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FINANCE AND TECHNICAL CHANGE: A NEO-SCHUMPETERIAN PERSPECTIVE

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Finance and technical change:
A Neo-Schumpeterian perspective

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Contents

Ever since Kuznets published his review[1] of *Business Cycles* questioning the sudden clustering of entrepreneurial talent that was supposed to accompany each technological revolution,[2] Schumpeter's followers have felt uneasy about this unexplained feature of his model. Yet apparently no one has stopped to question Schumpeter's dismissive treatment of the clustering of 'wildcat or reckless banking' as a random and unnecessary phenomenon to be excluded from his model, together with speculative manias.[3]

Keeping Schumpeter's basic assumptions about innovations based on credit creation as the force behind capitalist dynamics, this chapter will present an alternative model of the process of propagation of technological revolutions. On that basis it will propose:

a) An explanation of the clustering and the spacing of technical change in revolutions;

b) An argument for the recurrence of clusters of bold financiers together with the clusters of production entrepreneurs and

c) An interpretation of major financial bubbles as massive episodes of credit creation, associated with the process of assimilation of each technological revolution

The model is a stylized narrative, based on a historically recurring sequence in the process of gestation, diffusion and assimilation of each technological revolution by the economic and social system. But it is not merely descriptive. It is constructed through the identification of possible causal chains between agents and spheres in capitalist society. What it attempts to do is identify the repetition of certain underlying patterns and to propose plausible explanations.

The reader is asked to keep this purpose in mind, together with the additional *caveat* that neither the evidence nor much subtlety can be included in the limited space of a chapter.[4] Suffice it to say that this model is not a straitjacket to be forced upon history. Rather than ignore the immense richness of historical evolution, it emphasizes the uniqueness of each occurrence and recognizes the many irregularities and overlaps that cannot be captured by abstraction. Its only claim is to serve as a useful heuristic tool for historical exploration and as a framework for theoretical analysis.

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1 Kuznets (1940), pp. 261–2
2 Schumpeter (1939:1982) p. 223
3 Schumpeter (1939:1982), pp. 792, 877.
4 For a more complete presentation of the model, see Perez (2002)

A. THE ENTREPRENEUR AND THE BANKER

In Schumpeter's basic definition of capitalism as 'that form of private property economy in which innovations are carried out by means of borrowed money',[5] we find his characteristic separation of borrower and lender, entrepreneur and banker, as the two faces of the innovation coin. This is not, however, how his legacy has been interpreted and enriched by the great majority of Neo-Schumpeterians. The accent has almost invariably been on the entrepreneur to the neglect of the financial agent, no matter how obviously indispensable this agent may be to innovation.

Ironically, this bias can be traced back to Schumpeter himself. In many passages he defines the entrepreneur as the dynamic force driving innovations, he hails him as the leader, the real hero of development, the agent of profit creation,[6] whereas the banker is merely a 'bridge', a facilitator, the one that provides the means for the entrepreneur to exercise his creative will. [7]

Furthermore, whereas Schumpeter makes a clear distinction between the bold entrepreneur, breaking all routines, in contrast with the manager who simply conducts the daily business of the firm, he makes no equivalent distinction among financiers or bankers. These perform both the routine functions of intermediation and the selection of entrepreneurial projects for credit creation. In this latter function they are expected to be highly independent, experienced and serious.[8] Yet, as will be further discussed below, there is every reason to suspect that those radical innovative breaks also require bold and risk-loving bankers, because the 'serious' ones would share the same mental routines as the heads or managers of the established firms. In fact, the historical recurrence of bursts of 'wildcat or reckless' finance in the periods of intense investment in technological revolutions, suggests that these phenomena may be causally connected.

Essentially then, although Schumpeter emphasized the double agency in the process of capitalist development, he concentrated attention on the production entrepreneur and neglected the innovative side of the financier. This has shaped his intellectual legacy and influenced the work of his successors.

B. THE DOUBLE CHARACTER OF ROUTINES AS OBSTACLES AND GUIDES FOR INNOVATION

Schumpeter's innovator needs extraordinary will power not only because he is doing something truly new but also –and especially– because he must overcome the inertial force of established routines. Undoubtedly, radical innovations confront the stubborn resistance of routines on all fronts, yet routines have also been found to guide successive innovations. There is a wide body of neo-Schumpeterian literature analyzing the role of natural trajectories as sets of criteria steering the direction of –and stimulating the search for- incremental innovations. [9]

Chris Freeman questioned the validity of Schumpeter's treatment of incremental innovations[10], dismissing them and considering them simply part of the routine of continuous flow.[11] Indeed,

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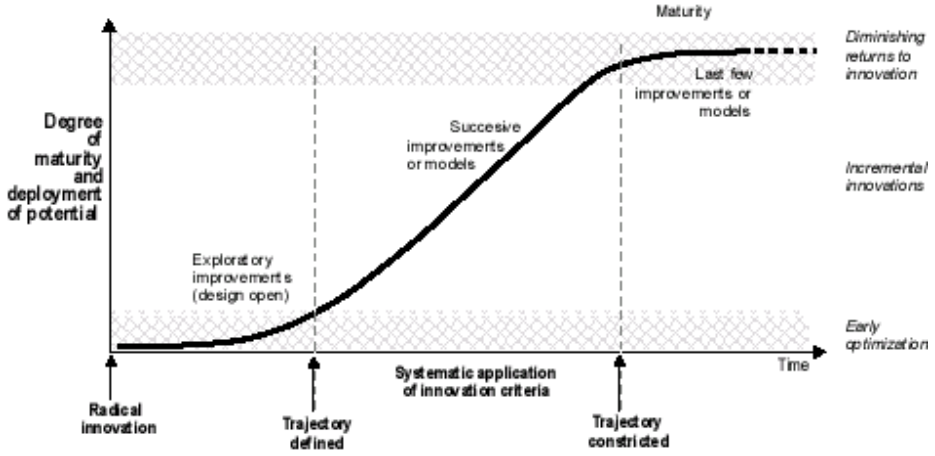
5 Schumpeter (1939:1982), p. 179
6 Schumpeter (1911:1961) pp. 92–94 and (1939:1982) pp, 405–6
7 Schumpeter (1911:1961) pp. 74, 107, 117.
8 Schumpeter (1939:1982) pp. 116–17.
9 Nelson and Winter (1982), pp. 128-36; Dosi (1982); Rosenberg (1969); Sahal (1985) and others. See Freeman ed. (1990)
10 Freeman (1992), pp. 75-81.
11 Freeman and Louça (2001) Ch. 2

