The Surprise that Transforms. An American Perspective on What the 2040s Might Bring

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ABSTRACT

Each long wave peak has been followed by a cluster of paradigm-shifting innovations that transform every aspect of work and life. We expect that the next peak of c. 2036 will also be followed by a decade-long cluster of innovatory changes in energy sources and use, artificial intelligence and robotics, widespread use of virtual realities, usage of block-chaining, and laying the foundations for a new age of exploration into and beyond the solar system.

The question is which new technologies will accompany the Kondratieff Wave that is emerging out of the deep deflationary depression of 2007–2011. Assuming that this wave unfolds in the same manner as the four industrial-era waves that preceded it, we predict that the next stagflation crisis will occur surrounding the next Kondratieff peak *c.* 2036 and will be followed by a cluster of innovations – a technological revolution – in the decade that follows, producing yet another paradigm shift in both economy and society.

The basis of this assertion is diagrammed in Fig. 1. Berry's long-wave clock embraces three mode-locked Kuznets investment cycles and six Juglar business cycles, as documented elsewhere (Berry and Dean 2012, 2015). The last technological revolution

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occurred after the 1980–1981 stagflation crisis and centered on innovations which changed behavior, sparked yet more innovations, created new industry and changed the ways we think and behave. The top four of these paradigm-shifting innovations of the 1980s is as follows:

1. Internet, broadband, www (browser and html).
2. PC/laptop computers.
3. Mobile phones.
4. E-mail.

These led to changes in every aspect of business and social relations in the years that followed. Together with the industries the new internet platform created on an international scale, these core innovations made possible a long list of consequential innovations that further accelerated economic change and social reorganization. We list them as follows:

5. DNA testing and sequencing/human genome mapping.
6. Magnetic Resonance Imaging (MRI).
7. Microprocessors.
8. Fiber optics.
9. Office software (spreadsheets, word processors).
10. Non-invasive laser/robotic surgery (laparoscopy).
11. Open-source software and services (*e.g.*, Linux, Wikipedia).
12. Light-emitting diodes.
13. Liquid crystal display (LCD).
14. GPS systems and geospatial science.
15. Online shopping/e-commerce/auctions (*e.g.*, eBay).
16. Media file compression (jpeg, mpeg, mp3).
17. Microfinance.
18. Photovoltaic solar energy.
19. Large-scale wind turbines.
20. Social networking via the Internet.
21. Graphic user interface (GUI).
22. Digital photography/videography.
23. RFID and applications (*e.g.*, EZ Pass).
24. Genetically modified plants.
25. Bio fuels.
26. Bar codes and scanners.
27. ATMs.
28. Stents.

29. SRAM flash memory.
30. Anti-retroviral treatment for AIDS.

There undoubtedly are others of equal salience. Even a cursory glance at the list reveals certain broad clusters of sometimes overlapping technologies, including gene sequencing and analysis, information and communication technology, energy and the software revolution. One is also struck by how much such technologies are, in the year 2015, taken for granted as many of us find ourselves immersed in such breakthroughs that are now decades old.

