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Evolution of Technology in the Digital Arena: Theories, Firm-level Strategies and State Policies

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Abstract

This paper analyses the evolution of technology, encompassing the characteristics and dynamics of innovation and technological change, as well as their interactions and interrelations across diverse technical areas that generate organisational changes and systemic socio-economic changes. It provides a brief overview of the various theoretical approaches that have examined technological evolution at different analytical levels, which is followed by a detailed discussion of Carlota Perez's techno-economic paradigm. We are currently witnessing the ultra-dynamic digital era within the information and communication technology (ICT) revolution, which has seen the emergence of the inter-related technological systems of Big Data, the Internet of Things, robotics, online platforms and artificial intelligence. The paper undertakes an analysis of the features and phases of the ICT revolution in detail, including the ongoing digital phase. It discusses the opportunities and challenges presented by each phase of the product/technological lifecycle at the firm level, to innovators, fast followers and incumbents. It also discusses different strategies used by the innovators and fast followers in the digital era for increasing their market share and erecting barriers to entry for new entrants.

It is argued that to realise the full potential of the possibilities of digital technologies, policies have to take into account opportunities and challenges at three levels: (i) those in the digital space itself; (ii) those associated with the digital transformation of services; and (iii) those associated with digital transformations in the production space whether in the industrial or agricultural sector. Increasingly, policy choices in the digital space may decidedly influence the other two trajectories as well as the overall societal outcomes. The impact of new technologies on productivity and its distributional consequences will depend on depend on the capacity to deploy and diffuse these technologies. Given the utmost importance of user interface in digital technology deployment, improving capabilities across the broader society has become more critical than ever. Equally critically, as Big Data has become an instrument with profound cross-sectoral applications, data "ownership" has critical implications. The challenging policy task, therefore, is to strike a balance between data needs for innovation on the one hand, and the issues surrounding privacy and data protection, on the other side. Further, in order to ensure that emerging models promote competition and broader developmental benefits, monopolistic tendencies and practices in the digital space need to be reined by regulations ensuring interoperability standards, platform compatibility, and multi-homing by users. Similarly, in order to capture the broad synergies in ICT deployment, intellectual property protection rules must favour technology diffusion. Attempts to include/expand on such issues in trade rules need to be resisted because strategic policies, by their very nature, have to country and context specific.

Keywords: Technology revolution, techno-economic paradigm, Carlota Perez, ICT, digital transformations, neo-Schumpeterian theories, firm-level strategies, innovations, online platforms, datafication

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1. Introduction

The dominant role played by technological advance as the key driving force of economic development has been recognised since the time of the early 17th century Italian economist Antonio Serra.[2] In the 19th century, the Classical economists also recognised that standards of living could not rise unless technological advances led to an increase in the productivity of resources. But Joseph Schumpeter was among the first few modern economic theorists to put technical change and entrepreneurship at the root of long-term economic growth. Schumpeterian theory divided up the history of economic growth since the Industrial Revolution into eras or cycles of roughly half century duration, with a relatively small set of technologies and industries driving economic growth in any particular era. It has also been recognised since Schumpeter that new technologies often have disruptive consequences for incumbent firms, as well as for existing organisational practices and structures of economic life, and require changes in firm and industry structures. Even though early neoclassical growth theories conceived technological progress as exogenous to firms, there has been significant evolution in the theoretical understanding of the processes underlying technological change subsequently. This is largely credited to the works of neo-Schumpeterian economists who brought together entrepreneurial/firm-level processes of

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[2] Reinert and Reinert (2003) shows that Serra's 1613 *Breve trattato* coherently presented the idea that systemic relationships and synergies which exist between different sectors of the economy influence the production and implementation of new knowledge or innovation, and thus economic development. This is the kernel of the 'national innovation system' approach that became popular from the early 1990s onwards.

innovation and industry-level dynamics with socio-economic conditions and policies supporting innovation through different phases of technological evolution.

As technologies evolve in a complex process influenced by a variety of factors, they present different opportunities and challenges to innovating firms and first movers, as well as for new entrants and fast followers. Accordingly, as technologies and products evolve and mature, the nature of competition in the market changes through the different phases, and the changed market structure in turn impacts the nature of innovation and diffusion of new technologies. The rate and effectiveness of the needed changes in firm and industry structures, as well as the pace and effectiveness of efforts to adopt and master new technologies, depend on the institutional structures enveloping the socio-economic spheres—in particular, on the extent to which state policies facilitate productive transformation through each phase of a technological revolution. All these micro, meso and macro level processes of technological evolution and diffusion involving complex interactions have been captured within the framework of evolutionary (or neo-Schumpeterian) economics, which is found in the most synthesised form in Carlota Perez's techno-economic paradigm.

We are currently witnessing the ultra-dynamic digital era within the information and communication technology (ICT) revolution, which, characterised by the generation, processing and dissemination of information, has seen the emergence of the inter-related *technological systems* driven by Big Data, the Internet of Things, robotics (or computation-intensive automation), online platforms and artificial intelligence. The transformative impact of ICT has been increasingly felt across most areas of social and economic life in the advanced core countries over the last two decades or so, while it has begun a phase of greater assimilation there and diffusion in developing countries since the last two-three years—following the advent of the digital era.

This study will analyse the evolution of technology encompassing the characteristics and dynamics of innovation and patterns in technological change and diffusion, as well as their interactions and interrelations across diverse technical areas that generate business organisational changes and systemic socio-economic changes. While the evolution of technologies in the digital era may also broadly follow the patterns observed under earlier techno-economic paradigms, we need to understand the unique characteristics that differentiate them from the previous technological revolutions. Apart from striving for a systematic understanding of technological change in the digital era and the dynamics of the accompanying competitive processes and organisational changes, it will also examine the role of the state in the underlying processes.

The scheme of the paper is as follows. The ensuing section provides an overview of the various theoretical approaches that have examined technological evolution at different analytical levels, followed by a detailed discussion of the techno-economic paradigm (TEP) framework. Section 3 undertakes an analysis of the features and phases of the ICT revolution in detail, including the ongoing digital phase. Section 4 discusses the opportunities and challenges presented by each phase of the product/technological lifecycle at the firm level, to innovators, fast followers and incumbents. Section 5 discusses the different strategies used by the innovators and first movers in the digital era for increasing their market share and erecting barriers for entry for new entrants and fast followers in different stages of product/technology evolution. Section 6 concludes by discussing the overall challenges for state policy.

2. Understanding Technological Change: A theoretical overview

There has been significant evolution in the theoretical understanding of the processes underlying technological change. Our current understanding on technological evolution is largely credited to the works of the neo-Schumpeterian economists Richard Nelson, Sydney Winter, Chris Freeman, Bengt-Åke Lundvall, Francisco Louçã, Carlota Perez, Luc Soete, etc. Among these, despite the path dependence and co-evolution of their theoretical advances, Carlota Perez is considered to have provided the most systemic framework on technological evolution through the elaboration of the 'techno-economic paradigm'. While the overall discourse on innovation and economic development has largely proceeded separately along two broad levels of analysis, namely, the entrepreneurial or firm-level processes of innovation or the socio-economic conditions and policies supporting innovation,[3] Perez's sequence model of techno-economic paradigm brings together the micro, meso and macro-level causal mechanisms that induce technological evolution, the accompanying shifts in firm-level organisation and strategies, and the transformation of the socio-economic and institutional contexts associated with successive technological revolutions at the national and international levels. After providing an overview of the various theoretical approaches that have examined technological evolution at different levels, we undertake a detailed discussion of Carlota Perez's techno-economic paradigm.

2.1 Evolution of the Theoretical Discourse

For Classical economists, technological progress was the central thread tying together the variables explaining economic growth. Subsequently, the growth models of neoclassical growth theorists which were based on capital accumulation found that technological progress helped explain the "Solow residual". That is, the portion of measured growth in national product that could not be attributed to the accumulation of inputs was credited to technological progress (Grossman and Helpman 1991 and Singh 2006).

[3] See Karo and Kattel (2011).

But early neoclassical growth models based on perfect competition treated technological progress as an exogenous process. It was evident that the process of innovation essentially involves the production of knowledge, which in turn calls for research and development (R&D). However, despite acknowledging knowledge creation as intentional, early neoclassical models with exogenous technology considered innovation as driven by basic research. This idea was implicit in the models who introduced a public research sector that contributes technical knowledge to the profit-seeking entities in Solow's model (Grossman and Helpman 1991: 22–23; 135).

It is new growth theory or 'endogenous growth theory', which not only recognised the importance of knowledge accumulation for economic growth, but successfully modelled the commercially oriented innovative investment (Singh 2006) as fundamentally endogenous.[4]That is, productivity gains arise from intentional investment in R&D by profit-seeking firms. This led to the acceptance of the idea that even though scientific discoveries typically provide the primary stimulus for inventions that often revolutionalise the technique of production, it is the expected profitability of inventive activity—reflecting conditions in the product and factor markets, that determines the pace and direction of industrial innovation (Grossman and Helpman 1991: 4).Returns to R&D were considered to come in the form of monopoly rents in imperfectly competitive product markets.

After empirical research in the 1950s and 1960s identified technological advance as the key driving force of macroeconomic growth, there was a surge of research by economists on the sources and processes of technological change and advance (see Singh 2006, Joseph and Abraham 2005 and Sampath and Roche 2012). This led to the rediscovery of the features of economic activity where innovation was important, as had been argued years before by Schumpeter in 1942 (Nelson 2006).

In his Theory of Economic Development—which was the first systematic framework to analyse the complex processes behind technological change—Schumpeter had strongly distinguished innovation, seen as the commercial introduction of a new product or a "new combination", from invention, which belongs to the realm of science and technology. He based his theory on the assumption that the usual macroeconomic equilibrium is being perpetually destroyed by entrepreneurs who try to introduce innovations (Perez 2001). This is very different from the approach in the traditional theory of the firm, which sees the firm as choosing inputs and production levels with given technology and factor prices in order to maximise profits. As Milberg and Winkler (2013: 28) rightly argue, therefore, the role of the firm in innovation necessitates a contrasting approach to the theory of the firm in capitalist development, wherein

[4] Although Arrow (1962)—among the old school neoclassical theorists was the first to view technological progress as a by-product of firms' private investment decisions and thus endogenous, Grossman and Helpman (1991) suggest that this was conceived only as an accidental occurrence (and not as a commercially-driven decision).

the firm is the locus of product and process innovation (in addition to being the place where profits and investments are made). Thus the firm does not take constraints as given, but typically makes great efforts and takes considerable risks to alter its cost structure.[5]

While the economy progresses as a whole during a phase of significant innovation, this goes hand-in-hand with a churning process of "creative destruction", which involves losers and winners at the firm and industry levels. This arises from the fact that a successful introduction of an innovation (i.e. a disruptive technology) disturbs the 'normal flow' of economic life and forces some of the already existing technologies and associated resources to lose their positions within the economy (Perez 2009).

Krugman's (1991) work on increasing returns and economic geography or Rodrik (2007)'s development economics have both been considered as remarkable attempts to try and extend the neoclassical analysis to include innovation into the centre of analysis (Karo and Kattel 2011: 179). However, despite all their efforts to model technological change, Nelson (2009: 269) emphasises that even modern versions of neoclassical models do not come to grips with the processes by which technology advances as documented by empirical scholarship over the last several decades. By contrast, economists inspired and influenced by Schumpeter have made the most significant progress in understanding the evolution of technologies and their role in transforming economies. In his survey of sources and patterns of industrial innovation, Dosi (1988) concluded that technical change reflects an interplay of technological opportunities created by scientific discoveries originating from basic research and inducements for applied research that emerge from market opportunities. That is, knowledge generation is driven by a combination of basic research and applied research powered by commercial interest.

Overall, the academic discourse has moved from micro level approaches to innovation (starting with Schumpeter 1939) towards a more systemic view of the influence of the socio-economic environment (Karo and Kattel 2011). Subsequently, the significant volume of scholarly work that focused on "national systems of innovation"—with its allegiance to new institutional economics—explored the complex processes involved in linking scientific research with product and process innovations, and highlighted the complexity of many market relationships that are embedded in broader social and institutional structures (Block and Keller 2011). The complex and changing network of interactions and cooperation among the many agents that contribute to innovations—researchers, engineers, suppliers, producers, users and institutions—as a technology system evolves, has been conceptualised as a national system of innovation. The original propounders were Chris Freeman, Bengt-Åke Lundvall (1992) and Richard Nelson (1993). This approach has subsequently led other researchers to the study of regional and

[5] Such behaviour is part of process innovation, but can also help overcome instability through product innovation and the development of the market. See Milberg and Winkler (2013: 28).

sectoral systems of innovation (*ibid*). Around the same time, other neo-Schumpeterian/evolutionary economists influenced by the new institutional economics developed the concept of techno-economic paradigm to analyse the processes of technological evolution. Evolutionary theory takes the nature and role of innovation and technical change in economic progress away from the confines of a hypothetical economic equilibrium context of neoclassical economics (Nelson 2006) and makes it helpful to analyse real world dynamics. As stated in Karo and Kattel (2011, p. 182):

> *While neoclassical arguments assume that technology is essentially freely available to all, competitors and countries alike, the evolutionary school argues that technological development is almost always path-dependent. The former view also assumes that technological development is more or less linear, towards ever more complex solutions yet with a rather clear path ahead. Thus, while neoclassical economists set out to rectify market failures that prevent the dissemination of technologies and skills, in the eyes of evolutionary economists, entrepreneurs seek technological innovation in order to create market failures. For evolutionary economists, technological development is anything but linear, and technology is anything but freely available. Path dependencies, linkages, spillovers, externalities, winner-takes-all markets and highly imperfect and dynamic competition make technology an unpredictable, high-risk and possibly high-return endeavor that drives on a tautological logic: technological development feeds on technological development (see e.g. Arthur 1994 and Perez 2002 cited in Karo and Kattel 2011).*

These characteristics engender long-term structural changes in economies in the form of technology trajectories, paradigms and geographical agglomerations. In particular, since the early 1980s, evolutionary economists have emphasized the latter, long-term characteristics of economic development that are directly related to technology and innovation.

Given that we are interested in specifying the processes underlying technological change and their driving dynamics at different levels, we discuss the evolutionary approach in more detail in the following sub-section.

2.2 The Neo-Schumpeterian Theory of Technological Evolution

Evolutionary theory of technological change, pioneered by Sidney Winter and Richard Nelson and others in the early 1980s, came into being as a result of bringing together institutional economics with Schumpeter's evolutionary approach.

Just as Schumpeter envisioned, innovation—the generation of new ideas and solutions, or novelty (technological, procedural, or institutional, organisational)—is the root of economic development and socio-economic problem-solving for evolutionary economics. It treats innovation as an inherently evolutionary phenomenon characterised by uncertainties, dynamism, frequent failures and constant learning. Technological change, according to them, is thus fundamentally dynamic, but it is also historical in the sense that they are irrevocable and path-dependent (Karo and Kattel 2011, Karo and Kattel 2016). But while Schumpeter did not address the role of institutions, evolutionary economists have drawn upon the research on innovation systems by Lundvall, Freeman, etc., and address the coevolution of technologies, firm and industry structures, the supporting and governing institutions, and their interaction as the driving dynamics (Nelson 2006). They highlight the role of non-market institutions involved in the early stages of the innovation process (particularly R&D) in many sectors—like university and public research systems, scientific and technical societies, government programs. Other institutions that shape economic dynamics in the innovation system more broadly have also been recognised such as the labor market, the education system, financial institutions, regulatory structures, etc. (Nelson 2006). Many of these innovation systems studies focus on the interface between the public and private sector, looking particularly at public funding of research and higher education, the growth of the scientific and technical labour force, the systems for establishing and protecting intellectual property rights for innovators, and the mechanisms that facilitate the movement of ideas from the research lab to the market (Block and Keller 2011).

Freeman himself introduced the term National Systems of Innovation in 1987 looking at the interconnections between technology, economics and institutions.[6] Thus their frameworks explore i) the exogenous and the endogenous sources and driving force of technological and social transformations with a focus on innovation, ii) their successful implementation, diffusion and persistence in a specific context (organizations, markets, states, society); and iii) their eventual decline and/or substitution with something more novel (Karo and Kattel 2016).

It has been noted that a number of scholars, such as Keirstead (1948) with his 'constellations' of innovations, or Freeman, Clark and Soete (1982) with their 'new technology systems', or Dosi (1982) with his 'technological paradigms' have demonstrated both a technological and an economic basis for the clustering of innovations (Freeman 2009: 136), and thus, technological change. However, the most comprehensive framework addressing technological evolution is that presented by Carlota Perez, with her conceptualisation of 'techno-economic paradigm' in 1984 (replacing "technical paradigm" used by Dosi 1982) as a meta concept—of technological change as the all-enveloping canopy encompassing and transforming economy as well as society.

[6] He also developed the notion of long waves, following on from the Russian economist Kondratiev and Schumpeter, using a historical approach—with Clark and Soete in 1982, with Perez in 1988 and with Louçã in 2001). See Kattel, Drechsler and Reinert (2009).

2.2.1 Carlota Perez's techno-economic paradigm

Perez synthesised the perspectives from the historical long-term framework of Schumpeter and the Russian economist Kondratiev on cycles and long wave theories of economic development[7]as well as the neo-Schumpeterian or evolutionary research on innovation, technological trajectories, creative destruction and institutions associated with the names of Richard Nelson, Bengt-Åke Lundvall, Giovanni Dosi, Luc Soete, etc., and in particular, Chris Freeman and Francisco Louçã.[8] For all these neo-Schumpeterian economists, the description of technological revolutions as processes of "creative destruction" is applicable not only to the economy but also to policies and institutions. However, Perez has gone further than that: by bringing in the fundamental role of financing in technological change, she also shows how the financial infrastructure interplays with innovations and economic activities. Thus she is able to relate microeconomic innovations with macroeconomic policies and activities by marrying the historical account (which grows out of Schumpeterian analysis) with institutional change and macroeconomic (e.g., labour market) and financial issues (Kattel, Drechsler and Reinert 2009).

Perez advanced the notion of technological revolutions and developed an over-arching meta paradigm to locate the *macro* phenomena of the mutual relationships between technology, economy, society and the institutional context in the micro-foundations of technical change. According to her, the meaningful space where technical change needs to be studied is that of *innovation* at the convergence of technology, the economy and the socio-institutional context (Perez 2009: 3). Perez's "techno-economic paradigm" concept is an umbrella notion for referring to the economic and technological factors guiding the general direction of innovation and the principles guiding change in each individual technology (Perez 2002 and 2007). This concept captures both the rhythm and the direction of change in a given technology.

The life cycle of a technology commences with the introduction of a new product based on an emerging technology. Perez (2001) suggests that even through there are specific differences

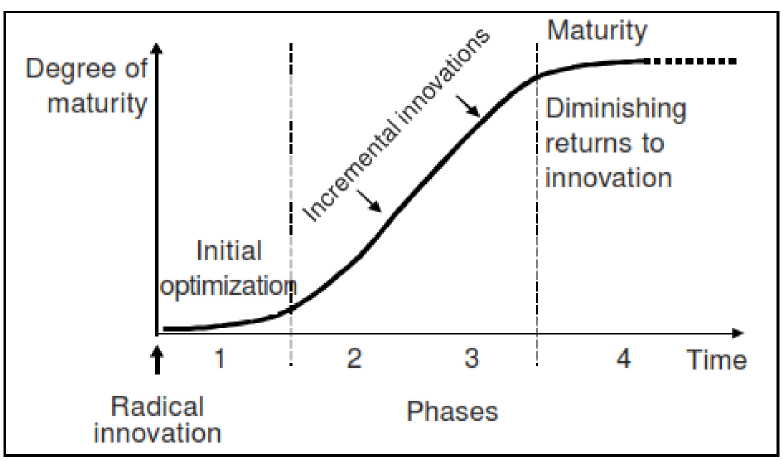
[7] Among the many theorists explaining or describing the regularities observed in the sequence of boom and bust that seems to characterise the capitalist growth process, there are some, such as Kuznets, who identify 15-25-year investment cycles; others, like Kondratiev, identify longer waves or cycles of 50-60 years. In the 1920s, Kondratiev had identified three 'long waves' that had already occurred, and predicted the crash of 1929 as the end of the fourth long wave. Subsequent authors associate such growth swings with major technical change, with Schumpeter being the most prominent among them. In *Business Cycles* (1939), Schumpeter made a thorough analysis of the technologies that could be associated with each cycle. See Perez (2017).

[8] In a blog post in 2017, Perez credits the development of her contribution to the inter-disciplinary nature of her approach, which added to the work of Schumpeter that of economic historians, innovation scholars, unorthodox economists, sociologists, public administration scholars, business historians, and the work of her neo-Schumpeterian colleagues. She has specifically credited the contribution in 2002 of Freeman and Louçã's *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 organisational paradigms and the institutional framework that shaped their diffusion. She has pointed out how this was a break with Schumpeter's prior assumption that 'markets' on their own defined the cycle and then overcame stagnation without government intervention. See http://beyondthetechrevolution.com/blog/second-machine-age-or-fifth-technological-revolution-part-2/

between technologies, most technologies tend to follow a similar trajectory as regards the rate and direction of change, from initial innovation to maturity. She describes this as follows.

> *After a radical innovation gives rise to the appearance of a new product, capable of generating a new industry, there is an initial period of intensive innovation and optimization, until the product gains acceptance in the corresponding market segment. Once market acceptance is achieved, they are subjected to a series of incremental innovations following the changing rhythm of a logistic curve (See figure 1). Interaction with the market soon determines the direction that improvements will take, and these often define a dominant design. From that point on, as the markets grow, successive incremental innovations are made to improve the quality of the product, the productivity of the processes, and the producers' market position. Changes occur slowly at first, while producers, designers/engineers, distributors and consumers engage in feedback learning processes; rapidly and intensively once a dominant design is established in the market. This process culminates in maturity, and changes begin to slow down once again as new investment in innovations begins to have diminishing returns. Depending on the importance of the product, the whole process can last a few years or a number of decades. In the latter case, the "improvements" usually take the form of successive models* (Based on Perez 2001:113–4 and Perez 2009: 3)

Figure 1. The lifecycle of a technology



Source: Perez (2001, p. 114).