anyone who witnessed, in the 1980s and 1990s, the 'creative destruction' processes in the microcomputer industry, during the ferocious competition for both the dominant design and the operating system, would find it difficult to range such incremental changes in Schumpeter's non-entrepreneurial routine operations.

In fact, what researchers have found is not only that continuous incremental change is guided by shared heuristic routines but also that many radical innovations emerge as a response to the critical conditions (or decreasing returns to investment in technical improvement) faced by the firm or the industry, when innovation along a technological trajectory reaches maturity.[12]

Figure 1 Technological trajectories as routines for innovation



Source: Based on Nelson and Winter, Dosi, Wolf, Abernathy and Utterback, Arthur and others.

Even radical innovations, however, are not usually isolated events, nor are they mainly the replacement of obsolete products or processes. As Schumpeter often insisted, radical innovations come in clusters. But, such clusters are not disconnected random agglomerations of new things. Following upon Keirstead's notion of *constellations*,[13] Chris Freeman proposed the term *new technology systems*[14] to emphasize the strong inter-relations and inter-dependences among the innovations within a Schumpeterian cluster. Such interconnected innovations in products and processes, in equipment and organization, technical and managerial, form a coherent and mutually enhancing set of technologies and industries, capable of carrying a wave of growth in the economy.

This suggests that the evolution of a new technology system also follows a certain collective logic, which approximates what Nelson and Winter termed *generalized natural trajectory*[15]. Such a set of

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[12] This pattern of *radical change-systemic increments-crisis-radical change* is what led Giovanni Dosi to use the term *technological paradigms*,[12] by analogy with Thomas Kuhn's (1962) description of a similar process in scientific practice.

[13] Keirstead (1948)

[14] Freeman et al. (1982), Ch. 4.

[15] Nelson and Winter (1977). See also Freeman et al. (1982), Ch.4, p.74

innovative routines will constantly inspire further scientific advances and interacting innovations that contribute to the growth potential of the whole system, stimulating change across several industries.

Thus routines play many roles in relation to change. There are routines for normal unchanged operation, which was Schumpeter's emphasis, and there are routines for guiding serial innovation, which Schumpeter tended to underestimate.[16] Live routines promote change along known trajectories and discourage change outside of them. Spent routines become obstacles to change but at the same time create the conditions to call forth radical change.

C. TECHNO-ECONOMIC PARADIGMS AS THE META-ROUTINES FOR A LONG PERIOD

Technological revolutions are a special type of cluster. Each one is, in fact, a cluster of clusters or a system of technology systems. The present author has suggested that what distinguishes a technological revolution from an individual technology system, however radically new, is its all-pervasive character, its capacity to go beyond the industries it creates and to provide generic technologies that modernize the whole economic structure. This overarching process of transformation takes place thanks to the gradual construction of a new *techno-economic paradigm,* a shared common sense model of best technical and organizational practice for the use of that set of pervasive technologies, which provides a generalized quantum jump in productivity and quality.[17]

The *techno-economic paradigm* of each technological revolution defines the meta-routines for the whole economy. It provides the application models for the spread of the new generic technologies throughout the production landscape as well as the general principles guiding operations and even the search for new solutions, be they to fuel growth or to introduce incremental or radical innovation, be they for modernizing the established products, processes or industries or for creating novel ones. Each paradigm constitutes a new and universally applicable organizational logic for taking best advantage of the wealth creating and modernizing potential that drives the whole Schumpeterian 'gale of creative destruction'.

Thus, one could see successive technological revolutions involving an interrelated set of new technologies, industries and infrastructures, establishing a set of innovative routines in the form of a techno-economic paradigm and lasting about half a century (See Table 1). Each set, however, can only become the standard after overcoming the resistance of those who had adopted and practiced the previous paradigm, who will fiercely hold on to it, even if it is no longer effective.

It is when these trajectories or meta-routines approach the exhaustion of their innovative possibilities that a paradigm shift is necessary. Radically breaking with the exhausted paradigm and opening whole new trajectories is the role of revolutionary innovators. It is in those cases that the Schumpeterian view of routines as obstacles to change is fully valid. Yet, those are precisely the situations when, to fulfill their role, the entrepreneurs will require the support of bold and innovative bankers, probably even 'reckless' ones.

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[16] See Nelson and Winter (1982) about 'routines as genes' pp. 134–6

[17] Perez (1984) pp. 441–2

Table 1. The industries, infrastructures and paradigms of each technological revolution