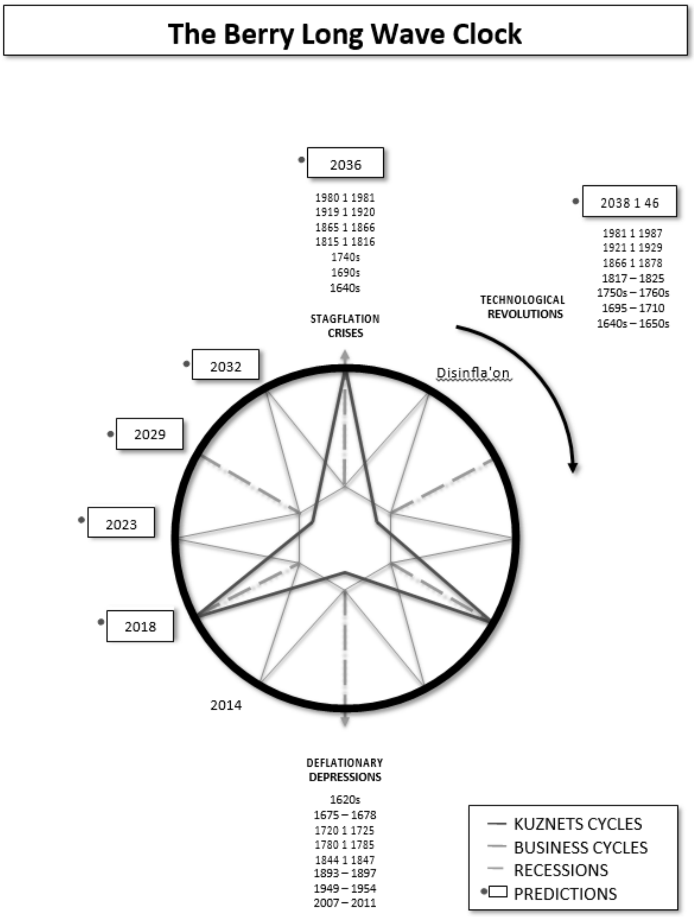

Fig. 1. The Berry Long Wave Clock

The model in Fig. 1 depicts the 55.8-year Kondratieff wave (K-wave) as a 24-hour clock which begins at midnight amidst a deflationary depression, shown at the bottom. Prices rise over the ensuing quarter century to peak at midday amidst a stagflation crisis, shown at the top. This is followed by a quarter century of disinflation leading downwards into the next deflationary trough. Mode-locked within this 55.8-year rotation are three Kuznets investment cycles (and six Juglar business cycles. Recessions occur in the six Juglar troughs (dotted lines), three of which coincide with the peaking-out of Kuznets cycles and one with the deeper deflationary depression. System-transforming innovatory clusters repeat once per K-wave, occurring in the decade following a Kondratieff-peak stagflation crisis. The model also shows predicted times for future events in the K-wave that is now unfolding.

LOOKING BACKWARDS

Fig. 1 also shows that prior technological revolutions also occurred in the decade following a Kondratieff peak. Proceeding backwards they were:

1921–29. 'The Roaring Twenties', when the transforming innovations were automobiles, aircraft and consumer durables produced on mass production lines, plus internal combustion and oil. Mechanization transformed agriculture, releasing labor for industry and land from producing feedstock for animals.

1866–78. 'The Gilded Years', when the transforming innovation was mass production of steel, accompanied by coal and steam power and the construction of heavy-duty railroads, producing the first wave of industrial urbanization and high-rise steel frame skyscrapers in the major central cities.

1817–25. 'The Era of Good Feelings', marked by use of wind and water power, construction of canals and improved waterways, clipper ships and first-generation steamboats, plus first stage industrialization stemming from the textile-industry inventions of the Industrial Revolution and the onset of the American System of Manufactures using replaceable parts.

Earle (1992) argues that the same Kondratieff-based periodic structure can be identified further back in American history. He identifies three more epochs, each of which transformed the nature of agriculture and therefore society in North America:

From the 1740s to the1750s. 'The Neomercantilist Era' during which direct grain trade with Europe led to the 'Golden Age of Colonial Culture'. In Britain the 1740s marked the beginning of an Agricultural revolution in which enclosure of open fields and the introduction of turnip/clover crop rotations significantly increased agricultural productivity, and these changes spilled westward over the Atlantic.

From the 1690s to 1700. An era of crop diversification changed the monocultural tobacco economy of the Virginias. Rice production began in the Carolinas to feed the new plantation labor force.

From the 1630s to 1640s. Tobacco topping and new curing methods significantly increased plantation productivity in Virginia but led to growing demands for slave labor. Sugar production introduced to Barbados.

If Earle is correct, analogous Kondratieff rhythms should be traceable farther back into history, for example in the 1590s in England after the crisis that culminated with the defeat of the Spanish Armada in 1588, before that in the 1530s, *etc.*

THE PERILS OF PREDICTION

Looking backwards carries with it a certainty that is absent when the attempt is made to forecast technological futures. As Deutsch (2011) has noted, the ability to forecast the technologies that might exist in some distant or even not-so-distant future is nearly impossible. Since we cannot possibly know what scientific advances will be made, say, five years from now, it becomes foolhardy to predict the technological advances that may flow from these discoveries. The IT Revolution of the 1980s dramatically changed society and culture, but during the preceding decades most leading entrepreneurs failed to predict what was to follow:

