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Capitalism Reinvents Itself

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If we know anything about capitalism, it is that it is flexible. Some commentators have drawn the inevitable parallel with software that is being constantly upgraded. Indeed, capitalism has survived not because it is inherently or invariably viable and efficient, but because it is adaptive: When circumstances have changed, it has simply reinvented itself.

To mention just the most obvious example, in the twentieth century it abandoned its commitment to free markets and *laissez-faire*, and was able to adapt to the perceived failures of free-market systems. Free-market capitalism proved unable to supply certain services such as health and education, to render a politically acceptable income distribution, and to deal with financial and macroeconomic instability. So it had to change. For better and for worse, the modern regulatory welfare state and free-market capitalism became bedfellows, and capitalism lives happily, if perhaps not ever after, in its current form. As circumstances change once more, one could expect that it will be able to adapt again. But will it?

The most dramatic transformation of capitalism occurred during the Industrial Revolution. Before 1750, roughly speaking, capitalist entrepreneurs made money primarily by exploiting commercial opportunities (buying low and selling high) and by taking advantage of underexploited resources. The Industrial Revolution opened a different window: technical innovation. In this new form of capitalism, entrepreneurs could make profits by venturing into something that had never been done before. They did so by taking advantage of the growth of useful knowledge, whether driven by the progress of science or by the sheer ingenuity of clever inventors. Technology, rather than finance or international trade, became the *primum movens* of capitalism.

Economists as different as Karl Marx and Joseph Schumpeter realized that industrial capitalism was different from commercial capitalism (though the two forms complemented each other nicely). The industrial economy could expand indefinitely as long as technology could keep expanding. Oddly enough, both men failed to fully recognize the adaptiveness of the economic system they so brilliantly described, and predicted (for very different reasons) the ultimate demise of capitalism. So far, they have turned out to be wrong. So much for predictions by economists. All the same, I shall rush in where these angels treaded carefully.

TALLER LADDERS

The history of the twentieth century shows that capitalism, in its diverse forms, was better capable of generating innovation and taking advantage of it than the command economies that arose to compete with it. The outcome was far from certain at the start, as the Soviets' achievements in the early space race and their ability to produce efficient military hardware were a source of great concern in the West.

Economists such as William Baumol believe that as long as the innovation machine is still working, capitalism will have a great future. There is no way of knowing this for certain: Professional historians know better than to mindlessly posit that "what has been will be again." Some economists, such as Robert J. Gordon and Tyler Cowen, predict that technological progress will slow down, because the low-hanging fruits have been picked and we will never again invent anything quite as useful as air conditioning or indoor plumbing.

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I disagree. Reflection on the history of technology suggests that technology—probably in some forms that we cannot fully imagine, let alone predict—will continue to grow and change. Maybe the low-hanging technological fruits have been picked, but is it not the function of science to help us build taller and taller ladders?

Futurists predict a variety of scenarios, from the "singularity" suggested by Ray Kurzweil, in which minds and machines merge into an undifferentiated mass, to the dystopias of unemployable masses leading empty lives ("the end of work") forecast by Jeremy Rifkin. As an economic historian, I take a different approach. I start with two fundamental propositions. One is that we cannot really afford (or even survive) a world of little or no technological change. The second is that the dynamics of technological progress are such that it is likely not only that innovation will keep advancing, but that it will do so at an ever more rapid rate. As a result, innovation of some sort will continue, presumably both propelling capitalism and compelling it to change again in new directions.

Biting back

Why is technological progress not only desirable but necessary? The wrong answer is: because a large part of the world has not been able to take full advantage of it yet. After all, if people in the developing world could emulate the lifestyle and technology available in the developed world, their living standards would eventually become comparable as well, and so no further innovation would be necessary, beyond tweaking the techniques to make them more suitable to other environments.

The correct answer is that technological change has a way of pushing back that requires further adaptation. It has an unusual dynamic: It solves problems, but in doing so it more often than not creates new ones as unintended side-effects of the previous breakthroughs. These problems in turn have to be solved, and so on.