Technological revolution (core country)	***New technologies and new or redefined industries***	***New or redefined Infrastructures***	*TECHNO-ECONOMIC PARADIGM* 'Common sense' innovation principles
FIRST: From 1771 **The 'Industrial Revolution'** (Britain)	Mechanized cotton industry Wrought iron Machinery	Canals Waterways Turnpike roads Water power (highly improved water wheels)	Factory production Mechanization Productivity/ time keeping and time saving Fluidity of movement (as ideal for machines with water-power and for transport through canals and other waterways) Local networks
SECOND: From 1829 **Age of Steam and Railways** (In Britain and spreading to Continent and USA)	Steam engines and machinery (made in iron; fueled by coal) Iron and coal mining (now playing a central role in growth) (*) Railway construction Rolling stock production Steam power for many industries (including textiles)	Railways (Use of steam engine) Universal postal service Telegraph (mainly nationally along railway lines) Great ports, great depots and world wide sailing ships City gas	Economies of agglomeration/ industrial cities/ national markets Power centers with national networks Scale as progress Standard parts/ machine-made machines Energy where needed (steam) Interdependent movement (of machines and of means of transport)
THIRD: From 1875 **Age of Steel, Electricity and Heavy Engineering** (U.S.A . and Germany overtaking Britain)	Cheap steel (especially Bessemer) Full development of steam engine for steel ships Heavy chemistry and civil engineering Electrical equipment industry Copper and cables Canned and bottled food Paper and packaging	World-wide shipping in rapid steel steamships (use of Suez Canal) World wide railways (use of cheap steel rails and bolts in standard sizes). Great bridges and tunnels World-wide Telegraph Telephone (mainly nationally) Electrical networks (for illumination and industrial use)	Giant structures (steel) Economies of scale of plant/ vertical integration Distributed power for industry (electricity) Science as a productive force World-wide networks and empires (including cartels) Universal Standardization Cost accounting for control and efficiency Great scale for world market power/ 'small' is successful, if local
FOURTH: From 1908 **Age of Oil, the Automobile and Mass Production** (In USA and spreading to Europe)	Mass produced automobiles Cheap oil and oil fuels Petrochemicals (Synthetics) Internal combustion engine for automobiles, transport, tractors, airplanes, war tanks and electricity. Home electrical appliances Refrigerated and frozen foods	Networks of roads, highways, ports and airports Networks of oil ducts Universal electricity (industry and homes) World-wide analog telecommunications (telephone, telex and cablegram) wire and wireless	Mass production/mass markets Economies of scale (product and market volume)/ horizontal integration Standardization of products Energy intensity (oil based) Synthetic materials Functional specialization/ hierarchical pyramids Centralization/ metropolitan centers-suburbanization National powers, world agreements and confrontations
FIFTH: From 1971 **Age of Information and Telecommunications** (In USA, spreading to Europe and Asia)	The information revolution: Cheap microelectronics. Computers, software Telecommunications Control instruments Computer aided biotechnology and new materials	World digital telecommunications (cable, fiber optics, radio and satellite) Internet/ Electronic mail and other e-services Multiple source, flexible use, electricity networks High speed physical transport links (by land, air and water)	Information- intensity (microelectronics based ICT) Decentralized integration/ network structures Knowledge as capital / intangible value added Heterogeneity, diversity, adaptability Segmentation of markets/ proliferation of niches Economies of scope and specialization combined with scale Globalization/ interaction between the global and the local Inward and outward co-operation/ clusters Instant contact and action / instant global communications

(*) These traditional industries acquire a new role and a new dynamism when serving as the material and the fuel of the world of railways and machinery

Source: Perez (2002), Tables 2.2 and 2.3, pp. 14 and 18.

D. PRODUCTION AND FINANCIAL CAPITAL: DIFFERENT AND COMPLEMENTARY AGENTS

Finance, in one form or another, accompanies most innovations, be they incremental or radical. Decisions to provide funds for innovations are only taken by the entrepreneurs themselves in those cases when they (or their firms) possess enough wealth to be self-sufficient. In most situations, the funding decision is taken by an investor or a bank manager, a stockbroker, a financial manager inside a big firm[18] or some other financial agent. The question is: by what criteria are those decisions guided? What gives the financial decision-maker the 'feeling' that a particular project is likely to succeed? The answer proposed in this chapter is that the financial side follows similar criteria to those followed by innovation on the production side. It is the techno-economic paradigm of each technological revolution that influences the entrepreneurs and the financiers, the managers and the innovators, the investors and the consumers, both in their individual decisions and in their interactions.[19] In other words, the paradigm constitutes the common thought model of all the economic agents, their shared 'common sense', for the whole period of propagation of that set of technologies.

Nevertheless, there is a fundamental difference between the agents of production capital and those of financial capital. They will share the same paradigm and act in unison to fund growth and innovation, as long as it is successful in practice and profitable. However, once signs of exhaustion appear, the different depth of commitment to a particular paradigm becomes evident. For the production enterprise, the exhausted trajectory is profoundly embedded in existing investment in equipment, in structures, in knowledge and experience, in the organization and the personnel and in the external networks of suppliers, distributors and clients.[20] For financial capital the paradigm is mainly a set of criteria for judging what was likely to be successful; basically a thought model, relatively easy to abandon when it fails, no matter how strongly rooted it may have been in ideas and in decision-making practice.

Production capital is the agent for the accumulation of wealth making capacity; its natural horizon is long-term and it remains tied to its expertise. Financial capital is the agent for reallocating wealth in order to constantly maximize short-term returns. Production capital is therefore path-dependent while financial capital is fundamentally footloose and flexible.[21]

This distinction in nature, function and motives, between production capital and financial capital will underlie the explanation provided below of the clustering of bold financiers in support of the swarms of entrepreneurs in the early diffusion decades of a technological revolution.

E. TECHNOLOGICAL REVOLUTIONS AND GREAT SURGES OF DEVELOPMENT

As indicated in Table 1 above, the world has witnessed five technological upheavals since the Industrial Revolution in England (although in Schumpeter's lifetime only three and a half were available for study). They are the creative gales of destruction that Schumpeter called *technological*

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[18] In modern times, most large corporations fund much of their innovation investment from retained earnings. Their organizations have internal mechanisms for decision making, whereby financial managers and 'intrapreneurs' (production, R&D or marketing managers) discuss and assess innovation projects from points of view that reflect their respective roles.

[19] Perez (2002), p. 9

[20] Perez and Soete (1988)

[21] Perez (2002), pp. 71–3

revolutions. In his view of the multi-cyclical nature of capitalism such massive changes underlay the longest of these cycles: the *long waves of economic growth*, lasting around half a century.[22]

The present author, focusing on the propagation of these technological revolutions and their assimilation by the economic and social system, has proposed the notion of *great surges of development*,[23] departing from Schumpeter's notion of long waves in some fundamental aspects.

