Second Machine Age or Fifth Technological Revolution? Different interpretations lead to different recommendations –

Reflections on Erik Brynjolfsson and Andrew McAfee's book *The Second Machine Age* (2014).

Part 2

The periodization of history into technological revolutions: why, what, how many and when?

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February 2018

Blog post: http://beyondthetechrevolution.com/blog/second-machine-age-or-fifth-technological-revolution-part-2/

This is the second instalment in a series of posts (and Working Paper in progress) that reflect on aspects of Erik Brynjolfsson and Andrew McAfee's influential book, The Second Machine Age (2014), in order to examine how different historical understandings of technological revolutions can influence policy recommendations in the present. The previous post [LINK TO PREVIOUS POST IN SERIES] introduced the aims of the series. Here we discuss various criteria used for identifying a technological revolution, why we undertake such an exercise in periodisations, and the key lessons to be gleaned from observing the regularities in the diffusion of technological change. Over the next few weeks, we will look at the different implications that stem from applying the 'machine ages' or my 'great surges' point of view to understanding the present moment. We will look at what we see as the virtues and limits of Brynjolfsson and McAfee's policy proposals, and why implementing policies appropriate to the stage of development of any technological revolution have been crucial to unleashing 'Golden Ages' in the past.

The periodization of history into technological revolutions: why, what, how many and when?

Why examine history? What are we looking for?

History is an unwieldy mass of information that can be interpreted in multiple ways depending on the lenses used by the author. Whether focusing on political hegemony, art, or technology, the purpose of distinguishing epochs is to learn something from the past that can shed light not only on the present – but on paths into the future. This is commonly done with the intent of providing policy recommendations, for proposing action or defending inaction. Therefore, explicitly identifying the nature of the lenses used to examine history should be a pre-requisite of all such attempts.

Since the late eighteenth century, industrial power suggests three major divisions: the 19th century was a time of British dominance; most of the 20th century saw power located in the US; and starting around the 1970s-80s, with the explosive diffusion of information and communication technologies (ICT), a strong process of globalization towards a multi-polar world can be observed. One could suggest that this broad brush is what has shaped the periodisations of capitalist history made by many political scientists, historians, economic historians and economists.

The work of Brynjolfsson and McAfee fits with more recent analyses which view the ICT revolution as a radical break with the past: as a new era. As noted in the introduction, they consider the first 'machine age' to be a single major period ranging from the industrial revolution to the current times, in which machines replaced muscle power. According to their periodization, we are now in the beginnings of a second machine age, which involves a shift in which machines replace brain power.

A third tradition in periodization is anchored in economic scholarship. It is based on recurring changes in economic performance; in the sequence of boom and bust that seems to characterize the capitalist growth process. Among the many theorists explaining or describing these regularities there are some, such as Kuznets, who identified 15-25-year investment cycles; others, like Kondratiev, identify longer waves or cycles of 50-60 years. Subsequent authors associate such growth swings with major technical change, with Schumpeter being the most prominent.

The neo-Schumpeterian approach to long cycles

More recently, evolutionary economists and scholars of innovation, such as Freeman, Louçã, Tylecote and myself, have shifted the emphasis from looking at the variations in economic growth brought by technical change to the analysis of the technologies themselves: their interrelations, their patterns of diffusion and impact on the direction of innovation; how they lead to transformations in the organization of business and institutions; the way in which they influence employment and social life; how they change and are changed by the structure of markets; and, finally, on how government action influences their impact on the economy.

This is the approach to which I subscribe, and it is in this tradition, usually referred to as neo-Schumpeterian, that ICT can be recognized as the fifth technological revolution. In the 1920s, Kondratiev had identified three 'long waves', as he called them, which had already occurred, and predicted the crash of 1929 as the end of the fourth. Schumpeter followed his lead and in *Business Cycles* (1939), made a thorough analysis of the technologies that could be associated with each cycle. Both roughly identified two periods in the British century and two in the American. In 2001, Freeman and Louçã published *As Time Goes By*, where they examined each of those four long waves, plus the current fifth, in terms of the technologies involved, the key organizational paradigms and the institutional framework that shaped their diffusion. This was a break with Schumpeter's prior assumption that 'markets' on their own defined the cycle and then overcame stagnation without government intervention. By this point, neo-Schumpeterians had also recognized a fifth period: the ICT revolution that began in the 1970s.