An obvious historical example is energy technology. The Industrial Revolution of the eighteenth century increased the use of coal enormously, with steam power replacing water mills, windmills, and horses. The new form of energy was far more powerful, versatile, and efficient than the previous techniques in use, but in turn it created new environmental problems, such as London's famous smog. The solutions (mostly gas and low-sulfur coal) reduced pollution, but eventually it was learned that relying on hydrocarbons for energy in *any* form leads to climate change. So further technological adaptations will have to be found that avert the problem.

Examples of technology "biting back" (as Edward Tenner has called it) are everywhere, but are especially prominent in our struggle against harmful organisms such as pathogenic bacteria and insects. Attempts to poison the creatures run sooner or later into their becoming resistant, requiring new solutions that will drive them back again for a while. This bite-back does not mean that we will actually lose the battles against pests, just that there is going to be a continuing effort that requires us to run to stay in place, that progress always takes two steps forward and one step back, and that we cannot ever rest on our laurels.

Technological progress is to a large extent the story of unintended consequences. From asbestos to birth control pills to the chlorofluorocarbon gases that threatened the ozone layer, our ingenuity produces outcomes we never anticipated. Hence we need to have a highly adaptive system that can send and receive signals that something has changed, which can make the system self-adjusting.

In capitalism such signals take the form of market prices. They work imperfectly perhaps, but they work better than any other system. Most economists would agree that, left to its own devices, a market mechanism may not be up to the task; when aided and supported by democratic governments (themselves sensitive to signals and public demands), it has a chance. But that chance depends on technology becoming better and more powerful. Will it?

Artificial revelation

The answer to this question requires us to unpack the dynamic of technological progress over history. What determines the rate of progress over time? Needless to say, it is a complex issue on which many volumes have been written. A persuasive hypothesis was provided by the historian of science Derek de Solla Price, who noted that a rather simple but powerful explanation of scientific progress was the advance in tools and instruments at the scientists' disposal.

While surely many other factors come into play, Price pointed to what he called "artificial revelation." What he meant was that our senses limit us to a fairly narrow slice of the universe that has been called a "mesocosm": We cannot see things that are too far away, too small, or not in the visible light spectrum. The same is true for our other senses, for our limited ability to make very accurate measurements, and for overcoming optical and other sensory illusions, not to mention the limited computational capability of our brains. It was only through the invention of scientific instruments that we could see and do things that take us far beyond our senses and natural capabilities.

The scientific revolution of the seventeenth century had many aspects, but it seems clear that it was driven to some extent simply by a whole set of new tools that emerged in that century, led of course by the telescope and microscope. Equally important was the vacuum pump, through which scientists such as Otto von Guericke and Robert Boyle were able once and for all to demonstrate the possibility of a vacuum, in contradiction of Aristotle's obiter dictum.

That insight, together with the invention of the barometer (through which Evangelista Torricelli demonstrated the existence of an atmosphere), led to a new physics. The physics in turn made possible the first atmospheric engines built by Denis Papin in the late 1690s. The new science did not "cause" the steam engine—indeed, most of the science behind it had to await the development of thermodynamics in the mid-nineteenth century, much of it inspired by scientists observing engines. The interplay between science and technology is a two-way street.

Will capitalism be able to adapt to a new world of petabytes?

The evolution of modern chemistry a century later, similarly, depended on better tools and instruments. A surprising part of that development was the Voltaic pile, the first battery, built in 1800. It had no commercial application for many years, but chemists realized its potential for electrolysis and the elaboration of the chemical worldview laid down in rough lines by Antoine Lavoisier and John Dalton. The great English scientist Humphry Davy wrote of the Voltaic pile that it acted as an "alarm bell to experimenters in every part of Europe."

