Blade Runner economics: will innovation lead the economic recovery?

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Revision 6, RP 25.06.2016 – *Research Policy*

Keywords: creative destruction, economic crisis, emerging technologies, long waves, science fiction; technological forecasting

ABSTRACT

According to Schumpeterian theories, economic expansions are associated with the introduction of successful new products, processes and services while depressions are linked to stagnant periods with few innovations. Can the economic crisis set in motion in 2008 be explained by the inability to innovate and upgrade production? And, conversely, will an economic recovery require a new stream of innovations? Drawing on the debate which emerged after the 1970s economic crisis, this paper tries to assess whether it is likely that the next long-term expansion will be linked to a new stream of innovations. While most evidence suggests that ICTs continue to provide the back-bone of economic activities, there is the prospect that biotechnology will eventually start to fulfil the promise envisaged over 30 years ago in the film *Blade Runner*.

1. **Artificial life in Venice**

I was just a boy when, in 1982, fate led me to watch *Blade Runner* at the Venice Film Festival. Ridley Scott and Harrison Ford were there, but I was much more impressed and fascinated by the fantasy of new technologies than by the celebrities in the cinema. I was not the only one: the film and its seven different versions have since become a "cult movie" and have been analysed not only for their artistic meaning but also for their social, political and economic implications (see, for example, the variety of perspectives presented in Kerman, 1997).

I would like to explore here the film as an experiment in technological forecasting. Many prospective technologies presented in the film, such as flying vehicles, were already predicted by previous science fictions novels, films and cartoons. However, some devices struck my imagination:

Electronics. Battery-operated electronic tills present everywhere, even in street kiosks. Voice-operated televisions. Gigantic electronic screens. Scanners (I do not think that the word even existed in 1982) that could in an instant enlarge photographs several times over.

Biological artefacts. Artificial animals (e.g. snakes, owls, ostriches). Artificial body parts (human eyes). Living toys (dolls, puppets and tin soldiers). And, of course, the very hero of the film, the Replicant, an artificial human who could be distinguished from real humans only after undergoing a rather complex psychological / oculist test.

Experts in science fiction will no doubt argue that any one of these innovations was already predicted in previous science fiction works.[1] Nevertheless, the narrative of *Blade Runner* makes these manufactured biological artefacts realistic and impressive for their pervasive social diffusion, perhaps because it portrays a vision of an entire industry based on what we might label today as a 'general purpose technology' (for a discussion of the concept, see David, 1990; Bresnahan and Trajtenberg, 1995), namely artificial life.

One distinctive aspect of *Blade Runner* should be underlined. It did not present a totally new society: many things were almost identical to the civilization of the 1980s. The structure of social classes depicted in *Blade Runner* is rather similar to what existed at the time of the film's release, and this is in itself an accomplished prediction since income inequality has become even greater in the last thirty years. Already Fritz Lange's *Metropolis* (1927) had

[1] Thanks to a very knowledgeable reviewer, I have learnt that "bio-engineered" animals could be found in Olaf Stapledon's *Sirius*, (1944) and that a mixture of humans and animals are also to be found in Cordwainer Smith's *The Dead Lady of Clown Town* (1964).

depicted a social stratification in which lower classes re-entered a state of slavery, and *Blade Runner* shows that the new lumpen-proletariat of Marxist remembrance has a new competitor: the non-human class of the androids. Like *Metropolis*, the film represents a peculiar urban stratification of social classes: it is not *horizontal*, as when you have different neighbourhoods, but rather *vertical*: lower classes are low also because they live on the ground floor, while the upper classes reveal their highflying nature almost literally, occupying the top floors of skyscrapers.

The dominant technologies are not identified by single innovations only, but by clusters of interrelated innovations. Surprisingly, however, the film fails to connect systematically the two clusters in Electronics and Biological artefacts. With the benefit of hindsight, we can today identify these technologies as belonging to two main clusters: "Information and Communication Technologies" (ICTs) and "Biotechnologies". Seen from the perspective of the early 1980s, both ICTs and Biotech had a potential that was still unexplored and that appeared equally revolutionary and promising.

After thirty years, I watched the film again in very exclusive company, namely that of my children. Like me, they found the film imaginative and exciting, but with some basic differences. On the one hand, all the innovations in the field of ICTs have become trivial for them: the mobiles in their pockets contain scanners, audio-visuals, photo enlargers and GPS navigators more powerful and much smaller than in the film. In the middle of the adventure, one of my kids wondered: "why does he not send an email with an attachment?", and the question was not that silly. If we accept the intriguing idea that science fiction can influence innovation as much as innovation influences science fiction (Bassett et al., 2013), we can now say that this influence has been much stronger for ICTs than for Biotechnologies. *Blade Runner* underestimated the pace of change in ICTs, to the point that it does not forecast what has become the most significant innovation of the last decade or so, namely the web. The TV screens, GPS navigators and video-telephones pictured in the film are, by contemporary standards, big and chunky.

On the other hand, none of the innovations in Biotechnology has to the same extent changed our lives. ICTs have created new companies and millions of jobs, and they have transformed the operation of traditional industries such as retailing. Biotechnologies, in spite of the massive investment in R&D, have not (yet) produced anything like the same effect. Biotechnology still has to produce the general purpose technology equivalent to the microprocessor and it remains confined to a very narrow niche.