Long waves, in Schumpeter's version, are measured by major fluctuations of GNP around the long-term dynamic equilibrium growth trend. They are the manifestation of a technological revolution in the economic sphere and are a consequence of the operation of the market mechanism. In conformity with this notion, Schumpeter sees no role for government policy or social intervention, except in very critical circumstances. Long waves are therefore to be understood as major *economic cycles*.[24]

Great surges of development, by contrast, would represent the gradual integral transformation of both the techno-economic and the socio-institutional spheres of the social system, through the assimilation of each major cluster of technical change. A great surge is thus defined as the process by which a technological revolution –and its techno-economic paradigm– propagate across the economy, leading to structural changes in production, distribution, communication and consumption, as well as to profound and qualitative social changes. Society, in turn, influences the path taken by the revolution. In other words, the concept stretches far beyond the economy.[25]

This significant shift in emphasis and in scope leads to very different dating and to another way of conceptualizing the relationship between technological, economic and social changes as well as between financial and production capital. The change in the term, from waves to surges, formalizes this break.[26]

F. THE SEQUENCE OF DIFFUSION OF EACH TECHNOLOGICAL REVOLUTION

Each great surge is initiated with a *big-bang*, a publicly recognized innovative breakthrough that inflames the imagination of entrepreneurs and launches the entrepreneurial swarming in restricted sectors and geographic regions, so much so that it is likely to go unnoticed in economic statistics. It's the microprocessor for the fifth, the Model-T for the fourth and so on back to Arkwrigths's Cromford mill for the first. From the big-bang on, there is an ever more intense process of diffusion and assimilation that in a few decades ends up encompassing the bulk of activities in the core country or countries. Each revolution sets a higher potential level of productivity and quality across the board so that, each surge is the movement onto that higher productivity plateau of the whole group of core economies involved.[27]

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[22] Schumpeter (1939:1982), pp. 164–74

[23] Perez (2002), Ch. 2 and pp. 22–3

[24] Schumpeter (1939:1982) pp. 695–700, after considering the wider socio-political implications, insists on keeping all non-economic effects of technical change out of his model, as 'external factors'.

[25] Perez (2002), p. 20 and Ch. 3

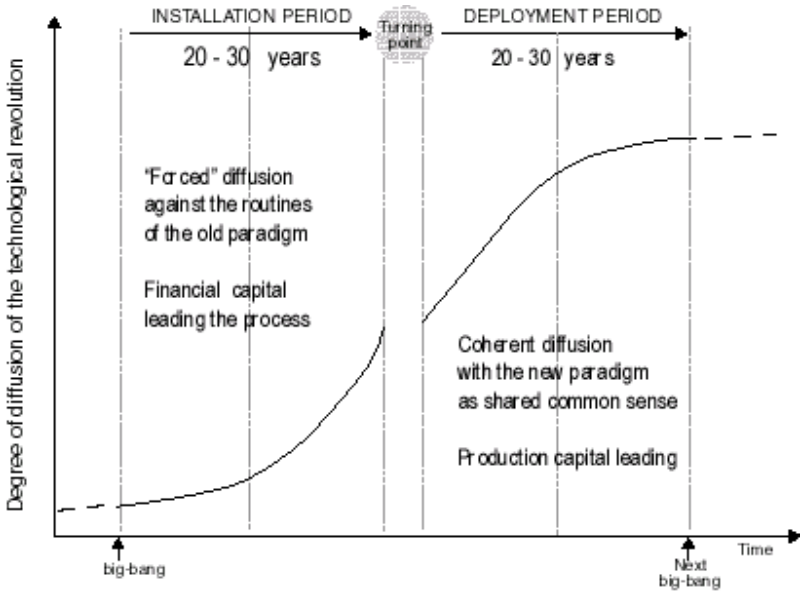
[26] Since 1983, in the author's work and in her collaboration with Chris Freeman (see Freeman and Perez 1988) both the term and the dating were kept as close to Schumpeter's as the need for differentiation allowed. It was when developing the whole model in 2002 that the break became indispensable.

[27] For dates of big bangs and indication of core countries see the first column of Table 1 above. For further discussion and dating see Perez (2002), p. 20 and Ch. 5, especially pp. 56–9.

As shown in figure 2, the process of diffusion involved in each surge can be seen as divided into two periods: *Installation* and *Deployment*, each lasting around twenty to thirty years.

The *installation period* begins with the big-bang of the technological revolution and represents the battle of the new entrepreneurs to overcome the resistance of the old paradigm, which is deeply embedded in the minds and the practices, in the equipment and the experience, in the norms and the law, as well as in the power structures of the economy and society. The leadership of the process in that period moves increasingly to the hands of financial capital, which can break free from the power of incumbent production capital, now becoming conservative, and back the new entrepreneurs in the process of establishing the emerging paradigm. A financial bubble usually characterizes the final phase of Installation. 'Canal mania' in the 1790s, 'railway mania' in the 1840s, the 'roaring 1920s' and the bubble of the 1990s are examples of such frenzy phases.[28] Thus the installation period ends with a financial collapse, after having accomplished its task, including the replacement of the industries –and firms- that act as the engines of growth of the economy, the installation of the new infrastructure providing externalities for everybody and the general acceptance of the 'common sense' criteria for best practice of the new paradigm.

