The Last Eighty Years: Continuities and Change

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The first time Paul Demeny asked me to write for *PDR* was in 1985 in a taxi in (as it was) West Berlin, going to a Dahlem Conference on Resources and World Development. At that time I was still spending about half of my time working on China, and so I wrote an article on the country's much-improved food supply. During the nearly three decades that followed, it was Paul's repeated nudging that led me to ask ''what next?" And so I wrote (always given a much-appreciated free range) about diet and heart disease, planetary warming, how many people the Earth can feed, environmental services, the nitrogen cycle and global population, eating meat, global catastrophic events, national socioeconomic and strategic trends, and harvesting the biosphere.

After so many different topics for *PDR*, I was not immediately sure what the present essay should be about. Eventually I proposed a topic, but then I decided to do something different, something obvious: to look back at the last eight decades in order to appraise the true nature of human advances and to emphasize our continuing inability to foresee fundamental changes.

Looking 80 years ahead did not tempt me at all because all truly long-range predictions are nothing but fairy tales, and hence must inevitably draw on an imagination that invariably tends to be either too feeble or too ridiculous. Looking back is actually one of the best ways to make clear the futility of looking far ahead: when such efforts are seen in retrospect, they seem forced, naïve, awkward, and, above all, wide of the mark in their inevitably prejudiced selectivity and (often risible) bias reflecting the changing concerns of the day (as global warming displaces acid rain and as economic crisis displaces global warming) and the herd instinct of learned prognosticators.

Growing frequency of forecasting and scenario-writing (by self-appointed experts, by think tanks of every leaning and consultancies, and by governments and corporations) might be seen as a proof that such products offer real insights and valuable guidance. But even a brief reflection dispels that impression. Evolution of human societies is marked by continually and gradually unfolding processes whose time-specific outcomes can be usefully approximated, and sometimes even more narrowly quantified. But the persistent impossibility of making long-range realistic forecasts several generations into the future is inevitable for three principal reasons.

First, while it is possible to forecast continuation (and intensification or attenuation) of some notable unfolding trends, spatial and temporal accuracy of such forecasts remains elusive. Second, it is most unlikely that even a near-perfect quantitative forecast will embrace all the qualities that make up a new reality, that it will capture the complexities whose interactions will produce subtly or profoundly altered wholes. Third, all those predictable gradual, evolutionary processes are often diverted, strongly modified, and even reversed by profound discontinuities and saltations, by surprises whose occurrences are utterly unpredictable, whose multifaceted impacts cannot be fully foreseen even after they begin to unfold.

As for the general trends, in 1932 it was clear that many unfolding changes affecting populations, economies, and societies would not only continue but would most likely intensify during the coming generations. Indeed (to choose just a few notable examples), expectations of declining fertility, rising per capita GDP, decolonization, and increasing participation of women in the labor force have all become realities. But I cannot imagine that in 1932 any forecaster (or any prescient committee) would have identified fertile Catholic Southern Europe (where even divorce, not to mention birth control and abortion, was a dogmatic anathema) as the region that would experience the continent's fastest decline in fertility to rates deep below the replacement level and foresee that the Protestant Nordics would be Europe's most diligent long-term procreators.

Similarly, it is most unlikely that anyone in 1932 would have identified Nigeria, Britain's richest African colony, as a paragon of post-colonial Africa's failed performance, corruption, and economic decrepitude (despite the country's enormous natural endowment and its discovery of rich oil and gas resources); or would have foreseen that the southern part of Korea, in 1932 a poor and exploited Japanese colony, would become the world's 15th largest economy in 2012, with per capita GDP almost the same as its former colonizer (despite the country's near complete lack of resources and the fact that by 1954 it was reduced to rubble). And as for women's participation in the labor force, who would have said in 1932 that among the affluent countries it would be the US, at that time already the world's richest economy, where nearly 60 percent of all women would hold jobs, while in Japan, a country where virtually all women had worked in traditional agrarian society, the rate would be among the lowest in the rich world?

To illustrate the second point, imagine that in 1980 a brilliant forecaster is immune to impressions left by the unfolding crises of the day—world crude oil prices rising close to $100/barrel in today's monies; Western car companies downsizing in a panic; consumers demanding small, energy-efficient models; newly ascendant mullahs getting comfortable in Tehran; and the Soviets taking over Afghanistan—and is able to pinpoint the continuing expansion of America's vehicle fleet during the next generation by putting its total at nearly 250 million cars and trucks in 2005.

