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Notes and Comments

Innovation–diffusion, the economy and contemporary challenges: a comment

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Abstract

According to Christopher Freeman technological revolutions play a key role in capitalist development. In this article, we ask to what extent more recent developments are consistent with the perspective advanced by Freeman. We focus on two issues in particular, the climate challenge and what has been dubbed "*A Fourth Industrial Revolution*" that is, advances in artificial intelligence and the proliferation of the internet of things.

JEL classification: O33, O44, O43

1. Introduction

The article by Chris Freeman (2019) published in *Industrial and Corporate Change* raises a pretty fundamental question for economists and historians alike, namely how to explain the diversity in economic performance across countries and over time. The perspective developed by Freeman in the article, and further elaborated in a subsequent book (Freeman and Louçã, 2001), places innovation and diffusion at the core of the explanation. Nevertheless, this does not mean that Freeman is a technological determinist, depicting innovation–diffusion as an autonomous force driving societal change. Rather the argument is that innovation and diffusion, and particularly their economic impacts, crucially depend on developments in other social "subsystems" or spheres, and on the extent to which the changes in these different spheres of society are congruent that is, support (instead of counteracting) each other. In so doing, Freeman joins a stream of thought in economic history (Abramovitz, 1986, 1994a, b) and development studies (Adelman and Morris, 1967), to which he makes frequent reference, emphasizing the roles of broader social factors in growth and development. But, while much of this literature treats such social factors as general and time-invariant (Shin, 1996), Freeman, following Schumpeter, aims for a more historically specific approach in which economic development is analyzed as a succession of (technological) regimes with quite different properties. Being able to explain the dynamics of these different regimes—and the transition between them—in a satisfactory manner is according to Freeman the very test of theorizing in this area.

As Freeman would have been the first to recognize, the open-ended nature of economic evolution implies that such explanatory frameworks and the theoretical perspectives underpinning them will be in constant need of scrutiny (and possibly revision): "*As Time Goes By*," as he put it. Hence, in this article, we ask to what extent more recent developments challenge the perspective advanced by Freeman. We are going to focus on two issues in particular. The first relates to the relationship between man and nature. In the article, Freeman acknowledges that "ecological factors may predominate in in determining the rate and direction of economic growth during the course of the 21st Century" but chooses not to discuss the matter further. However, since the article was written, this matter has become much more pressing, as exemplified by the climate challenge, and in the next section, we consider the implications for contemporary and future economic development. A second issue, to be discussed in section 3, concerns what has been dubbed "*A Fourth Industrial Revolution*" (Schwab, 2017) that is, the combined effect of advances in artificial intelligence (AI) and the proliferation of the internet of things. In fact, Freeman was a pioneer in analyzing the revolution in information and communication technology (ICT) and its societal impact, but could the consequences be even more far-reaching? Finally, section 4 sums up the lessons and considers the relevance of Freeman's approach for policy making.

2. Sustainability?

In this section, we discuss to what extent Freeman's analytical framework may throw light on the transition the global economy needs to go through in order to be sustainable.

Following Schumpeter, Freeman analyzes long-run economic development as a succession of technological regimes with quite different properties. At the core of each regime is a constellation of radical innovations, the diffusion of which generates many new applications, and—for a while—strong economic growth. Sooner or later, however, the growth-inducing potential of these technologies will start to be exhausted, and growth will slow down. Several such regimes have been identified in the literature, starting with—as in the present paper by Freeman—the industrial revolution in Britain. More recent examples, discussed in more detail in a subsequent book, include a cluster of innovations dating back to the first half of the previous century connected to production and use of fossil fuels (oil and gas, petrochemicals, plastics, internal combustion engine, cars, airplanes) and—closer to our own time—the ICT revolution. According to Freeman, in both cases a key role was played by a core production factor characterized by wide applicability, almost unlimited availability, and rapidly declining prices, fossil fuels in the first case and semiconductors more recently.