> 'I think there is a world market for maybe five computers.'
> *Thomas Watson, President of IBM, 1943*

> 'Television won't be able to hold on to any market it captures after the first six months. People will soon get tired of staring at a plywood box every night'.
> *Darryl Zanuck, executive at 20th Century Fox, 1946*

> 'There is no reason anyone would want a computer in their home.'
> *Ken Olsen, founder of Digital Equipment Corporation, 1977*

Even in the aftermath of the key innovatory changes of the 1980s the same clouded foresight has persisted:

> 'Almost all of the many predictions now being made about 1996 hinge on the Internet's continuing exponential growth. But I predict the Internet will soon go spectacularly supernova and in 1996 catastrophically collapse.'
> *Robert Metcalfe, founder of 3Com, 1995*

> 'Apple is already dead.'
> *Nathan Myhrvold, former Microsoft CTO, 1997.*

And even more recently:

> 'Two years from now, spam will be solved.'
> *Bill Gates, founder of Microsoft, 2004*

Admittedly, predicting future Kondratieff Wave technologies is fraught with risk as Deutsch emphasizes in his excellent work, *The Beginning of Infinity* (2011). The history of similar kinds of predictions is not especially favorable. No society has ever been able to successfully predict its own technological future. No futurist writing in the year 1950 predicted the biotechnology revolution resulting from the discovery of DNA just three years later, or the idea of ubiquitous global communications via a system of interconnected computers using software protocols that could not even be imagined in the 1950s. The exponential increase in computing power over the years that resulted in the ability to put supercomputer computing power in the hands of the average citizen through increasing miniaturization was inconceivable in the 1950s. No one spoke of nanotechnology except for a handful of theoretical physicists, and even they, individuals like Richard Feynman, did not see the consequences of their theoretical musings. The ability to manipulate matter at the molecular level, or the ability to manipulate biological material at the level of DNA, simply did not exist.

On the other hand, no self-respecting futurist of the early 1950s would have failed to include in their predictions the near certainty of human interplanetary spaceflight. Nearly all futurist scenarios assumed humans on Mars in a few decades, bases on the moon, giant orbiting space stations, flying cars (some of us are of a certain age to remember a popular American cartoon show, 'The Jetsons', that captured perfectly the optimism about the future). None of these scenarios proved to have a great deal of veracity. The excitement of the 1960s about space travel, captured so vividly by the 'Star Trek' generation, gave way to the apathy and loss of political will on the part of the US in the 1970s as human space flight was relegated to the back burner and a half-hearted effort to substitute robotic exploratory probes was substituted in their place, although in fairness to the unmanned space effort, there were enormous scientific advances borne of the missions to Mars and Jupiter, and even beyond. Yet the sense of excitement that might have come with a 'New Age of Exploration' was missing as human centered deep space travel was shelved, and a great 'turning around' at least in the West, has taken place. Today, the great hope (again, at least in the West) for human-centered space travel may lie with the private sector. Meanwhile, other non-Western societies and cultures appear deeply energized if not enthralled by the prospects of space exploration, as China and Russia lay plans for deep space exploration, and as India, a nation on the brink of being a technological superpower, begins to develop substantial space capabilities.

We all assumed in the 1950s and 1960s that nuclear power was the wave of the future. Cheap, safe, clean nuclear energy was taken as a given. Advanced nuclear fission reactors were expected, replaced within a few decades by the Holy Grail of energy technology, nuclear fusion. No one anticipated the succession of accidents and near-accidents that terrified western publics and that led to the near paralysis of nuclear power deployment in the West. Three Mile Island, Chernobyl, and later Fukushima, served to create a culture of fear in the West that has crushed hopes for a nuclear future. Moreover, the vast technical obstacles to controlled nuclear fusion, not to mention commercially viable fusion power, were not seen. Interestingly, while the West has retreated in the energy technology space, just as it, and especially the USA has retreated in the realm of human space flight and exploration, nations like China, India, Brazil and Russia are moving forward with massive nuclear fission deployment. The decades of the 2040s and 2050s will probably witness the kind of nuclear technology advancement in these countries that should have happened in the West 30 or more years ago. It is even possible that these nations will achieve the heretofore unexpected breakthroughs in fusion technology that will make the latter half of the twenty-first century the fusion century.