But would he also (amidst all those sudden changes and fears that were engendered by the second oil price crisis in eight years and in the total absence of anything called an SUV) predict that in 25 years the best-selling passenger vehicles would be massive truck-like designs, some of them direct derivations of armored military assault machines, that would be sold under an incongruous label of sports utility? Would he predict that the average performance of America's new passenger cars would double between 1975 and 1985, but then remain stagnant for the next quarter-century? Would he conclude that by 2005 two of the country's three domestic automakers, despite their near-record production run, would be very close to bankruptcy? And yet it was precisely the combination of these new realities, rather than the total count of vehicles on the road, that had the most important consequences for the US automotive industry and for the country's economy.

As for the third reality, the last 80 years have been repeatedly punctuated by such unpredictable leaps (mostly social and political rather than, as commonly but wrongly believed, those of a technical nature), by advances whose rapid adoption brought multifaceted changes (mass jet-powered airline travel is an excellent example, with impacts ranging from unprecedented ease of intercontinental travel to endless worries about airborne terror), and by reversals that had often no less profound effects (the US pivoting from the world's largest creditor to the greatest debtor nation). At the same time, this retrospective exercise will try to demonstrate that the most fundamental changes in the human condition during the past 80 years have not arisen from those surprising post-1930 discoveries and developments but rather from remarkable scaling up of techniques, machines, and processes that were already commercialized or commonly deployed by 1932 and from no less remarkable improvements in their qualities (that is in efficiency, convenience of use, reliability, and durability).

Changing populations

In order to appreciate how far we have traveled, it is necessary to list the key contrasts. In 1932 global population stood at just over 2 billion compared to 7.1 billion in 2012. The United States had 125 million people (about 40 percent of its 2012 total), China (at that time in disunited turmoil) was below 700 million (1.35 billion now), India (trying to slip from British rule) had just passed 280 million (nearly 1.2 billion now), and even relatively slow-growing European countries have grown considerably: for example, France added about 21 million people during the past eight decades to reach today's roughly 63 million. Total fertility rates (TFRs) were well above the replacement level even in the richest countries and very high throughout large parts of Asia and Africa, while by 2012 the demographic transition had run its course everywhere in the rich world, and TFRs are well below the replacement level not only in Europe and North America but also in China (at about 1.6 China's rate is virtually identical with the European mean), and the global average has been reduced to less than 2.5.

Eight decades ago life expectancies at birth were just above 60 years in the richest nations (where they are now close to or above 80) and they were below 40 in many parts of Africa and Asia, but even China's mean is now close to 75 years. In rich countries the pattern of dying was dominated by infectious diseases, there were no antibiotics and no polio vaccine, while in poor countries the combination of widespread malnutrition, communicable diseases, and unclean water kept infant mortality very high, commonly in excess of 200 per 1,000 live births. In contrast, today's lowest infant mortality rates are less than 3 per 1,000 (Sweden, Japan), the global mean is about 40, and China's rate is below 20. Today cardiovascular diseases and cancers are the main cause of adult death throughout the affluent world, a pattern now shared by megacities of Asia.

Growing populations, falling death rates, and rising longevity were made possible by improvements in overall quality of life that resulted from a nearly uninterrupted growth of GDP, from widespread industrialization followed by the rise of the service sector, from the expansion of international trade, from relentless urbanization, and from a much-increased mobility of populations. In turn, these epochal changes were primarily the function of rising energy consumption that led to adequate nutrition, improved water supply, better housing and sanitation, and greatly reduced mortality from communicable diseases (thanks to preventive inoculation) and bacterial infections (thanks to antibiotics). All of these changes, of course, now afford lives of material affluence for hundreds of millions of people.