2. **Schumpeterian insights**

The idea that clusters of innovations generate phases of economic development is older than *Blade Runner*. Marxist and Schumpeterian economists have for a century or more tried to relate stages of development to the emergence and decline of different technologies. According to this view, each historical period is dominated by the intensive and extensive use of specific production technologies. These technologies may be fostered or hampered by institutions and social beliefs, which often explain why they develop and are disseminated in some parts of the world rather than others.

Crucial to the Schumpeterian insight is that innovations do not have an economic impact in isolation: they become dominant because they are applied in different contexts, shaping and transforming original ideas. Innovations could occur in different economic arenas (e.g. steam engines and textile machinery), but they are mixed and recombined in the economic and social fabric (e.g. the steam engine provided power for textile mills). When the new knowledge associated with a few emerging technologies starts to become widely diffused in economic life, then it will generate a phase of economic expansion. New technological opportunities stimulate and open up new industries that did not exist before, leading to job creation and structural change. When the opportunities start to dry up, it is likely that there will be a lower rate of economic growth or even an economic crisis.

Regular patterns are always difficult to recognize, but Schumpeterian economists have attempted to identify five phases of capitalist development, each associated with a cluster of dominant technologies (Schumpeter, 1939; Freeman, 1984b; Mandel, 1995; Freeman and Louçã, 2001). Chris Freeman (1992) and Carlota Perez (2002) have termed these major phases “techno-economic paradigms”, identifying their key characteristics in terms of: i) core industries, ii) industrial organization, and iii) the modality to introduce innovations. Table 1 summarizes the key characteristic of each techno-economic paradigm.

Why do we need such a categorization? The main purpose is to understand the distinctive technological areas of a specific epoch and to trace their evolution. Archaeologists have found it useful to classify ancient societies into the Stone, Bronze and Iron Ages, since the techniques associated with each of these periods can explain quite a lot about their economic, social and even cultural and political life.[2] These ages do not necessarily occur simultaneously: for example, anthropologists consider that aboriginal communities in

[2] This periodization was originally suggested by the Danish archaeologist, Christian Jürgensen Thomsen, in the 1840s and it has since been widely applied.

Australia lived essentially in the Stone Age until the advent of European colonization. Indeed, it is sometimes said that “uncontacted peoples” in remote parts of South America, Asia or Oceania continue to this day to live in the Stone Age.

The French historian, Bernard Gille (1978), has further developed the archaeological approach by tracing the core “technical system” of each society. A technical system can be identified in terms of the core technologies used in a society and, above all, the interconnections between various devices. This requires the development of human skills to use the available techniques profitably, which in turn generates substantial changes in the distribution of employment across the various sectors of production. Mutual interdependence ensures the coherence and success of the overall economic and social system.

One of the core characteristics of development is that only a few previous technologies become totally obsolete. The innovations introduced in the first industrial revolution continue to be with us and it is difficult to imagine our life without simple technological artefacts such as the myriad of mechanical devices that came to the fore during the Enlightenment. Of course, several products and services were replaced by alternatives that have become more popular: steam power has been substituted by the combustion engine and the combustion engine will, one hopes, be replaced in due course by solar power. The rate of change has been even faster in communications: pigeon-post has been substituted by telegrams and telegrams by email. There is no implication, of course, that the last method is superior to the previous one and some very progressive societies have occasionally returned to techniques previously considered obsolete. Cities like Amsterdam and Copenhagen, for example, are fighting to bring back bicycles and trams in order to get rid of automobiles. But by looking at the techniques used, it is possible to recognize each epoch and to distinguish the technologies driving change?

The capitalist system in the last three centuries has made such development faster and more geographically comprehensive. Each phase can also be associated with the birth of firms with rather distinctive typologies. These companies are likely to exploit the new technological opportunities and organizational structures and to become the distinctive institutions of the new phase (see the last column of Table 1). When Keith Pavitt (1984) suggested his taxonomy of innovating companies, a taxonomy that proved very successful, one of his motivations was to show Freeman and his followers that innovative companies, with their expertise and competences, also need continuity, and more importantly that it was crucial to understand the differences across firms in the way that they introduced innovations.[3]

Even if it was originally designed to highlight the importance of knowledge accumulation in companies, institutions and nations, in one respect the taxonomy of Pavitt contributed, perhaps involuntarily, to the long wave theory, with each category of companies he identified being born in a specific stage. In a relatively short period of time, the emerging category became the dominant form of economic organization. The first industrial revolution is associated with the separation between traditional companies and producers of equipment, machinery and instruments. The second industrial revolution saw specialized suppliers becoming the front-runners of change. At the turn of the 19th and 20th centuries, a new type of firm emerged, based on the systematic exploration and exploitation of scientific opportunities in industries as diverse as chemicals, electrical machinery and engineering. We are familiar with the large companies based on Taylorism and Fordism that dominated most of the 20th century. And, of course, we have seen in the last thirty years how information-intensive companies, ranging from software producers to extensive users in banking and retailing, have shaped our lives. Pavitt himself had to face the problem of how quickly change could occur: information-intensive firms rose to prominence in just a few years. This category was absent in the first formulation of the taxonomy and had to be introduced a few years later (compare Pavitt, 1984 and 1990).