The failure of the dream of space travel and nuclear power are two examples of prediction gone awry. The failure to predict biotech and nanotech are the examples of technologies that arose that no one anticipated. There are other examples of technologies that were unknown 10–15 years ago and that will very soon dominate our lives. Hydraulic fracturing ('fracking') has revolutionized the American energy sector and is on the verge of making the US energy independent. Yet the essential technological foundations of this technology have been understood for decades. It has only been in the last decade or so that the economic incentives justified actual deployment to the nation's oil and gas extraction systems. Another example is the development of drone technology. Ten years ago no one even considered the use of drones for anything other than military purposes. Today there is a panoply of drone systems, and soon we will have an entire ecology ranging from the size of insects to several kilogram behemoths. These are increasingly being deployed for agricultural, environmental, health-related and a host of other functions and will increasingly have the ability to coordinate with each other and with other systems through what is becoming known as 'the internet of things'. Integrated with ubiquitous monitoring and surveillance systems, including the massive video coverage provided by small CCTVs, drone systems are being integrated into a complex network of devices that will provide real time feedback to powerful computational systems that will allow for constant improvement in the deep learning algorithms so prominent in increasing power of AI systems. Yet another example is the deployment of AVTs or autonomous vehicle technologies. These self-driving vehicles, merely an engineer's dream a few years ago are now being deployed on some highways, and will become a common feature of the automotive space by 2030.

It is no surprise that it is nearly impossible to predict the evolution of technology and the emergence of technological innovations.

One can conceptualize the economy as a self-organizing system that adapts and changes as its constituent elements interact in often unexpected and unanticipated ways. Kaufman (1993, 2000) conceptualized the economy as an econosphere in which technologies are born, live, mutate and die, depending in part on the fitness of the technology in question. Another way to think of the economy is by using the 'Lego' analogy, whereby the economy can be viewed as countless lego parts capable of combining and recombining a multiplicity of ways. And, as the number of 'objects' in the economy expands, the number of possible combinations expands as well. This concept of recombinant innovation is described admirably by Weitzman (1998), using the example of genetic recombination. The Internet can be thought of as a self-organizing system, as it adapts, changes and evolves in response to the countless interactions of literally billions of users. Such self-organizing systems cannot be predicted with any kind of precision. Even short-term prediction is difficult, and long-term prediction is impossible, again reinforcing Deutsch's argument.

SO WHAT MIGHT BE NEXT?

The point here is that technologies we are increasingly taking for granted were not even on the technological radar screen just a decade or so ago. Who knows what the next few years will bring? At the core of each industrial-era Kondratieff were transformations in energy usage (from wind and water to coal to oil to natural gas), in modes of transportation and communications (from animals to railroads to roads and airways to the Internet), and in replacement of human labor by machines. In keeping with such historical precedents we hypothesize that the transformative surprises of the next innovation wave will also include the transition to a new and different energy future, to radical changes in transportation and communications, and to the replacement of human by artificial intelligence. We discuss each in turn, accepting as axiomatic that nanotechnology and new graphene-based and other sheet-like materials such as molybdenum disulfide and phosphorene will ensure further miniaturization of whatever these new technologies are.

THE ENERGY FUTURE

It is less shortage-driven price rises for oil and gas that may impel a shift to different energy futures than political pressures at both the local and global levels. The Green Movement, combined with continuing global warming fears, maintains its vigorous assault on both internal combustion and on the nuclear fission alternative, while the rise of the Islamic State continues to threaten much of the global oil and gas supply. Two alternatives have appeared, exemplified by Elon Musk's battery-powered lithium-ion electrical systems and the possibility of a shift to a hydrogen economy. More speculative is the capture and storage of solar energy using Dihydroazulene-Vinylheptafulvene Systems and its release as heat for creating steam.

At present electric utilities work is a ‘just in time’ environment: electricity is produced as it is needed, delivered from power plants to consumers via a wired grid as required-not stored. Elon Musk has introduced a first-generation ‘Powerwall Home Battery’ that offers 7- or 10-KWh of storage that allows consumers to store energy they produce with a solar array and go off the grid if they choose. A lookalike ‘Powerpack’ is available to meet the needs of small business.