The spread of the fossil fuel regime to all parts of the globe led to strong growth world-wide in the post-Second World War period, as well as a strong reduction in the gap in productivity and income between the USA and a number of other (mostly Western) countries. However, in the 1970s, cracks appeared in the regime as fossil fuel producing countries began to flex their muscles, leading to unstable supply and, eventually, much higher prices on the regime's core factor that is, oil and gas. Moreover, from around the turn of the century onwards it became increasingly evident that the expansion of the fossil fuel-based regime had an unpleasant side effect that is, global warming caused by emissions from burning fossil fuels, and that these emissions needed to stop if serious damage on the environment was to be avoided. This of course hit the fossil fuel-based regime at its core. Burning fossil fuels is simply not sustainable any longer: nothing less than a new, sustainable technological regime—respecting planetary boundaries—seems to be required.

The task of creating a sustainable technological regime may seem overwhelming. However, as Freeman points out, a new technological regime does not appear fully developed at once, but evolves slowly at the margins of the extant regime. In fact, the broad contours of an emerging sustainable regime may already be visible. Arguably, the core factor of the new regime will be renewable energy, mostly in the form of electricity, which—if environmentally damaging climate change is to be avoided—has to substitute for fossil fuels in most current applications. Although there is a range of renewable energy technologies on the market, solar and wind stand out amongst the "new renewables" with the largest potential. However, the term "new renewables" does not mean that these are very recent inventions. In fact, the development of these technologies dates back at least to the 1970s, when several Western governments—influenced by the so-called "oil crises" at the time—felt inclined to support the search for alternatives to fossil fuels. In the early years the US market, largely as a result of very favorable policies for deployment there, was of critical importance for the emerging renewable energy industry. Later, this role was taken over by European countries, for example, Denmark and Germany. The latter's ambitious "Energiewende" became especially important as it provided a rapidly growing market and clear targets for continuing improvement of the new renewables, in particular, wind and solar. In fact, the share of renewables in German electricity consumption increased from <5% before the turn of the century to over 35% in 2017 (Figure 1), while the costs of deploying the new technologies continued to decline to a level equal to—and in many cases below—other ways of producing electricity (e.g. fossil fuels or nuclear). As a