Figure 2 Two different periods in the diffusion of technological revolutions



Between the two periods – characterized as Installation and Deployment– there would usually be a recession of uncertain duration, when all the negative social and economic consequences of the bubble come to the fore and gather intense pressure for radical policy changes. These new policies generally tend to regulate financial practices and to contribute to the expansion of markets through

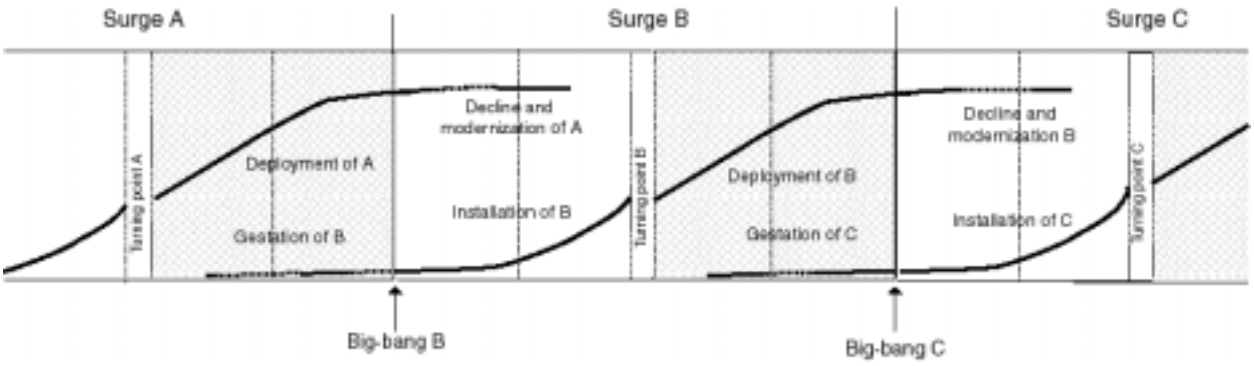
[28] The third surge, from the 1870s, is a peculiar case partly because it constitutes the first process of globalization and the first confrontation for the core role in the world economy, through the forging ahead of the USA and Germany as challengers and the decline of British power. For a discussion, see Perez (2002) p. 58.

public demand or income redistribution. In essence, at this *turning point*, the conditions are there for the socio-institutional framework to be modified in ways that would make it possible for the new production capital, incarnate in the already powerful new firms and industries, to take the helm of the economy away from financial capital.[29]

The *deployment period* that follows is the reign of the recently established paradigm and involves its growing embeddedness in all spheres of society. The economic process is now increasingly in the hands of the leaders of production capital, mainly the new but also the old giants already modernized. The meta-routines of the paradigm are now effective both for operation and growth and for continuous innovation, incremental and radical, product and process, organizational and technical. Major externalities, from low cost access to the new infrastructure to adequate distribution channels and the education of workers and consumers, facilitate innovations compatible with the now established paradigm. This shared logic based on shared advantages leads to the weaving of a strong mesh of economic inter-relations that tends to mold, exclude or marginalize innovations that are not directly compatible with it. This period ends when the potential of that revolution and its paradigm approach exhaustion and there is a constriction in the growth of markets, productivity and profits along the established trajectories.

However, no technological revolution grows in a 'green field site'. Before its *big bang*, the intervening technologies had gone through a long process of *gestation* in the midst of the Deployment period of the previous paradigm, being shaped by its requirements. Neither do the industries and technology systems of a revolution disappear meekly at maturity. They remain stubbornly struggling for survival, during the Installation of the next, and only gradually modernize adopting the new principles when they are forced by the market superiority of the new paradigm. These two long overlaps between the life cycles of successive paradigms (see Figure 3) are essential to the argument being presented here, because they are the scene of the battles between the forces of inertia and the forces of change, and it is the context and the nature of these battles that will determine the quality and the quantity of technological and financial opportunities at each phase.

Figure 3 The overlaps in the gestation, diffusion and decline of successive surges[30]



[29] Perez (2002) Ch. 11

[30] The figure evokes Mensch's (1975:1979) metamorphosis model of cycles of structure change.

G. WHY TECHNICAL CHANGE OCCURS BY REVOLUTIONS

For Schumpeter technological opportunities 'are always present, abundantly accumulated by all sorts of people'.[31] It is the entrepreneurs who decide when to turn those possibilities into innovations by exercising their leadership (if they find, of course, bankers willing to finance them). There is even a very strong statement in his *Theory of Economic Development,* warning that the excessive emphasis on invention may be 'downright misleading'.[32]

While agreeing that the relative independence of scientific and technological research constantly provides a vast untapped pool of potential innovations,[33] this still leaves some big open questions. If opportunities, entrepreneurs and supportive bankers are always equally available, why does technical change occur by revolutions? Why do actual innovations cluster and why do such clusters occur about every half a century? Some powerful process must be at work, providing an exclusion-inclusion mechanism.[34]

This chapter holds that the opportunities for entrepreneurs to profitably tap into the pool of usable science and technology change strongly over time and are very much shaped by the phases of each surge of development.[35]

Specifically, as Kuznets originally suggested,[36] the radical innovations conforming each successive technological revolution tend to come together into a powerful cluster only when the deployment of the previous revolution approaches exhaustion and maturity. This notion was also at the core of Gerhard Mensch's *Stalemate in Technology* as an explanation of the clustering of innovations.[37]

Embedded paradigms as inclusion-exclusion mechanisms

The mechanism at work is the social embeddedness of the techno-economic paradigm and its role as provider of externalities. During Deployment, the principles of the paradigm are not only present as common sense in production, investment, trade and consumption; they are also embedded in the territory in terms of cheap infrastructures, available suppliers and distribution channels, adequately trained personnel and established regulations as well as entrenched in the habits of a way of life. These massive externalities work as a strong *inclusion mechanism* to favor product innovations that are compatible with the paradigm and follow its expected trajectories. Such products are readily accepted and easily woven into the mesh of the growing economic system. In the fourth surge, for example, once most homes had electricity and learned to use the first few electrical appliances, such as refrigerators, radios and vacuum cleaners, a whole series of radical innovations were easily incorporated into the production and distribution streams and into the way of life of consumers, from washing machines, food-blenders and record players to dish washers, freezers and color-TV.

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31 Schumpeter (1911:1961), p. 88. See also p. 197

32 Schumpeter (1911:1961), p. 89

33 From the 1980s, a strong tendency has become prevalent towards forcing publicly funded research to be of immediate relevance to existing industry and towards concentrating support on the few already successful centers of excellence. One could ponder about the medium and long-term consequences of this for radical innovation potential.