Teece (1986)'s reference to the pre-paradigmatic stage of the technological evolution of a product/industry—quoting Abernathy and Utterback (1978) and Dosi (1982)—appears to parallel the period of initial optimisation in Perez's framework. According to Teece, "product designs are fluid, manufacturing processes are loosely and adaptively organized, and generalized capital is used in production. Competition amongst firms manifests itself in competition amongst designs, which are markedly different from each other… after considerable trial and error in the marketplace, one design or a narrow class of designs begins to emerge as the more promising to … meet a whole set of user needs in a relatively complete fashion." Once a dominant design emerges, competition shifts away from design to price and incumbents seek to lower unit costs by exploiting economies of scale and learning. However, once the product design stabilises, there is likely to be a surge of process innovations as producers attempt to lower production costs for the new product. This parallels the phases of incremental innovations in Perez's technology lifecycle.

It is clear that while new investment and economic growth is triggered by a radical innovation, investment expansion depends on numerous incremental innovations in product enhancement and process improvement that follow. The latter have an important impact on productivity increases and market growth. As production volume and productivity become crucial for market expansion, process innovations drive most of the scaling-up investment. Quoting Utterback and Abernathy (1975), Perez also asserts that sometime after the take-off, both the number and the importance of incremental process innovations tend to overtake product changes (Perez 2009: 4).

However, the evolution of technology is not random or isolated. Innovation is a collective process involving different agents (suppliers, distributors and many others, including consumers), and therefore is not isolated. Further, technologies interconnect and tend to appear in the neighbourhood of other innovations (non-randomness).[9] As a result, major innovations spur further innovations: facilitating similar ones; leading to complementary ones upstream or/and downstream; or inducing competing alternatives. In the first two phases there are many really important products with a long life cycle; afterwards, they tend to go down in number and importance, until the last ones are less significant and have a short life cycle (Perez 2001).

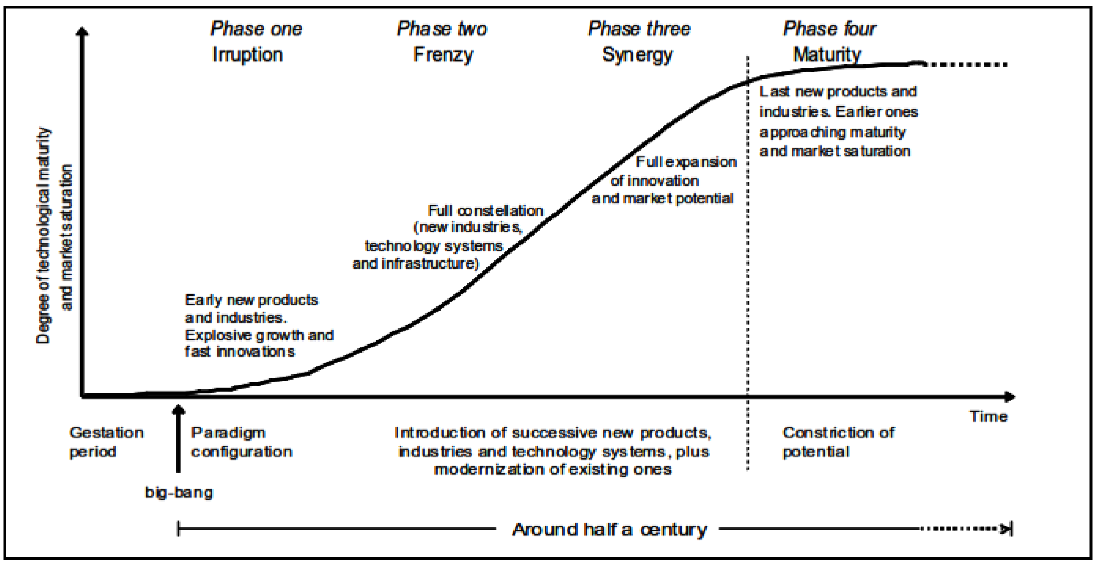
Thus Perez's *technological systems* consist of successive new products, services and related industries which build upon the innovative space inaugurated by an initial radical innovation (leading to a new product/technology) and that is widened by followers (Perez 2001). What holds for individual technologies in terms of regularities in the dynamism and direction of technical change occurs also at the *meso* level, in relation to the evolution of all the products in an industry and to that of whole sets of interrelated industries (Perez 2009: 4). At this meso level of analysis, it is found that the process of diffusion also follows a logistic shape. The incremental innovations along the trajectory are the new products, services and related upstream and downstream industries, rather than simple improvements in the original new technology (in terms of product enhancement and/or process improvement). Thus technologies are

[9] This dynamic interrelatedness has led to the notion of a technology system studied by Freeman to describe how the Schumpeterian clusters are formed and evolve. The Schumpeterian clusters are the result of techno-economic and social interactions between producers and users within complex dynamic networks.

interconnected in systems, and these, in turn, are intertwined and interdependent, both with each other and in relation to the physical, social and institutional environment.

Just as individual innovations are interconnected in technology systems, these are in turn interconnected in technological revolutions. Thus, on a first approximation, a technological revolution can be defined as a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems (Perez 2002, 2007). As in the case of individual technologies, industries and technology systems, the theoretical life cycle of a technological revolution tends to follow a logistic S-curve. During its unfolding, it functions as a sort of envelope influencing the life cycles of all the component technology systems, industries and products.

Figure 2. The lifecycle of a technological revolution



Source: Perez (2007, p.9)

Technological revolution has also been described as a set of technology systems following similar principles and obtaining benefits from the same externalities, which gradually create the necessary conditions for the appearance of new systems. The process of multiplication of innovations and technological systems, both up and downstream from the industries based on radical breakthroughs, form the core of each technological revolution. Each of these constellations of new technologies represents the opening up of a vast new territory for innovation and market expansion, and possesses enormous growth potential.

Perez identifies the first phase or “irruption” of a technological revolution to “the initial big-bang or first public introduction of the most emblematic and significant technology of that revolution. It is the moment when its enormous innovation potential is made visible to would-be entrepreneurs and investors" (Perez 2007). "It is Arkwright's Cromford mill in 1771, signalling the beginning of mechanization in the cotton textile industry. It is Stephenson's Rocket steam engine for the Liverpool-Manchester railway in 1829, which initiates the Age of Steam and Railways. It is Carnegie's huge Bessemer steel plant launching the world of heavy engineering in 1875; Henry Ford's first Model-T in 1908 inaugurating the Age of Mass Production, and Intel's 1971 microprocessor opening the Age of Information Technology" (Perez 2007).

Under this theoretical framework, the term 'great surge of development' is used to refer to the whole process of diffusion and social assimilation of each technological revolution, from big-bang to maturity. While there is the recurrence of a sequence—"irruption, frenzy, synergy and maturity"—in successive technological revolutions, there is uniqueness in each period.

The techno-economic paradigm framework thus offers a sequence model of the whole trajectory and structure of each technological revolution as an evolutionary process of its assimilation by economy and society. It is a historically-based model of the way in which successive technological revolutions are assimilated in the economic and social system, generating great surges of development[10], which follow a recurring sequence and involve major readjustments in both the economic and the socio-institutional spheres. "The changes involved go beyond engineering trajectories for specific product or process technologies and affect the conditions of production and distribution throughout the system and once established as the dominant influence on engineers, designers and managers, becomes a 'technological regime' … as a common sense best practice for several decades and across the whole economy" (See Freeman 2009: 136).[11]

In Carlota Perez's framework, the propagation of a techno-economic paradigm—the great surge of development—is divided into the installation period and the deployment period. In the installation period lasting 20–30 years or more, wherein a new technological revolution acts as the instigator of a new surge of development, financial capital plays a critical role in investments in new technologies. Finance is the handmaiden that allows the new TEP to be explored, exploited and installed before it is fully deployed (Kregel 2009). However, with yet limited scope in these new technologies, overinvestment in them and increased focus on financial profits eventually leads the way to the hyperinflation of asset values and the creation of a major market bubble. The nature of financial capital in avoiding longer-term investment to increasingly focus instead on short-term profits has been noted by many economists and analysts. As Kregel (2009) has pointed out, diverting funds from production into financial speculation, 'quasi-gambling',

[10] The processes of diffusion of each technological revolution and its techno-economic paradigm—together with their assimilation by the economy and society as well as the resulting increases in productivity and expansion—constitute successive great surges of development (Perez 2002).

[11]Freeman (2009) observes that Perez's concept corresponds closely to Nelson and Winter's concept of 'general natural trajectories'. However, it may be noted that Freeman and Louca (2002)'s last chapter is titled "The Emergence of a New Techno-Economic Paradigm'.

etc. and seeking financial gains for gains sake, all lead to the resulting bubble-driven inflation of paper values being out of sync with their real values and eventually becomes an obstacle to further development of the TEP. The subsequent inevitable crash leads to the 'Turning Point' in the middle of the propagation of a techno-economic paradigm.

Turning points, coming about after a huge financial meltdown, are historic occasions for institutional revival of significant proportions. This recessive period can last 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 huge rise in income inequality, and to reactivate the economy (Perez 2006 and 2017a). 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 (Perez 2017a).

As Kregel (2009) emphasises, the full deployment of the installed paradigm therefore necessarily requires the elimination of excessive financial layering through a financial collapse. It also simultaneously requires increased regulation of the financial system through more rigorous government control in a way that does not prevent the full deployment of the new technology led by production capital reaping the full economic and social potential of the prevailing paradigm (Kregel 2009: 203). Once the financial sector is reined in by regulation and simultaneously the incentives for investments have been tilted in favour of production appropriately, the new technologies tend to spread their transformative power across the whole economy over the next two decades or so. The latter constitutes the deployment period. The deployment period requires that production, investment and innovation have a direction to follow and that the financial world is drawn away from casino behaviour and back to supporting innovation and production (Perez 2017b).[12] The economy-wide increase in productivity leads to, what Perez has called, the Golden Ages.

Successive technological revolutions and their techno-economic paradigms are, as Perez shows, the fundamental feature of capitalism after the Industrial Revolution. As Perez (2006) sums up:

> *There has been a technological revolution every 40 to 60 years, beginning with the Industrial Revolution in England at the end of the 18th Century; each has generated a*

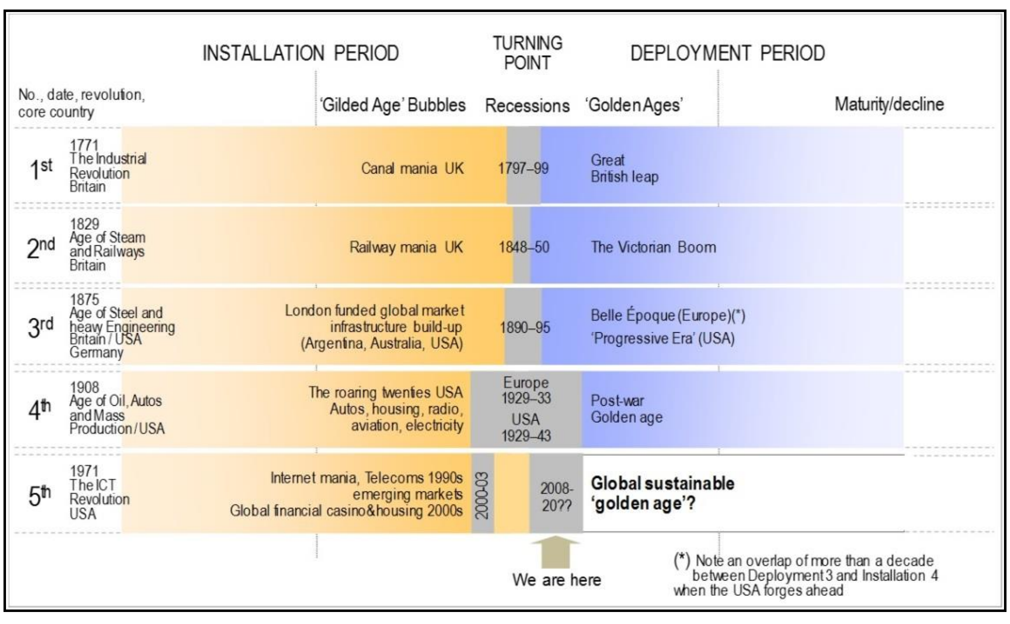
[12] http://beyondthetechrevolution.com/blog/second-machine-age-or-fifth-technological-revolution-part-3/

great surge of development[13]*, diffusing unevenly across the world from an initial core country. … The great wealth creating potential provided by each of them stems from the combination of the new technologies, industries and infrastructures with a set of generic technologies and organisational principles capable of modernising the rest of the economy. The resulting best practice frontier is superior to the previous one and becomes the new common sense for efficiency – a new techno-economic paradigm – that defines the guidelines for innovation and competitiveness. … The propagation is highly uneven in coverage and timing, by sectors and by regions, in each country and across the world.* (Perez 2006)

Thus there is an inevitability of the cyclical behaviour of the economy in the characterisation of the techno-economic paradigm. However, the theory is not deterministic because the cycles do not get repeated—each cycle is new and idiosyncratic. This is fundamentally because the crucial element determining the evolution of each cycle is the technological innovations that characterise it (Kregel 2009: 204), which are necessarily different in each cycle.

There have been five distinct technological revolutions and five surges in the last 250 years: i) the 18th century Industrial Revolution; ii) the age of steam and railways of the early 19th century; iii) the age of steel, electricity and heavy engineering in the late 19th century; iv) the age of oil, the automobile and mass production of the early 20th century; and v) the age of information and telecommunication from the second part of the 20th century.

Figure 3. Bubbles, recessions and golden ages of the five great surges of development



Source: Perez (2017a)

[13] Perez (2002) describes a great surge of development as "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.

Perez (2009) identifies a 'key factor' with each techno-economic paradigm (TEP), and characterises it in the following terms:

(i) it has low and declining relative costs;
(ii) its supply shows the potential for an enormous long-term increase or is inexhaustible in the foreseeable future (although temporary shortages may occur in a period of rapid build-up in demand);
(iii) it has massive potential for becoming pervasive in its applications and form a core element of a complex of technologies, processes and institutions; and
(iv) it is capable of increasing the power and decreasing the cost of capital and labour.
(Based on Perez 2009 and Freeman 2009)

As Freeman (2009) describes, these are applicable to a particular input or set of inputs, which may be described as the 'key factors' or 'core inputs' of that paradigm.[14] Indeed, in the Freeman-Perez formulation of the argument, a new TEP is characterised by three defining criteria: 1) changes in cost structure, with the emerging technological regime enjoying strong and increasing cost advantages; 2) expanded perception of opportunity spaces, creating multiple entrepreneurial opportunities for the application of the emergent bundle of technologies; and 3) new organizational models, where the new is better fitted to the emergent technologies and generates massive gains in terms of efficiency over those linked (or constrained) by the dominant paradigm (Mathews 2012).

All of the key factor/s may have existed (and were in use) long before the new paradigm developed. Therefore, as Perez argued, from a purely technical point of view, the explosive surge of interrelated innovations involved in a technological revolution, could probably have occurred even earlier and in a more gradual manner (Perez 2002, pp. 27–32). But they come about only when the full potential of key factors is recognised and made capable of fulfilling the four conditions above. This in turn occurs only when the previous key factors and their related constellation of technologies gave strong signals of diminishing returns and of approaching limits to their potential for further productivity increase.

That is, there are strong economic and social factors at play that serve as prolonged containment first and as unleashing forces later. The massive externalities created to favour the diffusion and generalisation of the prevailing paradigm act as a powerful deterrent to change for a prolonged period (Perez 2002). Paul David (1985 cited in Freeman 2009) had demonstrated some of the

[14] It was identified as 'key input' in Perez (1984). This was cheap water power for the mills and canals in the first revolution; cheap coal for the steam powered railways and mills of the second; cheap steel for the worldwide steamships, railways, the giant bridges and structures and the major chemical and electrical equipment of the third; cheap oil for the internal combustion engines of automobiles, trucks, airplanes and ships as well as for the production of electricity, and, finally, cheap microprocessors for the computers and telecom equipment of the current fifth.

ways in which the economy may become ‘locked in’ to a particular technology and talked about ‘containment’ forces in his theory of path-dependent processes. It is only when productivity along the old trajectories shows persistent limits to growth and future profits are seriously threatened that the high risks and costs of trying the new technologies appear as clearly justified. And it is only after many of these trials have been obviously successful that further applications become easier and less risky investment choices (Freeman 2009)

A techno-economic paradigm (TEP) is then the result of a complex collective learning process articulated in a dynamic developmental model of the best economic, technological and organisational practice for the period in which a specific technological revolution is being adopted and assimilated by the economic and social system. According to Perez (2002), while the dominant TEP moves through its mature phases (late deployment and decline),a new paradigm is gestating and moving into the early phase of installation.

It has been pointed out that in the irruption phase of a technological revolution, the innovations may initially appear (and may be in fact pursued) as a means of overcoming the specific bottlenecks of the old technologies. However, subsequently, the new key factors and related sectors soon acquire their own dynamics and successive innovations take place through an intensive interactive process, spurred by the limits to growth that are increasingly apparent under the old paradigm (Freeman 2009).

Under favourable conditions, business confidence improves, leading to an atmosphere of ‘boom’ in which, although there are still risks and uncertainties attached to all investment decisions, animal spirits rise leading to the frenzy phase. Such favourable conditions include complementarities between equipment, materials and component innovations and the emergence of an appropriate infrastructure, as well as some degree of political stability and institutions that promote, or at least do not hinder too much, the diffusion of new technologies (Freeman 2009).

In the synergy phase of a technology revolution, the most successful new technology systems gradually crystallise as an ideal new type of production organisation that becomes the common sense of management and design, embodying new rules of thumb, restoring confidence to investment decision makers after a long period of hesitation. This process has been seen very clearly with the interrelated and symbiotic growth of microelectronic components, computers, telecommunications, the internet and a wide range of new services and manufactured products (more later).

Among other things, as the technological revolution moves through the synergy phase and enters the mature stage, the new techno-economic paradigm involves:

- A new ‘best practice’ form of organisation in the firm and at the plant level;

- A new skill profile in the labour force, affecting both quality and quantity of labour and corresponding patterns of income distribution;
- New trends in both radical and incremental innovation geared to substituting more intensive use of the new key factor(s) for other relatively high cost elements;
- A new product mix in the sense that those products that make intensive use of the low-cost key factor will be the preferred choice for investment and will represent, therefore, a growing proportion of GNP;
- New trends in the location of investment both nationally and internationally as the change in the relative cost structure transforms comparative advantages;
- A particular wave of infrastructural investment designed to provide appropriate externalities throughout the system and facilitate the use of the new products and processes everywhere;
- A tendency for new innovator-entrepreneur type small firms also to enter the new rapidly expanding branches of the economy and in some cases to initiate entirely new sectors of production (Freeman 2009).

A climate of confidence for a surge of new investments is created through an appropriate combination of regulatory mechanisms that foster the full deployment of the new techno-economic paradigm (Freeman and Louçã 2001). In the TEP framework, unleashing the growth potential of each technological revolution in the deployment period requires overcoming the basic tensions inherited from the installation period. According to Perez (2007: 24), this means:

- favouring long-term over short term investment;
- stimulating productive investment and employment creation rather than feeding the financial casino or housing bubbles;
- aiming at innovations for true market expansion and not for quick financial gains; and inducing the search for profits from real production and not from manipulating money.

2.2.2 *Firm-level innovation*

The core ideas about individual and firm behaviour and innovation in evolutionary thinking are skills (as 'tacit knowledge') and routines (as 'organisational memory', 'learning by doing' and similar concepts going back to Nelson and Winter 1982). Both are related to and determined by technological change and result from constant learning and feedback inside and outside the organisation (the latter being the market). It is understood that organisations tend to rely on, or lock into, existing routines due to path dependencies and positive feedback dynamics (Kattel, Drechsler and Reinert 2009).[15] This makes firms' past experience increasingly important in predicting future actions.

In principle, innovative organisations are the ones that engage in search for novelty that denotes "all those organizational activities which are associated with the evaluation of current routines and which may lead to their modification, to more drastic change, or to their replacement" (Nelson and Winter, 1982, p. 400). This search for novelty is characterised by irreversibility, uncertainty and contingency as well as selection.

Karo and Kattel (2014) observed that sometimes the search for novelty itself is routinised in the sense that there exist routines for 'innovation' in the form of research and development, learning and experimentation. At other times it may grow out of non-routinised situations, e.g. conflict and competition between members of an organization or between organizations within a system, and/or autonomy of the organization or system to invest in the search for novelty as a result of managerial or financial 'slack'.[16] Thus organisational capabilities for innovation are understood by focusing on a) organisational routines and resulting firm- and industry-level capabilities; b) search and selection processes and the endogenous and exogenous sources of novelty creation; and c) the selection and feedback environments (Karo and Kattel 2014).

At the firm level, whether in the first phase of a new revolution or in the last phase of a mature revolution, entry by followers fundamentally requires new entrants to be knowledgeable about the current phase of the technological revolution to be able to recognise the available 'windows of opportunity' in different technological systems. Firms also have to understand the market structure in the case of different technologies/technology systems and assess the incumbent firms' competitive strategies as well as be able to formulate their strategies based on the prevailing broader context of the techno-economic paradigm. Both of these entail continuous learning capabilities at the firm level and national level. As shown by Cohen and Levinthal (1989), "a firm needs to sustain a critical mass of internal basic research to be able to identify and exploit potentially useful scientific and technological knowledge generated by universities or government laboratories, and thereby gain a first-mover advantage in exploiting new technologies". The same is true for spill-overs from a competitor's innovation (Ernst 2016). This

[15] Concepts like path dependency, technological trajectories, as well as forward and backward feedback linkages are related to the same idea of understanding based on loop-like processes of constant learning (Kattel, Drechsler and Reinert 2009).

[16] Linking the organisational focus and system/institutional-level analysis, evolutionary theory recognizes that organizational routines and search and selection processes are embedded in the selection environment – that is 'the ensemble of considerations which affect the well-being of the organization and hence the extent to which it expands or contracts. These are partly determined by conditions outside the firms in the industry or sector being considered, and also by the characteristics and behaviour of the other firms in the sector (Nelson & Winter 1982, p. 401). This has been conceptualised as the feedback environment, or context comprised of relevant, endogenous and exogenous factors influencing organisational routines, search and novelty creation (see Lundvall 2009 and Karo and Kattel 2014).

is because as soon as a country's economic agents reach close to a technology frontier, knowledge spillovers as a source of productivity growth cease to exist given that knowledge at that level becomes more and more tacit (Singh 2006).