Since *Blade Runner* was released, some of information intensie companies have become part of our daily life: Microsoft (US$87 billion sales in 2014), Apple (US$42 billion), Google (US$66 billion), Amazon (US$89 billion), Oracle (US$ 37 billion) and Facebook (US$12 billion) were all anticipated by the imaginary Tyrell Corporation, perhaps also because, as predicted by Ridley Scott, they continue to be associated with the vision of successful entrepreneurs. These relatively new and fast-growing corporations co-exist with established companies that have opened up business lines to exploit new opportunities such as HP (US$ 111billion before the 2015 subdivision into two corporations) or Sony (US$ 65 billion). One of the most significant cases of transformation of an old corporation is IBM, a company that has been in business for more than a century and that has managed to remain big and leading-edge by progressively abandoning its hardware component to embrace the emerging software services (Gerstner, 2002). This indicates that a new and growing industry

[3] Pavitt drew on a variety of sources to construct his taxonomy, including the organizational theory of Woodward , 1965).

can be populated both by brand new companies and by companies that have the resources and the competences to enter into the new field by reusing their accumulated competences.

The new techno-economic paradigm is not just shaped by large firms. All the companies mentioned, in spite of the invaluable contribution they have provided to the coming of the information society, are not sufficient to shape our economic life: without a myriad of smaller and often unknown firms, we would not be in a society that makes such intensive use of information. The fact that there is virtually no industry that does not benefit from ICTs shows the degree of pervasiveness and integration achieved today in the information society (ICTs are what David, 1990, and Bresnahan and Trajtenberg, 1995 as well as others have labelled 'general purpose technologies').

3. **Creative destruction or technological accumulation?**

To move from one techno-economic paradigm to another one is often a traumatic experience. *Blade Runner* describes a given society, but how smooth or traumatic is the change towards that particular society? Economists have for long debated the relative importance of the cumulative development of expertise, on the one hand, and the disruptive nature of change, on the other. Karl Marx compared capitalism to the ancient Greek myth of the giant Antaeus, who was able to obtain new energy every time he fell down and touched the earth. Marx underlined that capitalism needs economic crises to reorganize its production, to shift capital from the industries with lower profit margins and to reinvest it in the growing industries.

Schumpeter, an economist who was a fierce opponent of Marx as well as being among his most devoted readers,[4] also stressed the importance of disruptive change, noting that it, too, was associated with technological transformations. In one of his most quoted sentences – "Add successively as many mail coaches as you please, you will never get a railway thereby" (Schumpeter, 1934, p. 64) – he made it clear that radically new products and processes could not be obtained by incremental changes only. Discontinuities were therefore needed to allow the introduction of new technologies, and these were also likely to produce crises in the economic arena. Some could be confined to selected firms, industries, cities, regions or nations; others were likely to have a much broader impact.

[4] Schumpeter called his mentor, Eugen von Böhm-Bawerk, "the Marx of the bourgeoisie". But, as noted by his pupil, Paolo Sylos-Labini (1970), he would have been pleased to acquire such a nick-name himself. On the influence of Marx's thinking on Schumpeter, see Elliott (1980) and Rosenberg (2011).

Schumpeter stressed that there was not only a process of reorganization of capital, but also that such a process was associated with individual agency. Schumpeter, an admirer of Nietzsche as much as of Marx (on Nietzsche's influence on Schumpeter, see Santarelli and Pesciarelli, 1990, and Reinert and Reinert, 2006), understood that changes occur not only because there is unanimated capital willing to grow, but because there are entrepreneurs, a sort of Nietzschean superman in the economic sphere, that search out and exploit new opportunities. It is out of these animal spirits, as Keynes (1936, pp. 161-162) labelled them, that inventions are transformed into innovations and eventually diffused up to the point that they shape economic and social life.

The problem is therefore to understand which players will be able to grasp these opportunities. On some occasions they are associated with new, successful entrepreneurs: the automobile industry was shaped by Henry Ford and the electricity business by Thomas Edison. It would be difficult for us to imagine an information-based society without thinking of the rise of companies such as Microsoft, Apple, Oracle, Google, Amazon and Facebook, and we associate these with entrepreneurs such as Bill Gates, Steve Jobs, Larry Ellison, Larry Page, Sergey Brin, Jeff Bezos and Mark Zuckerberg. These entrepreneurs understood earlier and better than others that the supply of information could become much larger than conceived in the past and that, in spite of the fact that its cost per unit would drop by orders of magnitude (compare the cost of a telegram to the cost of an email), new technological opportunities were so huge that the overall market would grow.

On other occasions, established firms that have already accumulated organizational resources, labour and capital are the first to understand that times are changing and to adjust to the new paradigm. If they do not manage to do that, they are likely to be locked into their existing market and to decline with it. If, on the other hand, they manage to use their skills and competences to explore new opportunities, they may jump into a new profitable business. Take the case of Eastman Kodak and Fujifilm, two companies competing in the same core market, photographic film (*The Economist*, 2012; Gebremeskel, Tesfaye and Nguyen, 2012; Nonaka et al., 2014). The former has not managed to adjust to the digital revolution in photography; the latter has done so and, exploiting its knowledge of consumers and markets, has successfully managed to jump into a new technological paradigm, becoming a leader in digital technology (and indeed now aspiring to become one in pharmaceuticals).[5]

[5] See Peter Evans, 'Lure of cancer drug breakthrough drives pharma chief executives', *The Sunday Times*, 5 June 2016.