The nineteenth century, of course, developed more and better laboratory tools at every level. One of the most decisive was Joseph J. Lister's achromatic-lens microscope. It advanced the study of microorganisms and paved the way for the theory of germs, the greatest breakthrough in medicine before 1900. In physics, meanwhile, equipment designed by Heinrich Hertz allowed him to detect electromagnetic radiation in the 1880s. And Robert Millikan's ingenious oil-drop apparatus in 1911 allowed him to measure the electric charge of an electron. The list goes on and on.

POSITIVE FEEDBACK

Artificial revelation is a critical component of the great feedback loop in which technology stimulates science; science in turn helps drive technology, and thus we have a dynamic positive-feedback system, which may well be globally unstable. Certainly looking at the development of science in the past century, it is impossible to separate it from its technological components.

And the acceleration of this process in recent times is undeniable. The most famous discovery in the biological sciences in the twentieth century, the discovery of the structure of DNA by James Watson and Francis Crick in 1953, was made possible by x-ray crystallography. That technique was discovered much earlier (in 1912) by Max von Laue, but it took the skills of Rosalind Franklin to apply it to the structure of DNA.

Yet the machinery at the disposal of microbiologists today is vastly more powerful, including the automatic gene-sequencing machine, first developed at the California Institute of Technology in 1986 by Leroy Hood's laboratory. One might also mention the flow cytometer, automatic cell-sorting machinery which counts as one of the many applications of laser technology to the live sciences.

The science of astronomy, similarly, has at its disposal tools that were unthinkable just a few decades ago. We should think of the Hubble telescope (planned in the 1980s and launched in 1990), but more recently much cheaper and more accessible telescopes have been developed that remove the bane of every earth-bound astronomer, atmospheric distortion, through what is known as adaptive optics: technology that sharpens images by changing the shape of telescope mirrors up to 1,000 times per second.

Microscopy, too, has come a long way, from the electron microscopes developed by two German engineers, Ernst Ruska and Max Knoll, in the

1930s, to the scanning tunneling and ion beam devices used today for nanotechnology.

SEA CHANGE

But the greatest research tool that modern science has at its disposal is without question the computer. The question one can expect to encounter from researchers is not "what do computers do for me?" but "how did anyone ever do any research before we had them?" From advanced drug design to the prediction of weather patterns to computational engineering, high-capacity computers have brought about a sea change in scientific research.

Numerical simulations of complex physical systems require enormous computational power. In some cases they replace physical experiments; in others they allow researchers to approach problems that previously were essentially unsolvable. This is not merely a question of Moore's Law (which states that the number of transistors fitting on a microprocessor, and hence its performance, doubles every two years or so) and the growth in the power of modern computers, but also one of better software and algorithms. As one computer scientist told *The New York Times* in 2011, ingenious algorithms "have yielded performance improvements that make even the exponential gains of Moore's Law look trivial."

The capitalist system has been quite adept at preventing "technological unemployment."

An example of the potential of high-powered computing is fluid dynamics. Turbulence is famously one of the great unsolvable issues in modern physics: The English applied mathematician Horace Lamb sighed in 1932 that "I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic." Although the equations for turbulence (known as the Navier-Stokes equations) have been known since the nineteenth century, they could not be solved.

But supercomputers can make a dent in these problems, and in the process resolve major issues in weather prediction, aircraft design, fire control, and many other practical matters. The computational cost of simulating turbulence flows is extremely high; it requires, even for simple scenarios, months of calculations with the fastest computers covering only a small portion of a flow region. Computing, however, will surely continue to get faster. While it may still be a while before sufficient computing power can be placed at the disposal of turbulence theorists, there is no question that within the foreseeable future there will be progress on this front of a kind that the nineteenth-century mathematicians who developed the turbulence equations would not have dreamed of. Indeed, the impact of computing on research has affected not just "hard" science but also the humanities and social sciences—including economic history—and changed many of them beyond recognition.