Higher energy use and improved nutrition

In 1932 most of humanity (hundreds of millions of peasants in Asia, Africa, and Latin America) continued to live, as in preceding millennia, in a wooden age as they burned fuel wood (directly or used it to make charcoal), crop residues (mostly cereal straws), and dried dung. In global terms these biofuels supplied more than a third of all primary energy, and more than 90 percent in China and India. Global per capita supplies of fossil and biomass fuels (with the latter supplying at least a third of the total) averaged about 35 GJ/year (an equivalent of two tonnes of dry wood or 1.5 tonnes of good steam coal), while the national rates were only 20 GJ/capita in Japan but, even after falling some 30 percent between 1929 and 1932, about 150 GJ (six tonnes of excellent coal) in the United States. Eighty years later the world was consuming more than 500 EJ of primary energy, with traditional biofuels supplying less than 10 percent of the total, and per capita means were more than 300 GJ (equivalent of roughly 7 tonnes of crude oil) in the US, about 170 GJ in Germany and Japan, and, after a rapid rise since the early 1980s, about 80 GJ in China.

In the early 1930s only the industrialized countries of Europe and North America and Soviet Russia were large producers and consumers of coal whose combustion dominated their energy use (more than 80 percent of all fossil fuel). And only the US, with its exceptionally high car ownership (60 percent of households had a car before the Depression), was a large crude oil consumer (also by far the largest oil producer). No oil was produced in the Arabian Peninsula, and Soviet Russia relied only on the old Baku fields. Eighty years later crude oil was the largest component of global energy use (about 30 percent of the total), with coal still slightly ahead of natural gas. Russia, Saudi Arabia, and the US were the largest producers of crude oil, and two additional forms of primary energy became important since the early 1930s: hydro and nuclear electricity, each supplying about 5 percent of the world's primary energy (and a nearly four times higher share of electricity).

By 1930 the United States had just accomplished its industrial transition from steam to electricity (America's large factory manufacturing became almost fully electrified by 1929). But although some 70 percent of households were connected to the grid, electricity use was still fairly limited. Before the Depression, Americans were buying more light bulbs and more radios (50 percent ownership by 1930), but refrigerators were uncommon (in just 10 percent of households), TV was not yet commercialized, and there was no household air conditioning. Eight decades later America's average per capita consumption of electricity was about 13 times the 1932 mean as more than 90 percent of households had color TVs, telephones, and refrigerators and more than 80 percent owned clothes washers and dryers, electric ranges, microwave ovens, and an assortment of electronic devices. And electrification is now advancing rapidly in Asia, especially in China where it powers the country's fast-paced urbanization, its massive export-oriented manufacturing, and its new high-speed trains.

Eight decades ago food production was dominated by traditional, low-yielding cultivars. New short-stalked, high-yielding varieties of rice and wheat and hybrid corn, advances achieved thanks to the application of highly rewarding classical plant breeding techniques, changed all that: hybrid corn was introduced during the 1930s; much-improved rice and wheat cultivars were widely adopted during the 1960s. In 1932 American corn yields (at less than 2 t/ha) were unchanged since the 1880s; now the mean is over 10 t/ha. Similarly, European wheat harvests were generally less than 2 t/ha, while yields of 8 t/ha are now common. In 1930 soybeans, cultivated for millennia in East Asia, were a less important crop in the US than sweet potatoes; now soybeans are the country's second largest crop, yielding more than 80 Mt/year, and soybean meal (the residue after expressing oil for cooking) is the main source of protein in animal feeding. In 1932 draft animals were still indispensable not only in Asia but also in Europe and even in parts of the US and they, together with dairy cattle, pigs, and poultry, produced valuable manure whose recycling was the leading source of soil nutrients.

In the early 1930s most of humanity subsisted on overwhelmingly vegetarian and barely sufficient diets produced by traditional agricultures with almost no inputs beyond the closed, and fully solar, system of cultivation and animal husbandry. Dietary transition from traditional intakes dominated by carbohydrates (staple cereals and tubers) to a more varied diet with a higher share of animal foodstuff was underway only in the industrialized countries, but meat was still expensive as its small-scale production on mixed farms was inefficient: it took a year or more of feeding (any available biomass) before pigs were ready for slaughter, and chickens were not ready for at least three to four months.

Eight decades later sub-Saharan Africa is the world's only region with minimal external inputs into farming. In all affluent countries, as well as in the most productive regions of Asia and Latin America, food production is critically dependent on high (and in many places still rising) inputs of fossil energies, directly as fuel for field machinery (including irrigation pumps) and indirectly for the production of nitrogenous fertilizers, pesticides, herbicides, agricultural machinery, and trucks. Obviously, these external energy inputs are high in Iowa or Holland; but because intensive cultivation of rice demands high rates of nitrogen fertilizer applications (more than 500 kg N/ha a year), China is now even more dependent on fossil fuels for food production than is the US: without Haber–Bosch nitrogen, it could not feed some two-thirds of its population.