The idea of energy storage has been around for many years, but Musk's is the first practical venture, and offers possibilities for the three segments of the storage market: utilities, commercial and residential. At the utility scale, huge batteries could be built into the grid to balance energy demand and supply, making the entire system more resilient and efficient. Electricity generation could move from a relatively small number of big plants to ‘virtual power plants’ – small solar, wind and other installations around the country – because they would be able to store what is generated in batteries connected to the grid. Commercial customers could maintain a bank of batteries to reduce what they draw from the grid, particularly at peak times, when power costs more. Residential consumers would need rooftop solar panels, using power as it is generated and storing excess generation for times without sunlight. Musk's innovation offers a first step in this direction. The typical American home consumes around 30 KWh/day, so individual Powerwalls are insufficient, but this will surely change. Musk's Powerpack systems are scalable, meaning that three interconnected 10 KWh batteries could meet the demands of the typical household at a current cost of US$ 10,000, but with widespread adoption a Moore's Law of battery storage would kick in, prices would decline, and the world could be freed of fossil fuel dependence – particularly if vehicular fleets also are electrified either following Musk's Tesla automobile example, which needs utility-serviced recharging facilities, or via the emergence of a hydrogen economy.

Hydrogen, the most abundant element in the universe, is not found in a pure form; it must be produced from other materials, such as natural gas, biomass, or even water, consuming energy to do so. The vision of a hydrogen economy is one of using hydrogen as a low-carbon energy source for transportation and heating. Hydrogen can be produced in a fuel cell using low-carbon renewables to produce electricity. The only by product is water, but only around half as much electricity comes out of the fuel cell as was put in to produce the hydrogen in the first place. The rest is lost as heat. Despite this, hydrogen fuel cell cars have returned to Southern California, where there now are several hydrogen fueling stations. Instead of a plug-in battery that draws power from the electrical grid, fuel cells generate power from an electrochemical reaction between onboard hydrogen and oxygen in the air. Clean water trickles out the tailpipe as the only byproduct. This combination of a fuel cell and an electric motor is 2–3 times more efficient than an internal combustion engine. The current generation of vehicles has 300-mile ranges between recharges. Constraints include developmental-stage costs and thus the requirement of heavy subsidies, and the associated lack of any refueling station network.

Today, hydrogen is produced for two principal uses, half in the Harber process to make ammonia and half to convert heavy petroleum to lighter fractions. In a future full hydrogen economy, primary energy sources and feedstock would be used to produce hydrogen as stored energy; the production could be centralized and/or distributed. While generating hydrogen at centralized primary energy plants promises higher hydrogen production efficiency, difficulties in high-volume, long range hydrogen transportation makes electrical energy distribution attractive. In such a scenario, small regional plants or even local filling stations could generate hydrogen. While hydrogen generation efficiency is likely to be lower than for centralized hydrogen generation, losses in hydrogen transport could make such a scheme more efficient in terms of the primary energy used per kilogram of hydrogen delivered to the end user.

ARTIFICIAL INTELLIGENCE AND THE SECOND MACHINE AGE

Each of the last technological revolutions has separated humans from manual labor. The process continues apace: almost 100 million Americans are not in the labor force and fully a third of all current jobs are expected to be taken over by robots in the next decade; all-robot manufacturing plants are now being introduced in skilled-labor short Southern China; experimental driverless cars and trucks are now on the roads; and many items now transported can also be end-user produced on 3-dimensional printers, significantly reducing the need for goods transportation.

First generation robots are computer-driven machines that not only replace manual workers, they also shift the balance of power in favor of employers. The normal response is to encourage workers to acquire more skills, or to trust that the nuances of the human mind or human attention will always be superior in crucial ways. But when machines enter the equation the standard response is not sufficient. Machines are used because in many cases they do a 'good enough' job while also being cheaper, more predictable and easier to control than humans. Technology in the workplace is as much about power and control as it is about productivity and efficiency (Tufekci 2015). The danger is that replacement of manual labor at this level will swell the ranks of welfare-dependent underclass, leading to centralized power to ensure stability in progressively larger redistributive states, or to widespread social unrest triggered by the resulting inequality. Many predict that the jobless future will be one in which artificial intelligence enhances the control potential of the robots themselves.