Change is therefore driven not only by disruption but also by continuity. Disruption does not necessarily lead to progress or to greater economic efficiency, and if it is not properly managed it can lead not only to company losses, but to societal damages as well.[6] Competences and skills are needed to upgrade production, and they are often accumulated by individuals and organizations over many years of experimentation. The potential of creative destruction should be compared to that of creative accumulation, which assumes that individuals and organizations with an appropriate stock of competences are better positioned to introduce successful changes.[7]

Nelson and Winter (1982) and Malerba and Orsenigo (1995) have already taught us that there is no reason to assume that either creative destruction or creative accumulation can explain the process of change in all industries. Table 2 compares the characteristics of the models of creative accumulation and creative destruction to show that there are cases in which each of the strategies may allow companies to prosper. In the creative accumulation model, large firms systematically exploit new technological opportunities as a method to maintain their market shares and to keep outsiders out of business. In the creative destruction model, major innovations are introduced by small companies that become big precisely because they have won the bet on the potential of their new products and processes. It is not difficult to find examples in business history where successful companies prospered according to each of the two models. But are these models equally suited to identifying the companies that will, one hopes, lead recovery form the current economic recession?

4. **Who is investing in innovation after the 2008 economic crisis?**

Much has been written about the origins of the latest economic crisis and there is no consensus yet on either its causes or its consequences. In less than a decade, we have witnessed both the 2001 Dot-com bubble mostly associated with the difficulty of ICTs in keeping up with speculative expectations, and the 2008 financial and economic crisis which originated in a traditional sector, namely housing. Besides the fuse that generated the crisis, is it possible to identify the underlying structural causes? We have learnt from Keynesian economics (see Kindleberger, 1978, and Minsky, 1986) that the trigger of major economic crisis is often the financial market. The speculative tendencies of the financial markets could

[6] The disruptive effects of innovation, praised by Christensen (1997), have been critically addressed by Lepore (2014).
[7] One way to assess the relative importance of accumulation and destruction is to look at company case-studies see, e.g., Tripsas (1997) on the typesetter industry.

be tamed by good regulations. Ultimately a lender of last resort helps to avoid the deepening and the dissemination of adverse consequences.

The Kindleberger-Minsky model is also able to explain the 2008 events (see Shiller, 2008): speculative trends in the financial markets were not held in check by regulation (at least, not in the United States), but the willingness of governments and central banks to act as lenders of last resort has helped to prevent a deepening of the crisis. But can the crisis, or at least the difficulty in achieving an effective and timely economic recovery, also be linked with the drying up of technological opportunities and, therefore, with the difficulty of sustaining the expectations of high and steady growth? In other words, is there a convincing economic explanation linked to the rate of innovation that could be integrated with the financial analysis of the crisis?

According to a pessimistic view, it is now difficult to foresee technological opportunities comparable to those that the world economy experienced in the 1950s and 1960s. The rate of economic growth of these decades (what Angus Maddison, 1992, has labelled as the golden age) is likely to prove unique in history. Gordon (2012; 2016) has argued that "the rapid progress made over the past 250 years could well turn out to be a unique episode in human history". More optimistic observers, in contrast, claim that technological opportunities are still present, and they can guarantee new jobs and new prospects, provided the economic and social systems allow for their introduction and diffusion (Perez, 2013; Mokyr, 2013).

Eight years on from the beginning of the economic crisis, and with a few signs of economic recovery emerging, the core question is: in which direction will the world economy now grow? Which industries and technologies will take the lead? These are the core issues discussed by policy makers, business leaders and others. Perhaps economists of innovation should also offer some insights.

The first way to explore this is to check the willingness of economic actors to bear the costs and risks of innovation. Since investment in innovation represents a bet on the future, firms invest in new and improved products, processes and services when they expect that they will be able to repay the costs thorough successful market reception. We already know that innovation, more than other forms of investment, is an uncertain activity. Some projects may manage to introduce successful innovations that will repay the initial costs several times over, while others may not succeed in generating commercially successful innovations at all. In spite of this, businessmen's willingness to invest in innovation indicates a propensity not only to bear risks, but also to play the game. Moreover, without playing, there will never be winners.

The research that Andrea Filippetti, Marion Frenz and I have carried out has tried to identify businesses' reaction in terms of innovation investment as a consequence of the 2008 financial crisis (Archibugi et al., 2013a; 2013b). Using Eurobarometer data, we have identified three groups of enterprises according to their decisions to decrease, maintain or increase innovation investment from 2006 to 2009. The number of enterprises that decreased their innovation investment rose from less than 10 per cent in the pre-crisis period to 27 per cent after the crisis. This is hardly a surprising result: in the middle of the credit crunch and with gloomy business opportunities, companies may be tempted to reduce all costs including investment, or may be forced to do so to preserve some earnings and hence to protect share prices. The behaviour of these enterprises may lead to a deepening of the recession: Keynesian economics has shown that a reduction of investment depresses aggregate demand, and Schumpeterian economics has indicated that a reduction in the rate of innovation may lead to stagnation.