Pork and chicken for Western consumers, as well as for inhabitants of megacities in Asia and Latin America, come overwhelmingly from centralized animal feeding operations where the animals receive balanced rations of carbohydrates (mainly corn) and protein (mainly soybeans) supplemented by micronutrients; pigs now reach a slaughter weight of more than 100 kg in less than six months, and broilers are ready for the market in just 35–42 days. As a result, traditionally vegetarian India is now the only populous country with extremely low meat consumption: Annual meat supply (all rates in carcass weight/capita) is now around 50 kg in China, 80 kg in Brazil, and 120 kg in the US.

Gradual gains vs. fundamental breakthroughs

What has driven these profound changes in energy use and food production? Perhaps the clearest conclusion derived from looking back is that gradual development of established devices, processes, and systems has been cumulatively more important than even the most notable fundamental scientific and technical breakthroughs achieved since 1930. This may seem counterintuitive: after all, we are constantly told that all innovation has been accelerating and that we live in an era of unprecedented knowledge breakthroughs. But the fact is that when seen from a truly historical perspective (*longue durée*), the unparalleled era of scientific and engineering progress occurred between 1865 and 1914 when an amazing concatenation of advances created most of the fundamental technical and economic realities of the twentieth century.

The briefest list of those veritable pre–World War I saltations—qualitative and quantitative leaps in our capabilities that have come to define modern economies—would be limited to four defining components of modern civilization: energies, prime movers, materials, and information flows. The three epochal energy advances were the development of oil and gas industries, the invention and rapid maturation of electric systems, and the introduction of new mechanical prime movers. Coal combustion was nothing new by the mid-nineteenth century, but the pre–World War I decades saw the rise of hydrocarbon (oil and natural gas) industries, and the post-1930 decades saw the rise of these two fuels to become the leading energizers of modern world. Just a few decades after the commercial introduction of electricity, widespread adoption of electric lights, motors, and electrochemical processes revolutionized industrial production, eased or eliminated many household chores, and opened the means of inexpensive instant telecommunication.

The new prime movers of unprecedented power and efficiency included steam turbogenerators, large hydraulic turbines, and combustion engines (Otto cycle burning gasoline and Diesel cycle burning heavier fuels) deployed in all forms of transportation as well as in agriculture (tractors, combines, irrigation pumps). Inexpensive methods of large-scale steelmaking and aluminum smelting began to produce the two most ubiquitous metals of modern civilization, found in infrastructures ranging from roads to buildings and in machines ranging from the largest ship to the largest airplanes while chemical syntheses of ammonia, drugs, and plastics changed the ways we produce food, treat diseases, and manufacture industrial and consumer products. Finally, invention of the first electronic components launched a new era of wireless telecommunication.

By the early 1930s all of these innovations introduced before World War I were successfully commercialized as new categories of machines and processes were gradually diffused throughout the world's richest countries. Remarkably this adoption process was not derailed by the Great Depression, and after World War II came its second wave in newly industrializing countries of Asia and Latin America. Consequently, in so many fundamental ways the world of 2012 would be familiar to competent engineers working in the early 1930s and, with a few explanations, it would be readily comprehensible also to men like Thomas Edison (electric systems), Charles Parsons (steam turbogenerators), Nikola Tesla (electric motors), Fritz Haber and Carl Bosch (synthesis of ammonia), or Lee de Forest (inventor of the triode) whose work preceded World War I.

At the same time, engineers working during the early 1930s would be impressed by the twinned changes of scale and efficiency that have been achieved during the past 80 years. Just a few key examples illustrate this progress. In 1932 the largest commonly deployed steam turbogenerators had capacities of less than 100 MW, while by 2012 units in excess of 1,000 MW are common; and the efficiencies of the best large coal-fired power stations had nearly doubled to more than 40 percent. The best lights now convert electricity to visible radiation with efficiencies that are an order of magnitude higher than those of 80 years ago. Smelting of pig iron in blast furnaces now takes only half as much energy per tonne of hot metal as was needed in the early 1930s, while the global output of pig iron is an order of magnitude greater than even its pre-Depression peak in 1929. Energy needed to synthesize a tonne of ammonia has been reduced by nearly two-thirds, while the global output rose more than 60-fold, from about 2 to about 130 Mt/year. And even in the US, new high-efficiency cars now travel nearly three times farther on a unit of gasoline, while global car sales in excess of 60 million vehicles are more than 50 times the 1932 level.