My own contributions to the periodization debate have focused on expanding the analysis of the diffusion process of each technological revolution yet further. From research into the complex interactions that have occurred during each period, I introduced the concept of *techno-economic paradigms* in 1985 to define the new 'common sense' or 'best practice' that spreads across industries and institutions during each cycle. Further historical analysis led me to make a clear break with the notion of cycles as mere upswings and downswings of GDP, and instead to focus directly on the structure of each technological revolution, and, particularly, on the regularities in the process of its diffusion and assimilation in the economy and society. This led to the abandonment of Kondratiev's term 'long waves' for that of '*great surges of development*':

> *"A great surge of development is … the process by which a technological revolution and its paradigm propagate across the economy, leading to structural changes in production, distribution, communication and consumption as well as to profound and qualitative changes in society. The process evolves from small beginnings, in restricted sectors and geographic regions, and ends up encompassing the bulk of activities in the core country or countries and diffusing out towards further and further peripheries, depending on the capacity of the transport and communications infrastructures".* Perez 2002, p. 15

This shift in understanding was possible because of the inter-disciplinary nature of the approach, which added to the work of Schumpeter that of economic historians — Landes, Hobsbawm, Mokyr; of innovation scholars —Pavitt, Metcalfe, Lundvall, Geels, Stirling; of unorthodox economists — Galbraith, Boulding, Aglietta, Reinert; of sociologists — Bell, Castells, C. Wright Mills; public administration scholars —Drechsler, Kattel; business historians and management scholars — Chandler, Drucker, Handy; and, of course, the work of my neo-Schumpeterian colleagues — Freeman, Louçã, Nelson, Dosi, Soete — among many others.

The change of focus requires examining technologies as interrelated constellations of systems, evolving around major new infrastructural networks, new cheap and powerful materials and sources of energy, new products and processes and new forms of organization. Most importantly, it demands that we look at multiple different stages of technological revolutions, from genesis to maturity, and not, as often occurs, focus either on a single technological 'big bang', and/or on what can appear, from the blurred lens of temporal distance, like its inevitable impact. This approach is very different from the periodisations of Brynjolfsson and McAfee and others, which take a broad-brush approach to history, to economic growth and to technological 'progress'. In our view, as will

be discussed here, they not only overlook important fluctuations in data (in economic growth, employment, inequality and beyond), but also get trapped in anachronistic interpretations of the present.

The recurring pattern and its lessons

From the great surges analysis emerges a pattern of propagation of techno-economic paradigms divided in two periods, split by a major crash and what I call the *Turning Point*. The first, or *installation* period, is the initial, turbulent time of Schumpeter's 'creative destruction', in which the new technologies establish themselves in a massive competitive experiment that defines the winners and the losers in products and companies. This period may last 20-30 years or more, and in it the investment in the new technologies is led by the financial sector. Yet despite the hype, the new technologies themselves, as industries, have been a limited sector for investment in each technological revolution; therefore over-investment in these industries ends up in a major market bubble: canal mania (1790s), railway mania (1840s) (both in the UK), then the Southern hemisphere investment bubbles in the 1880s-90s, the Roaring 1920s stock market mania in the US – and, in our current surge, the recent double bubble of NASDAQ in the 1990s followed by the global 'easy money' boom of the 2000s.

Inevitably a crash follows, leading to the *Turning Point*, a recessive period that can last anywhere from two to thirteen years or more, depending on the behaviour of financial and production capital after the bubble collapse and, crucially, on the actions of government. After the crisis, the state typically moves to control the financial sector through new regulations, as well as to reverse some of the worst consequences of the financial excesses during the bubble (especially income polarization) and to reactivate the economy. The length of that parenthesis and the depth and breadth of the recession (even depression) depends on whether governments, in one way or another, manage to design and apply a set of policies that will set an appropriate *direction* for the expansion of the new production potential across the whole economy.