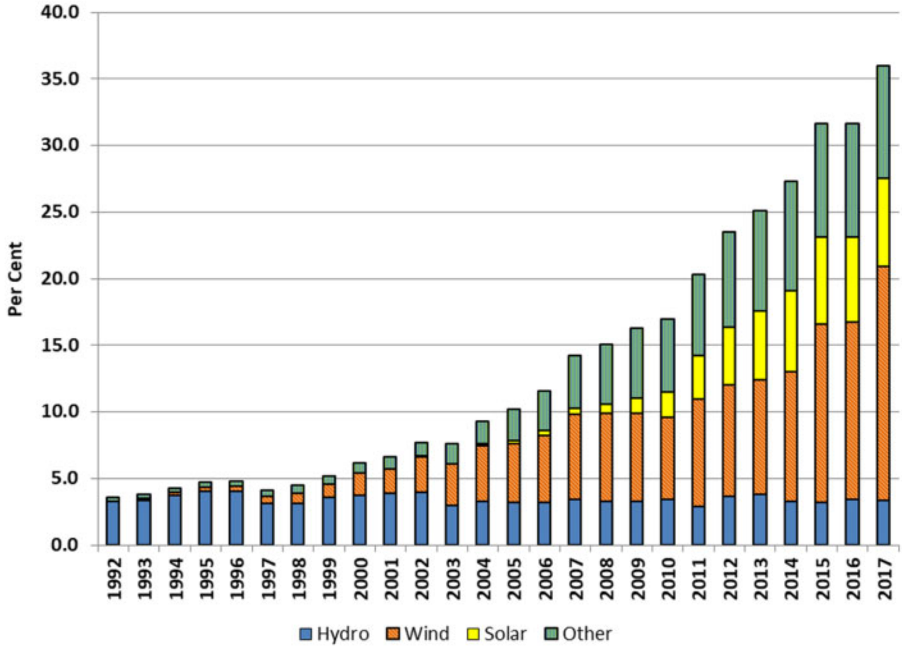

Figure 1. Renewables as a share of total German electricity. *Note:* Own calculations based on data from Bundesminister für Wirtschaft und Energie, http://www.bmwi.de/DE/Themen/Energie/Energiedaten-und-analysen/Energiedaten/gesamtausgabe, accessed on October 1, 2016, and, https://www.erneuerbare-energien.de/EE/Redaktion/DE/Downloads/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2017-excel.html, accessed on December 3, 2018.

consequence the demand for renewable energy technologies has grown rapidly world-wide, not the least in the developing part of the world, with China as the largest market globally (and an important producer of equipment as well).

Arguably, this pattern, that is, the provision of a factor (renewably produced electricity) with rapidly falling costs, potentially almost unlimited availability and very broad applicability, fits Freeman's narrative rather well, as pointed out by Mathews (2013, 2014). However, as emphasized above, these changes in renewable energy technologies—however revolutionary—are in themselves not sufficient to qualify as a new regime. To do that renewably produced electricity would need to substitute for fossil fuels in all parts of society, such as transport, heating/cooling, and industry, changes that will require numerous innovations in production, distribution, consumption, organization, and ways of life, the exact nature of which is difficult to foresee in detail. Continuing innovation in technologies for energy/electricity storage, distribution and use will no doubt be essential, for example, to make up for the fact that sun does not always shine and the wind does not always blow.[1] Nevertheless, in some areas change is already well underway, for instance, the need for change has revitalized the by now century-old concept of an electrical car, which currently is about to be cost-competitive with fossil fuel-driven cars, due to the much higher energy efficiency of electrical engines and, not the least, innovations in battery technology. As in the case of renewable energy technologies, costs have gone down over time as markets have expanded, to a large extent helped by favorable policies. For example, in Norway, where such favorable (diffusion-oriented) policies have been in place for a long time, electrical cars (zero emissions) now (June 2019) account for more than one-third of all new cars, compared with around 1% a decade ago.

In summary, this section has argued that a technological revolution with renewable energy as its core is well underway, although at different speed in different sectors/contexts, and that the broad contours of a new and more sustainable technological regime, though yet in its infancy, are clearly distinguishable. Several central features emphasized by Freeman, such as the role of a rapidly progressing core factor with multiple applications, and linked

1 Energy storage is essential in a system based on renewable energy, but it can be stored in several different ways, for example, in gas-form (hydrogen), and there is currently a lot of experimentation going on.

to a number of other radical innovations in a broad range of industries/sectors, are clearly prevalent in the present case as well. If the transition succeeds, the most damaging effects of climate change now foreseen may well be avoided, which would be a huge accomplishment for humanity.[2] However, the uneven pace of change across different sectors and parts of the globe raises doubts about whether the efforts will succeed (in time). As emphasized by Freeman, congruence of processes of change, extending beyond parts of a single nation to the global context, may be essential. A study of the transition so far also points to the central role of politics and civil society, categorized by Freeman in the political and cultural subsystem respectively, in driving change (Fagerberg, 2018). Arguably, these factors may be even more important in the future than in the past processes studied by Freeman.

3. A Fourth Industrial Revolution?

The other phenomenon to which we will try to apply Freeman's reasoning is the so-called Fourth Industrial Revolution (4IR). The notion of a 4IR fits Freeman's approach in the sense that it points to the large socio-economic impact that can be associated with a radical shift of technological paradigm. One may quarrel about the exact historical interpretation, as Freeman might look at this as a sixth industrial revolution rather than the fourth: he would typically distinguish the British industrial revolution (cotton, iron, and water power); steam and railways; steel and electrification; mass production, motorization, and fossil fuels; and ICT in its early format (silicon chips and data). But, the exact historical periodization and delineation is not of core importance in our view.