Thus for evolutionary economists, firm behaviour is explained through concepts like skills, routines, path dependency within firms and industries, and imperfect competition, all of which are, to a large extent, determined by technological change. The macroeconomic world, on the other hand, is better explained through incessant change driven by the firm-level changes leading up to the process of creative destruction. Both these processes also explain, in their view, the difference between countries and regions (see Dosi 1982 and Soete 1988 cited in Kattel, Drechsler and Reinert 2009)

2.2.3 Catching-up by follower countries

In Perez's theoretical framework, each TEP gives rise to great surges of growth initially in the core group of industrialised countries, where, in addition to the explosive expansion of the new industries, the new technologies also encompass and gradually rejuvenate most of the existing industries. For less developed countries, a catching-up development process based on mature technologies is extremely unlikely for various reasons (Perez 2001: 112). This is because mature technologies reach a point where they have almost no room left for improving productivity and have only minimal potential for producing profits, while they face stagnant markets. Thus generally speaking, using the maturity phase as a starting point is costly and is neither very profitable nor very promising. However, as Perez (2001) is quick to emphasise, when they approach maturity, technologies tend to use highly standardised, mechanised and automated processes. Ironically, this shifts the advantages in favour of capital-poor countries (with unskilled labour) precisely when the production process is marked by more intensive use of capital. This makes it probably the best starting point for creating a basic industrialisation platform for less developed countries as well as to generate the learning capacity, establishing the basic infrastructure and other externalities needed to back up a development effort. A strategy could be designed for accumulating technological and social capabilities through the use of mature technologies and then making use of that base for gaining access to new and dynamic technologies. However, this possibility depends to a large extent on the specific opportunities created by a technological revolution and a variety of socio-economic factors.

That is, it is towards the end of the process of a TEP deployment, when the primary industries of a particular technological revolution face maturity and market saturation that the process spreads to the periphery, while in the core countries the next great surge is already irrupting.

Citing the case of countries which had little success in promoting their development during the mass production age, even though they apparently applied "similar" procedures for making use of imported technology like the newly industrialised East Asian developing countries (such as South Korea, Taiwan, etc.), Perez (2001) argued that the reasons for the different outcomes are "connected with the nature of the windows of opportunity created by the technological evolution of the leading countries and the capacity for consciously or intuitively taking advantage of them." During the late 1950s to the late 1970s, catch-up development strategies adopted by several developing countries were successful owing to the nature of the techno-economic paradigm in place at the time. While relocation of production from the mature industries in the advanced countries which were faced with "technological exhaustion and market saturation" in their countries provided the push factor, developing country governments adopted different models of import-substitution industrialisation strategies to attract relocation of production by multinational corporations (MNCs). The eruption of the ICT revolution along with the changes in the international trade rules that 'penalise' import-substitution industrialisation strategies and promote export-led growth strategies that pushed several developing countries simultaneously into the export markets for similar products, have together meant that these conditions have radically changed.

In fact, Perez has also observed that apart from the mature phase of technologies, the other moment when weaker players confront surmountable barriers is not in phases two or three, rather in phase one of irruption. This is because catching-up supposes a dynamic development process that is fuelled by local innovation and growing markets, and this requires an entry as early as feasible. The irruption phase happens to be the most promising entry point because of the reasons discussed earlier.

Indeed, in the paradigm transition involving ICT, in the irruption through the frenzy phases, a very strong third possibility to catch-up appeared within the context of globalisation. In contrast with how the industries of the mass production paradigm were deployed nationally first before moving internationally, many industries in the ICT paradigm have operated globally from phase one. This opened up the possibility of participating in global value chains in many roles and with varied arrangements. Despite this, the experiences of different countries with respect to the degree of integration into value chains and net benefits drawn by them have varied.

As argued in Francis (2017), a significant body of empirical research has established that the manner in which the relatively strong catching-up region of East Asia (including China) managed to create sustainable links to global production and innovation networks as well as lead to the rise of indigenous firms as market leaders has been through highly targeted and selective government policies that have created capabilities and steered the actions of actors participating in these global networks (see Perez 2001, Amsden 2001, Lall 2007, Ernst 2009 and the references cited in Francis 2017). This is so mainly because global networks remain hierarchical, and moving up the ladder requires high levels of policy efforts to invest in increasing absorptive capacities and innovative capabilities both at the firm level and across industries (Karo and

Kattel 2011, p. 177). These factors in turn seem to have become enabling factors in the relative success of East Asian firms from South Korea and Taiwan and subsequently, China, in becoming leaders in ICT-based industries. The fact that the state has had a strong influence in shaping the markets in each case, in particular by protecting the learning efforts, has been pointed out to be a crucial factor in the success of these economies.

It is therefore amply clear that whether follower firms are able to "catch-up from behind" (that is, in phase 4 of mature technologies; Perez 2001) or forge ahead from the frontlines (phase 1 of irruption)[17], state policy has played differing roles in fostering and managing national technological development processes.

The factors influencing a country's ability to catch-up are also significantly connected with existing capabilities and the surrounding environment. Hausmann and Klinger (2006) has highlighted what classical and development economists have pointed out for long—the importance of increasing returns activities and synergies between different types of economic activities that influence a country's development trajectory.[18] As argued by Hausmann and Klinger (2006), the assets and capabilities—human, physical and institutional capabilities—needed to produce one good are imperfect substitutes for those needed to produce another good, with varying degree of asset specificity. Each product involves highly specific inputs such as knowledge, physical assets, intermediate inputs, labour training requirements, infrastructure needs, property rights, regulatory requirements or other public goods. This clearly means that the assets, capabilities and opportunities accumulated in the production of a good affect the productivity in the production of another good (Hausmann and Klinger 2006). This would imply that the ability of firms to transition to new goods or services in a changed techno-economic paradigm is constrained or even obstructed if they are specialised in goods/services that require assets and skills very specific to their current product that belongs to a previous paradigm. Hausmann and Klinger (2006) categorises oil producers or producers of tropical products, raw materials, etc. in this category. By contrast, light manufactures, electronics and capital goods tend to involve skills and assets that are much closer to those required by other goods. While according to them specialisation in such goods can facilitate the transition from one product to another more easily, technological foresight, necessary skill retraining and upgradation as well as institutional support are essential prerequisites for such transitions to materialise effectively.

Success in using new technologies also depends on the existence of certain important complementary factors such as dynamic advantages and different types of externalities, especially the physical, social and technological infrastructure (as discussed above), and often,

[17] Here we make a departure from Perez (2001)'s "forging ahead into the front ranks" to recognise innovator/first mover firms from developing countries (like China's OFO, the bike-sharing firm).

[18] See Reinert and Kattel (2009) and Francis (2017) for further discussion.

the existence of competent and demanding local clients (linked to social capital).[19]As Perez points out, these elements may have been built-up before with mature technologies, or they can be acquired through intensive learning processes and investments in the improvement of the social and economic environment.

All these imply that the uneven and varied response of governments, firms and industries to the threats and opportunities posed by a new wave of technologies tends to accentuate the uneven process of development globally. Newcomers are sometimes more able to make the necessary social and institutional innovations than the more entrenched social structures of established leaders. This means that changes of techno-economic paradigms are likely to be associated with the temporary aggravation of instability problems in relation to the flow of international investment, trade and payments as well as with catching-up processes and changes in the relative ranking of nations (Perez and Soete 1988). In this sense, the framework of the techno-economic paradigm is remarkable in its analytical ability to explain varied global economic processes, keeping technological evolution at its core.

In the next section, we undertake an analysis of the features and phases of the ICT revolution in detail, including the ongoing digital phase.

3. Phases and Features of the ICT Revolution

3.1 Phases and Features

As observed by Perez (2001 and 2007), the current ICT revolution—which had erupted in the early 1970s—opened a first technology system around microprocessors and other integrated semi-conductors and their specialised suppliers. This went hand-in-hand with their initial uses in calculators and other personal consumer devices, games, civil and military miniaturising and digitalisation of control instruments and others.

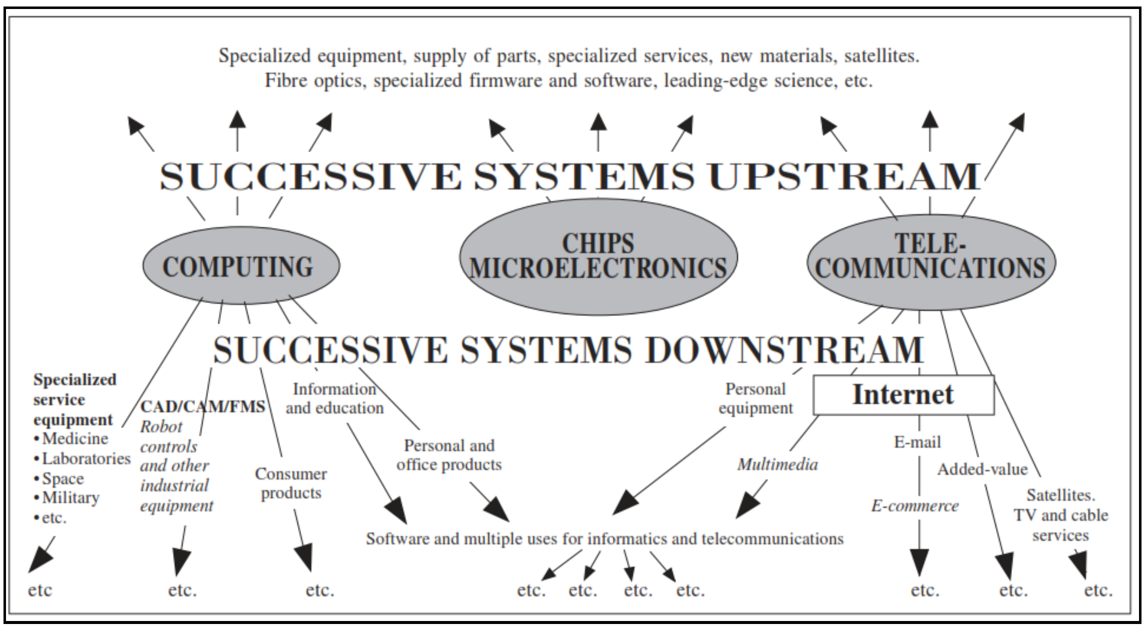
Many of the products of the microelectronics technology system reached phase 2 at the beginning of the 1980s. The decade of the 1990s was marked by the vigorous development of the new telecommunications infrastructure, the wider adoption of the internet leading to emerging industries and the modernisation of existing ones. Subsequently, there was an overlapping sequence of minicomputers and personal computers, software, telecoms and the internet, each of which opened new technology systems trajectories, while being strongly inter-related and inter-

[19]Perez (2001:123) also pointed out that the quality and quantity of the opportunities deriving from the regulatory framework during a TEP vary as a function of the conditions and disposition of the different economic agents and of the countries in which they operate.

dependent. As they appeared, these systems interconnected and continued expanding together with intense feedback loops in both technologies and markets.

The inter-related upstream and downstream technology systems that have evolved under the fifth technological revolution—the current ICT revolution (variously referred to in the literature as information technology/IT revolution, information revolution, etc., are captured in Figure 3. Having crossed the Turning Point of the ICT revolution (Perez 2002, 10–12, 14 quoted in Drechsler 2009) sometime in the first decade of the 21st century, it appears that we have moved into the synergy phase (within the deployment period) of the ICT revolution, referred to as the digital era.

Figure 4. Technology systems under the ICT revolution



Source: Perez (2001, p. 116).

The eruption of the ICT paradigm gave rise to a massive, ever-increasing demand for electronics and information technology systems, products, components and other manufactured hardware. As seen in Figure 3, the development upstream of a common network of suppliers of inputs and services as well as interdependent distribution outlets is driven through very strong inter-linkages, they often being the main market for each other. For example, the more growth and innovation there is in data processing equipments, the more growth and innovation there will be in semiconductors and *vice versa*. Their diffusion generates coherent patterns of consumption and use so that the learning in one system facilitates the learning in the next, and the installation of conditions for the use of one set of products becomes an externality for the next. Once there is broadband internet connectivity, it paves the way for the use of all services that can be offered online such as bookselling, education, brokerage, travel agents, payments and many more (as we will see in a while).

An integral part of the shift from the fourth technological revolution to the present one based on ICT—especially since the 1980s and the 1990s—has been the transformation of business organisation from the old rigid hierarchical pyramids of the mass production age into flexible organisation and adaptable networks. The contrast between the old, rigid, vertically integrated business models and the new adaptable networks has been made in innumerable ways, including as "the shift of accent from tangible to intangible value-added, from homogeneity to diversity and from energy-intensity in the old paradigm to information intensity in the emerging Knowledge Society" (Perez 2001).

Figure 5. Change of Paradigm in the ICT Revolution

	MASSPRODUCTIONMODEL **Petroleum and automobile era**	**FLEXIBLENETWORKSMODEL** **Information technology era**
Inputs and value	**Intensive use of energy and raw materials** in products, processes, transport, etc. **Tangible products**	**Intensive use of information and knowledge** Saving of energy and raw materials **Intangible services and value**
Products and markets	**Standardized products** **Mass markets**	**Diversified and adaptable products** **Highly segmented markets** –from the basic mass product to small niches
Form of operation	**One best way** Optimum routine is the goal pursued	**Continuous improvement** Change is the main routine
Structures	**Centralized organizations** Hierarchical pyramids Functional departments Rigid channels of communication	**Decentralized networks** Strategic centre Semi-autonomous multifunctional units Interactive communications (vertical and horizontal)
Personnel	**Human resources** Labour viewed as a cost Training viewed as an expected externality	**Human capital** Labour viewed as an asset Training viewed as an investment

Source: Perez (2001); p. 118.

The emergence of global production networks (GPNs), and subsequently, global value chains (GVCs), has in fact been the organisational or business model innovation that accompanied this ubiquitous globalisation under the ICT revolution. Technically, the spread of GVCs has been largely driven by the reduction in transport, communication and transaction costs enabled by the major leaps in supply chain management facilitated by the ICT revolution. Thus just-in-time production has been extended from the vertically integrated manufacturing plant to a network of suppliers located close to the plant, and globally subsequently. The exogenously-imposed and autonomous policy changes that occurred across the developed and developing world, which have continuously liberalised trade and capital flows (FDI and non-FDI investments) have been equally important handmaidens in the spread of GVCs (Francis 2018).

Milberg and Winkler (2013) showed that offshoring by developed country firms—a key component of the globalisation of production—has also been linked to changes in the financial sectors. The latter have involved: (i) a desire to focus on "core" activities and allocate greater resources to financial activity and short-run shareholder value (due to a realignment of the interests of shareholders and managers); and consequently, (ii) a search for lower costs and greater flexibility to implement a process of "mass customisation" (Milberg and Winkler 2013: 12). Thus even though there are differences in network structures across industries, and crucially between manufacturing, services and natural resources, the ICT revolution has seen oligopolistic/monopolistic innovating firms from the developed countries (and subsequently, a few developing countries) externalising non-strategic activities through various network formations to reduce costs and to coordinate and rationalise the various linkages in these network formations.[20] At the same time, strategically, this allows them to increase barriers and alter market structures to their advantage. Complex production and market profiles are achieved through decentralised integration and network structures.

While the driving force for the Perez cycle is a new technological paradigm in the productive sector, Kregel (2009: 205)'s question whether it is innovation in the financial sector that provides the increased financing that allows for the exploration and installation of the new technological paradigm, has become increasingly significant. The causation, it seems, has run both ways. Clearly, the advances in ICT have enabled, and continue to enable, financial innovations through the design of new financial products and increasingly complex transactions.[21] On the other side, increased risk taking and financing enabled by financial sector innovations have played a significant role in funding further innovations and advances across technological systems. This interface implies that financial sector innovations are playing a more significant role in the diffusion of the ICT revolution as compared to earlier revolutions.

Another feature of the current phase of the ICT revolution is the following. While there was a rapid geographic dispersion of markets, finance and production in the 1990s and 2000s, increased globalisation has since led to "an increase in the organizational and geographical mobility of knowledge" (Ernst 2016 and Soete 2015). Together with the emergence of IT-enabled governance mechanisms to coordinate and manage distributed knowledge, the latter has led to the expansion of global innovation networks (GINs), as acknowledged by many analysts. GINs involve multi-layered global corporate networks, which integrate engineering, product

[20] See also Ernst (2016).

[21] This becomes ever more relevant in the context of the blockchain technologies on which cryptocurrencies are based.

development, and research activities across firm boundaries and geographic borders (Ernst 2016).

Asymmetrical power relation is a fundamental characteristic of GINs like for the GPNs that preceded them. Multinational corporations (MNCs) from developed countries dominate as network lead firms and define network organisation and strategy. These networks now involve multiple actors and firms varying in size, business model, market power, and nationality of ownership, giving rise to a variety of horizontal and vertical networking strategies involving equity and non-equity relationships (once again, reflecting the complex financing arrangements made possible by the ICT-financial innovation interface) and complex network architectures. The lead firms that control key resources and core technologies, and therefore, garner the highest share of the value added created within the chains, are still overwhelmingly from the United States, the European Union and Japan (see Milberg and Winkler 2013, Banga 2013, Das and Hussain 2017, Francis 2018, etc.).

At the same time, there are also now lead firms from some emerging economies, especially from Asia, which construct their own GINs. A prominent example is Huawei, China's leading telecommunications equipment vendor, and the second largest vendor worldwide (See and Lee and Mathews 2014, Ernst 2016, Durand 2017, etc.). However, such examples are limited to a few cases, precisely due to the differential ability of different developing countries to anticipate/recognise the techno-economic paradigm shift under the ICT revolution and adopt the necessary policy changes that built up the underlying capabilities required for utilising the windows of opportunity that arose.

3.2 New Technologies in the Production Space

The synergy phase of the ICT revolution has been witnessing critical innovations in generic industrial technologies. Called "Advanced Manufacturing Technologies" in the US and "Key Enabling Technologies" in Europe, the latter allow for new ways of manufacturing existing products, as well as for manufacturing new products (see Ernst 2016). According to Montalvo (2014), Ernst (2016), Ross (2016) and Schwab (2016), new enabling industrial technologies encompass for instance:

- Continuous manufacturing of pharmaceuticals and bio-manufacturing
- Environmental and renewable energy technologies for sustainable manufacturing
- Photonics[22]

[22] Photonics is space where information signals carried by electrons are converted to photons and *vice versa*. It allows for optical transmission of information and applications cover a range of areas including lasers, consumer electronics, telecommunications, data storage, biotechnology, medicine, illumination and defence. The main developments are being driven by the telecommunications industry for smart phones and increasing bandwidth for internet transmission. See Alcorta (2014)

- Industrial biotechnology
- Nanotechnology
- Additive manufacturing (or 3D printing), etc.

Direct ICT application areas include control technologies, advanced visual and physical human-machine interfaces, navigation and perception technologies, monitoring and diagnostics devices, locomotion technologies and integrated product-process-production system design and simulation techniques (Alcorto 2014).

Innovations in all these enabling technologies together with synthesised advanced materials, and custom-designed and recycled materials are expected to lead to new products and new industries. Advanced materials[23] with improved characteristics such as increased functionality, lower weight and higher energy efficiency are expected to enable new manufacturing possibilities through novel products and improved production processes and operations.[24] Examples of "new" products range from auto electronics, nano-scale semiconductors, implanted sensors to RFID (radio frequency identification) tags, etc. In addition, programmable manufacturing which needs less capital-intensive tooling and fixtures may facilitate manufacturing in smaller, agile and flexible production facilities, closer to end-users (Soete 2015 and Ernst 2016. See also Montalvo 2014).

According to Montalvo (2014), new ICTs and advanced manufacturing technologies are enabling the re-organisation of two core aspects of industrial organisation: (i) Remote monitoring and control of key aspects of manufacturing activities (materials, inventories and flows, quality monitoring and maintenance of machinery); and (b) the digitisation and creation of design platforms for customer intimacy directly linked to the production of goods and services. The latter promises the extension of relatively low cost manufacturing beyond modular to individualised design and production, leading to fully individualised mass customisation. In turn, this is expected to enhance productivity and flexibility in large-scale manufacturing as well as in supply and distribution chains (for instance through RFID tracking and Human-Robot-interaction).

As Alcorta (2014) observes, the effect of the developments described above on manufacturing cannot be seen in isolation since many of them are interrelated and hence will build on each

[23] Advanced metals include stainless steel and super alloys. Advanced polymers encompass engineered plastics, conducting polymers and advanced coatings. Advanced ceramics and superconductors embrace nanoceramics and nanocrystals. Novel composites include polymer composites, metal matrix composites, nanopowders and nanotubes. Advanced biomaterials embrace bioengineered materials, bio-synthetics and catalysts.

[24] Advancements in the materials sciences are allowing robots to be constructed through new materials. Ross (2016) describes highly flexible components like air muscles (which distribute power through tubes holding highly concentrated pressurized air), electro-active polymers (which change a robot's size and shape when stimulated by an electric field), and ferro-fluids (magnetic fluids that facilitate more human like movement). Such technologies have been used by researchers at Tufts University to build a robot that is even bio-degradable.

other. This will magnify the effect over individual products, processes or industries. For instance, industrial biotechnology is likely to have an impact over food, chemicals, energy, pharmaceuticals and textile industries. Patent data suggests that nanotechnologies will be used in the chemical, pharmaceutical, metals, engineering, electronics and healthcare industries. Applications of Additive Manufacturing (AM) have taken advantage of the capabilities of rapid prototyping to produce parts with customised geometries, and include consumer products, medical implants and tools, dental implants, aerospace products, etc.

Simultaneously, advances in digital technologies are themselves moving at an accelerating pace giving rise to new possibilities, while having the capacity to continue transforming the old. As Zysman and Kenney (2016: 11) point out, at the core of the economic and social transformation led by transformative technologies, which ultimately touch most everything in a society, are not only the new products but also the new needs created by the new technology. By breaking down geographical barriers as well as sectoral distinctions, digital technologies have dramatically altered the creative opportunities for disruptive innovation; for new forms of internal and/or external organisation of creating value, visible as well as invisible; and for locational advantages based on "smart specialisation" (Soete 2015). The radical innovations in production organisation and business models enabled by the progressive digitalisation of business processes and transactions will lead to further transformations in manufacturing and agriculture-related activities.

