machines that augment or substitute *intellectual power* is altogether more revolutionary and harder to understand. Advances in Artificial Intelligence are bringing technology into a cognitive arena which traditionally has been the preserve of humans.

Smart machines have of course been around for a while. In 1979, VisiCalc was launched: this was the first fully working version of the now ubiquitous computer spreadsheet. It replaced literal spreadsheets – large 11 inch by 17 inch sheets of paper on which a clerk added rows and columns of numbers, a time-intensive process subject to human error. Much has changed since 1979: crucially, the current generation of smart machines make their own calculations in order to achieve set goals, as opposed to following predefined rules to perform specific tasks.

Enabling this goal-directed breakthrough has been machine learning (ML), which rather than a sequential form ('if – then') of calculation uses algorithms, usually a neural network.[10] This means machines can compute their own understanding of a problem and adapt to changing circumstances. In doing so, AI mimics some of the operations of the human brain – but does so more quickly. This shift to ML makes full use of the quartet of laws which together enable the fast transmission and processing of vast amounts of information.

Consider the AlphaGo program that in 2017 defeated Lee

Sedol, the eighteen-time 'Go' world champion. AlphaGo was created by DeepMind, a British AI company acquired by Google in 2014. Three different versions of AlphaGo were created: Lee, Master and Zero.[11] The Lee and Master versions were, to different degrees, trained by being provided with the rules of the game, knowledge of past matches, human guidance and instructions provided by experts. Zero, by contrast, was simply given the rules of the game and instructed to play the game a large number of times itself, thereby devising its own playing strategies. In other words, AlphaGo Zero was its own teacher. Over forty days, AlphaGo Zero played 29 million games, building up a database unrivalled by any human player. Within four days it was outperforming AlphaGo Lee; within thirty-four days, it was beating AlphaGo Master.

What's fascinating is that AlphaGo Zero was able to develop strategies that were qualitatively different to those used when humans play. As the creators wrote: 'In the space of a few days, starting *tabula rasa,* AlphaGo Zero was able to rediscover much of this Go knowledge, as well as novel strategies that provide new insights into the oldest of games.'

While VisiCalc was programmed to quickly and reliably perform complex calculations, AlphaGo instead was instructed to achieve a goal – win the game. It uses in some sense judgement and intention to effect outcomes beyond human capability.

It is this combination of ability and intent, replacement and augmentation that means, regardless of whether you are a cashier, a truck driver, a lawyer or a financial advisor, the nature of your job will change profoundly. With that, of course, comes the risk of job losses – with spreadsheets came the loss of around 400,000 bookkeeping jobs.[12]

Ying is an accountant in Sydney and is experiencing this first-hand. Her firm's investment in AI brought a dramatic reduction in employees needed in the account-processing department, which Ying managed. Her plan had been to work until she retired at sixty-five, but now at fifty-five she has been told to find another job in the next six months. Ying feels she is well qualified with a bachelor's degree in accounting and a

postgraduate qualification as a chartered accountant, but despite making several job applications she hasn't been asked for a single interview. Previously it has been those with less education who have been most impacted by technology but Ying, even with her professional qualifications, is struggling.

Estelle works as a cashier in a London supermarket and is facing similar problems to Ying. As ever more customers use the self-service checkout, the time doesn't seem far away when her own store will copy the Amazon Go convenience stores and introduce a no cashier policy. That worries her as she receives a limited financial contribution from her ex-husband, who has already lost his warehouse job to automation. To supplement her income, Estelle is working night shifts in the local nursing home. Her friends have suggested that she work there full-time, but that role requires a qualification that takes two years. She has already dropped out of two evening courses and feels she has neither the time nor the money to go down that route.

Ying and Estelle show the breadth of the educational challenge society faces as technology and longevity combine forces. Educational institutions will need to evolve and provide new courses and support to help them with such challenges. Governments too will have to extend their involvement in education to support lifelong learning.

In which areas will humans outperform machines?

If the quartet of laws continues, then future technologies will make AlphaGo seem as limited and unexciting as VisiCalc does to us today. Whilst current machines are smart at performing particular tasks such as chess, Go, and poker, they are not really intelligent in a way a human is.[13] Human brains are incredibly well adapted to asking and framing questions, posing hypotheses, switching between a variety of different problems, and imagining future possibilities. With this in mind, the ultimate goal is General AI (AGI) – machines that can successfully achieve any intellectual task a human can. The breakthrough moment for AGI will be achieving 'the singularity' – this is the point when machines are capable of inventing

machines smarter than themselves, leading to an inevitable rapid development cycle until these machines become vastly more capable than humans in all dimensions.