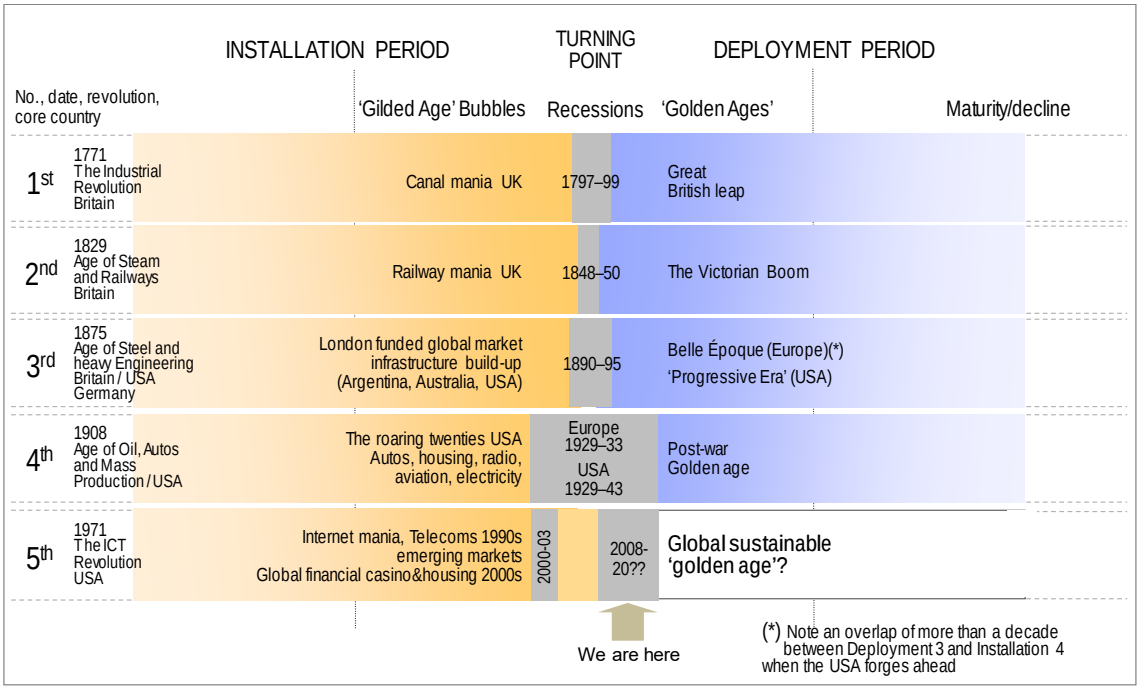
What do we mean by production potential? Typically, the bubble times are periods of intense experimentation with new technologies and infrastructures. However, the new industries that rise up in the period of creative destruction are merely the tip of the iceberg of the new potential for wealth creation. Each revolution is capable of changing the techno-economic paradigm and providing a leap in productivity across the whole economy, but innovation can happen in many directions, most of which are in themselves of uncertain profitability unless conditions are established to reduce risk and increase convergence and synergy. In other words, markets cannot perform their best and get the most out of the potential inherent in the installation of new technologies, processes and infrastructure until government tilts the playing field appropriately.[1] Once the playing field has been tilted appropriately, the next two decades or so constitute the period of *deployment*, during which the new technologies spread their transformative power across the whole economy, producing what have been called the Golden Ages.

[1] A clear example of such a set of policies is the one associated with suburbanization, home ownership and the social safety net that guided innovation in the Age of the Automobile and unleashed the post-war boom

Recognizing these recurring patterns moves us from broad brush periodisations to the identification of five very distinct 'technological revolutions' (see Figure 1). Indeed, it is an understanding of the repeated commonalities in each surge that actually allows us to grasp the specific nature of each one.

Figure 1

The historical record: bubbles, recessions and golden ages



Defining technological revolutions

According to the periodization presented here, a technological revolution is then a very specific set of interrelated innovations, powerful and highly visible, comprising new and dynamic technologies, products, materials, sources of energy, industries and infrastructures, capable of bringing about an upheaval in the whole fabric of the economy and of propelling a great surge of development lasting multiple decades (see Perez 2002, p8). Typically, it will have an important all-pervasive low-cost input, which will drastically reduce the cost of the products and services using it and will move both producers and consumers to its intensive use. Presently, the low-cost inputs are microelectronics, and, consequently, information; during the fourth surge, that of mass production, the low-cost inputs were oil, electricity and plastic materials; steel was the cheap input of the third or heavy engineering surge; cheap coal of the second, the iron railway age.

The other crucial element of a technological revolution is the appearance of a new infrastructure, strongly connected with the key input, capable of widening the frontier and increasing the speed and reliability of transportation and communications, while drastically reducing their cost. Canals were the revolutionary infrastructure of the first surge, changing the geographic parameters of trade; national railways and the telegraph changed the socio-economic structure of the industrializing nations in the second; transcontinental railways and transoceanic shipping and

telegraph heralded the first wave of globalization in the third; highways, airports, electricity and telephone networks radically reshaped society in the fourth; and the global internet has changed the world yet again in the fifth (see Table 1).