3.3 Business Model Innovations

Business model changes have been fundamental to the disruptions being brought about by digital technologies. Based on Christensen's (1997) discussion on disruptive innovation, Markides (2006) explains that while any new technology, product, or business model is disruptive to incumbents, a disruptive business model innovation is different from a disruptive technological innovation or a disruptive product innovation. Business model innovation is the discovery of a fundamentally different business model in an existing business. Business model innovators do not discover new products or services; they simply redefine what an existing product or service is and how it is provided to the customer. By emphasising characteristics or dimensions of a product or service different from that of existing products, innovators are able to make their products or services attractive (at least originally) to a different niche of customers.

For example, when Amazon launched its online book store, it competed with Barnes & Noble in the book retail business in fundamentally different ways (Markides 2006). Clearly, Amazon did not discover bookselling; what it did was to totally redefine what the service is all about, what the customer gets out of it, and how the service is provided to the customer—all with the help of ICT. To qualify as an innovation, the new business model must enlarge the existing economic pie, either by attracting new customers into the market or by encouraging existing customers to consume more (Markides 2006).[25] As Schwab (2016, p. 61) explains, these end-to-end business models build their competitive advantage on superior customer experience which is bundled with reduced transaction and friction costs. These companies not only match demand and supply in a rapid and convenient manner (which sidesteps the business models of incumbents), they also bundle the superior customer experience with the physical product and "optimise the utilisation of the asset". Early examples include how Charles Schwab, easyJet, and Dell compete in their respective industries in substantially different ways from their competitors such as Merrill Lynch, British Airways, and HP or IBM (Markides 2006).

These kinds of innovations making use of the ongoing ICT revolution have been occurring in a swathe of industries and fields ranging from the automotive industry and the financial industry to the healthcare industry. These disruptive business models have used digital assets and combinations of existing digital platforms to reorganise relationships with physical assets—making a notable shift from ownership to access (Schwab 2016: 61). As Schwab (2016) and Kostakis, Pazaitis and Bauwens (2016) note, in most industries, disruptive ways of combining products and services through digital processes dis-intermediate the existing relationship between businesses and customers and have dissolved traditional boundaries between industries. The industry convergence this leads to, progressively erodes the long-established positions of incumbents. New disruptors or fast followers can rapidly scale at a much lower cost than the incumbents, increasing their profits in the process, as David Teece noted in his 1986 study. However, once an innovator company has established confidence in the customers, it creates new opportunities for the company to offer other products and services, across multiple industries, as observed in Google and Amazon's cases (more later). These innovations arise in different ways, have different competitive effects, and require different responses from incumbents.

3.4 Advancing Digitisation and its Features

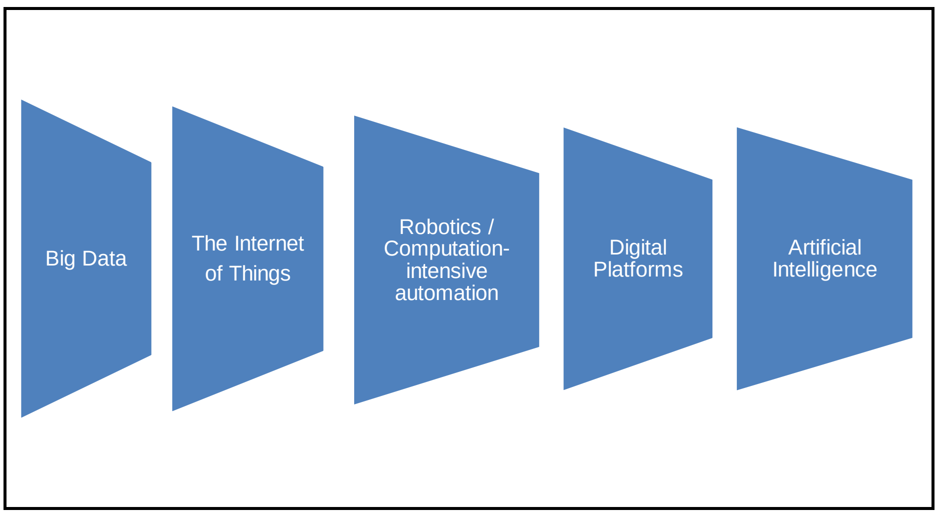
The 2010s has seen the emergence of new technological systems in the digital space, which have been enabled by simultaneous and intertwining innovations in the areas of networking, interfacing and services/content/knowledge creation through Web 2.0. The latter has been considered the biggest leap forward in the history of the whole ICT revolution since the introduction of the PC (Burgelman, 2009). The Web 2.0 movement, which has turned the old communication paradigm on its head—wherein the end user (individual or collective) turns from being a passive viewer or consumer of content to an 'active agent', by becoming "a content provider (social media), a capacity provider (peer-to-peer) and an interface provider (open

[25] The requirement to enlarge the market implies that a business model innovation is much more than the discovery of a radical new strategy on the part of a firm; rather it involves the introduction of new business models in their respective markets that attract new consumers. See Markides (2006).

software)"—goes well beyond YouTube and Facebook (Burgelman 2009 and Soete 2015). Simultaneously, the exponential increase in computing capacities—referred to as Moore's law—and the consequences of doubling processing power every two years and data storage on a roughly similar trajectory, has changed the game (Zysman and Kenney 2016). In particular, the availability of cloud computing has led to further sizeable advances in computing power.

Together, these advances have led to the emergence of the inter-related technological systems of Big Data, the Internet of Things, robotics (or computation-intensive automation), online platforms and artificial intelligence (AI).[26] Incremental innovations in product and process improvements in the core technologies in these systems seem to be have led to new disruptive innovation processes, often with end-user involvement. In all these cases, the shift from the old simple Internet technologies to Web 2 with interoperability (wherein the website or computing system can work smoothly with other products, systems and devices)[27] enable information processes to be organised differently (Soete 2015).

Figure 6. The current digital technology systems of the ICT evolution -The 2010s



Source: Author's illustration

Cloud computing delivers computing services—data storage, computation and networking—to users at the time, to the location and in the quantity they wish to consume, with costs based only on the resources used (Zysman and Kenney 2016: 7). This means that powerful computing resources can more easily be assembled and deployed as needed. In other words, cloud computing expands the availability of computing while lowering the cost of access to computing

[26] Burgelman (2009) calls this a 'change of paradigm', while TDR (2017) refers to some of these as belonging to 'the next technological wave'.
[27] Interestingly, the term Semantic Web (sometimes referred to as Web 3.0) has already been coined by Berners-Lee to refer to a web of content where the meaning can be processed by machines.

resources. Value in computing moves up the value chain from provision of the basic data infrastructure, to the creation and deployment of applications based on the same. And since computing can be moved from a capital expense to an operating expense, the ability to create, experiment with, and launch platforms is radically improved (*ibid*). This abundance of data storage, computing power and networking abilities—enabling the analysis of data on a scale never imagined before and cross-sectoral coordination—permits the reorganisation and transformation of not only services and manufacturing, but also agriculture.

As observed by Ross (2016), huge masses of real-time data on weather, water, air quality, soil nutrient levels, disease—specific not just each farm or acre, but precise at the level of each inch of farm land—can be collected through sensors located on and off the farm. Big Data is evaluating this real time data accumulated to the cloud combined with GPS and satellite-driven weather data, and is beginning to transform developed country agriculture into "precision agriculture". The algorithms based on such real-time analysis enables the customised delivery of fertiliser mix to each defined portion of farm land.

While cloud computing facilitates Big Data and analytics, digital platforms and computation-intensive automation; advances in analytics, platforms and artificial intelligence together with advanced materials and manufacturing technologies are leading to the Internet of Things (IoT), and in turn to further advances in computation-intensive automation. The Internet of Things refers to sensor-enabled objects that interact through digital platforms.

The platforms themselves facilitate the aggregation and analysis of data with the intent to control systems and/or actions. In turn, new data is constantly being generated through the Internet of Things,[28] online platforms, etc. As a result, together with advanced computing power, access to the huge amount of digital information/data being constantly generated and made available for analysis is leading to further advances in artificial intelligence such as neural networks[29], machine learning,[30] etc. At another level, the integration of artificial intelligence with the Internet

[28] According to IDC market intelligence firm, IoT data will alone account for 10 per cent of all the data registered globally in 2020.

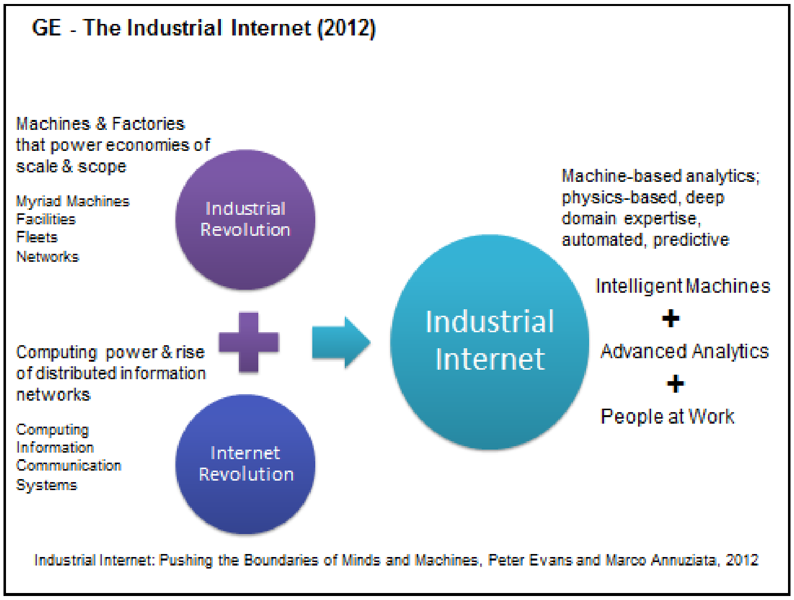
[29] A neural network is a computer system designed to work by classifying information in the same way a human brain does, by working on a system of probability. Based on data fed to it, it is thus able to make statements, decisions or predictions with a degree of certainty. It involves "learning"—by sensing or being told whether its decisions are right or wrong, it modifies the approach it takes in the future. See https://www.forbes.com/sites/bernardmarr/2016/12/06/what-is-the-difference-between-artificial-intelligence-and-machine-learning/2/#619aca1e483d

[30] Machine learning is a current application of AI (using neural networks) based around the idea that with access to data, machines will be able to learn for themselves and mimic some of the human decision-making processes. AI is the broader concept of computer systems able to carry out tasks that normally requires human intelligence. This is leading to huge innovations around another AI area, Natural Language Processing (NLP). Deep learning focuses on a subset of ML tools and techniques and uses them to solve problems that require "thought". An example includes

of Things, is giving rise to autonomous, self-teaching systems, leading some technology analysts to wonder whether it will substitute for computation-intensive automation.

According to Ernst (2016), concepts like GE's "Industrial Internet" are already being implemented to increase productivity gains across different stages of the industrial value chain. All these transformations can also be expected to lead to shifts in the global value chain strategies of manufacturing firms.

Figure 7. The concept of the 'Industrial Internet'



Source: Ernst (2016)

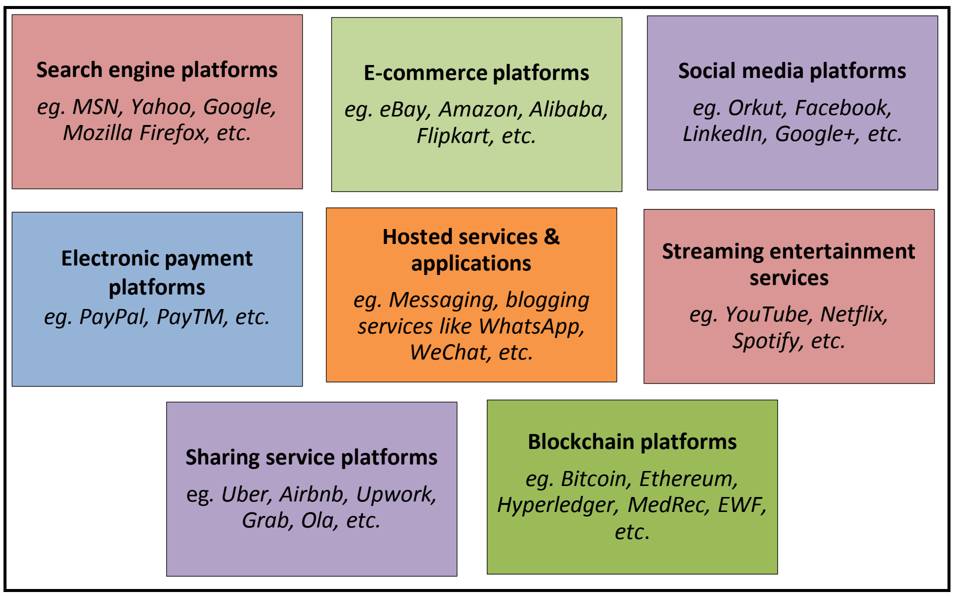
With service activities getting codified and converted into computable processes, there has been progressive digitisation of business processes and transactions (Ernst 2016). Such digitisation has been occurring at many levels, sometimes through distinctly new innovations (say, electronic payment) and at other times transforming the old with advances originating in other technology systems.[31] Zysman and Kenney (2016) has observed that such digital/algorithmic transformation of services, which was initially observed in the early internet phase of ICT-enabled business processes in communications, finance, media, etc., but which spread further across other services through digitisation, underpins the "platform phase" of the digital era.

navigating self-driving cars. See https://www.forbes.com/sites/bernardmarr/2016/12/08/what-is-the-difference-between-deep-learning-machine-learning-and-ai/#51800a1326cf

[31]A recent good example for the latter is bot or chatbot, which is a computer program that provides a chat-based interface, where clients can interact with a company through text chats or voice commands. It can be embedded and used through any major messaging application. This is an AI-based automation of business process. In effect, it is a virtual customer service assistant in many contexts.

According to the computational understanding of the term, the platform is an infrastructure that enables the development and deployment of applications. But from an economic point of view, platforms refer to intermediaries of multi-sided[32] digital markets (credited to Evans 2003 and Rochet and Tirole 2003), which create value by facilitating, shaping and intermediating the terms on which economic agents (often, but not always buyers and sellers of services or products) interact with one another in a manner that makes everyone better off (Ross 2016, p. 91 and Evans and Schmalensee 2013).Companies operating a platform create products or services that facilitate value creating exchanges between different types of market participants, and, create new markets by doing so (See Figure 7).

Figure 8: Platforms—The multi-sided markets



Source: Author's illustration

[32] A market is typically called two-sided or multi-sided if indirect network effects (or cross-side network effects) are of major importance. Indirect network effects are distinguished from the so-called direct network effects related to the size of a network. Direct network effects mean that the utility that a user receives from a particular service directly increases with an increase in the number of other users. For example, a service such as Skype is more attractive for users the larger the number of other Skype users, as the possibility to communicate increases with the number of users. Similarly, if a large customer base is already using a certain social network such as Facebook or LinkedIn, this attracts even more users to join, as a large customer base increases the probability to find valuable contacts. These are direct network effects. In contrast, indirect network effects arise indirectly if the number of users on one side of the market attracts more users on the other market side, as the larger the number of users on one side of the market, the larger the expected gains on the other market side (Haucap and Heimeshoff 2013, p. 3). This is the case, for instance, for individuals visiting a match-making service, or for buyers of goods and services participating in a marketplace, a large number of sellers give them access to greater diversity. Thus the participation of at least one of the user groups in the market impacts the value of participation for the other group. Multi-sided platforms have been present in diverse industries such as financial exchanges, internet portals, payment card systems, newspapers, television broadcasters, directories, smartphones, mobile and fixed telecommunication networks and estate agents (Amelio, Karlinger and Valletti 2017). Some of the key papers discussing theoretical and empirical issues relating to multi-sided markets are Caillaud and Jullien (2003), Rochet and Tirole (2006) and Evans and Schmalensee (2013). See also Lehtiniemi 2016.

Evidently, the products that facilitate these markets where distinct user groups interact are the internet platform services themselves: a search platform enables transactions between users, content providers and advertisers; and asocial media platform helps users, advertisers and application developers to meet (Lehtiniemi 2016). The platform increases value for these economic agents by solving a coordination problem between these groups and by reducing the transactions costs they must incur in order to interact (Evans and Schmalensee 2013: 7).

Three defining characteristics of platform companies are the following:

- Platforms are characterised by the existence of indirect network effects, whereby the attendance of end-users on one side of the market creates a positive externality that makes participation for the other more attractive, and vice versa (Amelio, Karlinger and Valletti 2017).
- The services provided to both end-users and customers are based on the collection and leveraging of data about the users (Lehtiniemi 2016); and
- The platform can use its fee/pricing structure to influence the volume of transactions between different users to maximise platform value (Amelio, Karlinger and Valletti 2017. See also Evans Schmalensee 2013 and Rochet and Tirole 2006).

These characteristics arise from the fact that the multi-sided platform literature assumes the presence of multiple customer groups with demand that is interdependent in various ways (Evans and Schmalensee 2013 and Rochet and Tirole 2006). Such indirect network effects function something like economies of scale on the demand side and increase the value economic agents can realise from the platform (Evans and Schmalensee 2013). The interdependence and indirect network effects also mean that the prices charged on one side of the market need not reflect the costs incurred to serve that side of the market. If we define one side of the market as the buyer side and the other as the seller side, then the price charged to one side (say, the buyer side) will tend to be lower when either:

- each additional buyer generates significant extra revenue on the seller side; or
- it is difficult to persuade buyers to join the platform.

While the consumer end-users get the services of platforms free of charge, the profit-turning side of the market consists of paying businesses which often pay both a membership fee and a usage fee (see Haucap and Heimeshoff 2013, Evans and Schmalensee 2013, Lehtiniemi 2016 and Amelio, Karlinger and Valletti 2017). Thus it has been pointed out that the businesses of online platforms are made possible by ‘datafication’, or the transformation of the social actions of their users into quantified data (Mayer-Schönberger and Cukier 2013 cited in Lehtiniemi 2016), which is used to capture value.

In the case of Google search, Rieder and Sire (2013) identify three distinct parties whose interactions the platform mediates: users, content providers, and advertisers. These interactions take place on two markets. On one of them, the search service allows the users and content providers to meet. Consumers who query the search engine are not its paying customers. On the other market, Google sells targeting of consumers to advertisers to finance the system; the advertisers hope to grow their visitor number and sales realisation through targeting. The provision of the targeting services to advertisers is based on the search market: advertisements are displayed to users beside the search results based on data collected and information gained from the consumers in that segment. (See the discussion in Haucap and Heimeshoff 2014 and Rieder and Sire 2014).

Although pioneered by Google, this model dominating in the digital space currently—which is a specific form of informational capitalism (Castells 1996)—is shared not only by other large companies, but also by default most online start-ups (Lehtiniemi 2016).

Electronic commerce or e-commerce is one of the fastest growing platform segments. In its broad generality, e-commerce refers to all buying, selling, and transferring of products, services and/or information via computer networks including the internet (Soete 2000). Thus B2B electronic commerce (business-to-business segment) has been around longer[33] than the B2C e-commerce (business-to-consumers e-commerce, or retail e-commerce) segment now included among the digital platforms listed above. While the B2B segment was considered in most forecasts as the driving force behind the expected rapid growth of e-commerce in the first decade of the 2000s, it is retail e-commerce that has been growing rapidly recently. This is so because retail e-commerce gives: (i) greater opportunities (than B2B commerce) for substitution of physical commerce by electronic commerce; (ii) increased possibilities for greater market transparency allowing consumers to identify products at the lowest price; and (iii) new opportunities for suppliers to "version" goods (Varian 1997) more directly to consumers' needs (Soete 2000). Its long-term growth impact is believed to be even more significant than the B2B segment. Most of the expected high growth impact of electronic commerce is associated with the typical dual features of technological advance: a significant cost reduction impact from reduction in transaction costs and the disappearance of intermediaries (disintermediation); and long-term growth impacts associated with the reorganisation of production and markets, and new commercial transactions (Soete 2000).

On the other side, all the "sharing economy" companies use a combination of technology platforms packaged as apps on mobile phone, behavioural sciences and mobile phone location

[33] In this perspective, B2B e-commerce has been considered as the efficiency-improving factor in a long series of improvements in logistics and wholesale and retail trade activities—from bar coding, EDI (electronic data inter-change) to e-commerce—that has already existed between various supply chains from raw materials production down to retail sale businesses in highly developed economies such as the US, Japan or Europe (Soete 2000).

data to create peer-to-peer (P-to-P) market places (Ross 2016). These marketplaces take underused assets (eg. an empty hotel room; empty tables in a restaurant, empty seats in a car; or skill as a professional) and connect them with people looking for a specific service. These platform firms are transforming industries by connecting "producers" with customers in new ways. This applies for instance to Airbnb, a platform that helps people rent out lodging, including private rooms, entire apartments, boats, and other properties, or in the case of Uber, a platform which enables customers to submit a trip request which is then routed to drivers who use their own cars. In other words, they both commodify things, that is, idle resources (rooms or cars), which were not previously up for sale (Kostakis, Pazaitis and Bauwens 2016).

In some cases, this is displacing or threatening existing, often regulated, service providers such as taxis and hotels (Zysman and Kenney 2016). In other cases, it is formalising previously less organised or locally organised work. Other platforms such as application stores and streaming services like YouTube are creating entirely new value-creating activities that are formalising into what can be seen as precarious careers in the so-called "jig economy", such as a YouTube producer or smartphone app developer (*ibid*. See also Ross 2016 and Schwab 2016).

Thus the scope of impact of the platform economy—as it diffuses through other services and industries, points to increased and broader informalisation than just in traditional industries like transport and hospitality. It is clear, as Zysman and Kenney (2016) observed that the impact on productivity will depend not just on the technical possibilities that are created, which are enormous, but on the capacity to deploy and diffuse those possibilities. The estimated size of the global sharing economy was $26 billion around 2015, and it is projected to grow to be more than 20 times larger in size by 2025 (Ross 2016: 91).