In contemplating this future, it's important to make a distinction between AI and AGI. Many of the bleakest views – economically, socially and existentially – are informed by potential developments in AGI, which suggest an unnerving world where machines are better at everything than humans. However, research is currently far from this point and even fairly basic tests, like identifying road signs in pictures that CAPTCHA[14] demands, outwits most AI. Exactly when or even if AGI will emerge is subject to much debate. MIT's Max Tegmark quotes a survey of computer scientists whose estimates range from between a few years to never.[15] The average estimate is that AGI will be developed by 2055 – within the possible lifetime of anyone currently below the age of sixty. But until the advent of AGI, humans will have advantages over machines.

As AI advances, the type of skills and jobs where humans outperform machines will inevitably change. Hans Moravec of the Robotics Institute, Carnegie Mellon University, visualises this with a metaphor of the 'landscape of human competence'. Imagine a map of islands and sea with the contours of the map representing human competence. The higher the elevation of a peak, the more pronounced is human competence. Now imagine the current sea level represents the tasks AI can already perform. Over time, the sea level rises and ever more areas of human competence are lost to the surging tide of AI proficiency.

Those human competences that are already submerged include arithmetical calculations in spreadsheets, pattern recognition and playing chess and Go. The water level is currently lapping on the shores of the human competencies of translation, investment decisions, speech recognition and driving. By the time you read this book these areas may already be under water.

The areas of human competence first conceded to machines are those involving routine and programmatic tasks. The higher, more impregnable peaks include more 'human'

aged over one hundred is the fastest-growing demographic group across the world.

Madoka is in her twenties and as a Japanese woman is one of those who define best practice life expectancy. Whilst life expectancy in the UK and US has in recent years been declining,[18] in Japan it continues to rise. Between 2010 and 2016, life expectancy for Japanese women aged sixty-five increased at a rate of eight weeks a year, roughly 1.5 years a decade.

Madoka lives in one of the most developed countries of the world – what can Radhika, living in India, expect? She doesn't yet have the same chance of reaching a hundred but developing countries like India are experiencing even more dramatic *increases* in life expectancy as they catch up with the richest countries. So Radhika can expect to live a great deal longer than her parents. In India (and China) over the last fifty years, life expectancy has increased by twenty-six (and twenty-four) years. That's a much faster *rate* of increase than in rich countries – equivalent to five years in every decade. The life choices that Radhika's parents made offer little guidance to Radhika given how much longer she can expect to live. Madoka and Radhika will have to do, something that neither their parents or grandparents ever had to do namely to try and structure and finance for a potential hundred-year life.

How can we stay fit, healthy, active and engaged for longer?

Radhika and Madoka welcome these gains in life expectancy but they want to live these added years in good health. At seventy-one, Clive is much fitter and healthier than his parents were at that age and is looking forward to many more years of life. Yet whilst some of his older friends are in good health, others are struggling. He is wondering how to spend his retirement to maximise his chances of remaining in good health.

In most countries, the good news is that the majority of these years of extra life are healthy. Broadly, the proportion of life spent in good health has remained at least constant as life

expectancy has improved,[19] and in many countries it has increased. For example, in the UK between 2000–14, life expectancy increased by 3.5 years, of which 2.8 years were healthy (on a self-reported basis). Looking forward, a UK study estimates that by the year 2035, more than 80 per cent of those aged 65–74 will be living free of chronic conditions (today it's 69 per cent).[20] More than half (58 per cent) of those aged 75–84 can expect to do the same (today it's 50 per cent). This improvement in how we age means that these extra years of life have not been inserted at the end of life, simply extending a period of frailty. Rather it is as if late middle age and early old age has been extended instead.

The challenge is that as people live longer, they tend to suffer more from non-communicable diseases, such as Alzheimer's, cancers, respiratory problems and diabetes. They are also more likely to experience these simultaneously, leading to a rise in 'co-morbidities'. It is important though to distinguish between two distinct effects. If we compare a fifty-year-old and an eighty-year-old, the older person is more likely to suffer from non-communicable diseases and co-morbidities; but over time, because people are aging better, an eighty-year-old today is less likely than an eighty-year-old twenty years ago to suffer ill health.

Should Madoka and Radhika plan for an even longer life than Clive and their parents? In the debate about technological innovations and the likely continuation of Moore's Law, there are arguments that past trends can't be expected to continue into the future. The same debate is taking place for those who study longevity. Some experts believe life expectancy has reached a limit and may now even fall as diabetes, obesity and rising resistance to antibiotics take their toll. Others point out that whilst evolution has helped remove many genetic abnormalities, it has never really had an influence on old age as this occurs after humans are reproductive. This matters because, if gains in best practice life expectancy are to continue at their historical rate, it will require an acceleration in the rate of improvement of the survival chances of older people.