Artificial intelligence is the intelligence exhibited by software embedded into machines. Control features include reasoning, knowledge, planning, learning, natural language processing (communication), perception, the ability to move and manipulate objects, and ultimately general intelligence – the ability to simulate the sapience of *Homo sapiens*. While a decade or so ago many were questioning the prospects for a breakout in AI technology, today advances are being made on a broad front. Driven by major theoretical breakthroughs in what is called 'deep learning' that emulates in important respects human cognition, a wide range of applications is taking shape. Advances have been such that remote medical robots assist doctors and robots surpass humans at a variety of games, including chess. At this level artificially intelligent robots not only take over blue collar jobs; they also start to take over white collar professions. The machines of the Industrial Revolution overcame the limitations of human muscle, while the robots and artificial intelligence of today are overcoming the limitations of individual minds. Experts are calling this movement the Second Machine Age. Today, as Tufekci (2015) writes, machines can process regular spoken language and not only recognize human faces, but also read their expressions. They can classify personality types, and have started being able to carry out conversations with appropriate emotional tenor. They are getting better than humans at figuring out who to hire, who is in a mood to pay a little more for that sweater, and who needs a coupon to nudge them toward a sale. In applications around the world, software is being used to predict whether people are lying, how they feel and who they will vote for. To cite one example, a simulated network of artificial neurons learned to play Atari video games better than humans in a matter of hours given only data representing the screen and the goal of increasing the score at the top, but no preprogrammed knowledge of aliens, bullets, left, right, up or down. With these capabilities experts see an intelligence explosion in which machines work independently to advance artificial intelligence, walking just like humans to improve their own capabilities, resulting in exponential increases in their intelligence. The fear is that super-intelligent machines will then deem humans to be superfluous, a continuing theme in contemporary science fiction in which the key concern is whether artificial intelligence can separate itself from human regulatory interaction, an independence that might be avoided in a world governed by 'collaborative intelligence' in which humans continue to do things that they are better at – pattern recognition and problem solving – while intelligent robots do the many things at which they are superior.

THE EMERGENCE OF VIRTUAL REALITY

Virtual reality is the ability to simulate physical presence in an alternative world – real and distant, or imagined. Most current virtual reality environments are displayed either on a computer screen or with special stereoscopic displays and some simulations include additional sensory information and emphasize real sound through speakers or headphones targeted towards VR users. Some advanced haptic systems include tactile information, generally known as *force feedback* in medical, gaming and military applications.

The technology is changing rapidly, stimulated by both computer gamers and the military. What is central is that virtual reality brings the experience to the individual rather than the individual having to move to the experience – one can experience and perhaps enjoy without the need to travel. This change is facilitated by modern Geographic Information Science (GIS) which is producing new Global Positioning Systems (GPS) technologies that identify real world locations within centimeters and permit globally-referenced 3-D rays and multiplayer virtual reality games in which highly accurate position and orientation are critical. Centimeter-accurate positioning systems are already used in geology, surveying and mapping, but the survey-grade antennas these systems employ are too large and costly for use in mobile devices. The breakthrough is a powerful and sensitive software-defined GPS receiver that can extract centimeter accuracies from the inexpensive antennas found in mobile devices.

Virtual Reality provides 'telepresence' and 'tele-existence' to users in simulated environments that can be similar to the real world in order to create a lifelike experience – for example, in simulations for pilot or combat training – or differing significantly from reality, such as in games. The technical limitations involve processing power, image resolution, and communication bandwidth, but the enabling technologies are becoming more powerful over time, especially as new fleets of GPS-capable satellites continuously monitor the earth and provide the opportunity for on-site experiences at remote locations. That Virtual Reality will advance is made clear by the variety of emergent uses – not only in fiction, gaming, or combat simulation, but throughout education as a historical tool, recreating past environments, or a geographical tool, experiencing what it is like to be somewhere else. Other applications are in architecture and engineering, fine arts and music, and as a therapeutic tool. One can also imagine the use of VR to occupy the times and imaginations of robot-displaced redistribution-dependent populations – but this needs more exploration by creative writers of science fiction.