What matters more is the general setting in which the debate on the 4IR takes place. We would loosely define the 4IR as the creation of radically new technologies through use of advanced ICT (including AI) in more traditional and older parts of the techno-socio-economic realm , such as additive manufacturing (3D-printing), the internet of things, synthetic biology, etc. Much of the analysis of the 4IR consists of technological foresight studies and is hence subject to severe uncertainty and even speculation. But, interestingly, the core of such speculations revolves, to a large extent, around the central importance of the co-evolutionary nature of technology and the socio-economic environment, a point that Freeman makes in the current paper, as well as in other parts of his work.

For example, Schwab's (2015) opening statement is that:

> "[w]e stand on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. We do not yet know just how it will unfold, but one thing is clear: the response to it must be integrated and comprehensive, involving all stakeholders of the global polity, from the public and private sectors to academia and civil society."

Hyperbole apart, this is essentially a repetition of Freeman's argument that radical innovation may have a large economic impact only if the technological subsystem and other (social) subsystems coevolve in a symbiotic fashion.

One aspect of the 4IR that has received much attention in the academic literature is the likely effect that it may have in the labor market. Frey and Osborne (2017) provide an estimate of how many current jobs would be in risk of being replaced by 4IR technology, and conclude that

> "47% of total US employment is in the high risk category, meaning that associated occupations are potentially automatable over some unspecified number of years, perhaps a decade or two" (p. 265).

It is far from clear what the exact consequences of this will be. Some have taken it as a sign of massive unemployment,[3] but others, such as Vermeulen *et al.* (2018), expect the negative employment effects of automation to be compensated by the rise of new sectors and new jobs that are necessary to sustain the technology, hence they see no "end

2 Although a huge accomplishment, and essential for the transition to sustainability, other planetary boundaries may continue to merit concern. Sustainability would require that these are addressed as well, which would most likely require further changes, the nature of which cannot be dealt with in the necessary detail here.

3 For example, The Guardian headlined "Robots are the ultimate job stealers. Blame them, not immigrants," (https://www.theguardian.com/commentisfree/2018/feb/14/resentment-robots-job-stealers-arlie-hochschild) while Mother Jones warned that "You Will Lose Your Job to a Robot—and Sooner Than You Think" (https://www.motherjones.com/politics/2017/10/you-will-lose-your-job-to-a-robot-and-sooner-than-you-think/).

of work" on the horizon. This type of analysis is related to Freeman's work (with others) on the topic of employment and technological revolutions, for example, Freeman et al. (1982) and Freeman and Soete (1987). Although Freeman and co-authors do not shy away from analyzing the "employment compensation effects" of new technologies, they do not subscribe to the argument that over the long run there will be little or no employment effects of major technological revolutions. However, the emphasis in their work seems to be on the changes in (un)employment rates during the prolonged periods of strong structural change that arises from the introduction from new radical innovations, and, in particular, the changes in skill requirements that this causes (e.g. Freeman et al., 1982, chapter 7; Freeman and Soete, 1987, chapter 8).

Apart from the employment effects of 4IR, there may (also) be a very significant shift in the (functional) income distribution that will require major changes in social protection policies (for a theoretical argument to support this view see Nomaler and Verspagen, 2019). However, the relevance of these kinds of policies was not so much highlighted by Freeman and co-authors in their work on employment and technology. For example, Freeman and Soete (1987: 254–255) state that

> "[. . .] in order to achieve sustained employment growth [. . .] we would see some scope for macroeconomic wage and incomes policies [. . . but . . .] we would see more scope for long-term occupational wage flexibility, and occupational mobility, with [. . .] major training implications".