Concentrating on the fundamentals also makes it clear that electronic computing, nonexistent in 1932, has not been the most significant innovation in recent history. This claim is now often made because of the ubiquity of electronic hardware and software, with microchips controlling everything from cars to cellphones, and with complex programs watching over electric grids and air traffic as much as they do over electronic telecommunications and bank transactions. Those who make that claim betray their uninformed bias by the fact that their use of "technology" is limited to only computer-related electronic devices and processes, as if securing adequate energy supplies and growing enough food does not entail any technical skills. And they also argue a clear cart-before-the-horse proposition since all electronic computing and allied telecommunications would cease immediately without a massive and extraordinarily reliable (and largely fossil fuel–generated) electricity supply: as amazing and as potent as they are, they are still a class of secondary innovations dependent on a system whose fundamental concept emerged during the 1880s and whose global coverage has been created by decades of cumulative development.

Obviously, computerization has made many products and processes cheaper, and most of them also more reliable and more convenient to use. But it has not changed the physical and biophysical fundamentals of energy and food production, the two great pillars of any civilization. High quality of life is perfectly possible without ubiquitous microchips: after all, we had a rich and (by all rational measures) affluent civilization before 1970, the year when the first integrated circuit was designed by Intel. But high quality of life is unthinkable with persistent malnutrition, contaminated water, unheated homes, and material poverty. Technical advances that eliminated those deprivations and shortcomings had predated electronic computing by decades and generations. Indeed, if the qualification "most significant" is taken, logically, as making the greatest positive difference for the largest number of people, then none of the great innovations introduced after 1930—whether electronic computing, nuclear electricity, genomics, or medical diagnostics—qualifies.

Unprecedented growth of human population during the past 80 years could have happened without any solid-state electronics—but not without fossil fuels to power industrialization and urbanization, the two transformations that have employed and sheltered billions, and not without growing enough food for an additional 5 billion people, an achievement fundamentally predicated on an adequate supply of plant nutrients. We could do without packing more and more transistors on a chip, but we cannot do without providing sufficient quantities of essential amino acids to growing infant brains and adolescent muscles: nitrogen in proteins, not silicon in chips, has been (and will always be) the indispensable element of quality.

I have called the development of nuclear electricity generation a successful failure. The industry now generates about 13 percent of global electricity, but its expansion in the US stopped three decades ago, in the EU it was in retreat even before the Fukushima disaster, and, remarkably, traditional biomass fuels (wood, charcoal, and crop residues) still contain more energy than the fission-based generation. And great strides in lowering infant mortality and extending longevity throughout Asia and Latin America had nothing to do with the sequencing of the human genome and hardly anything to do with the number of magnetic resonance imaging (MRI) or computerized axial tomography (CAT) machines per 100,000 people, but plenty to do with properly cased new wells, old-fashioned sewage treatment plants, and more animal protein from milk and chicken in children's diets.

Failures of imagination and reluctant commitments

The preceding argument was not about denigrating the role of innovation, merely about separating fundamentals from the less important factors responsible for the great changes of the past 80 years. Those decades brought plenty of impressive and diverse innovations that truly matter, and perhaps their most surprising shared attribute is how unanticipated they were. In 1830, with science being still a restricted domain of curious (and often well-off) individuals, with no industrial research (indeed with no centralized, highly productive industries), with steam-driven transportation in its infancy, and with no means of effective telecommunication, it was exceedingly difficult to anticipate any important technical advances that would change the world over the next one or two generations. By 1930 science had become a substantial enterprise, industrial research was an essential part of modern production, news traveled rapidly on radio waves, and looking into the future was both a popular literary pastime and a scientific quest.