FROM BITCOIN TO BLOCKCHAIN

In addition to the aforementioned technologies, other disruptive technological systems may be on the horizon. One of these that has already gained a substantial degree of notoriety is bitcoin. Bitcoin is a cryptocurrency that is used in peer-to-peer transactions that do not require some mediating or central authority. It is referred to as a crypto currency because in order for the technology to succeed transactions are encrypted to prevent some third party from gaining access to the information being sent. Bitcoin has gained its greatest visibility as a means of developing a currency that does not require central bank authority and control. In that sense, bitcoin is a disruptive technology that challenges the authority and prerogatives of the state. While it is far too early to know if digital currencies will eventually replace our current monetary and financial arrangements, it seems safe to say that, at a minimum, cryptocurrencies will find their way into mainstream society, and indeed are already present. What will be interesting is the extent to which we observe the emergence of hybrid financial and monetary systems consisting of traditional, digital and cryptocurrencies, private moneys competing with traditional systems.

However, bitcoin itself is merely the tip of the iceberg. The real importance of bitcoin lies in the underlying technology known as block chaining. Blockchains are a revolutionary new kind of information technology that may well have a vast array of users beyond those of digital currencies like bitcoin or other digitally-activated assets. Blockchains are a transparent permanent public ledger of transaction records, independently-verified and recorded, and available for inspection at any given moment (Swan 2014).

While serving as the foundation for bitcoin, or for possible future cryptocurrencies, blockchains could have extremely important applications in the development of smart, self-executing contracts and the development of what are known as DACs or distributed autonomous corporations. DACs, or DASs (distributed autonomous societies) are decentralized narrow-AI autonomous agents performing certain pre-specified tasks without any human involvement and acting under the control of ‘an incorruptible set of business rules’ (Swan 2015). Such technologies could transform the organizational landscape of society, from government to the private sector. They could become essential in managing a complex ecology of countless smart appliances and a rich and variegated combination of both biological and non-biological intelligences where the technology would provide a mechanism for these devices to communicate and negotiate with each other and establish pricing points for particular transactions.

The downside is to be seen in the discussions at the 2015 Bilderberg Conference that centered on the abolition of cash and the imposition of capital controls on ordinary citizens in the name of stopping tax fraud and allowing more state control over people's finances by giving central banks and governments the power to directly control finances under the justification of preventing an economic collapse and bank runs. At its most authoritarian extreme, this means having to obtain government permission every time individuals withdraw or spend a moderately large sum of money, bringing to fruition the day when people cannot buy or sell anything without government approval. Since Kondratieff waves result from the collective buying and selling decisions of individuals, the replacement of individual choice by government control would effectively terminate the associated economic rhythms.

FROM EARTH TO SPACE: LAYING THE FOUNDATIONS

While we can expect nanotechnology, biotechnology, advanced robotics and computing to be aided by enhanced computational capabilities, creating positive feedback loop, precisely how these technologies will come to be deployed lies beyond our event horizon. We are confident, however, that the effects of the next technology will not just be felt on Earth. We have addressed briefly some of the disappointments of those of us at a certain age who grew up dreaming of deep space travel and humanity's destiny in space. It has been a great disappointment to see these dreams put on the back burner by political elites who have seemingly lost any vision of what a New Age of Exploration might entail for civilization. At the same time, we remain hopeful as those original sparks of interest, while smoldering in the West, burn brightly in other nations and cultures who have their own aspiration. Over the next thirty years, the human race will increasingly find its destiny moving to Earth orbit, the lunar surface, asteroids and comets, and eventually to Mars and the gas giants of Jupiter and Saturn, before moving to the outer planets and eventually into the Kuiper Belt and even the Oort Cloud. Not all energy will be directed out into the solar system, but in toward the Sun, with Venus and Mercury and the space inside the orbit of Mercury. The 2040s and 2050s may see the beginnings of an early Type 1 civilization that is beginning to utilize the resources of the entire solar system rather than merely the resources of just one planet. Of course, not all of these activities will take place in the 2040s or 2050s, or even the immediately decades beyond, but the fundamental technological foundations will have been laid, and we can dream…