Those that are confident of the virtues of technological accumulation would be reassured to discover that as many as 60 per cent of enterprises kept their innovative investment unchanged: there is apparently an innovative routine that it is not affected, not even by major events such as the 2008 financial crisis (before the crisis, about half of the enterprises reported steady innovation investment). For most economic organizations, steady knowledge accumulation is vital to their survival. The number of enterprises that behaved anti-cyclically, i.e. that increased innovation investment after the crisis, is comparatively small: a mere 9 per cent. If we compare it to the situation before the crisis when as many as 40 per cent of enterprises were increasing their innovation investment, we can really appreciate how the decision to expand innovative activities may be affected by adverse events. Could such a small number of daring enterprises have a "detonator" effect on the whole economy?

Here lies a fundamental difference between investment in general and investment for innovation in particular, a difference implicit in the Schumpeterian tradition but never properly assimilated by Keynesian economics. While investment in general is a steady proportion of aggregate demand, investment in innovation has unpredictable economic effects. A few successful innovative projects may create the Schumpeterian band-wagon effect, generating jobs, profits and structural change that could potentially revitalize the whole economy. The innovation multiplier can be much larger than the investment multiplier.

The effect of the innovation multiplier is not equally distributed across the economic space, and we see that there are exceptional agglomerations in selected cities, regions and nations. It is no surprise that the areas with the most sustained economic growth rates are also generally those which entered first into the innovative driving sectors.

In some European countries, the number of companies that have maintained or even increased innovative investment is greater than the number of companies that have reduced it. Within Europe, the most innovative nations, such as Sweden, Switzerland, Finland and Germany, were the ones least affected by the crisis. This might also be the result of other institutional factors such as their rather conservative banking regulations compared to those of liberal market economies. Nevertheless, these countries cannot avoid continuing to invest since they are highly specialized in areas where you innovate or perish. If they stop innovating, they may well be forced out of business.[8]

It is instructive to compare Europe with other continents. In a large national innovative system such as the USA, knowledge-intensive states such as California have also increased their R&D expenditure after the economic crisis, while other, less innovation-intensive states have reduced it. In emerging economies, including China and India, the growth of innovation-related activities has been so phenomenal that the presence of an economic crisis can scarcely be noted from time-series statistics on R&D or patents. One of the consequences of an economic crisis is also to accelerate change across regions, and we are aware that, at the end of the economic crisis, the OECD member countries will have to compete with more assertive and more capable emerging areas.

The profile of the innovators becomes fundamental in attempting to predict what the overall economic impact of the investment will be. Who is likely to generate new ideas and introduce innovations? In other words, who will "swim against the stream"? Our data associate such enterprises with the following traits:

- They tend to be of small size.
- They had an R&D department before the crisis.
- There is a high proportion of young enterprises (created after 2001).
- They combine innovation with the exploration of new market opportunities.

[8] These findings are consistent with Amore (2015), who has shown that many companies manage to capitalize their innovative routine even in bad times.

- Their competitive strategy is more likely to be based on products than on costs.[9]

Eurobarometer data are not particularly robust, providing an indication of the broad trend but no reliable data on how much is being spent on innovation. However, data based on the Community Innovation Survey for the UK seems to confirm this picture (Archibugi et al., 2013b), in particular in terms of a greater concentration of innovative resources in fewer companies. In other words, there are signs to suggest that recovery will be led by creative new enterprises rather than incumbent ones. This would confirm the idea that during crises radical new opportunities are less likely to be exploited by incumbents, while newcomers may exhibit the energy and the willingness to challenge the current steady state (Dosi et al., 2008). We have detailed an identikit of the innovators: but where they will innovate?

5. **Where are emerging technological opportunities?**

Already in *The Coming of Post-Industrial Society*, Daniel Bell (1973) predicted that information would replace goods as the leading product, and that service industries would replace manufacturing as the major employer. In a similar vein, Toffler (1980) tried to identify the set of technologies that would serve a post-industrial society. Both these predictions were fulfilled but this, in turn, required tools able to assess the economic and social impact of emerging technologies.

Dosi (1982) and Freeman (1992) made an attempt to identify technologies that could create a genuine revolution. In the early 1980s, Freeman (1984a) set out five criteria to identify the emerging technologies of greatest impact:

1) drastic reduction in the costs of many products and services;

2) dramatic improvement in the technical characteristics of many products and processes;

3) social and political acceptability;

4) environmental acceptability;

5) pervasive effects throughout the economic system, i.e. the potential to become what was later labelled as a general purpose technology.

[9] Our data only accounts for surviving enterprises and therefore are not able to detect those that may fail after a short period. However, other evidence corroborates the intuition that small innovative companies have lower survival expectancy (see Buddelmeyer et al., 2009; Dosi et al., 2008).

Using these criteria, he was able to predict that micro-electronics was going to become the back-bone of the coming techno-economic paradigm, while the economic and social impact of nuclear technology, then considered by some commentators as a would-be leading innovation, was grossly exaggerated.

Business analysts invest much time in exploring market and technological opportunities.[10] A recent and very detailed attempt to identify and explore new technological opportunities was released by the McKinsey Global Institute (Manyika et al., 2013). They tried to identify the core technologies expected to have a major impact by 2025. The four criteria they used are:

1. Technology is rapidly advancing or experiencing breakthroughs.
2. The potential scope of impact is broad.
3. Significant economic value could be affected.
4. Economic impact is potentially disruptive.

As can be seen, the McKinsey exercise follows very closely the Schumpeterian tradition as set out many years earlier by Freeman (1984a), Perez (2002) and also Dosi (1982).