And yet the historical record reveals several constancies demonstrating that our capacities to anticipate future technical advances did not improve. First is the continuing lack of bold but realistic imagination. There is never any shortage of irrelevant speculation about colonizing Mars, flying to work in small private planes, or eating food entirely encapsulated in pills. But my searches have not uncovered any previsions of the US Midwest planted to soybeans for animal feed or a widespread use of horizontal drilling in oil and gas production. Similar examples could be chosen for every decade and for every class of innovations, and when looking for a combination of importance and variety I chose the year 1938 when the discovery of polytetrafluoroethylene (Du Pont's now ubiquitous Teflon) was as much a surprise as the first major discovery of crude oil in Saudi Arabia and Frank Whittle's turbojet engine.

In the first instance it was, as with so many inventions, pure serendipity as Roy Plunkett accidentally pumped freon into a cylinder that was left overnight in cold storage and found that the resulting white powder had not only an extraordinary slipperiness but also high resistance to cold, heat, and acids. The other two cases illustrate a much more common reality of institutional incredulity, aversion to risk taking, and lack of imagination. The Anglo–Persian Oil Company (active in southwestern Iran, just across the Gulf, since the early 1900s) believed throughout the 1920s that no oil would be found in Saudi Arabia. Standard Oil of California secured a concession only in 1933 and the first production well flowed in 1938: how different might world history have been had Saudi oil been discovered in the early 1920s?

A similar question can be asked about Frank Whittle's jet engine. The young pilot-engineer patented his idea of a jet engine (gas turbine) in 1930; but even after years of trying, his enthusiasm about this superior mode of air propulsion was not shared by the British Air Ministry, which in 1935 refused to pay the trifling £5 fee for his patent's renewal. The approach of World War II eventually changed those calculations, but the accelerated post-1939 development of jet engines and fighter planes came too late to make a difference to the length and the outcome of the war. But what difference might those machines have made if the Royal Air Force had begun to manufacture jet fighters three or five years ahead of the Luftwaffe?

There is yet another constancy regarding risk aversion and lack of imagination: even a cursory look back shows many instances in which the organizations that invented new products or processes were reluctant, even quite unwilling, pioneers of these innovations, choosing not to pursue them further and not to convert working prototypes into commercial products. I know of no more astounding example of this behavior than the way Xerox treated the innovations that came out of its Palo Alto Research Center (PARC) during the 1970s. PARC created most of the indispensable components of user-friendly desktop computing: it was the first place in the world where one could find a standalone machine operated with the aid of a mouse, WYSIWYG editing, graphical user interface with icons and pop-up menus, laser printing, spell checkers and thesaurus, text editing and graphics, and access to file servers and printers with point-and-click actions.

But Xerox never attempted to commercialize its remarkable system, and the company nearly disintegrated. Meanwhile PARC's accomplishments were exploited by Steve Jobs and Steve Wozniak to launch the first successful commercial PC in 1977 and then by IBM and Microsoft to introduce PARC-derived Windows 1.0. Again, another fascinating consideration for alternative history: what if Xerox's aggressive development of PARC-based personal computing had preempted the rise of Apple and Microsoft?

Xerox has not been the only major corporation failing to grasp an early chance: Intel's first microchip designed in 1970 did not go into a consumer product made by an electronic giant, but into a small calculator made by Busicom, a Japanese company that folded just a few years later. And, to choose just one more example from a very different industry, production of steel in basic oxygen furnaces (now the principal method of smelting the world's most important metal) was not commercialized by any of the world's leading steelmakers but in an unlikely place, at *Vereinigte Österreichische Eisen- und Stahlwerke AG* in Linz, Austria.

But the current obsession with innovation assumes that things will be different as entrepreneurs pursue development of specific solutions rather than waiting for a natural winnowing and eventual emergence of truly distinguished contributions. So far, this deliberate quest has had a very limited success even in those cases where large sums were spent on new solutions. After all, the world is not running solely on nuclear electricity (although the industry has received tens of billions in subsidies since the 1950s), fuel cell–powered cars are nowhere to be seen, electric car sales account for less than 0.1 percent of the market, algae do not produce gasoline (Exxon Mobil alone spent $600 million on the quest before abandoning the effort), and new renewables cover a tiny share of the global energy demand. Is the situation any better as far as our foresight regarding major social, economic, and strategic trends is concerned? Do the past eight decades reveal some real progress toward a more successful anticipation of transformational socioeconomic changes? The answers are uniformly negative.