NEEDLES IN HAYSTACKS

The other reason to believe that the "you ain't seen nothin' yet" model applies to the future of technology is closely related. Progress in the past has had much to do with how easily *existing* knowledge could be accessed. After all, useful knowledge is cumulative, and scientists stand on the shoulders of others (not all giants, but even standing on the shoulders of midgets allows you to see further, especially if there are a lot of them). But there is more: Good access to previous research minimizes the number of reinvented wheels, and may reduce the number of dead-end projects and scientific cul-de-sacs entered.

In invention, moreover, knowledge of what is already known to work is even more important, because so much involves less the generation of wholly new ideas than the recombining and hybridizing of *existing* gadgets and devices, what the British author Matt Ridley has compared to ideas "having sex" and fertilizing one another. When searching for a missing piece of technical puzzles, search engines are crucial because they provide fast and cheap access.

The technology of storing information and then allowing others to search and access it has been an important component of the growth of useful knowledge in human society. While science and technology were always only a small fraction of all the information stored (relative to philosophy, religion, history, poetry, and pornography), their role in economic development became increasingly important at about the same time that capitalism was ready to move from its commercial to its industrial version. I have called this stage "the industrial enlightenment." It provided the crucial transition between a Malthusian subsistence economy and one in which ever-improving technology meant that living standards could continue to rise with no obvious end in sight.

By 1700, both Europe and China had thriving book industries, having mastered the techniques of paper and moveable type printing. To that were added search engines based on alphabetization (such as technical encyclopedias and dictionaries), so that searches became easier. Knowledge had to be organized and classified. A typical work of this age was the 80-volume *Descriptions des arts et métiers* (1761–88), edited by two of the most wide-ranging scientists of eighteenth century France, René Réaumur and Henri-Louis Duhamel du Monceau. The enormous set included 13,500 pages of text and over 1,800 plates describing virtually every handicraft practiced in France at the time in minute and accurate detail.

In this respect the modern age represents the greatest discontinuity in many centuries, dwarfing the advances of the Age of Enlightenment. As Ridley remarks, "The cross-fertilization of ideas between, say, Asia and Europe that once took years, decades, or centuries can now happen in minutes." Copying, storing, transmitting, and searching vast amounts of information are fast, easy, and for all practical purposes free.

We no longer deal with kilobytes or megabytes, and even gigabytes seem small potatoes. Instead terms like petabytes (a million gigabytes) and zettabytes (a million petabytes) are bandied about. Scientists can find the tiniest needles in data haystacks as large as Montana in a fraction of a second. And if science sometimes still proceeds by "trying every bottle on the shelf"—as in some areas it still does—it can search with blinding speed over many more bottles, perhaps even petabottles.

FILTERS, PLEASE

Again, technology bites back, and the law of unintended consequences raises its head. There clearly is a danger of information overload, as anyone struggling with an e-mail inbox knows all too well. The one fixed factor in the information equation is the capability of human minds to process data, which obviously is bounded, though the exact limits are yet unknown and depend on the tasks and challenges at hand. Information theorists have suggested numbers between 50 and 60 bits per second, which are a minute fraction of what computers can do.

Overload is one hazard; bogus information is another. How is one to filter wheat from chaff, serious scholars generating reliable knowledge from crackpots, flat-earthers, and climate-change deniers? Who will review billions of sites and sources, including many zettabytes of data, for veracity? And who will review the reviewers?

Many such issues, it will be said, do not have a "technological fix"—they need intangibles like human trust. But without ever-better processing technology that allows us to discriminate between what is plausible (and perhaps even "true") and what is blatantly misleading and tendentious, such trust will be hard to establish. To establish trust, we need filters. Cyber-kooks, much like cybercriminals, will try to fool the filters. Then we will need to design better filters. Much like the war against insects and our efforts to keep the planet's environment people-friendly, this is an ongoing process, in which we may have to run in order to stay in place.

PROTECTING ASSETS

Will capitalism be able to adapt to a new world of petabytes? Not without another major transformation. The economics of a world of information and automation is radically different from that of a world of wheat, steel, and railroads. One issue, clearly, is property rights. Capitalism depends on well-defined and enforced property rights; it thrives in worlds where the distinction between mine and thine is clear and respected.