34 This was one of the main challenges made by Rosenberg and Frischtak (1984) to long wave proponents

35 Perez (2002), Ch. 3, pp. 27–35

36 Kuznets (1953), p.113

37 Mensch (1975:1979)

The same happened with the long series of important radical innovations in synthetic materials and fibers, which were gradually incorporated into the textile, engineering, packaging and consumer goods industries, transforming the input profile of the economy and the machinery required for a wide spectrum of processes.

Non-compatible products, by contrast, find it difficult to penetrate the established patterns and tend to either be shaped to adapt or to be marginalized and even excluded. In those cases, the reigning paradigm and its embedded externalities act as an *exclusion mechanism.* Semiconductors in their initial phase, for instance, found an ideal mass production niche by serving to stretch the life of mature consumer audio-equipment, through making them portable and rejuvenating their markets. The first integrated circuits, however, were marginalized in hearing aids or special military applications. Far back in history during the first great surge, the early steam engines were used to drain water out of mines, before anyone could imagine the major role they would play in transport years later. It is out of those technologies that are "waiting in the wings", going through a sort of *gestation period*, that the next revolution is likely to come together, when conditions become favorable.

During Deployment, then, both production and financial capital are satisfied with the successive investment and innovation opportunities associated with the successive new technology systems of the current technological revolution. New products appear regularly in expanding markets, strong companies are further strengthened, and profits are good… until maturity sets in.

Exhaustion of opportunity trajectories leading idle money to search elsewhere

Once there is paradigm constriction, once the innovation trajectories of successive products, industries and technology systems start drying up, there are less and less profitable uses for the mass of profits still being produced. Such idle money ends up piling up in the hands of financial capital, which begins to experiment. It will accompany production capital in its search for faraway markets and/or lower cost production locations and it might 'innovate' in speculative schemes or in ways of making doubtfully legitimate profit.[38]

Financial capital is also likely to find and fund two types of eager creditors with important consequences. On the one hand, there is the opportunity of making easy loans abroad. From the canal building credit given by the British to various States in the USA during the maturity and decline of the first surge (1820s-30s), to the diverse forms of development funding given to the Third World in those of the fourth (1960s-70s), each wave of such loans has later led to a debt crisis.[39]

On the other hand, the dearth of innovative opportunities in the old paradigm opens the eyes of the financiers to truly path-breaking possibilities. The new entrepreneurs, the potential bearers of the next technological revolution, can be noticed and can get the funds they might not have secured a few years earlier. It is their obvious initial success that will, in Schumpeterian fashion, launch the swarm of imitators. Both the entrepreneurs and the financiers will concentrate their efforts and

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[38] For the behavior of financial capital when the fourth surge reached maturity, from the 1960s onwards, see Strange (1986)

[39] Perez (2002), Ch. 8

resources on furthering, expanding and multiplying the products and industries of the new technology systems of the revolution.[40]

The role of finance in fostering the new paradigm

As Schumpeter expected, the new combinations will usually be made by new firms.[41] The entrepreneurs pushing the technological revolution are likely to be inexperienced in business and will also often be young. They will, therefore, need the help of bankers or financiers in more ways than just funding.

Yet it is not evident that the truly experienced financiers will be capable of understanding the essence of the new technologies or of visualizing the implicit change in direction. Their expertise is deeply rooted in the waning paradigm. J.P. Morgan, at the height of his power and after having been the financial brain propelling the third surge, rebuffed Henry Ford, considering automobiles as rich men's toys.[42] Paradigm blindness is a natural phenomenon associated with the 'over-adaptation' experienced by society as it engages in the full deployment of a particular technological revolution. J. Watson Sr. the first head of IBM, less than two decades away from the information revolution, thought that a few computers would fulfill all of the world's needs.

Hence, not only do the new entrepreneurs need to be imbued with the logic of the emerging technologies, their financial counterparts need to share that understanding. This is why the early financiers of each technological revolution tend to be family, friends and gradually, venture capitalists, who believe in the technologies and are willing to take the risks that the big traditional ones will not assume. A much younger J.P. Morgan in 1878 did take big risks with new ideas. He funded Edison at the very beginning of electricity. In a sense, the early financiers backing the revolutionary products are true risk takers and often participate actively in the business management of the innovation process itself. In this sense, they could be seen as *financial entrepreneurs*.[43]

An endogenous process with a specific rhythm

The gradual exhaustion of the innovation potential within the trajectories of the prevailing paradigm puts more and more idle money in the hands of financial capital, inducing it to break loose and to go looking for whatever opportunities may be available outside the well-trodden paths. The search will include supporting entrepreneurs that are tapping the vast pool of possibilities underestimated by the prevailing paradigm. This creates the conditions favorable for the coming together of the next technological revolution, which appears to both potential entrepreneurs and potential financiers as an opportunity explosion in what was becoming a barren innovation landscape. The extraordinary profits and the extraordinary growth rates that characterize the early innovations will be the force unleashing the clusters of entrepreneurs and bold financiers.

Thus, the clustering of innovative entrepreneurs –and of bold financiers– is not a random phenomenon, even though such audacious potential agents of change may be randomly distributed

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[40] Every one of these processes takes a uniquely different form, depending on the peculiar features of the particular revolution. There is a huge difference between designing and making minicomputers in a garage and designing and making steam engines or electrical generators.

[41] Schumpeter (1911:11961), pp. 66, 75, 137, 156

[42] Chernow (1990), p. 221.

[43] Janeway (1986) suggests that venture capital plays a double role as banker and entrepreneur.

in the population at any point in time. The conditions for the double clustering are endogenously generated by the techno-economic system. It is the exhaustion of the current potential that lifts the exclusion mechanisms and opens the door for the aspiring entrepreneurs and the bold financiers to come together and bring forth new solutions.