However, even under these pessimistic assumptions, many


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in the years ahead. Some of the most optimistic researchers even believe *longevity escape velocity* could be reached: that happens when life expectancy increases by more than a year every year. If this were to occur, humans would be entering the realms of immortality. Lifespans of 500 or 1,000 years are startling, but the most likely immediate pay-off from this research will be improving *health span* by slowing down the rate at which chronic conditions and non-communicable diseases arise. This offers the extraordinary possibility of remaining healthy until the final moments of life.

The foundational principle here is that how we age is malleable and not fixed. Historically, osteoporosis and Alzheimer's were considered a normal part of aging but are now classified as diseases by the World Health Organisation. Will the same eventually happen to aging itself? If so, it would be one of the most outstanding displays of human ingenuity in history. There have already been some fascinating results: research has managed to increase the lifespans of worms tenfold,[24] and longevity gains have also been achieved in mice and dogs. The big question is whether these results will carry over into humans.

Although progress is being made, the signs of escape velocity remain some way off. There are obvious challenges to testing treatments on humans, especially as the success can only be known at the very end of life which implies lengthy trials. However, given the growing interest and research in the area, it seems plausible that treatments will be developed that continue to contribute to further increases in health span and potentially lifespan. If best practice life expectancy is to continue to increase at the same rate as the past fifty years, then these scientific breakthroughs will be needed.

What will be the impact of longevity on families and communities?

Madoka in Japan and Radhika in India can expect to live longer than their parents, and a great deal longer than their grandparents. As the same happens to millions of other people

These demographic shifts are also having an effect not just on the structure of the population but also its size. Whether a population is growing, static or even declining depends on the stage of the country's demographic transition. Many African countries are at an early stage of the transition where mortality rates are falling faster than the birth rate and so the population is increasing. Take Nigeria, which in 1950 had a population of 38 million. By 2017 this had grown to 186 million with half of the population under the age of fifteen, and only 3 per cent over the age of sixty-five.

As countries move through the demographic transition the birth rate declines to a similar level as the mortality rate and population growth begins to slow. In some cases, where the birth rate goes below the mortality rate, more people are dying than being born and so the population starts to decline. In 1950 there wasn't a single country at this stage – between now and 2050 it is estimated that more than fifty countries will see population decline.

In Japan and China, where the fall in fertility has been very pronounced, the population size has and will decline dramatically. Madoka knows this already, she reads constantly in the press about the shrinking Japanese population – from a high in 2004 of 128 million, to an expected 109 million by 2050, declining to 84.5 million by 2100. When Ying talks to her relatives in China, they are also aware of this. Currently the population is 1.36 billion; forecasts suggest that by 2050 it will have declined to 1 billion people.

How can everyone remain economically productive and work for longer?

Madoka worries about what this will mean for the economy too. All things being equal, for every 1 per cent fall in population, there is a 1 per cent fall in GDP growth. So if in Japan the population declines to 88 million by 2065, this would result in a decline of 30 per cent from its current value. This means that over the next fifty years, GDP growth will be lowered by around 0.6 per cent per annum. Across the world this issue is rising up


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for individuals it raises profound questions about how to live life so as to age as healthily and happily as possible.

How can constructive intergenerational relationships be forged?

Hiroki is in his early twenties and both his parents are alive, as are all four of his grandparents. Whenever his family gathers together, he and his cousins feel both young and outnumbered. Compared to past generations, Hiroki has fewer siblings, fewer cousins and so family gatherings are less dominated by the young. Hiroki and Madoka are very mindful that although they may have fewer children than their parents, they will have substantial obligations to older relatives.

The obligation that Madoka and Hiroki feel to their family is reflected at the society level in terms of the possibility of intergenerational conflict. Government policy around the world is changing to accommodate longer lives: retirement dates are being pushed back, pensions reduced, and taxes increased. But, from an intergenerational perspective the worry is that whilst the younger generation are paying higher taxes to finance the pensions of the old, they will have less generous pensions for themselves. One UK study estimates that over their lifetime, future generations will be worse off by nearly a £100,000 in terms of lower benefits or higher taxes.[28] All this is occurring at the same time as economic growth seems to be slowing compared to that which their parents experienced.

Concerns about intergenerational equity are not restricted to public finances: the young will also inevitably experience more transitions and work for longer. They may also find that a university qualification will not be a sufficient entry to a professional job. In some subjects, the graduate wage premium is becoming non-existent.

As technology and longevity change the fundamentals of how we live and work, social ingenuity will be crucial to find ways to make good the promises made to past generations, while also offering progress and opportunity to the young. We have to ensure that the young and old equitably share the burdens and

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