In a traditional world, in which assets consisted of concrete items such as land and machines, "excludability" (the odd economic term to describe the lines drawn by possession) was not much of an issue. A good fence and, if needed, an alert security guard were enough to enforce most property rights. In a digital world, in which assets may consist primarily of ideas or of readily copied information (such as music or video), and in which many of the most valuable assets can be reproduced at will at very low cost (think of three-dimensional printers in the future), what will it mean to own an "asset"?

Intellectual property rights have been with us for centuries, but they have been a controversial area of economics, and for good reason. Their main *raison d'être* has always been to create sufficient incentives for "creative" people to invent new gadgets and write novels, yet it has never been very clear how good patents and copyrights are at doing this. Many critics argue that all they do is create high incomes for a few creative people for doing things they would have done anyway. Such high incomes are known as "economic rents," and they can easily be eliminated without slowing down economic progress, provided other incentives are created that make innovation feasible.

So far, digital technology has been able to preserve such rents, and big companies whose assets are (mostly) digital have been very creative at generating high profits by adapting to the new digital characteristics of what they are selling. Different models have emerged, but Microsoft, Facebook, Twitter, and Google all have found unique ways to thrive in a world in which digital assets are very different from the grim and grimy "mills" of the early Industrial Revolution.

ENTER ROBOTS

Even more challenging is the question of what will happen to "work." The history of technology is to a large extent the history of machines replacing humans in arduous or routine tasks. Whether spinning cotton yarn, shoveling coal, or selling subway tokens, mechanization and automation have made work easier and less dangerous, and on average have made it possible for people to do less of it (and thus enjoy more leisure).

Automated factories have fewer and fewer workers on the shop floor. The robots of the future will be able to replace people in an ever-increasing range of activities. Robots today can read, hear, and sense; they can search for and process information, make snap decisions, and drive cars. Robots taking care of the elderly and the sick and teaching the young are just a few years away.

Will capitalism be able to cope with "the end of work?" In some ways, we could regard the effect of technological progress on the position of labor as the greatest example of bite-back. Technological change is inherently disruptive and destructive, and it has in the past made hard-learned skills and valuable equipment obsolete and worthless. Could it do the same to labor as a whole?

History, as always, does not provide an answer, but it offers some clues. One is that the sharp distinction between "work" and "leisure" is being eroded. At the height of the industrial age, there was little ambiguity about it. Work took place in the plant, the office, the store. The worker showed up on time and worked until the shift ended, and then went home to "consume leisure," in the strange lingo of economics. Work, by and large, was debilitating, dull, and dangerous.

These lines have slowly but certainly become blurry. Hard physical work has become rarer. For more and more people, leisure and work are not as distinct as they used to be. On the one hand, work-related matters chase people through smartphones and laptops into their kitchens and bedrooms. On the other hand, the computer has made on-the-job consumption of leisure far easier. Every year in the month of March, college basketball distracts millions of Americans at work. A recent study estimated the springtime mania costs US companies at least $134 million in foregone productivity the first two days alone. And that is saying nothing about the loss of output due to workers playing computer games year round on company time.

At the same time many workers—though surely a minority—like their work so much that even if they did not have to work for financial reasons, they would anyway. Work allows many people to be creative, to connect with others, and to feel they have in some sense accomplished something. Leisure is not what it used to be.

KEYNES'S GRANDCHILDREN

Will machines not create a dystopia in which people become redundant? Another clue from history is that the capitalist system has been quite adept in the past at preventing "technological unemployment." It has done so in three ways.