The major advantages provided to the participants in the deployment of a paradigm also explain the spacing between successive revolutions, allowing enough time for each one to run its course. The amounts of investment involved in the growth of the new industries and in the expansion of each infrastructure, the need to massively unlearn the old paradigm and adopt the new, the significant changes that must be induced on the territory, in the institutions and in the minds of people and society, will all contribute to exclude any new revolution from irrupting before most of the wealth creating potential of the current one has been exploited. That same energy of contention and exclusion will turn into a powerful force to invite change, once the established investment and profit opportunities dwindle.

H. FINANCIAL BUBBLES AS MASSIVE PROCESSES OF CREDIT CREATION

The irruption of a technological revolution finds an environment that is inevitably unfavorable and even hostile. It is, by definition, a breakthrough; it is the abandonment of the accepted trajectories and practice; it means the introduction of a novel way of doing things and a set of new products, industries and infrastructures that threaten the existing ones in one way or another. It is Schumpeterian *creative destruction* at its most visible. It will therefore elicit ferocious resistance both from those that are really set for losing and from those that have not yet discovered they might benefit from it.[44]

While the powerful firms from the previous surge may be willing to use some of the new technologies to stretch their stagnant productivity or solve some of their problems, they are unlikely to be the champions of the emerging constellation. They might, on the contrary, be particularly conservative, especially if direct threats to their products are apparent.

The power of finance backing the paradigm shift

The new firms are too small, too weak or too inexperienced to confront the resistance of the establishment by themselves. The difference between weight and rate marks the early diffusion of each technological revolution. The heavyweights that still make the bulk of the economy grow slowly or decline while those with the fast growth rates are still too lightweight to make a major difference. Only with the increasing power of financial capital on their side can they successfully wage the battles to change the socio-institutional routines, to generate the adequate manpower, to establish the new norms and other favorable conditions and to remove the many obstacles inherited from the old paradigm. This is increasingly important for financial capital, as it gets more and more involved with the new technologies and the new industries. As Schumpeter insisted it is the capitalist that faces the risk; 'the entrepreneur never bears the risk'.[45]

So the early venture capitalists are true adventurers and not mere bridges for innovation. They are in the front line of the battle against the old routines and the obstacles and in favor of the construction of an enabling environment to facilitate the diffusion of the emerging paradigm.

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[44] Schumpeter (1911:1961), pp 86-7

[45] Schumpeter (1911:1961), pp 75, 137 and (1939:1982), p. 104.

Historically, they have tended to do this through the unmitigated defence of free markets and *laissez faire*, turning the installation periods into the hardest and most individualistic form of capitalism. Hence, in terms of institutions, the creative destruction process in this period tends to have an overdose of destruction.[46]

In the early –or Irruption– phase of the installation period, both the entrepreneurs and their financiers are engaged in an intense exploration process, trying to understand what is successful from the new range of the possible and under what conditions. This trial and error process involves high risks and can yield high stakes. The higher the prizes obtained, the more intense the swarms of imitators will be; the more consistent the key features of success, the more clearly the general trajectories of the techno-economic paradigm will become visible facilitating further innovation on a wider and wider spectrum.

The Model-T gave high visibility to the principles for mass production, which soon fuelled swarms of imitators not only in automobiles and their components but also in other mechanical and electrical manufactures. The full spread of the paradigm as such will come later, when completely unrelated industries such as food, packaging or even tourism make leaps in productivity and quality by applying the same principles.

The making of the bubble

In essence, the techno-economic paradigm, once it is fully articulated and has spread enough, turns into a *risk-reduction mechanism*, partly real, partly illusory. Gradually, certain ready-made formulas become paths to ready-made profits and the new financiers entering the game no longer need to be so knowledgeable, only audacious. In the first surge, making a canal from any river to any other looked naturally profitable. Decades later, in the 1840s, a railway uniting any two cities was perceived as an obviously winning bet, just as in the late 1990s the dot.com craze was seen as the quick path to becoming a millionaire. Whether such expectations are warranted or not is irrelevant. The phenomenon has occurred with every surge a decade or two after the big-bang and, in every case, the faith in the profit making power of the industries and infrastructures of the revolution spreads widely and attracts all available money into the financial whirlpool. It is the making of the financial bubble, the collapse of which will end the installation period.

Opportunities grow explosively. Innumerable entrepreneurs will offer their projects to the also growing number of financiers. If they seem to follow the new paradigm, all projects, good and bad, honest and crooked, are likely to have access to the required funds. In particular, the infrastructure of the revolution will be able to spread very far and will most likely over-invest, if judged by its overall profitability and by the capacity of the economy to use it at the time. Existing firms will also be funded when they propose to modernize by applying the new paradigm.

But again, the weight-rate factors come into play. Even growing at an amazingly frantic pace, the new or modernizing industries cannot absorb the growing amounts of investment money brought to the stock market in pursuit of the extraordinary profits now expected by all. However, financial capital will not be deterred. It will now innovate in ways that turn the stock market into a casino, decoupling from the real economy and building extraordinary paper mountains. It will speculate

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[46] It should be noted that in many cases the technologies at the center of the revolution are based on a previous accumulation of a common pool of scientific and technical knowledge, often funded by public institutions, during the gestation period and even earlier. But once they make the market breakthroughs and become the source of extraordinary profits, there is enough attraction for private funds to take over, even for a substantial part of the required scientific research.

with whatever is at hand, from gold to real estate, and will also invent all sorts of bonds and derivatives, inverted pyramids and even less legitimate schemes.[47] High profit expectations will be kept alive by the financial wizards and for a while people will actually receive them, even if in the real economy only very few firms are actually generating such levels of profit (though some fraudulently simulate having them).

Thus, the bold and entrepreneurial financial capital of early Installation becomes the reckless capital of the late –or frenzy– phase of that period. In its search for newer and newer ways of guaranteeing a high return on all investment, be it related with the technological revolution or not, it systematically contributes to the hyperinflation of assets that underlies the bubble. As paper profits are further reinvested in the same casino, they intensify the phenomenon even further and attract ever more investors, including those who had never put their money anywhere beyond the family coffer or the corner savings bank.