The top technologies identified in the McKinsey foresight exercise in terms of substantial growth are all in the ICT area (see Table 3). The top four, *Mobile Internet*, *Automation of knowledge work*, *Internet of things* and *Cloud technology* all belong directly to the ICT cluster. For the next two, *Advanced robotics* and *Autonomous vehicles*, although they seemingly belong to the Machinery and Transport industries, the core innovative component is software. The next six emerging technologies are predicted to have a lower economic impact, but are also associated with a broader knowledge base. Amongst these we find *Next-generation genomics*, the fundamental component needed to implement the *Blade Runner*'s Replicant, *Advanced materials*, and issues associated with energy production and distribution such as *Energy storage*, *Renewable energy* and *Advanced oil and gas exploration*. *3D printing*, again heavily based on software, seems to be another important extension of the information society.

Science and technology indicators provide a somewhat similar picture. If we concentrate on the two clusters of ICTs and Biotech, we find that patent applications in 1981,

[10] For a recent scholarly attempt to define what is meant by an "emergent technology", see Rotolo et al. (2015). Most of the attempts considered here were based more on intuition than rigorous analysis.

at a very early stage in both technologies, numbered around 1,000 in ICTs compared with 119 in Biotech. Both fields have grown exponentially, and in 2012 there were some 60,000 patents in ICTs, while there were less than 10,000 in Biotech (see Figure 1). In spite of the significant different propensity to patent (see Danguy, et al.,), these numbers confirm the impression that while ICTs have become a general purpose technology, developed by companies belonging to a variety of different product industries and used in an even larger number of applications, Biotech is still largely confined to specific products and areas, notably human health and food. The profit-seeking community, as represented by the patents taken out, has clearly made a greater investment and has more optimistic expectations regarding ICTs than Biotech. The problem with technology indicators, however, is that they may report what is already in the pipe-line rather than the innovations that will fulfil their full potential at some stage in the future. Data from scientific publications, which are more likely to reflect the activities promoted by the academic community and the public sector, reveal a rather different picture: the Web of Science reports a basin with more than six million publications with the word DNA and just over one and a half million with the word semiconductor. We need more data on the current direction of scientific opportunities and this is not sufficient evidence to infer that academic research has already moved in another direction. But it seems that scientific and technological indicators point out at diverging trends.

If the trends revealed by technology indicators and the predictions of McKinsey prove to be accurate, the next decade will continue to be dominated by the ICT techno-economic paradigm while the Biotech cluster will account for only 5-10 per cent of the expected economic potential of new technologies. We would expect a consolidation and deepening of the current paradigm rather than the emergence of radically new technologies. Biotech, anticipated as an emerging industry, and not only by Ridley Scott (see Orsenigo, 1989), may still have to wait its turn since, thus far, it has not fulfilled the earlier optimistic expectations. Economists of innovation soon recognized the very peculiar characteristic of the Biotech industry and four factors were singled out (see Pisano, 2006). First of all, the major breakthroughs were generated in universities and in publicly funded research centres. Second, the business sector, often though a direct affiliation of academic staff, was very fast in exploring its commercial potential. Third, the industry found new forms of financing based on expectations that research could bring new and successful drugs to the market (Orsenigo, 1989). Fourth, the lag between R&D and product innovation has proven to be longer than originally expected. The fundamental scientific advances which occurred several years ago have not yet been exploited in terms of sales, profits or job creation and have not led, thus far, to a distinctive new type of company.

What has happened to the pioneering companies in the area seems to confirm this impression: most of the ground-breaking companies in Biotech have been acquired by other, larger companies: Genentech was eventually fully acquired by Hoffmann-La Roche in 2009, and Genzyme by Sanofi in 2011, indicating that the main output, so far, has been knowledge rather than commercial products entering the market. Very large firms have acquired the pioneering companies because of their knowledge and competences. The business leaders in ICTs, such as Microsoft, Google and Facebook, have exhibited a rather different pattern: they started as small companies and have grown to their current size, up to the point where they possessed the resources to acquire fast-growing companies based on new ideas and technologies such as Skype, Android and WhatsApp. The process of creative destruction of the ICT industry, which dominated for nearly three decades, has now turned into one of creative accumulation, with grown-up companies able to scan and exploit new opportunities, including through the acquisition of small and emerging companies. This suggests that the dominant techno-economic paradigm is now being consolidated through adoption, development and diffusion.

6. Questioning the coming paradigm

One of the key characteristics of disruptive technologies is that they do not knock gently at the door: they enter social and economic life suddenly and unexpectedly. To look at R&D expenditure by considering patents taken out and scientific publications alone could be misleading, since they point to a Schumpeterian swarming that is already at a relatively advanced stage. Business reports show that in 2014 the Biotech industry exceeded all previous records in terms of R&D expenditure and net income (see Ernst and Young, 2015). Even if their overall economic impact is not yet comparable to that for ICTs, these new opportunities could play an unexpected role, especially if properly combined with ICTs. In the past we have seen how steam power and mechanical engineering, synthetic materials and electrical machinery evolved simultaneously. Should we expect a new alliance between ICTs and Biotech?