The first is to restructure the economy so that more and more people work in service industries where automation is slower and harder, so that today we have far more dental hygienists and veterinarians relative to factory hands and railway workers than we had in 1914. Cleaner teeth and healthier dogs are desirable outcomes, but they were made possible by the automation of many factory jobs. Second, new technologies have created jobs and tasks that would have been unimaginable without the digital revolution. Who, in 1914, could have foreseen jobs such as video game programmer or identity-theft security guard? Third, people are working far less than in the past. Early retirement, prolonged educations, two-to-three-day-long weekends, and paid vacations are luxuries that were hard to discern or predict in the nineteenth century. Yet economies are producing *more*, not less, and that is thanks to labor-saving technology. Is that a danger or a great source of hope for the future?

In 1931, in the midst of the Great Depression, John Maynard Keynes addressed this question, trying to see beyond the immediate short-term miseries of a deflationary world. Could it be, he asked in a short essay entitled "Economic Possibilities for Our Grandchildren," that "our discovery of means of economizing the use of labor [was] outrunning the pace at which we can find new uses for labor"? His answer may surprise those who regard him as the prophet of unemployment: "all this means in the long run [is] *that mankind is solving its economic problem*" (italics in the original).

Contemplating a world in which work itself would become redundant thanks to science and capital (Keynes did not envisage robots yet, but they would have strengthened his case), he felt that the age of leisure and abundance was frightening because "we have been trained too long to strive and not to enjoy." Could ordinary people with no special talents occupy themselves in the free time of a 15-hour workweek, he wondered?

At least in this regard, Keynes was underestimating the capability of technology to meet human needs. The technological improvement of mass leisure in the twentieth century has vastly expanded options. The aristocratic and wealthy leisure classes in the past had to be taught to enjoy leisure: the classics, musical instruments, dancing, and hunting were all skills that demanded a fair investment of human capital. Modern technology, driven by demand in a market economy, has made the enjoyment of leisure far easier and cheaper.

It is likely not only that innovation will keep advancing, but that it will do so at an ever more rapid rate.

A bewildering choice of programs on television, the rise of mass tourism, access at will to virtually every film made and opera written, and a vast pet industry are just some examples of how capitalism has responded to the growth of free time. The cockfights and eye-gouging contests with which working classes in the past entertained themselves have been replaced by a gigantic spectator-sports industrial complex, both local and global. Video games are rapidly transforming themselves into virtual realities in which people can choose to re-fight the Battle of Kursk or besiege Troy from the safety of their living rooms.

THE END OF CAPITALISM?

But, one may ask, who will pay for all this? Keynes, brilliant and intuitive economist that he was, realized right away that such a question is not relevant in a world in which the "economic problem"—that is, scarcity—has been solved. In a world without scarcity, there will be no place for prices and no need for income.

Whether this utopian scenario can ever come to pass on a planet with finite resources is hard to know. Some form of scarcity is likely to persist. All the same, in a world such as the one Keynes envisaged, he realized that we would need a different kind of economics, in which "the accumulation of wealth is no longer of social importance." The entire world would become a bit like Kuwait or Norway today, where most of those who work only do so because they want to.

In that sense, in the limit, the entire human race would become like the leisure classes of days past, except that the noblemen had servants, and Keynes's "grandchildren" will have robots. With technological progress happening at the rate that seems plausible, it may be hard to tell the difference.

What this transformation will look like is difficult to predict: Distributional issues and other social questions will need to be resolved, and there is no way of knowing whether political and economic institutions will prove up to the task. A lot can and no doubt will go wrong. As Sigmund Freud noted in *The Future of an Illusion*, "While mankind has made continual advances in its control over nature and may be expected to make still greater ones, it is not possible to establish with certainty that a similar advance has been made in the management of human affairs." No economic historian would disagree.

Will there be a capitalist element to such a world? Perhaps not: Keynes, whose insights may well have saved capitalism from collapse in the 1930s, speculated that in this brave new world "the love of money as a possession . . . will be recognized for what it is, a somewhat disgusting morbidity . . . one of those semi-criminal propensities" that we shall "be free, at last to discard," along with the economic practices supporting them. The practices he spoke of are, of course, the heart and soul of capitalism. So, in the end, capitalism in true dialectical fashion may outgrow itself. But it will have left humankind a splendid heritage. ■