Yet another revolutionary technology that has the potential to transform business processes is Blockchain. Although it was initially developed in 2008, Blockchain is only now undergoing optimisation and witnessing a series of innovations. Blockchain is based on distributed ledger technology,[34] which generates a difficult-to-hack record or ledger of digital transactions/information across a peer-to-peer network. Given that the essence of a Blockchain-based system lies in ensuring the integrity of a data record based on the previous data records, a data record, once registered in a Blockchain database cannot be altered. This feature makes Blockchain ideal for decentralised and secure processing of events and transactions (Purkayastha 2018). Decentralisation of a business process leads to faster processing and less overhead. Some

[34] A distributed ledger is a database of transactions that is shared and synchronised across multiple computers and locations—without centralised control. Approved data is entered into the ledger as a collection of "blocks" and stored in a chronological "chain" that cannot be altered. Blocks are linked and secured using cryptography. Every participant can see the data and verify or reject it using consensus algorithms. Each party owns an identical copy of the record, which is automatically updated as soon as any additions are made. See https://www.sap.com/india/products/leonardo/blockchain.html

use cases of Blockchain are expected to be: organised supply chain; multiparty financial transactions; tracking of quantifiable or tangible assets; decentralisation of business processes; etc.[35] Thus it is expected that blockchain could help business companies to reduce costs and improve certain processes, advance product and customer data tracking and security, increase product safety, and reduce fraud and counterfeiting.[36]

According to Accenture, blockchains attained a 13.5% adoption rate within financial services in 2016 (Wikipedia). Although it was originally created for trading Bitcoin, it has been observed that this new technology's potential reaches well beyond cryptocurrencies, and has immense potential in its cross-sectoral impact. For instance, blockchain ledgers can include land titles, loans, identities, logistics manifests, etc. and has been forecast to include applications in citizen-centric governance tools also. According to Wikipedia, the Commercial Customs Operations Advisory Committee, a subcommittee of the U.S. Customs and Border Protection, is working on finding practical ways Blockchain could be implemented in its duties. Chinese e-commerce giant JD.com helped form the Blockchain Food Safety Alliance together with retail giant Walmart, IBM and Tsinghua University. The effort seeks to pilot blockchain technologies in bringing greater levels of transparency to the country's food supply chain. The system, JD.com says, will record a range of information, including where the livestock was bred and raised, where the meat was processed and how it was transported. Meanwhile, IBM, Microsoft, etc. are providing Blockchains as cloud service platforms that customers can use to construct secure blockchain networks for customised applications.

3.5 The Present Phase of Some of the Digital Technologies

The current synergy phase of the ICT revolution is one where inter-related innovations in technological systems, markets and organisational forms are occurring at a rapid pace. Arguably, the *technology systems* of Big Data, digital platforms and the Internet of Things are going through the phase of incremental innovations (intermediate phase 2 or 3 in Fig 1—The evolution of a technology) and are advancing fast due to their inter-related nature. Currently, the other technology systems like robotics (or computation-intensive automation) and artificial intelligence seem to be in the initial optimisation phase immediately following introduction. While there's a lot of research work and investment in these two technology domains and vast potential, there are still not too many commercially-viable and production-ready products/solutions—with several technical challenges remaining to be resolved. Given their inter-related nature which enables them to build on each other, however, advances in any or some of these and other related technology systems can accelerate their movement through the intermediate phase. For instance, it is observed that advances in data analytics have combined

[35]Purkayashta, Shyam (2018), "Have an idea around Blockchain? Here are eight Blockchain platforms that you can choose from", available at http://radiostud.io/eight-blockchain-platforms-comparison/

[36] See https://blockchainatberkeley.blog/a-snapshot-of-blockchain-in-enterprise-d140a511e5fd

with exponentially greater sets of experiential robot data to enable programmers to develop robots that can now intelligently interact with their environment, rather than being stand-alone pieces of electronics with capabilities that were limited to the hardware and software inside the unit.[37] By becoming networked devices, constantly connected to the cloud, robots can now incorporate the experiences of every other robot of their kind, learning at an accelerating rate (Ross 2016: 23–24).

Within the platform technology system, while e-commerce, sharing service platforms, electronic payment platforms and streaming entertainment services appear to be in the incremental innovations phase (intermediate phase 2 or 3 in Fig 1) of their evolution variously, Blockchain is in the initial optimisation phase following introduction. Similar to the case of AI and robotics, while there is a significant amount of research and investment happening, domain experts point to the immaturity of the underlying technologies that still hampers implementation on a wider spectrum. However, there are intense feedback loops between all these technology systems.

Within the broader timeframe of the fifth techno-economic paradigm, the ICT revolution has entered the synergy phase. While Perez herself had pointed this out back in 2007, these technologies have become all-pervasive and can be incorporated into the most sophisticated processes for biotechnology, nanotechnology or space travel as much as into the most traditional production systems, from global positioning of sheep to information about fishing conditions for small fishermen (Perez 2007: 21). The more varied the users, the wider is the innovation and wealth creating space/ potential.

In this context, it is pertinent to draw attention to Mathews (2012), who argues that the neo-Schumpeterian discussions of techno-economic paradigm barely engages with the ongoing revolution in energy technology—widely perceived to be essential to curbing carbon emissions. He links the current surge in renewable energy investment to the theorising over long (Kondratiev) waves and techno-economic paradigm shifts. The paper argues that the ongoing renewable energy surge can be best comprehended as a shift from gestation to installation of a new sixth techno-economic paradigm within the matrix of the fifth. It is argued that this emergent 6th paradigm is a continuation and fulfilment of the 5th, where ICT is applied to the electric power grid, and both are in conflict with the still-incumbent 4th and 2nd paradigms based on fossil fuels and centralised power generation. According to Mathews (2012), carbon lock-in is a central feature of the oil-based fourth techno-economic paradigm and its extension into the fifth

[37] According to Ross (2016: 23), two key developments have dovetailed to make this possible: improvements in modelling belief space and the uplink of robots to the cloud. Belief space refers to a mathematical framework that allows us to model a given environment statistically and develop probabilistic outcomes. It is basically the application of algorithms to make sense of new or messy contexts. For robots, modelling belief space has opened up the way for greater situation awareness leading to breakthroughs in areas like grasping. Cloud robotics refers to the fact that when robots are linked to the cloud, they can access vast troves of data and shared experience to enhance the understanding of their own belief space.

paradigm based on IT/ICT. Thus he considers that the scale of the techno-economic and institutional upheavals that will be needed to break the carbon lock-in will be a key challenge for the emergence of a new era based on renewable energies. While the latter observations related to carbon lock-in challenges are entirely valid, it may be argued that renewable energies are offering a new energy system within the fifth techno-economic paradigm centred on ICT, and not a new TEP by itself.

As Parthasarathy (2013) observed, as ICTs have become increasingly powerful, affordable, and versatile, their revolutionary nature has led to a level of convergence. ICT has now come to be a term that refers to everything from the technology itself, whether hardware or software, to its use for digitisation and information processing in fields ranging from banking, design and medicine[38] (Parthasarathy 2013, p. 7), to agriculture, automobiles, education, renewable energy, governance, etc. They are refining and re-defining existing industries as well as introducing new technologies and industries, while transforming the material conditions of societies and entailing new governance and institutional formats (see also Tapscott and Williams 2010, Ross 2016 and Schwab 2016). Indeed, as the synergy phase of the ICT revolution proceeds through the deployment period of the ICT paradigm, this is what we would expect under Perez's techno-economic paradigm framework.

Perez had predicted 'the turning point' for the current ICT-led techno-economic paradigm to occur during the first years of twenty-first century. The bursting of the dot-com bubble in 2000 that ended in 2008 as a full-blown global financial crisis is considered the Perezian turning point for the ICT techno-economic paradigm. As noted by Kattel, Drechsler and Reinert (2009), the world economy in the late 2000s thus confronted the need for sweeping institutional changes to bring forth a Golden Age based on the global spread of the growth potential of the current paradigm based on ICT. But there are various signs which suggest that in the core countries, as elsewhere, the challenges in the financial sector are far from being resolved. Similar is the case with the persistence of the old fossil fuel-based technologies. Both of these will critically influence how the synergy phase of the ICT revolution moves forward, which has implications for all countries.

Having looked at the phases and features of the ICT revolution, the next section will examine the opportunities and challenges each phase of technological revolution present at the firm-level to innovators and fast followers as well as incumbents.

[38] For instance, nano-robots promise a future in which autonomous machines at the scale of 10^{-9} meters (far, far smaller than a grain of sand) can not only diagnose but also treat diseases at the cellular level. Ross (2016: 25)

4. Firm-level Opportunities and Challenges

Technological revolutions that involve sharp changes of direction in technological progress offer a varied set of opportunities to innovators and fast followers as well as existing firms. These opportunities differ in the various stages of a technological revolution as the nature of competition in any particular market segment is influenced and shaped by the stage in which that technology is situated.

As noted earlier, a new techno-economic paradigm develops initially within the old, usually during the mature phase of the previous paradigm. Innovating firms (and other first movers) are (by definition) those able to search for and identify a scientific or technological breakthrough in the maturity phase of an existing paradigm and simultaneously realise the associated profitable opportunities in commercialising a new product or service (based on the breakthrough). As Teece (1986: 291) pointed out, distribution of outcomes from an innovation are influenced by three fundamental factors: the appropriability regime, complementary assets, and the dominant design paradigm. A regime of appropriability refers to the environmental factors that govern an innovator's ability to capture the profits generated by an innovation. The most important dimensions of such a regime are the nature of the technology, and the efficacy of legal mechanisms of protection. The existence of a dominant design is also of great significance to the distribution of profits between innovator and follower. According to Teece (1986), when imitation is possible and occurs coupled with design modification before the emergence of a dominant design, followers have a good chance of having their modified product anointed as the industry standard, often to the great disadvantage of the innovator.

Whether and how easily imitation is possible depends on the nature of the innovation under question. Different kinds of innovations produce different competitive effects and different kinds of markets, and therefore differ in the kind of opportunities and challenges they present to new entrants/fast followers. As Ernst discusses (2016: 68–70), it is useful to distinguish between incremental, modular, architectural, and radical innovations. Incremental innovations take the prevailing architecture and the dominant component design, but improve on cost, time-to-market and performance. They require considerable skill and ingenuity, especially complementary “soft” entrepreneurial and management capabilities. But barriers to incremental innovations are relatively low as tools and methodologies are familiar and investments tend to be limited and predictable. By constrast, modular innovations introduce new component technology and plug it into a fundamentally unchanged system architecture. They have been made possible by a division of labour in product development. The barriers to producing such modular innovations are substantial. High technological complexity requires top scientists and experienced engineers in various fields. In addition, investment requirements can be very substantial, as are risks of failure (Ernst 2016: 72)

Architectural innovations, on the other side, use existing component technologies but change the way they work together. A defining characteristic of architectural innovations is that they require strong system integration and strategic marketing capabilities, but they are much less demanding than modular (and especially incremental) innovations in terms of their needs of science inputs and investment thresholds. Architectural innovations tend to have particularly favourable impact on the innovating firms increasing their market share and the profitability significantly. Further, given that they destroy the usefulness of the architectural knowledge of established firms, such game-changer innovations threaten incumbent market leaders (Ernst 2016).

Radical innovations involve both new component technology and changes in architectural design. The great attraction of radical innovations is that once they have generated intellectual property rights for a blockbuster technology, the innovating firm may become a market leader in a short period of time. The flip side, however, is that radical innovations require breakthroughs in both architectural and component technology (Ernst 2016).[39] The latter in turn makes it very difficult to imitate and creates very high entry barriers.

These differences in the kind of opportunities for imitation and entry different kinds of innovations give rise to apply to the general discussion of opportunities presented in each phase of any technological revolution.

4.1 Dual Opportunities during the Irruption Phase

The first attempts by the original innovating firm/s signalling the rise of a new technological revolution open up a wide range of new investment and profit opportunities. In this irruption phase, there is a unique new combination of technical and economic advantages, which create opportunities for follower firms/ new entrants.

As pointed out by Perez, potential profits are high in this phase as "investment costs are relatively low" given that new technologies in their early phases tend to be less capital-intensive and more skilled labour-intensive. But this requires firms to have high levels of scientific and technological knowledge and dynamic advantages. There is also significant space for market expansion and productivity growth in this initial phase.[40] Thus the installation period of a new techno-economic paradigm seems to be a period in which players from developing countries can make entry (Perez 2001) if there has been sufficient investment in the continuous development of local technological capabilities (and given the right combination of external and internal enabling factors as discussed below).

[39] See Ernst 2016 for examples of each type of innovations and for more discussion.
40 According to Perez, even R&D investment for a follower can often be lower than that of the original innovator, if the new products belong to the early phases of a technological revolution. This is the case when the relevant technical knowledge tends to be in the public domain (available in universities, for example). (Perez 2001).

The irruption phase of a new technological revolution is also a period wherein existing industries can get restructured and rejuvenated through the application of the new technologies. Thus during the transition from one paradigm to another when new technologies co-exist with old technologies, there are what Perez (2001) calls "dual technological opportunities". As discussed above, it is possible to try to enter new industries directly when there are important discontinuities in technological evolution, which become windows through which latecomers can leap forward as many firms in developing countries did in the case of microelectronic products (South Korea, Taiwan and China) and software (India).

But apart from the window of opportunities provided to dynamically capable firms to enter a market during the installation phase of a new paradigm, the transition period also offers opportunities to firms in the old paradigm. New generic technologies and organisational principles associated with a new techno-economic paradigm can significantly increase the potential productivity of most existing activities, and can be applied in order to modernise and rejuvenate mature technologies (and even traditional technologies) in terms of dynamism, productivity and profitability. This gives opportunities to dynamic incumbents.[41]

However, when technological revolutions throw up radically new technologies or impose new management models which make the previous ones obsolete for existing industries, those incumbent firms that fail to identify the changing technological trajectories or are resistant to business model changes and fail to innovate their strategies stand to lose. As Utterback (1994) pointed out, the sunk investments and the accumulated experience can become an obstacle[42] in the absence of technological foresight. Sometimes, the very factors that contributed to a company's success in an old technology—focus on a segment and innovative workflow processes, for instance—could eventually result in its failure, especially in the face of disruptive change (Christensen 2017). It is for this reason that Perez (2017) refers to incumbent firms as 'dinosaurs'.

Indeed, an integral aspect of technological evolution and innovation that has been recognised since long is that they have both creative and destructive impacts on incumbent firms. This is because while they may provide a new growth impetus to existing firms, they may also make them vulnerable—by disrupting the demand for existing products and eroding the value of accumulated capabilities—depending on the situation and multiple factors. While innovation leads to monopoly rents, competition reduces them and pressures firms to increase productivity. Without improvement in productivity, when a radical innovation based on a different technology

[41] This occurred during the fourth techno-economic paradigm of mass production, for example, in the automobile industry and other sectors in Japan, the shipbuilding and steel industries in South Korea, surgical instruments in Pakistan, and exports of fresh flowers from Colombia and fresh salmon from Chile (Perez 2001).

[42] According to Utterback (1994), "failing firms tend to be remarkably creative in defending their entrenched technologies, which often reach unimagined heights of elegance in design and technical performance only when their demise is clearly predictable".

arrives on the scene, it will start disrupting the demand for existing products/services of an incumbent firm slowly or swiftly.[43] That is, in order to stay relevant and grow, incumbents must recognise the emerging technological challenges and not only be innovative, but also be able to execute the internal transformations necessary to overcome legacy issues.

4.2 The Frenzy and Synergy Phases

Perez pointed out that during the frenzy and synergy phases of a technological revolution (phases 2 and 3), innovators and early adaptors (or fast followers) of new technologies try to expand their markets by seeking economies of scale, forming oligopolies, and opening international marketing outlets to capture new markets. After the first innovations, the innovator firms acquire advantages, not only through patents, but also through the experience accumulated with product, process, business model and markets. This tends to keep the corresponding general and specialised know-how in the hands of the innovators and their suppliers, making it less and less accessible to new entrants (Perez 2001: 113–114). There is significant literature which highlights the importance of such 'tacit' technology. Apart from these general features, the nature of competition and opportunities for entry in digital markets are influenced and moulded by their unique characteristics. But before considering them (which we do in detail in the sub-section below), it is useful to understand the overall dynamics of the processes creating new opportunities for entrants in the frenzy and synergy phases.

According to Perez, despite the attempts by incumbent firms to consolidate their market position, greater opportunities will become available to new entrants in the frenzy phase. This is attributed to the fact the generic technologies that emerge as part of the new TEP and spread from one sector to another provide ample space for innovations through the availability of new infrastructures, as well as new materials and equipment.[44] Under the ICT paradigm, clearly the Internet has been the new infrastructure, which has led to major reshaping of structures and behaviours in finance, trade and other socio-economic spheres. Soon after, lateral innovations related to intermediaries or capital goods (tools, machinery, etc.) or other products/services using the new technology as a base both happen. The former reduces the cost of the original product. The subsequent drop in cost leads to a growth in demand, which attracts other entrants into the industry. The success of the original inventor firm also attracts other enterprises to the product or

[43] This can lead to the destruction of firms, and even industries in some cases, causing job losses and income re-distribution in favour of those employed in the new industries.

[44] As Perez (2009) discussed in detail, in the fourth surge, the networks of roads and electricity to the home became the infrastructure that made widespread suburban living possible. Equipment such as the steam engine, in the second, liberated industry from the need to be near a source of water power. The individual electric motor, in the third, allowed industry to do away with the forest of belts and the simultaneous operation of all machines; it also allowed small scale powered industry. In materials, the molecular "lego" trajectory of innovation in the petrochemical technology system opened a wider and wider range of application opportunities across the economy during the fourth surge, from successive plastics for packaging or structures, through textile fibres and fertilizers to detergents and pharmaceuticals (Perez 2009).

activity. As we saw in the earlier section, the rapid expansion in the Internet along with the advancements in telecommunication in the 1990s has seen ever-increasing demand for electronics and information technology systems, products, components and other manufactured hardware. Each of the technology systems that followed—in an overlapping sequence—minicomputers and personal computers, software, telecoms and the internet, opened new technology systems trajectories, while being strongly inter-related and inter-dependent. These led to widespread innovations, giving rise to a combination of interrelated product and process, technical, organisational, managerial and marketing innovations during the frenzy phase. As Perez (2009) explains, the processes underlying such new innovations is spurred by the growing cost advantage of the new infrastructure in two main ways: (i) directly through decreasing prices (as operational volume decreases the unit cost of transport/exchange); and (ii) indirectly through increasing market reach and therefore allowing greater economies of scale in production and distribution.

4.2.1 Unique characteristics of digital markets

In the case of digital technologies, specific unique features have been observed in addition to the business model innovations discussed earlier. As pointed out by Soete (2000), electronic markets by their very nature are wrought with problems of non-excludability, non-rivalry, and often, non-transparency. Owners of digital commodities selling their products/services on the market will have difficulty in preventing buyers, or anyone else for that matter, from copying and reselling it. The creation and enforcement of excludability is, therefore, an absolute and first condition for such markets to exist. This explains the focus on encryption, watermarks and various other forms of tracing and monitoring property rights as a central response by innovators and fast followers to create artificial excludability. The creation and strengthening of property rules has of course immediate implications for market structure and the degree of competition in such markets. High levels of property protection create significant challenges for new entrants and lead to less than optimal competition in a market (Soete 2000). Apart from a focus on intellectual property rights, innovators in digital markets create excludability and erect entry barriers through various other business strategies, as we will see in detail in Section 5.

Despite the tremendous opening up of trading possibilities and the increase in market transparency, the actual exchange of a digital commodity also involves, almost by definition, a high degree of information asymmetry between sellers and buyers (Haucap and Heimeshoff 2013). Many of the new forms of internet markets—the platform companies discussed earlier generating value out of providing intermediation services—are considered innovative responses to this problem of non-transparency.

It is useful to discuss how platform companies deal with the issue of non-excludability. As pointed out in Caillaud and Jullienne (2003), intermediation services usually are not exclusive as users often rely heavily on the services of several intermediation providers. For instance, a web-surfer looking for some specific good or service will usually visit and register with several intermediation service providers to increase his chances of finding a match. Similarly, firms offering various services register with different intermediaries in order to benefit from their different user bases. Excludability is therefore often imposed by intermediaries to ensure that their efforts in processing the users' demands end up with a transaction, or because registration involves the specific building of a profile that the intermediary may consider proprietary. Caillaud and Jullienne (2003) has pointed out that the use of transaction fees is central in these pricing and business strategies. Matchmakers rely on two pricing instruments: registration fees, which are user-specific and paid ex ante, and a transaction fee, paid ex post when a transaction takes place between two matched parties. By and large, ruling out transaction fees raises intermediation profits.

It needs to be highlighted that at one level, platform companies (search engine services such as Google, Bing or Baidu and e-commerce firms like Amazon, Alibaba, EBay, Flipkart, etc.) have increased competition. New entry is facilitated by the fact that their coded nature makes these markets available even to the smallest vendors/participants and this increases competition (Ross 2016). At another level, however, in many of the digital markets, we see a highly concentrated structure with a monopoly or a duopoly (Caillaud and Jullienne, 2003). In fact, many online markets have been characterised by a large degree of Schumpeterian competition where one temporary monopoly is followed by another.[45] The reasons for these high concentration levels are the economies of scale and indirect network effects that characterise platform companies. Increasing returns to scale arises from the fact that typically, multi-sided markets are characterised by a cost structure with a relatively high proportion of fixed costs and relatively low variable costs. Most of the costs arise from managing the respective databases, while additional transactions within the capacity of the databases usually cause hardly any additional cost (Haucap and Heimeshoff 2013, p. 6).

In the case of e-commerce, while new growth opportunities will depend on the substitution possibilities of physical commerce with electronic commerce, followers' business strategies invariably focus on entering the market and expanding by differentiating the kind and variety of products and services offered. Whether in e-commerce or other platform companies, the higher the degree of heterogeneity among potential users and the easier it is for platforms to differentiate among users, the more diverse the platforms that emerge and the lower the level of concentration and therefore barriers to entry for followers.

[45] A notable exception has only been eBay which has managed to hold on to its dominant position for more than a decade now (Haucap and Heimeshoff 2013).