Politics, economics, and social transformations

Many political shifts and economic discontinuities that result in major social changes and sudden strategic reversals are the result of hard-to-miss trends, but that does not make it any easier to anticipate their outcomes in the only way that would make a useful difference: by realizing the totality of their eventual impacts. Once Hitler attacked the Soviet Union in June 1941 and once the US entered the war in December of that year, the ultimate Nazi defeat was only a question of time required for mobilization of America's enormous natural and industrial resources and for the reassertion of Russia's strategic strength. Predicting an Allied victory in December 1941 was thus an unremarkable feat, but nobody could have predicted the war's most important long-term outcomes: that less than four years later the destruction of two Japanese cities would launch a new era of a decades-long, extremely expensive and perilous nuclear arms race; that less than five years later the two great powers would be adversaries in the Cold War that would eventually involve countries as far-flung as Angola and Vietnam; and that less than nine years later Europe would be partitioned over the next four decades and that China would be under Communist Party control.

Observations of elusive outcomes can be made for every one of the past eight decades and for all major global actors, and I will limit myself to just four more cases of epochal events in recent history: China's transformation after Mao Zedong's death; the collapse of the Soviet Union; Japan's great turnaround; and America's economic retreat. All of them were easy to predict in theory (after all, every man has to die, no dictatorship is eternal, no economy can grow at rapid rates forever, and no great power is immune to internal rot), but neither their specific modalities nor their complex consequences could readily have been predicted. Hence their arrivals came as a surprise, and the world lives with their enormous consequences.

There was a high likelihood that many changes would take place after Mao's death in 1976, but who could have predicted that just two years later his old comrade Deng Xiaoping would begin a slow reversal of some of the key Maoist policies, that this process would accelerate after the Tian'anmen killings of 1989, that in just one generation China would become the workshop of the world, and that just three decades later the Chinese Communist Party would be a *de facto* owner of one trillion dollars of US government debt?

Would such predictions have sounded more credible than saying in the early 1980s—when Ronald Reagan was launching an expensive arms race with the Soviet Union and when the CIA was still making worrisome assessments of enormous and growing Soviet power—that a decade later there would be no Soviet Union and that its dissolution would be inexplicably rapid and, even more surprisingly, almost completely non-violent?

Also during the 1980s America's political and corporate elites convinced themselves that Japan's rise was unstoppable as the Nikkei index had quadrupled in five years to nearly 40,000 by December 1989, and as Japan was widely perceived as the premiere candidate for economic and technical supremacy in the twenty-first century. But by 2012 the Nikkei index was below 9,000 (the equivalent of the Dow Jones being just above 3,000 in 2012 instead of trading above 13,000), and Japan (to be sure, still rich in global comparison) was looking back at two decades of lost direction, economic stagnation, and political drift while contemplating the future of de-industrialization, rapid population aging, and declining population size.

Lastly, in 1980, as America began to worry about Japan, it was still (as it had been for the previous eight decades) the world's largest creditor nation; but in September 1985 the US Department of Commerce revealed that the US had become a net debtor. Who would have said by the end of that year, as the deficit reached trifling $28 billion, that 20 years later America's annual current account would be nearly $700 billion (a sum larger than the total GDP of Saudi Arabia or Switzerland) in debt and that most of the goods sold by Walmart, its and the world's largest retailer, would be made in China? How many things, and how many prospects, would be different if America had remained a large net creditor nation with a manufacturing sector almost as strong as it was in the mid-1980s?

Humanity in control?

The past matters in so many obvious genetic, cultural, and social terms, but in modern consciousness it is being reduced to ever briefer intervals between the incoming e-messages (one billion people incessantly checking and rechecking trivial Facebook ephemera, yet unable to place even epochal events within the correct century). Modern societies are animated by promises of a better future, a future designed to their preferred specifications, and some of our past successes have deluded many people into thinking that we can do progressively better, that we are finally close to being in control. That is why innovation has now become the mantra of affluent Western societies. Too many experts and too many influential opinion-makers are now trying to persuade us that the accelerating pace of technical fixes will solve our most complex problems: renewable energy conversions will soon displace fossil fuels, transgenic crops will feed the world, carbon capture and sequestration will prevent global warming, nanomaterials and additive manufacturing will produce anything cheaply and rapidly, and personal genomics will have us all living as long as Methuselah.