Theodor Adorno warned us that “life does not live”. To paraphrase him, technological opportunities do not enter into economic and social life without deliberate efforts and choices. We should be able to envisage new forms of organization associated with emerging technology. ICTs have already changed our lifestyle even more than our economic life: they have generated jobs and profits, but above all they have transformed the way we use our time and interact with the world. Biotech could bring about even more radical social transformations at the core of our life. Why have these not yet been delivered? What can be done to unleash their potential? There are a few basic questions that need to be addressed.

- Investment in Biotech has mostly been made by business corporations. Universities and public laboratories, in spite of the fact that they were the origin of many scientific advances, are today second in line. As noted by Pisano (2006), a science-based industry with a very long gestation period before new discoveries are transformed into products may encounter major problems if it is driven by profit-seekers. Many of the new openings in Biotech are either kept confidential or protected by intellectual property rights, and this may delay the diffusion of knowledge. In an area where most advances are interrelated, public sharing could be crucial to avoid dead-ends. Is profit-driven research today obstructing the industry's potential?

- If more active public and non-profit research is needed, how should it be integrated with market-oriented research? A revision of the current division of labour between public and private players may be needed. The triple-helix model (Etzkowitz and Leydesdorff, 2000) has somehow blessed the idea that the leading dancer in innovation should be the business sector even if the business sector funds a very small proportion of the R&D carried out in Universities and public research centres (Archibugi and Filippetti, 2016). Should we give universities and public research centres greater responsibility in efforts to disseminate and distribute the knowledge to final users?

- To what extent could the full potential of Biotech be tapped if properly integrated with the dominant general purpose technologies, i.e. ICTs? Is there the possibility that Biotech will manage to reinvigorate what has already been delivered by ICTs? In the past, cross-fertilization has multiplied the benefits of new technological opportunities. Can we forecast a successful alliance between ICTs and Biotech?

- Finally, there is the problem of identifying the impact of new technological opportunities. Do we have appropriate indicators to measure their economic impact in a changing context? So far, we have mostly concentrated on economic indicators, such as employment, sales and profits. These indicators are certainly crucial for business performance, but they need to be integrated with others able to assess their social benefits. The rise of Biotech may be one of the cases that force us to assess the potential of radically new innovations partly through social indicators, such as life expectancy or quality of life. If we do, perhaps we may be forced to re-evaluate the relative impact of Biotech and ICTs.

7. Back to the cinema?

As usual, cinema has been quick to forecast some of these opportunities: the film *Transcendence* by Wally Pfister already describes the total integration of Biotech, ICTs and another emerging technology of the 21st century, nano-technology. This science fiction film has taken into account the reality of exponential expansion of nano-technologies and their capacity to be as pervasive as ICTs have been over the last thirty years. The location should be noted: like *Blade Runner*, the film takes place in California, although the final parts, those devoted to the birth of revolutionary innovations, have been set in New Mexico, an area envisaged to become the leader from scratch. Such a suggestion might seem peculiar if the size and the absolute amount of R&D expenditure is taken into account, but it may seem less implausible given that New Mexico has the highest R&D to GDP ratio in the USA (as high as 8 per cent, see National Science Foundation, 2014, Chapter 8, Table 8-40).

The film *Transcendence* is suggesting that the integration of various domains of knowledge could be crucial and this will perhaps be another case where science fiction is able to provide an inspiration to captains of industry, scientists, bankers and politicians; sometimes science fiction may be pioneering and may act as a source for suggestions to be implemented in the real word (see the challenging review on the interactive relation between science fiction and innovation by Bassett et al., 2013). The film shows that the quality of human life could change substantially and the next major advances to shape our lives will not be associated with our ability to connect everywhere and with everybody, but with a better understanding of how our bodies work and how to use this information to increase our well-being. Portable devices that tell us instantaneously when it will rain this afternoon are already installed in the mobiles in our pockets, and there are apps teaching us how to prevent diseases in different environments. Soon new devices will be able, on the basis of our genome, to inform us of the effects of every single event in our organism and possibly even to fix it.

Through the exploitation of big data, new challenges such as growing urbanization, an ageing population and environmental risks could also be addressed through more advanced instruments.

If I watch *Blade Runner* again with my grand-children, my forecast is that they will be totally unimpressed by the innovations in both ICTs and Biotech, as an artificial cat tries to jump up on their lap. I wager that my grand-children will note with wry amusement that the film underestimated progress in all respects since the real advances will be occurring in nano-technologies or in areas for which I will have no understanding. When they pet me as the thick and rather dumb grandfather, I will shield myself with an evergreen lesson: economists, futurologists and business analysts often get it wrong. But artists, real artists, more often tend to get it right!

Acknowledgements

Previous versions of this paper have been presented at the Association of the European Schools of Planning (AESOP) Annual Congress 2014, Utrecht, July 2014; at the International Seminar convened by the Institute of Research on Innovation on "The New Agendas for Innovation Studies and Policy Implications", Madrid, March 2014; at the Science Policy Research Unit, University of Sussex, October 2014; and at the Workshop Explaining Economic Change, Sapienza University of Rome, November 2014. I wish to thank the participants in these and also Cristiano Antonelli, Luuk Boelens, Rosaria Conte, Andrea Filippetti, Marion Frenz, Ben Martin, José Molero, Paul Nightingale, Luigi Orsenigo, Pari Patel, Maria Savona, Ed Steinmuller and two referees for their comments on previous versions of this discussion paper. Special thanks goes to Ben Martin and Alice Pease for editing my English. A grant from the School of Business, Economics and Informatics of Birkbeck College is gratefully acknowledged.