That is, while on the one hand, indirect network effects, increasing returns to scale and proprietary ownership of technology platforms will drive increasing concentration in multi-sided markets, on the other side, capacity limits (and the associated the risk of platform overload),[46] product differentiation and the potential for multi-homing (i.e., the parallel usage of different platforms such as in search engines like Google, Yahoo or Baidu, or online travel agencies such as Expedia) will decrease concentration levels (See Evans and Schmalensee 2008 cited in Haucap and Heimeshoff 2013. See also Martens 2016). How easy it is for consumers to multi-home depends, among other things, on: (a) switching costs (if they exist) between platforms; and (b) whether usage-based tariffs or positive flat rates are charged on the platform. Consequently, despite indirect network effects, every digital platform market is not automatically highly concentrated. For example, several competing platforms coexist in the case of online real estate brokers, travel agents, many online dating sites, etc. (Haucap and Heimeshoff 2013).

While no significant direct network effects exist for Google (i.e., it does not directly matter how many other people use Google), this is not true for social networks such as Facebook where the number of users is a very important factor for users' utility. Even though switching costs between search engines are very modest for consumers, entry into the search engine business is not easy due to the indirect network effects discussed earlier and the economies of scale that are (a) at least partly based on learning effects, which depend on the cumulative number of searches made over the network in the past, and (b) on decreasing average costs, which are caused by substantial fixed costs of the technical infrastructure (Haucap and Heimeshoff 2013, p. 7–8).

Hackl et al. (2012) has shown that while entry and exit of e-commerce firms is very prevalent, newcomers are more likely than in well-established physical markets to be able to influence the market structure at the core. This is because of the cheap and easy establishment of online shops, and the fact that many such shops operate only online, without a brick-and-mortar store or physical storehouse. Investigating the impact of the number of firms on mark-ups and price dispersion in e-commerce using data from an Austrian online price-comparison site (price search engine) for digital cameras, they found that the number of firms had a highly significant and strong negative effect on mark-ups. Having one more firm in the market reduces the mark-up of the price leader by the same amount as the competition between existing firms in a period of three additional weeks in the product lifecycle. This was found to be especially true for markets for consumer electronics, where product lifecycles are particularly short.

Even so, the success of new entrants in e-commerce is not guaranteed. This is partly because indirect network externalities give rise to a "chicken & egg" problem: to attract buyers, an intermediary should have a large base of registered sellers, but these will be willing to register

[46] Advertising space is often restricted since too much advertising is often perceived as a nuisance by users, and therefore, decreasing the platform's value in the recipients' eyes (Haucap and Heimeshoff 2013, p. 6).

only if they expect many buyers to show up (Caillaud and Jullienne 2003, p. 310). However, as Haucap and Heimeshoff (2013) has shown, it is not easy for sellers (or buyers) to use competing online trading platforms simultaneously—that is, to engage in multi-homing. This creates a fundamental bias against new e-commerce entrants. First of all, multi-homing is difficult for small sellers because they often sell unique items and heavily benefit from a large group of customers to find buyers for their products. Additionally, it is difficult to build up reputation on several platforms, as reputation depends on the number of transactions a seller has already honestly completed on a given network.[47] Investment into one's reputation is typically platform-specific so that there are significant costs involved in switching to another e-commerce platform. Furthermore, selling on smaller platforms bears the risk of selling the product at prices below its market value, as the price mechanism works best with a sufficiently large number of market participants on both sides of the market, i.e. with sufficient market liquidity or "thickness". As long as sellers do not switch to other trading platforms, there is only a very limited benefit for consumers in starting to visit and to search through other trading platforms (*ibid.*).

In this context, it must also be kept in mind that lower search costs and lower switching costs for internet users increase price elasticity (Smith, Bailey and Brynjolfsson 1999). That is, all strategies and techniques which increase the cost of switching to another platform, lowers price elasticity and simultaneously provide premium pricing opportunities for innovators and become entry barriers for followers. By reducing actual or potential competition, such high market entry costs makes it possible for existing market players to sustain price premiums. This is helped along by the fact that customers' search costs (which in turn reduces information asymmetry) and sellers' menu costs[48] are both lower online than in conventional outlets. Retailers may also be able to charge a price premium by leveraging customers' switching costs.

Various types of loyalty programs are one such strategy used by platform companies to increase switching costs of the participants. Towards this, goods might be offered for free or paid for by advertising or by subsequent upgrades; or a limited preview of the goods might be offered for free; etc. (Soete 2000, and Lehtiniemi 2016). Citing Rochet and Tirole (2003), Lehtiniemi (2016) also points out how platform companies' pricing strategy often entails selling products on one market segment below cost. Losses on one market segment are incurred in order to stimulate the sales of products in other, profit-turning market segments, which subsidise the loss-incurring segment (see also Rieder and Sire 2014). Varian had pointed to such complex and diversified set

[47] In fact, it has been documented by many studies that a good reputation on eBay translates into higher prices for sellers. See Melnik and Alm, 2002; Bajari and Hortaçsu, 2004; Dellarocas, 2006 etc. cited in Haucap and Heimeshoff (2013).

[48] Menu costs are the costs incurred by retailers when they make price changes. In online markets, it is comprised primarily of the cost to make a single price change in a central database, rather than physically changing price labels on shelves. Retailers will only make a price change when the benefit of the price change exceeds the cost. Lower online menu costs allow Internet retailers to make significantly more, small price changes than conventional retailers. See Smith, Bailey and Brynjolfsson (1999).

of exchange methods in which the value of the content offered by a seller is likely to differ strongly amongst individual consumers (See Varian 1997 cited in Soete 2000). This so-called versioning can be seen to be influencing switching costs, and in turn, multi-homing.

The integration of various forms of verticals may be seen as another strategy to generate customer loyalty. This for instance, is visible in Amazon and Flipkart's strategy to process a large part of their payments directly. They push their payment applications—Amazon Pay and PhonePe respectively—with steep cashbacks and incentives for shoppers, which serves to increase switching costs.

Thus at the firm level, growth in e-commerce will depend on how it can monetise advantageously the trade-offs involved in not only replacing the particular features and relative merits of physical commerce over electronic communication and exchange, including the payments of money, but also in the ability to build loyalty (and therefore, significant switching costs) through various strategies.

Perez had pointed out that once innovators and early adaptors' experience accumulated with product, process and markets reach a high point, this speeds up their incorporation of subsequent innovations, so that it is even more difficult for latecomers to catch up with the leaders. Amazon is a case in point. The value creation models of large-scale internet platforms can be observed in Amazon's strategies to maintain lead market share, which has involved several of the above kind of innovative strategies. These have led to Amazon's transformation from an online book seller to a marketplace for third party sellers with a premier membership program. As reported by LaVecchia and Mitchell (2016), already half of all U.S. households are subscribed to the membership program Amazon Prime, half of all online shopping searches start directly on Amazon, and Amazon captures nearly one in every two dollars that Americans spend online. Amazon sells more books, toys, and by next year, apparel and consumer electronics than any retailer online or off, and is also investing heavily in its grocery business.[49] Beyond acquiring Whole Foods, the US grocery store chain, Amazon has now shown that it is serious in expanding its physical presence by moving further into "offline" stores. Using computer vision, machine learning algorithms and sensors to figure out what people are grabbing off its store shelve, which are added to a virtual cart,[50] it has launched its Amazon Go concept in Seattle, which lets shoppers take goods off its shelves and just walk out. Amazon's technology charges customers after they leave by charging the customer's credit or debit card to a smart phone. There are no cashiers, no registers and no cash in this new business model of Amazon's for store shopping.

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[49] For more on Amazon's market power and anti-competitive practices, see also Budzinski and Köhler (2015).

[50] See https://economictimes.indiatimes.com/small-biz/startups/newsbuzz/get-your-stuff-and-go-amazon-opens-store-with-no-cashiers/articleshow/62617852.cms

Social networks such as Facebook also share many characteristics with other online platforms. In order to assess the potential for competition and potential barriers to entry for followers, here again, it is important to understand whether (a) switching costs play a major role or not and (b) how easy it is for consumers to engage in multi-homing (Haucap and Heimeshoff 2013). Overall, market for social networks shows lower concentration levels than other Internet markets because user preferences are more heterogeneous, and, secondly, it is not very costly for users to be present on two social networks, i.e., to engage in multi-homing. For example, one network (such as *Facebook*) may be used for social contacts while a second network (e.g., *LinkedIn*) may be used for business-related contacts and exchange. Given this market segmentation, the degree of competition between various business-related networks and various social networks may possibly decline to some extent though, as direct network effects are rather strong for social networks. The main value of the network lies in the number of members subscribed to the network. However, new networks (as Google+ did in 2011) can still emerge, as multi-homing is rather easy and switching costs are not too substantial (*ibid*.).

In Perez's framework, passing successfully through phases 2 and 3 (of frenzy and synergy) requires growing support from the economic environment—especially the physical, social and technological infrastructure/capabilities, constant innovation and the existence of competent and demanding local clients and consumers (See also Parthasarathy 2013). While state policy has a role to play in enabling many of these—as will be discussed in Section 6, equally crucially, capital-intensive investments and great manoeuvrability in terms of markets and alliances also play major roles (Perez 2001). In fact, innovators and fast followers are making use of various ingenious strategies to entrench their competitive positions. Such strategies are being used to leverage the various synergies enabled by digital technologies as well as to generate new synergies based on new business/organisational models and other innovations. We will discuss this in detail in Section 5.

At the same time, it is crucial to understand that the synergy phase of the ICT revolution offers immense opportunities to fast followers and new disruptors/innovators (as well as to incumbents in facilitating their reincarnations). The availability of platforms, cloud, data analytics, AI, Blockchains, etc. as infrastructural utility services and an increasing array of other digitised services being offered through all of them, along with the availability of risk capital (from venture capital and other funds), enable fast followers and new disruptors to self-organise, scale up rapidly and generate rapid financial returns.

David Teece had pointed out way back in his 1986 paper that profits from innovation may accrue to fast followers or imitators with certain complementary assets and successful business strategies with respect to integration and collaborations, rather than to the original developers of intellectual property. This together with their own dynamic capabilities can enable some of the fast followers to overtake the original innovators in some markets.

However, in the synergy phase of the ICT TEP, continuing interactions between the evolving technological systems and the subsequent ones that may emerge means that the lifecycles of the related new upstream and downstream products/services may involve much shorter phases of maturity than under the previous TEP. Some products may atrophy and die out before even reaching maturity. Further, the immense opportunities to small businesses do not usually lead to the same wealth generation capabilities for them as the owners of the platforms or cloud or AI or Blockchain due to the fact that value gets concentrated due to the latter's proprietary ownership of platform design and monetisation of the data generated (more in Section 5).

4.3 The Mature Phase

As Perez points out, in the final phase, mature technologies reach a point where they have only minimal potential for producing profits, face stagnant markets, and have almost no room left for improving productivity. Thus innovator firms and fast followers who made it through the synergy phase into the mature phase of a technological revolution face significant challenges in overcoming each of these constraints by innovating further and/or identifying and moving on to a new technological revolution. In the earlier technological revolutions, because mature technologies do not require much prior know-how or experienced managers, and the processes can use unskilled labour, the determining advantage is the comparative cost profile. Therefore, as technology and markets reach maturity, phase four has also offered opportunities for follower firms from developing countries. This is also attributable to the fact that innovators and first movers are more likely to transfer their technologies once these technologies have reached the phase of maturity or/and when such firms face demand/market stagnation.

However, as we discussed, in the current synergy phase of deployment of the ICT revolution, technological change is occurring at a more rapid pace than ever before. This implies that the targets for catching up and development are constantly moving and that market opportunities change quickly in today's world. Promoting sectors based on mature technologies, while offering a good platform for promoting manufacturing, may not lead to catch-up (Perez 2001). Accordingly, the requirements to access and apply new technologies and to capture market opportunities may be more difficult to meet than before. This is all the more true given the increasing focus on intellectual property protection in many markets (more later), and particularly exacerbated given the distinctive features of digital markets discussed above (and in Section 5).

Furthermore, as pointed out in Lee and Mathews (2012), the "constraints" of the conventional fossil fuel-based industrial model reflected in its inability to scale up and provide a sound source of income and wealth for all the world's inhabitants have to be confronted, and an alternative sustainable model of development needs to be created. This means, in effect, that developing countries need to avoid carbon lock-in approaches that constrain the uptake of renewables and low-carbon technologies in the advanced world, while securing advantages from the adoption of renewables. While these offer new opportunities to leapfrog into new technological systems based on renewable energies, the challenges are enormous.

5. Strategies by Innovators and Constraints for Followers

Overlapping and inter-linked innovations, rapidly falling average total costs, zero marginal costs, strong network externalities, standards battles and path dependence (Ernst 2016) as well as digitisation and datafication are the hallmarks of digital technologies. Arguably, internet markets are not as friction-less as suggested way back in 1999 by Smith, Bailey and Brynjolfsson (1999). They had attributed the former to low search costs, strong price competition, low margins, and low deadweight loss in internet markets for consumer goods. However, other characteristics peculiar to digital technologies and speeding waves of creative destruction may be creating greater friction and therefore more complex challenges to competitors and followers in the digital era.

In this section, we discuss the main strategies adopted by innovator/leading firms to extend their market power by generating sustained competitive advantages and consolidating monopoly positions under the following six categories: (i) expansion of IP protection into new spheres; (2) embeddedness of software in hardware; (3) proprietary ownership of platforms and networked data; (4) exclusionary practices (5) acquisition of competitors and innovator start-ups; and (6) "private innovations" in government support. All of these erect significant barriers to entry and challenges to follower firms. Arguably, they seem to variously play the role of "an irrevocable commitment of investment in entry deterrence", which as Dixit (1980) pointed out, can alter the initial conditions of the post-entry game to the advantage of the established/incumbent firm. In the second sub-section, we see that many fast followers, including from developing countries, are following strategies similar to that of developed country innovators, probably with the critical exception of proprietary ownership of technology platforms, which gives asymmetrical power and advantages to the developed country innovators.

5.1. Strategies Adopted by Innovator Firms

5.1.1 Expansion of private property rights to new spheres and standards setting

Most often, in the previous technological revolutions, general information (applied science) was considered to have an essentially public good character. This meant that innovating firms could only appropriate returns to product-specific information. By contrast, proprietary ownership of technology platforms and other characteristics of digital technologies make the nature of monopoly rents quite different. As elaborated in Burlamaqui (2006), in the so-called new economy industries, not products or processes alone, but intellectual property is the corporation's main output or asset. This means that the ability of innovators to combine first movers' advantages with trade secrets, patents, copyrights, brand loyalties and network externalities may grant them highly secure monopolistic positions in their market.

There has been an increasing trend towards patenting generic knowledge, business models, etc. in addition to the traditional modes of trade secrets, confidentiality contracts, copy rights, trade markets and registered brand names (Burlamaqui 2006:6). It has also been observed that research often is directed not at producing new products, but at extending, broadening, and leveraging the monopoly power granted through the patent. Thus high tech companies are often unable to innovate without violating other companies' intellectual property rights since innovation often requires the use of currently existing IP. This leads to blocks (sometimes called a patent thicket), that delays and reduce innovation because of the long and costly negotiations involved in obtaining the multiple permissions needed. An increasingly dense "patent thicket" in a world of products requiring thousands of patents has sometimes stifled innovation (Baker, Jayadev and Stiglitz 2017). Clearly, the greater the IP protection, the narrower the scope and opportunities for competitors and followers to "invent around or for innovating on the shoulders of the patent holder" (Burlamaqui 2006:6). Thus overly high IP protection goes hand-in-hand with high entry barriers.

Some firms are also involved in "strategic patenting"; that is, acquiring patents that the firm has no intention of using/exploiting, but patenting it solely to prevent others to use and profit from it (Burlamaqui 2006, Block and Keller 2011). An individual or firm that acquires a portfolio of such strategic patents can sometimes make a significant return by suing other firms for infringement of those patents (Baker, Jayadev and Stiglitz 2017 and Block and Keller 2011). Patent trolling, whereby innovators face suit from others who simply own IP to profit by licensing of litigation rather than undertaking production themselves, can challenge the entry of followers. It has been observed that large corporations have been aggressive in acquiring substantial portfolios of strategic patents as a defensive manoeuvre (Block and Keller 2011). If they are sued by another firm for infringing an existing patent, they might use some of the patents in their portfolio to mount a countersuit against the other firm (remember the Apple *vs* Samsung battles not so long ago) to arrive at a negotiated settlement.

Yet another IP-related trend identified in the literature is the "second enclosure movement" credited to Evans (2005). There are two sides to it. The defensive side focuses on intensifying the enforcement of protected monopoly rights to exclude others from using information that is under IP protection. An example is Google's litigation related to use of the phrase "to google it". The offensive side involves taking information that has been considered "nature" or common cultural and informational heritage of human kind and transforming it to private property.

Companies also invest large sums of money into emerging technologies that have not yet been deployed, not solely for the patents, but because they will also give them room to influence the setting of standards, which give them long-term competitive advantage in several related markets. This is currently the case with 5G, a short-hand for fifth-generation wireless technology. By sending billions of bits of data per second, up from peaks of hundreds of millions today, 5G could bring ultrafast wireless speeds to people.[51]

5.1.2 Increasing embeddedness of software in hardware

Another business strategy that is used to generate and sustain monopoly rents, but has not been explicitly linked to IP protection, is to embed patented software in hardware. In the present synergy phase of the ICT technological revolution with their widespread application across sectors and spheres, the maximum size of market for intangible products is defined by the possession of the hardware by the users and the existence of the communications links. As pointed out by Perez (2007:22), this means that hardware and telecom networks penetration are the true market frontiers for the ICT industries, rather than the "invisible" territorial ones. This is an important reason why global software companies are increasingly investing in hardware technologies, and *vice versa*, as a strategy to retain monopoly rents. The fact that Alphabet—Google's parent company, has an autonomous car technology on which it has invested hundreds of millions of dollars over nearly a decade, is just one such instance of this attempt to maintain leadership by entering hardware segments that will see growth due to advances in the emerging technological systems. There are also ride-sharing platform firms like Uber that sees its future as dependent on self-driving cars and is investing in the same.

These trends in offering integrated solutions through bundling of physical products with services and software point towards complex emerging issues in the areas of interface between competition policy and IPR policy. For example, Zysman and Kenney has argued that the DMCA (Digital Millennium Copyright Act) enacted by the US, which was intended to protect Hollywood, has implications for the broader digital economy and for goods with embedded software. Indeed, some firms were reportedly using DMCA to sue and force customers of equipment such as tractors to return to the manufacturer for repair, citing risk of violation of copyrighted software in the control systems (Zysman and Kenney 2016).

Similarly, proprietary owners of personal assistant software are releasing their own hardware as a strategy to increase integration of their own software and set trends. Reportedly, Google—the Internet-company-turned-product-giant's—strategy is to get people used to talking to the Google Assistant, whether it is on their own products or the ever-growing list of third-party products that leverage their VPA (Virtual Personal Assistant). Amazon has not lagged behind. As a result, for

[51] Other 5G features would allow autonomous cars and industrial equipment to reliably exchange short bursts of data at blinding speed.

instance, in the consumer electronics industry, smart speakers and other electronics are being powered by personal assistants and voice interfaces owned by Google (Google Assistant), and Amazon (Alexa), or both. Apple is also releasing its own voice-controlled speaker, the HomePod—its first Siri-enabled smart speaker. Fast followers are attempting to copy such strategies at their own level. To fight the continuing risk of commoditisation in the consumer electronics space and to deal with competition from the leaders, the media streaming company Roku, for instance, is developing its own virtual assistant and plans to license it to smart speaker manufacturers in an attempt to own the entertainment experience more fully.[52] The competition to make differentiated offers to consumers is leading to integration strategies being adopted at multiple levels such as product, software, services and marketing.

5.1.3 Acquisition of competitors and innovator start-ups

There have been several instances of mergers or acquisitions of competitors and start-ups by leading firms to protect their dominant market position. Many firms have cut back their R&D efforts or shifted funds towards product development. As Block and Keller (2011) argues, the financial orientation of top executives means that they see new technologies as simply another asset that can be acquired rather than produced internally (see also Ernst 2016). They are confident that when the time comes, they can either license the technologies they need or buy up the firms that are producing innovations. Acquisitions enable the leading firms to achieve many advantages: i) to transfer the ownership of patents on the latest technological advances; ii) to absorb the capabilities; and iii) to crush competition and often significantly delay new competition until the leader is able to garner the premium profits in a new product.

Buying other companies' technology to bolster its own is widespread among innovator firms in the digital economy. For example, Google purchased Boston Dynamics, a leading robotics design company with Pentagon contracts, in 2013. It also bought DeepMind, a London-based artificial intelligence company founded by wonderkid Demis Hassabis, which had taught computers how to think in much the same way that humans do. Google has been applying its expertise in machine learning and systems neuroscience to power the algorithms as it expands beyond internet search into robotics (Ross 2016, p. 25).

Sometimes acquisitions take years before they bear fruit. For example, Apple bought up the technologies it needed to launch its latest iPhone X with face-tracking technology ((that superseded fingerprint-based touch ID) and Animoji, years before its eventual launch in 2017. Apple had bought up PrimeSense, maker of some of the best 3-D sensors on the market, as well as Perceptio, Metaio, and Faceshift, companies that developed image recognition, augmented reality, and motion capture technology, respectively. These technologies enabled Apple to

[52] https://codeburst.io/3-takeaways-from-ces-2018-ca239c903ace

eventually come out with the face tracking technology which allows users to unlock the phone with their face or to lend their expressions to a dozen or so emoji with Animoji.[53]

A related strategy for lead innovator firms, especially when they enter emerging markets like China and India[54] with specific domestic market requirements (including stringent government regulations), is to acquire local start-ups. For instance, when it entered China, Amazon bought up an online book retailer Joyo.com. Sometimes acquisitions take place at the personal level of top level executives of lead firms. An example is that of John Chambers, executive chairman of Cisco Inc. picking up a 10 per cent stake in Chennai-based speech recognition solutions company Uniphore Software Systems Pvt. Ltd.[55] In addition to their technologies, acquisitions in developing countries also provide global firms with valuable insights into the business models used by domestic firms.

More recently, companies have also been signalling interest in blockchain technology through strategic acquisitions. In 2016 and 2017, AirBnB, Daimler, Rakuten, and several others acquired blockchain-related start-ups, while the investment arms of Jaguar Land Rover, JetBlue, Verizon, and others made blockchain-related strategic investments.