Table 1

The industries and infrastructures of each technological revolution

Technological revolution	*New technologies and new or redefined industries*	*New or redefined infrastructures*
FIRST: From 1771 *The 'Industrial Revolution'* Britain	Mechanized cotton industry Wrought iron Machinery	Canals and waterways Turnpike roads Water power (highly improved water wheels)
SECOND: From 1829 *Age of Steam and Railways* In Britain and spreading to Continent and USA	Steam engines and machinery (made in iron; fueled by coal) Iron and coal mining (now playing a central role in growth)* Railway construction Rolling stock production Steam power for many industries (including textiles)	Railways (Use of steam engine) Universal postal service Telegraph (mainly nationally along railway lines) Great ports, great depots and worldwide sailing ships City gas
THIRD: From 1875 *Age of Steel, Electricity and Heavy Engineering* USA and Germany overtaking Britain	Cheap steel (especially Bessemer) Full development of steam engine for steel ships Heavy chemistry and civil engineering Electrical equipment industry Copper and cables Canned and bottled food Paper and packaging	Worldwide shipping in rapid steel steamships (use of Suez Canal) Worldwide railways (use of cheap steel rails and bolts in standard sizes). Great bridges and tunnels Worldwide Telegraph Telephone (mainly nationally) Electrical networks (for illumination and industrial use)
FOURTH: From 1908 *Age of Oil, the Automobile and Mass Production* In USA and spreading to Europe	Mass-produced automobiles Cheap oil and oil fuels Petrochemicals (synthetics) Internal combustion engine for automobiles, transport, tractors, airplanes, war tanks and electricity Home electrical appliances Refrigerated and frozen foods	Networks of roads, highways, ports and airports Networks of oil ducts Universal electricity (industry and homes) Worldwide analog telecommunications (telephone, telex and cablegram) wire and wireless
FIFTH: From 1971 *Age of Information and Telecommunications* In USA, spreading to Europe and Asia	The information revolution: Cheap microelectronics. Computers, software Telecommunications Control instruments Computer-aided biotechnology and new materials	World digital telecommunications (cable, fiber optics, radio and satellite) Internet/ Electronic mail and other e-services Multiple source, flexible use, electricity networks High-speed physical transport links (by land, air and water)

* These traditional industries acquire a new role and a new dynamism when serving as the material and the fuel of the world of railways and machinery
Source: Perez 2002, Table 2.2, p.14

The need for socio-political shaping of the playing field

What is crucial to understand is that each great surge of development does not stop there, with the cluster of new technologies and infrastructures brought by each revolution. The assimilation of each of these sets of interrelated changes produces and also requires a change in the socio-economic context and the socio-institutional framework, in order to enable the full deployment of the wealth-creating potential of the new industries, the modernization of the industries deployed in the previous surge and the flourishing of new services and activities that emerge in response to changes in *lifestyles*: in other words, changes that the new technologies and infrastructures bring to the manner in which we live our day-to-day lives.[2]

It is also key to note that the emphasis on the technological aspects of these revolutions does not imply straightforward technological determinism. The development of each techno-economic paradigm very much depends on the capacity of society and governments to realize the huge transformative potential that each particular technological revolution installs, and to generate a context and a specific type of dynamic demand that can bring forth the innovations and investment that are there to be unleashed. The playing field must be tilted in a general *direction* that will get the best out of markets profiting from the installed technological potential. For example, in the third great surge, the potential for global trade provided by steamships and transcontinental railways was realized and pushed by national and imperial government procurement for infrastructure; the mass production capacity inherent in the fourth was unleashed by suburban infrastructure investment, the provisions of the Welfare State (which protected workers, permitting them to consume uninterruptedly) and by military procurement for the Cold War.

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It is only when we come to deeply understand the relationship between the nature of a technological revolution and the types of demand that can make it come to full fruition, that we can develop a solid foundation for policy design and for socio-political choice. In the next post, I will discuss on which grounds I do recognize the value in seeing the fifth surge as the beginning of a 'second machine age' – but also start to unpick exactly why overlooking the recurring patterns of technological development and diffusion by slicing industrial history into only two epochs risks missing valuable signposts to the future.

[2] Again, using the same example as the previous footnote, the suburban lifestyle associated with the 'American Dream', was a result of the rise of the automobile, highways and plastics; at that time of mass production and mass consumption, the 'customized' element as well as many aspects of our digitally-mediated lives today would have seemed inconceivable.