When the job is done, it's time for the changeover in leadership

In this way, financial capital unwittingly guarantees that the industries and infrastructures of the technological revolution will become large enough to influence the economy and the firms involved powerful enough to serve as the leaders and engines of growth for the next Deployment period. The bubble at the end of Installation can be understood as a gigantic process of collective credit creation, orchestrated by the financial world in the stock market.[48]

The collapse of the bubble will inevitably come and much of the illusory paper wealth will disappear. But the installation of the paradigm in the minds and in the territory –as principles, as industries and as fully-fledged infrastructures– will have been achieved.

After the ensuing recession reveals the ills of the bubble and the tensions behind it, there will be the need to swing the pendulum back both in terms of greater attention to social interests, as opposed to the greedy individualism fueled by the financial frenzy, and of limiting the powers of financial capital, thus handing over the guidance of the economy to production capital, now represented by the new engines of growth. Regulation and other conditioning factors will bring financial capital back into a complementary role, until the end of the surge calls it out again for the next transformation.

I. SUMMARY AND CONCLUSION

This chapter has argued that financial capital has a fundamental role in the articulation and propagation of technological revolutions. It also proposes an inclusion-exclusion mechanism that would explain why technical change occurs by successive revolutions with several decades between them. In doing so, it reaffirmed Schumpeter's view of the clustering of entrepreneurship in certain periods. But, in contrast with Schumpeter, it held that the bunching of intense radical change must also bring forth clusters of bold –sometimes reckless- financiers in support of the production entrepreneurs. Major financial bubbles would be interpreted as massive processes of credit creation to install each technological revolution. The arguments are rooted in a stylized

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[47] Perez (2002), Ch. 10 and 13.

[48] In the first two surges, the stock market was not fully developed and the bubbles were inflated by bold ambitious characters such as Hudson in the British railway boom of the 1840s. But the basic social nature of the money whirlpool phenomenon is the same.

model of the diffusion and assimilation of technological revolutions based on historical recurrence, the main purpose of which is to serve as a heuristic device.

Finance and paradigm shifts

A central element in the model presented is the concept of *techno-economic paradigm* as the set of generic technologies and organizational principles that emerge with each technological revolution and guide its diffusion, through being adopted as shared best-practice common sense by all the economic agents. It is this aspect of each technological revolution that provides the potential for modernizing the whole economy, which gradually reaches a higher productivity plateau. This process, designated as a *great surge of development*, would take about half a century to unfold in a very uneven manner, sometimes turbulent, sometimes more harmonious.

Each paradigm becomes so embedded in the techno-economic and the socio-institutional spheres of society that all compatible innovations benefit from massive externalities and their success and profitability are greatly facilitated. What is suggested is that, through the agency of the embedded paradigm, each surge establishes an inclusion-exclusion mechanism that rewards innovations following the meta-routines of the paradigm and discourages or marginalizes non-compatible innovations, which would be much more difficult and less profitable.

Only when the potential of that revolution is exhausted can the conditions become favorable for the next revolution to come together, but at that stage the new paradigm will confront enormous resistance. Incumbent producers are likely to be among the main inertial forces. By its very nature, production capital is tied to its previous history of investment, knowledge, experience, personnel and external networks.

Financial capital, by contrast, is fundamentally mobile. It can therefore break loose from the mature sectors of the economy and reallocate funds to any emerging technologies outside the well-trodden paths. In this manner, it contributes in the articulation of the next technological revolution and the diffusion of its paradigm. In searching its own enrichment through sharing in the extraordinary profits of the new products and industries, it also helps remove institutional obstacles and strengthens the successful entrepreneurial firms, which will gradually become strong enough to replace the engines of growth of the previous paradigm.

The model thus proposes a causal chain with a mechanism for the spacing of technological revolutions, giving a role to financial capital in their articulation and in facilitating the replacement of the leading firms of each surge. It is based on the notion of techno-economic paradigms as meta-routines for innovation and on the functional separation of production and financial capital. Both aspects would be essential to the dynamic character of capitalism.

Clusters of bold financiers and the invisible hand for credit creation

The bunching of innovation opportunities with the irruption of each technological revolution would be the cause behind the periodic clustering of audacious entrepreneurs. It would also explain the subsequent clustering of bold –even reckless- financiers accompanying and fostering the paradigm shift and gradually leading to a major financial bubble.

These recurring episodes of reckless banking or stock market manias, rather than being anomalies, would work as an invisible hand for massive credit creation, facilitating the full installation of each technological revolution and its paradigm.

The hyper-inflation of assets provides enough funds for experimenting widely with the new technological possibilities of the revolution, for modernizing much of the existing firms and plants, for over-investing in the new infrastructure and also for setting up innumerable forms of casino-like speculative schemes.

Assigning a role to financial bubbles in the diffusion of technological revolutions would assign a role to reckless finance in the dynamics of capitalist growth, ranging the phenomenon among the 'natural' features of capitalism, in stark contrast with Schumpeter's view on the matter.

The research ahead

Much research is still required to further test the validity of the model presented and to achieve a deeper understanding of the difference between the recurrent phenomena and their unique manifestations.

If the interpretation presented here is accepted as plausible, it begs the question of the inevitability of the bubble. Would this be the only way in which capitalism can install a paradigm and lure enough capital into investing in its particular infrastructure to make it into an all-pervasive externality? Does understanding the phenomenon open the way for the construction of a solution that is less socially painful?

In any case, further research will contribute to deepen the understanding of the relationship between finance and innovation as well as of the impact of technological innovation on financial practice. This could correct the imbalance that has heretofore prevailed among Neo-Schumpeterians and –unheeding Schumpeter's warnings against them– would enhance the capacity to provide policy recommendations.

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