As to who will be leading this charge into the solar system and beyond, we suspect that new national and private sector actors will emerge. The old US-Soviet rivalry of the Cold War will give way to nations like China, India and Brazil along with Russia which, if it can maintain its political will, will likely play a leadership role. The USA will certainly play an important role as well, but given the vast array of problems sure to be faced by the US in the next decade or two due to the endemic deficit and growing sovereign debt problems, it seems unlikely the US will have the financial resources necessary to play a dominant role. Unmanned missions to Mars will continue and there may be a potentially enormous scientific windfall resulting from a successful robot exploration of Europa. At the same time, private sector actors can be expected to play a significantly more important role in the next several decades. Large corporate and multinational entities may well find sufficiently profitable prospects in the heavens to justify the kind of massive resource allocation necessary to establish a commercial presence in space.

Many technologies that will be developed over the course of the next few decades will likely play crucial support and ancillary roles. We may see the construction of one or more space elevators as a means of cheaply transporting humans and material into earth orbit. The development of smart materials, nanotechnology and super-strong carbon fiber material will facilitate the construction of structures located on the equator that will carry supplies into space. Meanwhile, biotechnological advances and robotics will play key roles in efforts to create more livable environments on otherwise hostile planetary bodies. Such technologies will also play an important role on Earth, in the eventual transformation of the oceans into permanent abodes for humans in underwater cities, and the increasing use of the polar regions to support permanent habitation.

With such foundations what will the new age of exploration look like? Effort will be directed toward exploitation of the absence of gravity and the vacuum of space for manufacturing. Large space manufacturing facilities will likely appear in the 2040s or 2050s both in relatively near earth orbit, in geostationary and Lagrangian points between Earth and the lunar surface, and on the lunar surface itself. These facilities will be staffed by robots and semi-sentient AIs.

There will almost certainly be mining ventures and other commercially-related activities on the Moon. But within a decade Chinese explorers will not only have landed on the Moon, but will have established the first permanent base there. By the 2040s, the Moon will be increasingly a component of an advanced economic web. One possibly critical lunar resource may be Helium-3, an element non-existent on Earth. This element could play a major role in powering advanced nuclear fusion plants if the technological problems surrounding fusion are resolved.

Additionally, the vast resources of the asteroids are not to be disregarded, particularly the NEOs (Near-Earth-Objects) that lie within a few million miles of Earth. Over the next few decades the job of shepherding asteroids and even comets into stable orbits around Earth from which they can be mined will be commonplace.

Looking beyond the 2040s and 2050s, the robotic exploration of the gas giants of Jupiter and Saturn and their moons, will accelerate. Europa, orbiting Jupiter, and Enciladus, likely contain vast oceans of water beneath their frozen surfaces. While the water may prove to be of enormous value, the possibility of discovering extraterrestrial life beneath the surface of these moons could lead to a revolution in biotechnology as we come to have a much better idea as to the chemical and biochemical processes of life.

Combined with nanotechnology and biotechnology advances, the standard technologies of Earth in the mid-twenty-first century will flourish in space. We can even envision nanotechnologically-sized spacecraft sent on deep space missions to land on distant moons, not only to explore but even to begin the process of transforming the surfaces of barren worlds in ways that will lead to human colonization over time.

Self-replicating Von Neumann-type probes and other replicator systems may not only be extremely important for deep space missions, but also for an increased focus on the inner solar system as Venus and Mercury are eyed with a view toward commercialization. There are areas high in Venus's atmosphere that are temperate and where humans could live comfortably, possibly in floating cities constructed of super-lightweight materials. Such cities could serve as the foundation for the mining of Venus, and may also serve as an initial starting point for the exploration of Mercury.

CONCLUSIONS

What does all this speculation mean? Will the 2040s bring to individuals a hydrogen-powered artificially intelligent virtual world poised to move outward to space or will the result be lives constrained by the Orwellian use of new information technologies and networks of sensors or monitors? This tension will surely be one of several competing futures, but there are many that we cannot yet imagine. The nature of paradigm-shifting technological revolutions is that at their beginning there is an entire basket of alternatives. Out of these one or two capture imaginations and take off to shape what we can only hope will be a safer, saner and more creative new world. We simply do not know, but of one thing we can be sure: whatever the surprise may be, it will transform.

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