It must be noted that such acquisitions are becoming strategically important in varied sectors including agriculture, transforming agri-business firms to ICT firms. Ross (2016) discusses how current major investments are being undertaken by the largest agribusinesses such as Monsanto, DuPont, and John Deere. Convinced about the opportunities in the use of Big Data to agriculture, Monsanto has gone on a buying spree of farm data analytics companies. Even if hardware costs on sensors, smart phones and tablets come down, the business model likely to be pushed by big agribusinesses will mean that costs and therefore challenges to followers will come from the cost of precision agriculture software as a service.

It is important to note that these various strategies for expanding IP protection, increasing embeddedness of patented software in hardware, and acquisitions of competitors and start-ups also help these corporations to set new interoperability standards. The latter are necessary to transfer and render useful data and other information across geographically dispersed systems, organisations, applications or components (see Ernst 2016). Interoperability standards are crucial in the deployment phase of the ICT techno-economic paradigm. This is the why Prescott and Williams (2010) believe that the future of successful companies in the digital era of networked intelligence will be those that adapt collaborative innovation (as a way to pooling competencies and reducing R&D costs). According to them, the future lies in hybrid models where participants

[53] See Stinson (2017)

[54] Parthasarathy (2016) has also discussed these strategies as a form of frugal innovation.

[55] See "Uniphore's products help government and companies reach rural customers by interacting with them in vernacular languages", Hindustan Times, 1 Dec 2017.

both share and appropriate at the same time —the spectrum of options between closed and open IPR models. This requires reimagining IPR options.

5.1.4 Proprietary ownership of technology platforms and networked data

But the central barriers to new entrants in the platform businesses are their emphasis on proprietary technology platforms and “ownership” of networked data.

In typical sharing economy platforms (and other multi-sided markets), while the front-end of the technological infrastructure is P2P, the design is in the hands of the owners (Kostakis, Pazaitis and Bauwens 2016). The latter controls its potential monetisation through their ownership of the platforms for P2P communication. As observed by Zuboff (2015), these companies employ specialised means of production that rely on proprietary knowledge and material capabilities. The “proprietary capabilities” include “ownership” of the data assets that are potentially extracted over a wide range of users and data sources. As we saw in detail, platform owners, who are crucially dependent on the trust of user communities, exploit the aggregated attention and input of the networks in different ways, even as they enable it (Kostakis, Pazaitis and Bauwens 2016).In other words, the production capabilities of the company rely on its position as the aggregator of data about many individuals and from multiple sources (Zuboff 2015, 83).

As stressed by Kostakis*, Pazaitis and Bauwens (2016), the monetisation of the surplus value produced is exclusionary, keeping the users/producers out of that process. Nearly everything is controlled by the owners of the platforms. The answers to questions about what kind of data is extracted and what is learned from it are all shaped by the underlying institutional market form of platform companies. As Zuboff (2015) has argued, the assumptions of these multi-sided markets are embedded in the ways platform companies organise their markets and collect, store and use personal data about their users. That is, digital platforms are regulatory structures, which set the rules and parameters of action for participants, whether it is Uber/Lyft, Google, Facebook, Airbnb, or others (Zysman and Kenney, 2016: 23). The governance rules of such sharing platforms are, as Larry Lessig argued years ago, an outcome of the code itself, and therefore, deeply exclusionary (see Lessig 2015 and also Kostakis, Pazaitis and Bauwens 2016).

According to Zuboff (2015), the value creation process in the platform-based markets takes place in three phases: data extraction, behaviour prediction, and monetisation of predictions. In the first phase, the company provides products or services for people to use, and targets the users with ubiquitous extraction processes to collect data about them. The users become the sources of what Zuboff calls surveillance assets, a raw material for later phases of production. In the next phase, the company uses the extracted data as input material to produce prediction products from surveillance assets. The conversion of surveillance assets to prediction products happens by employing highly specialised analysis capabilities, i.e., surveillance capital. Predictions include qualities, preferences, characteristics, intentions, needs and wants of users. The third phase is about converting prediction products into revenue. Accordingly, revenues come from beneficiaries of prediction products, who are not limited to only advertisers. Thus the very revenue model of platform companies is to produce “objective and subjective data about individuals and their habits for the purpose of knowing, controlling, and modifying behaviour to produce new varieties of commodification, monetisation, and control” (Zuboff 2015, p. 85).Each of the above value creation phases continues with new transactions producing new possibilities to extract raw data. Thus as observed by Ross (2016: 93), the manner in which the intermediary company redirects each of the transactions between multiple user groups through their proprietary technology platform leads to greater concentration, because revenue flows to the owners of the platform rather than the participants of the transaction.

Further, the greater the volume of data (in terms of both breadth of data from a single user as well as the breadth of user base), the greater is its predictive power through analysis, and therefore, its revenue potential. Therefore, as Rieder and Sire (2013) have argued, these companies have incentives to collect as much information as possible from the users. Moreover, when extraction and analysis of data about user behaviour improves service quality, extracting more data leads to more users and advertisers choosing the particular service, which in turn leads to better service (Lehtiniemi 2016, p. 4).This also contributes to highly concentrated markets.

Thus the main competitive challenge for firms competing with search platform companies like Google and other innovator platform companies becomes the limited availability of high quality user data, which is firm specific. In Google’s case, due to its significant market share, Google also has the best access to (also historical) search data. This is an important aspect for success in search engine markets, as search data is needed to refine the engines’ search algorithms. The more search data an operator has, the better are the refinements of its search algorithm. This process results in superior search engine quality and provides a competitive advantage for the market leader, i.e., Google. Consequently, for search engines competing with Google to catch up or even overtake Google is very difficult due to missing online search data to develop better search engine algorithms (Haucap and Heimeshoff 2013, p. 9–10). Micro-level analysis of Google’s tangled activities on different segments of multi-sided markets has shown that the company has incentives to organise its interactions with the users in a self-serving way (Rieder and Sire 2013) in order to optimise its revenues (Lehtiniemi 2016, p. 5). In fact, there have been numerous complaints that Google is abusing its dominant position, especially to favor its subsidiaries (such as Google Map or Google Travel) over competing platforms (Haucap and Heimeshoff 2013).[56] As Rieder and Sire (2014, p. 198) point out, there are economic incentives to ‘orient’ search results in self-serving ways which follow from Google’s double role as both search and advertisement business. Thus Rieder and Sire (2014: 197) have argued that Google’s

[56] Also see the discussions on Google in Rieder and Sire (2014) as well as Mäihäniemi (2016).

monopoly position is more than a historical accident, but rather a structural effect and expected consequence of the way in which the search market is currently structured.

Evidently, the leadership position of the innovator tends to get entrenched due to the advantageous access to capabilities of data collection and analysis. The material and knowledge asymmetries—both in the data extraction phase and the analysis phase—institutionalise the leader's position in multi-sided markets. This asymmetry has been rightly described as the "big data divide" by Mark Andrejevic (2014) (see Zuboff 2015).This is reflected in the fact that Facebook and Google now control 73 per cent of US revenue in the digital ad market.

LaVecchia and Mitchell (2016) show how increasingly Amazon too controls the underlying infrastructure of the economy through its advantageous position as the innovator/leader. Its marketplace for third party sellers has now become the dominant platform for digital commerce. On the other side, its Amazon Web Services division provides the cloud computing backbone for much of the country, powering everyone from Netflix to the CIA. Its distribution network includes warehouses and delivery stations in nearly every major U.S. city, and it is rapidly moving into shipping and package delivery for both itself and others (LaVecchia and Mitchell 2016). By controlling the critical infrastructure across various sectors (and not just verticals), Amazon both competes with other companies and sets the terms by which these same rivals can enter the market in each and all of these segments. Moreover, redirecting all these transactions through its own proprietary technology platforms also enables this company to entrench its market leader position further through "ownership" of data collected from the different sectors.

Clearly, the "ownership" of networked data by the platform owners puts further hurdles on follower firms' attempt to catch-up. As Ross (2016: 13) pointed out, "whereas land was the raw material of the agricultural age and iron was the raw material of the industrial age, data is the raw material of the information age". Further, as already mentioned, the extraction of data increasingly goes beyond the platforms.

The strategies for IP protection, the embeddedness of patented software in hardware, and acquisitions of competitors and start-ups can be variously used by corporations to set new interoperability standards, which are crucial in the deployment phase of the ICT techno-economic paradigm.

5.1.5 Exclusionary practices

As we saw, platforms generate indirect network effects through pricing, product design, marketing, and other efforts to attract agents on each side and reach a viable scale and to overcome the "chicken & egg problem". As pointed out by Fletcher (2007), such network effects can tip the market towards being served by just one or two platforms.

One of the strategies by incumbents is to "divide and conquer". These involve subsidising agents in the most price-sensitive group, then using their participation to attract agents in the other group (Evans and Schmalensee 2013:10). Such strategies whereby one group of buyers is locked in by the incumbent with very favourable offers, so as to prevent a potential entrant from reaching the critical scale, allow the incumbent to monopolise the rest of the market (Amelio, Karlinger and Valletti 2017). This exclusionary strategy deployed by the incumbent in a multi-sided market is identified in the literature as "naked exclusion" (*ibid*). Caillaud and Jullienne (2003: 310) had argued that in the case of exclusive services, an incumbent might forego all potential profits in order to protect a monopoly position.

However, with nonexclusive services, intermediaries may avoid fierce price competition and make positive intermediation profits. By and large, ruling out transaction fees raises intermediation profits. In the cases in which global multi-homing (i.e., the parallel usage of different platforms) is efficient, however, transaction fees enable competing intermediaries to profitably differentiate, one offering low registration but high transaction fees, the other adopting the mirror pricing policy (Caillaud and Jullienne 2003).

Another strategy is "limit pricing". Dixit (1980) had pointed to entry deterrence through limit pricing, where an incumbent can discourage entry by setting a price just low enough (for producing an output just high enough) to render prospective entry unprofitable. The pricing or output choices are made in such a manner that leaves no room for entrants to establish their business alongside the incumbent in the market.

According to Amelio, Karlinger and Valletti (2017: 4), the intermediation market is therefore partially contestable: depending upon the pricing instruments and the exclusivity of services, concentrated market structures may go along with limited or zero intermediation profits. Intermediation providers therefore have an incentive to open up the intermediation market. When intermediation providers allow users to turn to several intermediaries simultaneously, it moderates price competition and reinforces market power and intermediation profits.

Fletcher (2007) pointed out that "predation" can occur where an incumbent platform prices its total service at a level that fails to cover its avoidable costs of providing the total service, taking revenues from both sides of the market into account. In such a case, a competing platform may be unable to make a positive profit, regardless of how it structures its pricing, and therefore may be excluded from the market. Secondly, and more subtly, it may be possible in some circumstances for a dominant platform to predate through asymmetric pricing between the two sides of the market (Fletcher 2007: 223). It has been pointed out that in markets where firms are not entirely symmetric, if the dominant incumbent can successfully turn extra business on one side of the market into incremental revenues on the other (and prices accordingly), then the same opportunities and pricing incentives will not apply to its smaller competitors, or newer entrants.

The latter have less ability than the dominant incumbent to turn extra business on one side of the market into incremental revenues on the other because it is very hard to compete against a very asymmetric pricing structure. This leads them to be excluded from both sides of the market. This in turn may restrict or eliminate competition between platforms (Fletcher 2007: 223).

In the context of competition policy, the question of whether multi-sided platforms need to be treated differently from companies in one-sided markets has been a contested one. On the one side, there are some studies like Evan and Schmalensee (2007) and Vasconcelos (2015), which argue that the former deserve a more relaxed approach even when it comes to below-cost/predatory pricing, because their practices are not “intentional”. On the other side, scholars like Amelio, Karlinger and Valletti (2017), Haucap and Heimeshoff (2013), Budzinski and Kohler (2015) and Lehtiniemi (2016) have argued that exclusionary behaviours taking place in multi-sided markets need to be considered in the context of anti-trust rules, particularly in the context of platform competition.

A related strategy used by innovators and incumbents that severely limit opportunities for new entrants is to invest in one side of the platform to make it more attractive to new users on the other side (Rieder and Sire 2014, p. 199-200). This can be seen, for instance, in Microsoft’s practice of spending heavily on tools and support for software developers to help them build programs that make the MS platforms more attractive. As observed by Rieder and Sire (2014), such well-designed investments (on the ‘right side’—that which exerts the strongest externality on the others) can generate significant network effects and economies of scale that outweighs the opportunity cost of foregoing the revenue generation from that side. The latter in turn can lead to a situation in which the appeal of one side of the market is strong enough to capture the entire market on the other. Levecchia and Mitchel (2016) documents how by using Prime to obtain an ever-larger share of online shoppers, Amazon has left rival retailers and manufacturers with little choice, but to become third-party sellers on its platform. In effect, Amazon is supplanting an open market with a privately controlled one, giving it the power to dictate the terms by which its competitors can operate, and to levy a kind of tax on their revenue (ibid., pp. 17–19)

In the case of Google, there has been what Rieder and Sire (2014) refers to as the larger economic embedding of Web search: Google offers a number of services that are mass-media related such as YouTube, Google Books, Google News, etc. (as content providers), but also operate an online office suite, two operating systems, a cloud hosting service, two social networking sites, an email platform and a hardware manufacturer (Motorola) Rieder and Sire 2014: 196). Arguably, the strategy to provide Cloud platforms, retail platforms, security platforms and blockchain platforms can also be seen as forms of exclusionary strategies. As we saw earlier, the multiplication of activities defying industry segmentation by Google is also observed in the case of Amazon.

5.1.6 "Private innovations" in government support

It is a well-researched fact that the US government financed the bulk of the R&D involved in the development of all general purpose technologies from interchangeable parts and mass production to internet (through DARPA—the Defense Advanced Research Projects Agency that invented ARPANET, the predecessor to the internet) and biotech. This has led to the emergence of corporations such as the IBM, GE, Boeing, and a host of other giants in software, hardware and biotech. The origins of consumer technology's most impressive accomplishments also can be traced back to university research laboratories. In the case of Animoji (mentioned above), the research happened nearly a decade ago at a pair of Europe's top technical schools (Stinson 2017).

Some technology leaders have now formulated new "business strategies" around government support, which go beyond the externalities from publicly-funded research and development. It was widely reported in the media that as a result of a "company contest" by Amazon to pick a location for its second headquarters from among the cities and states across North America, the company has been receiving offers of billions of dollars in tax breaks and other subsidies from sub-federal governments that have entered into the contest. Thus we have the bizarre situation that instead of companies' bidding for government contracts, now governments are bidding to win "contracts" from private companies and getting pitted against each other in the process! According to Reuters (19 October 2017), since its beginnings as an online bookseller in 1994, Amazon has collected no sales tax for many purchases until recent years (See Levecchia and Mitchel 2016 for details). It is this company that is now pitting governments against each other to win more tax breaks as part of their competitive strategies globally.

5.2. Strategies Adopted by Developing Country Followers

Just as for innovators, a significant element of the strategies by followers in the digital era too appears to be the business model innovations enabled by digital technologies. As described by Markides (2006), new business models invade an existing market by emphasising different product or service attributes to those emphasised by the traditional business models of the established competitors. While this was how the innovator firms in the platform economy came into being, the rise of start-ups from developing countries has seen these follower firms use business strategies which attempt to differentiate their market segment. These include the ride-sharing firms such as India's Ola, South-East Asia's Grab, Brazil's 99, Estonia's Taxify (serving Europe and Africa), Dubai's Careem (which serves the Middle East), etc. The Indian ride-sharing company Ola—as a fast follower of Uber—won greater market share by launching a premium subscription service like Select and entertainment offerings like Ola Play, besides localising by adding autos. The Chinese firm Didi runs car pools, minibuses and buses, in addition to taxis and luxury cars. It also has services for the elderly and an option to send a driver to take you home in your own car.

Similarly, both leaders and fast followers are looking to build their ecosystems so as capture a higher share of the market by expanding to or making acquisitions in new segments. This is very clearly witnessed in India and China, for example. One set of start-ups has focussed on unexplored verticals of existing technologies (entertainment-streaming app HOOQ in India that focuses on the Hollywood movies, ride-sharing start-ups in China that focus on bikes). Similarly, while on the one side, Flipkart and Amazon India, which are strong in online retail, are entering segments like payments, on the other side, the payments platform Paytm is reportedly entering into online retail.

Another type of followers is able to offer pioneering solutions to the new problems that cropped up with the pioneering technologies. China already has two bike-sharing start-ups, Ofo and Mobike, which transformed the two-wheeler into a cloud-connected intelligent transport device. "Because tracking technology removes the need for dedicated docks, they can be picked up and dropped off anywhere. This convenience creates new problems. Ofo is pioneering a credit-scoring system that rewards well-behaved users and punishes naughty ones, such as those who park in the middle of roads" (Economist 23 Sep 2017). Ofo's rise builds on the explosive growth in smart phone, mobile payments and the Internet of Things in China—a huge market of mostly young population willing to adopt new technologies. According to the Economist, Chinese innovators who battle it out with several other well-funded start-ups chasing novel ideas and new business models in the large domestic market are expected to have an advantage in the world market. Thus Ofo is already operating in the US, Singapore, and Britain. The willingness of local consumers in China to experiment is also said to have helped shape the innovative business model of China's Nio, a 3-yeard old start-up making cars for the digital era.[57]

Follower firms also appear to be adopting another innovator strategy of acquisition of competitors and strategic technologies. The Chinese phone and appliances maker Xiaomi Corp and its sister company Shunwei Capital have purchased minority stakes in six Indian internet companies (including Hungama and KrazyBee) and invested over $4 billion in over 300 companies and plans to invest about $1 billion in 100 start ups in India in businesses such as content, financial technology, hyper local services, including mobile phone repairs and manufacturing over the next five years.[58] The aim is to replicate Xiaomi's most successful ecosystem business model of China in India: to create an ecosystem of apps around its smart phone brand involving all types of products and brands and integrate them. This enables the company to focus only on a few things while the partners provide everything else. The company

[57] See Economist, 23 September 2017, The Next Wave.
[58] See Dalal, Mihir and Amrit Raj (2017), "Xiaomi to invest $1 billion in 100 tech startups in India", The Hindustan Times, 20 November.

appears to be focussed on increasing mobile internet adoption in the country through this strategy for long-term advantage with data. Unlike the two Chinese internet giants Alibaba and Tencent, Xiaomi is looking only for investments that will expand mobile internet usage and get its customers hooked onto its 'value-for-money' phones by providing entertainment content and other services and thus differentiating them from those of its competitors like Samsung, Vivo, Oppo and others. According to IDC, Xiaomi, which entered the Indian market in 2014 already accounted for 23.5% of smartphone shipments in the country in second quarter of 2017 (a jump from 17% in the first quarter), sharing the top position with Samsung.

There are also other strategies being adopted by follower ICT firms from developing countries that attempt to capitalise from forming GINs of unique characteristics. Ernst (2016) describes the two-pronged strategy being pursued Huawei: it is building a variety of linkages and alliances with leading global industry players and universities, while concurrently establishing its own global innovation network of more than 25 R&D centres worldwide. In the European Union, Huawei has more than 800 R&D specialists across 14 R&D sites in eight countries. The choice of these locations reflects Huawei's objective to be close to major global centres of excellence and to learn from incumbent industry leaders: Plano, Texas, is one of the leading U.S. telecom clusters initially centred on Motorola; Kista, Stockholm, plays the same role for Ericsson and, to some degree, Nokia; and the link to British Telecom was Huawei's entry ticket into the exclusive club of leading global telecom operators (Ernst 2016).

Yet another strategy being adopted is to develop strategic alliances. Chinese' e-commerce giant Alibaba is exploring an alliance with the top-ranking supermarket chain in the US, Kroger, as a way to counter Amazon, after the latter's aggressive expansion into physical stores by acquiring the US retail chain, Whole Foods. Alibaba has been trying to increase its relatively small presence in America to better compete with Amazon on a global basis. Alibaba is similar to Amazon in that it operates supermarkets that use Amazon Go-like technology that allows cashier-less stores. Alibaba has reportedly teamed up with Kroger to speed up the integration of its online and off-line sales. Alibaba could provide its Alipay platform to Kroger to let customers pay for goods through an app—something it already does in its stores in China. Shoppers can order delivery from inside the store or through mobile apps, and items can be delivered in as little as 30 minutes within 1.9 miles of the store.[59] Also, Kroger could direct customers to the Alibaba site, where they could buy general merchandise. An Alibaba-backed food retailer, Hema Xiansheng, is at the forefront of technology. It serves as a warehouse and distribution centre for online sales.

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[59]https://nypost.com/2018/01/24/krogers-answer-to-amazon-go-alibaba/?te=1&nl=dealbook&emc=edit_dk_20180125

6. Policies for Strategic Technology Guidance

In a rapidly evolving digital technology space, it is increasingly evident that the new technologies will be integrated into the production of most goods and services in myriad ways. The flexible production paradigm that has accompanied the ICT revolution and the transformation of industrial production, services and business processes associated with rapid advances in digital technologies have led to the simultaneous spread of mass production and information (even though asymmetrically) together with multiple specialisations and differentiated markets globally.[60] This has gone hand in hand with the continuing intertwining innovations in the areas of networking, interfacing, knowledge creation and exchange enabled through Web 2.0, which has led to the emergence of new technological systems led by Big Data, the Internet of Things, robotics (or computation-intensive automation), online platforms, artificial intelligence (AI), etc. To realise the full potential of the transformative potential of digital technologies, policies have to therefore take into account the following three kinds of ongoing transformations:

(i) those in the digital space itself;
(ii) those associated with the transformation of services; and
(iii) those related to transformations in the industrial and agricultural production spaces.

Importantly, given that we are passing through the synergy phase of the ICT revolution, policy choices in the digital space will, to a large extent, influence the trajectories of transformations in production and services as well as their societal outcomes.

Further, the impact of new technologies on productivity and its distributional consequences will depend on the scope of subsequent job opportunities and the pace at which they materialise (TDR 2017, p. 37 and Zysman and Kenney 2016, p. 14). The latter in turn, depends on the capacity to deploy and diffuse these technologies. This is largely because new technologies do not arrive as a *deus ex machina,* but are embodied in (and disseminated by) capital equipment, institutional routines and human capabilities (TDR 2017).