Answers are promised for everything, fate and chance are risible terms that have no place in the modern discourse of the future—as if the world (everything else being equal) would not have been different if the trench gas had killed rather than just temporarily blinded Hitler in October 1918, if Stalin had his fatal stroke in March 1943 rather than in March 1953, if in 1945 Truman decided to support Mao rather than Chiang, or if the Soviet hardliners had prevailed in Moscow and Cuba in October 1962. This is hardly a new argument, but one repeated with a much greater insistence: this time it is really different, this time we are really at a threshold of a truly new world because infinitely intelligent machines will soon make humans superfluous (one of Raymond Kurzweil's scenarios has that scheduled for as early as 2045) and will run everything on our behalf with wondrous perfection. Similarly, Diamandis and Kotler promise an imminent unfolding of "the most transformative and thrilling period in human history" whose miraculous advances will bring the age of abundance, of unprecedented material plenty and a pristine environment enjoyed by everyone.

Although the claims of accelerating change appear to be well supported by the relentless rise of computing power and by the shrinking intervals between the releases of new models of electronic gadgets, a closer look reveals the fallacy of this claim. It is a perfect case of *pars pro toto* error or, as I called this specific instance, Moore's curse, a mistaken belief that the progress of all innovation resembles the biennial doubling of transistors crowded on a microchip, the rule formulated by Gordon Moore two generations ago. But this rule does not apply to the ways we produce our foods, energize our societies, transport our resources and goods, build our cities, and extend our lifespans: these activities have seen many improvements but no radical shifts and no steadily accelerating advances.

In this essay I have tried to demonstrate that the changes of the past 80 years were primarily due to unprecedented quantities, scales, and magnitudes rather than to radical shifts in kind, and although I hesitate to make any long-range forecasts I would expect that the next 80 years will not be much dissimilar where those existential fundamentals are concerned. Obviously, I do not foresee (*pace* Kurzweil) the world run by the eternal wisdom of self-generated software, nor do I take seriously the fairy tales of a superabundant era that is almost upon us.

But what if the next 80 years will see another period of epochal advances akin to those fundamental changes that took place between 1865 and 1914? How can we be sure that another burst of such creativity does not lie ahead? Of course, we cannot, but it is highly improbable because such discontinuities have been exceedingly rare during human evolution. Limiting the span to the last million years leaves us with the mastery of fire (as early as 790,000 years ago), hunting with projectile weapons (spears, some 400,000 years ago), the appearance of modern *Homo sapiens* (about 200,000 years ago), domestication of plants and animals (6,000–11,000 years ago), and the rise of the cities (3,000–5,000 years ago).

Preindustrial mechanical prime movers (water wheels, wind mills) were fairly common only in some regions, and even there they did not change the overwhelming reliance on animate primate movers (human and animal muscles); and while some countries were able to secure more reliable food supplies, famines remained common well into the early modern era and crop yields remained insufficient well into the nineteenth century. Unless one subscribes to the unproven notion of accelerating evolution, anything resembling the great saltation of 1865–1914 is most unlikely to be reprised just a century or two later. But I do foresee events strongly shaped by contingencies and chance, and I hope that we will benefit from some important innovations that will be as unanticipated, and in their overall impact as surprising, as the jet engines or integrated circuits that helped to change the world of the past four generations.

And what of the planetary threat of global warming? We cannot be sure whether the eventual outcome will be tolerable (average global temperature increase of less than 2⁰C), highly worrisome (2⁰–4⁰C), or catastrophic (>4⁰C). In any case, there does not seem to be any resolve to confront the challenge, and it may be helpful to think of the alternative. The relative stability of climate that has prevailed during the past half-millennium will have to end, sooner rather than later: after all, we live in just another interglacial era. Would we prefer another period of global cooling akin to the last episode, which left a large chunk of mid-latitudes—regions where most of the world's economic product and most of the planet's food surplus now originate—under thick layers of ice or that converted those landscapes into tundra or cool steppe (Canada's Prairies, the Corn Belt, France and Germany)? Would it be easier to adapt to a pronounced cooling than to a substantial warming?

But I would confidently predict that the most consequential impacts of the coming social, political, strategic, and environmental shifts will not be those that now dominate our concerns. Looking back reminds us about the enduring power of unruly realities, and to think that the coming decades will be profoundly different because we will be, finally, in control is only the latest addition to a long history of hubris and wishful thinking.

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