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Table 1 - Phases of Capitalist Development and Pavitt's Categories of Firms

Period	Successive Techno-Economic Paradigms	Industrial organisation	Typical industries	Rise of Pavitt's category of firms
1770-1830	Early Mechanisation	Growing importance of small manufacturing firms	Textiles, Potteries, Machinery	Supplier dominated
1840-1880	Steam power and railway	Separation been producers of capital and consumption goods	Mechanical engineering, Steel and Coal	Specialized suppliers
1890-1930	Opportunities associated to scientific discoveries	Emergence of large firms	Chemicals, Electrical machinery, Engineering	Science based
1940-1980	Fordist and Taylorist revolutions	Oligopolistic competition for mass consumption	Automobiles, Synthetic products, Consumer durables	Scale intensive
1980-2010	Information and communication	Networks of firms, strong user-producer interactions	Microelectronics, Telecoms, Software	Information intensive

Source: Author's Elaborations on Freeman (1987), Table 15. Last column derived from Pavitt (1984; 1990).

Table 2 - Innovative firms' characteristics under the creative accumulation and creative destruction models

Categories	*Creative accumulation*	*Creative destruction*
Characteristics of the innovating firms	Innovations are driven by large, incumbent firms that seek new solutions through formal research exploiting their pre-existing capabilities.	Small firms, new entrants are the key drivers in the innovation process. They use innovation and economic turbulence to acquire market share from incumbent firms.
Type of knowledge sources	High relevance of past innovations and accumulated knowledge. Importance of formal R&D, in-house but also jointly performed or externally acquired.	Greater relevance of collaborative arrangements leaning towards the applied knowledge base (other firms). Exploration of new markets and technological opportunities.
Type of innovations	The innovation process is dominated by a large number of incremental innovations. Organizational routines dominate the generation of innovations.	The emphasis is on path-breaking innovations often able to create new industries. New organizational forms contribute to generating innovations.
Characteristics of the market	Barriers to entry are high due to relative importance of appropriation and accumulation of knowledge and high costs of innovation. Dominance of oligopolistic markets. Technological advancement based on path dependent and cumulative technological trajectories.	Low barriers to entry into the new industries. A high rate of entry and exit leads to low levels of concentration and high competition. Discontinuous technologies are available that generate growing markets and new opportunities.

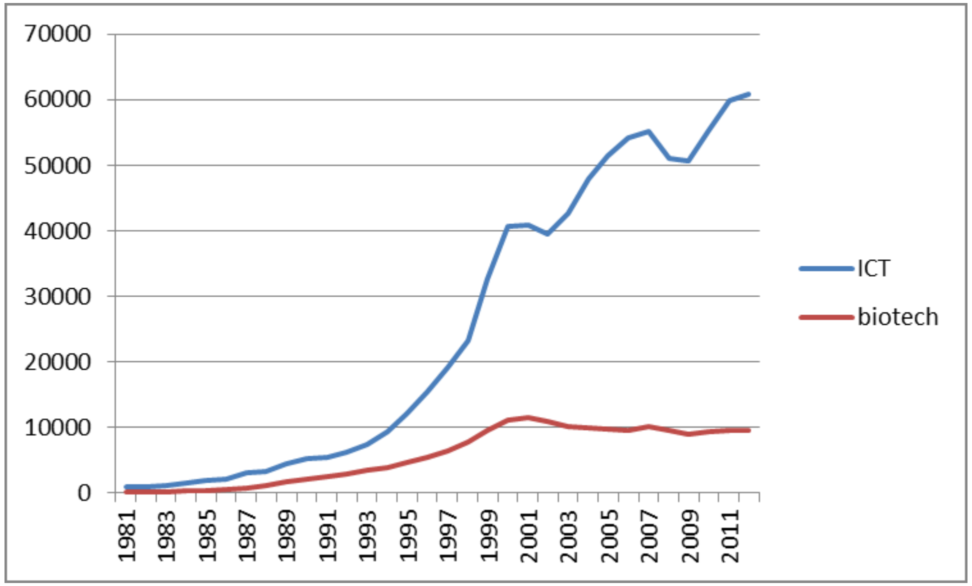
Source: Archibugi and Filippetti (2011) on the ground of insights of Freeman (1984a; 1992), Dosi (1982); Pavitt (1984; 1990), Malerba and Orsenigo (1995).

Table 3 – Estimated potential economic impact of technologies from sized applications in 2025, including consumer surplus $ trillion, annual to 2025

	Technologies	Estimated impact	
		Min	Max
1	Mobile Internet	3.7	10.8
2	Automation of Knowledge work	5.2	6.7
3	Internet of things	2.7	6.2
4	Cloud technology	1.7	6.2
5	Advanced robotics	1.7	4.5
6	Autonomous vehicles	0.2	1.9
7	Next generation genomics	0.7	1.6
8	Energy storage	0.1	0.6
9	3D printing	0.2	0.6
10	Advanced materials	0.2	0.5
11	Advanced oil and gas exploration	0.1	0.5
12	Renewable energy	0.2	0.3
	TOTAL	16.7	40.4

Source: McKinsey Global Institute (2013)

Figure 1 – Patents in ICTs and Biotech, 1980 - 2012



Source: OECD database, elaboration on Patent Cooperation Treaty by year of application,