As seen in the different post-WW II development experiences during the previous technological revolution, technologies themselves do not dictate the outcomes. Every emerging technology makes available different trajectories with new possibilities. While technological learning and accumulation account for the most important endowments—and thus do explain differences between countries' levels of development (Dosi and Soete 1988), these technological trajectories and their outcomes are determined by policy choices regarding the deployment of technologies concurrent with a vision of the kind of society envisaged by a country/countries. These policy

[60] Perez (2007: 23) had argued that the typical structure of modern markets is hyper-segmented—from standard products and services to the most adapted and specialised niches.

choices, in turn, influence labour market outcomes as well as the associated macroeconomic and industrial policies. In other words, technology is, in its development, always dependent on the policy framework and the conditions created by the latter (Kattel, Drechsler and Reinert 2009).

For developed as well as for developing countries, development strategies and policies have to constantly evolve according to the phases of deployment of successive paradigms. As Carlotta Perez and Chris Freeman have elaborated, the key technologies and industries of different era require different sets of supporting institutions.

According to Perez (2017):

> *The interpretation of historical precedent presented here sees the installed technologies of each technological revolution as merely providing an innovation potential to be shaped by socio-political choice. The industries of the new technologies that emerge and proliferate in the period of creative destruction are merely the tip of the iceberg of the new potential for wealth creation... What is crucial to understand is that those new ultra-high productivity sectors are not the primary engine of job creation: rather, the greater wealth they create overflows into other lower-productivity activities that cater to the new model of everyday life and cover complementary services for the new production practices. That is the source of the replacement jobs. It is the combination of both that brings the so-called 'golden ages' of each surge. ..However, such results can be achieved if – and only if – bold and effective policies are set up providing appropriate conditions for the best outcome, as indeed occurred after WWII.*
>
> *According to this interpretation, we are yet to emerge from the turning point of the ICT revolution, and the space for shaping the future is much wider than it seems. To give a sense of the range of the viable, we can again look back at the 1930s, the turning point of the last surge. The shaping of the potential of mass production (under the fourth technological revolution) manifested in very different ways under Nazi-Fascism, Sino-Soviet socialism and Keynesian democracies, and with great variations in each – as between Mussolini and Hitler; Russia and China, Sweden and the USA. The present moment,…, is when institutional innovation is called upon to shape and direct the new technologies.*

Formulating and implementing policies appropriate to the stage of a technological revolution is therefore critical in ensuring proper deployment of its underlying technologies across economic and societal spheres and to lead to sustainable developmental outcomes. Furthermore, even if technologists may develop good strategies, their implementation requires capabilities among the broader workforce and society. Given the utmost importance of user interface in digital technology deployment, policy efforts have to go beyond just capability development in a few selective job profiles in sectors currently perceived as high-technology sectors and aim for improving capabilities across the broader workforce and society. The latter is critical to draw economy and society-wide beneficial impact of digital technologies.

As Tuomi (2007) observed a decade ago, the innovation economy and knowledge society are not only about the greater importance of innovation and knowledge in making profit, it is also about new approaches in producing innovation and knowledge. This is because as we saw, information and knowledge are 'generic technologies' under the ICT paradigm (especially in the synergy phase) even more than steam, electricity, steel or petroleum were in the earlier paradigms. This has consequences for skill demands[61] as educational institutions have been optimised for the requirements of the past production models under the previous technological revolution. Therefore, policy innovation has to fundamentally guide new ways of linking learning and social and economic change.

In a recent study on innovation and development, Baker, Jayadev and Stiglitz (2017) have argued that while individual industries and firms can often be close to the frontier, the generalised adoption of latest generation technologies and the garnering of the positive externalities that often result from these is a key feature of advanced industrialised economies. For local firms from developing countries to be able to enter and shape markets, prices and technological trajectories at a time when both the capability requirements and market contours are constantly changing due to disruptive technical changes, there has to be continuous and sustained learning and innovation at the firm level, industry level and sectoral level, linking forward and backward industries, universities and other research institutes, etc. (see also Karo and Kattel 2011, Ernst 2016 and Francis 2017). Finding the policy mix that enables these interactions in a mutually reinforcing way, which will lead to a kind of virtuous circle and create appropriate institutions (and/or transform the existing ones) in order to foster the deployment of the current paradigm is the challenge before policy makers.

Thus it is a critical governance challenge to envision the emergence of new technological systems within the deployment phase of the ICT paradigm and effect and guide the transition of policies and institutions. As many analysts have emphasised, these are moving goals that need to be continuously modified to accommodate constantly evolving needs. Policy ingenuity is required in shortening the period of institutional and organisational adaptation for new technologies such that opportunities for entry and expansion at opportune phases of a technological revolution are not missed. As emphasised by Soete (2015), regulatory innovation

[61] This, according to Tuomi, means that the challenges of vocational education will be surprisingly similar in countries that vary widely in their current economic level of development.

will be even more crucial because it will influence not just the uptake and diffusion of new technological and organisational innovations, but also determine, to a large extent, the success in financing innovation. These will determine whether the follower firms can eventually overtake the new markets over incumbents.

Enveloping all these interlinked policy issues is the emergence of data as the basis of evolving technology systems. While information and knowledge are ‘generic technologies’ under the ICT paradigm, Big Data has become the prime driver of new technology systems in the ICT paradigm’s synergy phase. The increased use of sensors in devices and application-driven machines and the growth in networked devices are also continuously increasing the scale and scope of real time data extraction. As we saw earlier, greater the data for analytics and predictive modelling, the greater is the innovation that follows it. Advancements in the new technological systems such as artificial intelligence, network technologies, robotic process automation and cloud robotics, blockchains, etc. are all contingent on Big Data and data analytics. Thus data ownership has critical implications for innovative capacities and on development trajectories. This is more so, as Big Data is transitioning, as Ross (2016) described, from a tool primarily for targeted advertising to an instrument with profound applications in diverse sectors and for addressing social problems.

As pointed out by Zysman and Kenney (2016), the ongoing battle for market control amongst platform companies such as Google, Amazon and Facebook, each with its own private rules and regulations, is leading to conflicts between private governance and public responsibility. It is therefore imperative for developing countries to quickly put in adequate rules and regulations concerning data ownership. This entails a challenging policy task to strike a balance between data needs for innovation on the one hand and issues surrounding privacy, data protection and the ethics of data use (including for AI for eg.), on the other side. Further, in order to ensure that emerging models promote competition and broader developmental benefits, monopolistic tendencies and practices in the digital space need to be reined by regulations ensuring interoperability standards, platform compatibility, and multi-homing by users. Similarly, in order to capture the broad synergies that will become available through ICT deployment, intellectual property protection rules must strike a balance in favour of technology diffusion. These are various policy areas that demand immediate research prioritisation. Meanwhile, attempts to include/expand such issues in trade rules at the multilateral, regional or bilateral levels need to be resisted, because strategic policies required for achieving sustainable development, by their very nature, have to be country and context specific.

All these call for state capacities—competencies and capabilities necessary to perform policy functions—which need to constantly evolve through the technological revolution just like markets and society, as Karo and Kattel (2016) emphasise, and guide the evolution of the latter two along desirable paths. As the same authors rightly pointed out in an earlier paper, the dual qualitative shift necessary for systemic catching-up by developing countries can only be achieved through a high level of coordination or embeddedness between the development of technological and institutional (policy and entrepreneurial) capacities and capabilities (Karo and Kattel 2011) that are required to bring about the required complementarities in institutional and social innovations. The latter includes the development of institutions that create the underpinnings for both public- and private-sector capacities and capabilities.

References

Alcorta, Ludovico (2014) "Strategic Specialization: Policy responses to a changing global manufacturing landscape", in Giessen, Annelieke van der, Claire Stolwijk, and Jos Leijten(eds.), (2014) *Can Policy follow the Dynamics of Global Innovation Platforms*?, *Collection of Conference Papers*, Delft: 6CP.

Amelio, Andrea, Liliane Karlinger and Tommaso Valletti (2017) "Exclusionary practices and two-sided platforms", Directorate for Financial and Enterprise AffairsCompetition Committee, OECD.

Amsden Alice H (2001) *The Rise of "The Rest": Challenges to the West from Late-Industrializing Economies*, New York, Oxford University Press.

Baker, Dean, Arjun Jayadev and Joseph Stiglitz (2017) *Innovation, Intellectual Property, and development: A Better Set of Approaches for the 21st Century*, Azim Premji University, University of Cape Town (UCT), Intellectual Property Unit of UCT, FIOCRUZ and ENSP.

Bakos, Yannis and Erik Brynjolfsson (2000) "Bundling and Competition on the Internet", *Marketing Science*, Vol. 19, No. 1, Special Issue on Marketing Science and the Internet, pp. 63–82.

Block, Fred and Matthew Keller (2011) "Where do Innovations come from? Transformations in the US Economy, 1970–2006", in Leonardo Burlamaqui, Ana Celia Castro and Rainer Kattel (ed.), *Knowledge Governance: Reasserting the Public Interest,* Anthem Press.

Budzinski, Oliver and Karoline Henrike Köhler (2015) "Is Amazon the next Google?",Ilmenau Economics Discussion Papers, No. 97.

Caillaud, Bernard and Bruno Jullien (2003) "Chicken &Egg: Competition among intermediation service providers", *RAND Journal of Economics*, Vol. 34 (2), pp. 309–328.

Das, Abhijit and Zaki Hussain (2017) "Global Value Chains: Asymmetries, Realities and Risks*",* *Centre for WTO Studies Working Paper No. 36*, Indian Institute of Foreign Trade, New Delhi.

Dixit, Avinash (1980) "The Role of Investment in Entry Deterrence", *The Economic Journal*, Vol. 90 (357), pp. 95–106.

Drechsler, Wolfgang, Rainer Kattel and Erik S. Reinert (ed.) (2009) *Techno-Economic Paradigms: Essays in Honour of Carlota Perez,* London and New York: Anthem Press.

Ernst, Dieter (2016) “Trade and Innovation in Global Networks: Regional Policy Innovations”, in Giessen, Annelieke van der, Claire Stolwijk, and Jos Leijten (eds.), ed., *Can Policy follow the Dynamics of Global Innovation Platforms*?, *Collection of Conference Papers*, 6CP, Delft.

Evans, David S. and Richard Schmalensee (2013) “The Antitrust Analysis of Multi-sided Platform Businesses”, in Roger Blair and Daniel Sokol, eds., *Oxford Handbook on International Antitrust Economics*, OUP.

Fletcher, Amelia (2007) “Predatory Pricing in Two-Sided Markets: A Brief Comment”, *Competition Policy International*, Vol. 3, No. 1, Available at SSRN: https://ssrn.com/abstract=987875

Francis, Smitha (2017) *Towards a Progressive Industrial Policy in the Time of Global Value Chains and Free Trade Agreements: An overview with a focus on India*, Rosa-Luxemburg-Stiftung (RLS), Brussels.

Freeman, C., R. Nelson, G. Silverberg and L. L. Soete (eds.) (1988) *Technical Change and Economic Theory*, Pinter Publishers.

Gehl Sampath, Padmashree and Roffe, Pedro (2012) *Unpacking the International Technology Transfer Debate: Fifty Years and Beyond*, ICTSD Programme on Innovation, Technology and Intellectual Property, Issue Paper No. 36, International Centre for Trade and Sustainable Development, Geneva.

Gnyawali, Devi R, Weiguo Fan and James Penner (2010) “Competitive Actions and Dynamics in the Digital Age: An Empirical Investigation of Social Networking Firms”, *Information Systems Research*, Vol. 21, No. 3, Digital Systems and Competition (September 2010), pp. 594–613.

Grossman, G and Helpman E (1991) *Innovation and Growth in the Global Economy*, The MIT Press, Cambridge, Massachusetts.

Hackl, Franz, Michael E. Kummer, Rudolf Winter-Ebmer and Christine Zulehner (2014) “Market Structure and Market Performance in E-Commerce”, Discussion Paper No. 11-084, Centre for European Economic Research, available at ftp://ftp.zew.de/pub/zew-docs/dp/dp11084.pdf

Haucap, Justus; Heimeshoff, Ulrich (2013) “Google, Facebook, Amazon, eBay: Is the internet driving competition or market monopolization?,”Dusseldorf Institute for Competition Economics, DICE Discussion Paper, No. 83.

Hausmann, Ricardo and Bailey Klinger (2006) “Structural Transformation and Patterns of Comparative Advantage in the Product Space”, CID Working Paper No. 128, Centre for International Development, Harvard University.

Hobday, Michael (2009) “Asian Innovation Experiences and Latin American Visions: Exploiting Shifts in Techno-Economic Paradigms”, in Drechsler, Wolfgang, Rainer Kattel and Erik S. Reinert (ed.) 2009, *Techno-Economic Paradigms: Essays in Honour of Carlota Perez,* London and New York: Anthem Press.

Joseph K J and Vinoj Abraham (2005) “Moving Up or Lagging Behind? An Index of Technological competence in India’s ICT Sector” in Saith and Vijayabaskar (2005) eds. *ICTs and Indian Economic Development: Economy, Work, Regulation*. New Delhi: Sage Publications.

Karo, Erkki and Rainer Kattel (2011) “Should Open Innovation” Change Innovation Policy Thinking in Catching-up Economies? Considerations for policy analyses”, *Innovation: The European Journal of Social Science Research*, Vol. 24 (1–2), 173–198.

Karo, Erkki and Rainer Kattel (2016) ‘Innovation and the State: Towards an Evolutionary Theory of Policy Capacity’ in Wu, X., Howlett, M. and Ramesh, M. (eds.) *Policy Capacity: State and Societal Perspectives*, Palgrave.

Kattel, Rainer, Wolfgang Drechsler and Erik S. Reinert (2009) “Introduction: Carlota Perez and Evolutionary Economics”, in Drechsler, Wolfgang, Rainer Kattel and Erik S. Reinert (ed.) 2009, *Techno-Economic Paradigms: Essays in Honour of Carlota Perez,* London and New York: Anthem Press.

Kostakis, V. (2012) “The Political Economy of Information Production in the Social Web: Chances for reflection on our institutional design”, *Contemporary Social Science* 7(3): 305-319.

Kostakis, Vasilis, Alex Pazaitis and Michel Bauwens (2016) “Digital Economy and the Rise of Open Cooperativism: The Case of the Enspiral Network”, *Working Papers in Technology Governance and Economic Dynamics*, No. 68, The Other Canon Foundation, Norway, Tallinn University of Technology, and Ragnar Nurkse School of Innovation and Governance.

Kregel, Jan (2009) “Financial Experimentation, Technological Paradigm Revolutions and Financial Crises” in Drechsler, Wolfgang, Rainer Kattel and Erik S. Reinert (ed.) 2009, *Techno-Economic Paradigms: Essays in Honour of Carlota Perez,* London and New York: Anthem Press.

Kregel, Jan (2008) ‘Financial Flows and International Imbalances: The Role of Catching Up by Late-Industrializing Developing Countries,’ The Levy Economics Institute of Bard College Working Paper, No 528. Available at http://www.levy.org/pubs/wp_528.pdf

LaVecchia, Olivia and Stacy Mitchell (2016) *Amazon’s Stranglehold: How the Company’s Tightening Grip is Stifling Competition, Eroding Jobs, and Threatening Communities*, Institute for Local Self-Reliance.

Lee, Keun and John Mathews (2013) "Science, Technology and Innovation for sustainable Development", CDP Background Paper No. 16, The Committee for Development Policy, UN.

Lessig, Lawrence (2006) *Code version 2.0*, Basic Books, New York.

Lundvall, Bengt-Ake, ed. (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, Pinter Publishers, London.

Markides, Constantinos (2006), "Disruptive Innovation: In need of better theory", *The Journal of Product Innovation Management*, Vol. 23, pp. 19–25.

Martens, Bertin (2016) "How online platforms challenge traditional views of the firm and the regulation of market failures", Paper submitted to the Conference on 'Internet, Policy and Politics', the Oxford Internet Institute.

Mathews, John A. (2012) "The Renewable Energies Technology Surge: A new techno-economic paradigm in the making?, Working Papers in Technology Governance and Economic Dynamics No. 44, The Other Canon Foundation, Norway, Tallinn University of Technology, and' Ragnar Nurkse School of Innovation and Governance.

Mäihäniemi, Beata (2016) The role of innovation in the analysis of abuse of dominance in digital markets: The analysis of chosen practices of Google Search", Paper for the ASCOLA Workshop, Leiden 30.6.-2.7.2016.

Milberg, William and Deborah Winkler (2013) *Outsourcing Economics, Global Value Chains in Capitalist Development*, Cambridge University Press, New York.

Montalvo, Carlos (2014) "Global innovation and production networks: New rationales and policy Challenges", in Giessen, Annelieke van der, Claire Stolwijk, and Jos Leijten eds. (2014) *Can Policy follow the Dynamics of Global Innovation Platforms*?, *Collection of Conference Papers*, Delft: 6CP.

Nelson, Richard (2006), "Economic Development from the Perspective of Evolutionary Economic Theory", *TUT WP* No.2.

Nelson, Richard R. (2009) "Technology, Institutions and Economic Development" in Drechsler, Wolfgang, Rainer Kattel and Erik S. Reinert (ed.) 2009, *Techno-Economic Paradigms: Essays in Honour of Carlota Perez*, London and New York: Anthem Press.

Nelson, Richard, R. and Sydney G. Winter (1982) *An Evolutionary Theory of Economic Change*, Cambridge, Massachusetts: Harvard University Press.

Nelson, Richard, R., ed. (1993) *National Innovation Systems: A Comparative Analysis*, New York: Oxford University Press.

Parthasarathy, Balaji (2013) “Reversing the flow of ideas? Frugal innovation for India and the world beyond”, Australia India Institute Chanakya Papers.

Pavlus, John (2017) “Clever Machines Learn How to Be Curious”, 19 September, https://www.quantamagazine.org/clever-machines-learn-how-to-be-curious-20170919/

Perez, Carlota (2001) “Technological change and opportunities for development as a moving target”, *CEPAL Review*, December, pp. 109–130.

Perez, Carlota (2002) *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*, Edward Elgar, Cheltenham, UK

Perez, Carlota (2007) ‘Great Surges of Development and Alternative Forms of Globalisation’, *Working Papers in Technology Governance and Economic Dynamics*, No. 15, The other canon foundation, Norway and Tallinn University of Technology, Tallinn.

Perez, Carlota (2009) ‘Technological revolutions and techno-economic paradigms’, *Working Papers in Technology Governance and Economic Dynamics*, TOC/TUT Working Paper No. 20, The Other Canon Foundation, Norway and Tallinn University of Technology, Tallinn.

Perez, Carlota (2017) “Second Machine Age or Fifth Technological Revolution? (Part 2)”, Blog piece available at http://beyondthetechrevolution.com/blog/second-machine-age-or-fifth-technological-revolution-part-2/

Prahalad, C. K. (2006) ‘The Innovation Sandbox’, Available at http://www.strategy-business.com/press/freearticle/06306

Reinert, Sophus and Erik S. Reinert (2003) “An Early National Innovation System: The Case of Antonio Serra’s 1613 Breve Trattato”, *Institutions and Economic Development/Istituzioni e SviluppoEconomico*, Vol. 1, No. 3.

Richard R. Nelson (2006) Economic Development from the Perspective of Evolutionary Economic Theory, *Working Papers in Technology Governance and Economic Dynamics*, No. 2, The Other Canon Foundation, Norway, and Tallinn University of Technology, Tallinn.

Rieder, Bernhard and Guillaume Sire (2014) “Conflicts of Interest and Incentives to Bias: A microeconomic critique to Google’s Tangled Position on the Web”, *New Media & Society*, Vol. 16 (2), pp. 195–211.

Ross, Alec (2016) *The Industries of the Future*, Simon and Schuster UK, London.

Schwab, Klaus (2016) *The Fourth Industrial Revolution*, Penguin Random House, UK.

Singh, Lakhwinder (2006) “Innovations, High-Tech Trade and Industrial Development: Theory, Evidence and Policy”, UNU-WIDER Research Paper No. 2006/07.

Smith, Michael D., Joseph Bailey and Erik Brynjolfsson (1999) "Understanding Digital Markets: Review and Assessment", in Erik Brynjolfsson and Brian Kahin, eds, *Understanding the Digital Economy, MIT Press, 1999,* Available at http://ecommerce.mit.edu/papers/ude

Soete, Luc (2000) "Towards the Digital Economy: Scenarios for businesses", *Telematics and Informatics*, December.

Soete, Luc (2015) *From the old ERA to a new era of "Open Knowledge Creation' in Europe,* Policy Brief by the Research, Innovation, and Science Policy Experts (RISE), European Commission.

Sokol, D. Daniel and Roisin Comerford (2016) "Does Antitrust Have a Role to Play in Regulating Big Data?", Cambridge Handbook of Antitrust, Intellectual Property and High Tech, Roger D. Blair & D. Daniel Sokol editors, Cambridge University Press, Available at: http://ssrn.com/abstract=2723693

Stinson, Elizabeth (2017) All the Face-Tracking Tech behind Apple's Animoji", 24 October,https://www.wired.com/story/all-the-face-tracking-tech-behind-apples-animoji/?mbid=nl_102417_daily_list1_p1

Tapscott, Don and Anthony D. Williams (2010) *MacroWikinomics: Rebooting business and the world*, Atlantic Books, London.

Tuomi, Ilkka (2007) "Learning in the Age of Networked Intelligence", *European Journal of Education*, Vol. 42, No. 2, pp. 235–254.

Utterback, James (1994) "The Dynamics of Innovation", Massachusetts Institute of Technology.

Vasconcelos, Helder (2015) "Is exclusionary pricing anticompetitive in two-sided markets?", *International Journal of Industrial Organization*, Vol. 40 (C), pp. 1–10.

Zuboff, Shoshana (2015) "Big Other: Surveillance Capitalism and the Prospects of an Information Civilization," *Journal of Information Technology*, Vol. 30, pp. 75–89.

Zysman, John and Martin Kenney (2016) "The Next Phase in the Digital Revolution: Platforms; Abundant Computing; Growth and Employment", *BRIE Working Paper*, No. 2016–3, Berkeley Roundtable on the International Economy.