In our view, perhaps the 4IR is a reason to re-asses this conclusion. For example, AI may potentially replace even high-skill tasks, such as analyzing legal texts. This means that even some high-skill workers will have to accept wage rates that are able to compete with machines (or software), potentially leading to a very high degree of inequality. Unless, we develop policies for the labor market and social protection that will keep inequality within bounds, the upcoming 4IR may be unsustainable because of socially unacceptable levels of inequality. Moreover, for the 4IR to succeed, it will have to develop within the context of the renewable energy transition that we discussed earlier. We therefore conclude with a brief discussion of the role of 4IR technologies in dealing with the climate challenge (see e.g. Perez, 2016).

Figure 2 compares the share of "green" patents in patents associated with so-called smart manufacturing, which we consider as the core of the 4IR, and the share of green patents in all patents.[4] 4IR (smart manufacturing) patents appear as set of technologies with above-average green content. In 1990, the relative occurrence of green in smart manufacturing was about 1.8 times as high as in all patents, and this increases to about 15 times as high in 2015 before it falls back somewhat (but remains much above the share in all patents). In fact, the green patents in smart manufacturing are mainly found in one specific technology class: "Enabling technologies with a potential contribution to greenhouse gas [GHG] emissions mitigation" (Y02 P 90) and specifically "Total factory control, e.g. smart factories, flexible manufacturing systems [FMS] or integrated manufacturing systems [IMS]" (/02). This points to a close connection between the emerging 4IR and the renewable energy revolution.

4. Concluding remarks

Our reading of Freeman's "History, Co-evolution and Economic Growth" (2018) is that his perspective is more relevant than ever. The article provides a core theoretical argument about how the interaction between technology, the economy, and the broader social and political system crucially shapes long-run economic development. This theory is a radical break with mainstream economics, most of all because of the role that it assigns to coevolution. As a result of this co-evolutionary perspective, the article continues to provide a fresh view on the causal relations between endogenously generated technological developments and the transformations to which they are associated.

A basic strength of Freeman's approach is that it relates to the core challenges of today's global economy. It sketches a crucial understanding of the broad factors that drive structural transformation and development, how

4 The figure uses patent families to eliminate double counting when a patent is filed in more than one jurisdiction. For the definition of smart manufacturing technologies, see Foster-McGregor *et al.*, 2019, which is the source of the underlying data. The data exclude 3D printing. To identify green patents, we use the so-called Y02 tag, which is a code that may be attached to a patent in case it is seen (by the patent examiners) as contributing to climate change mitigation. The data for all «patent families» uses DocDB patent families in PATSTAT.

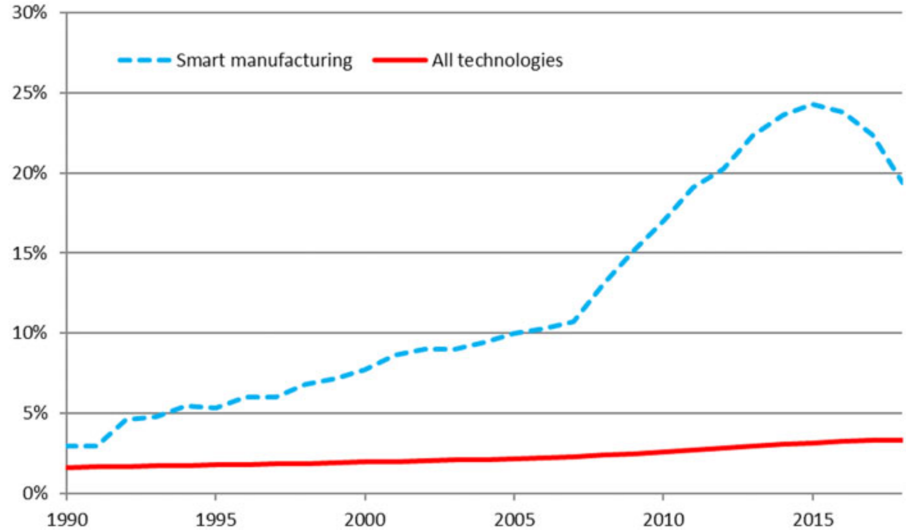

Figure 2. Share of green technologies in smart manufacturing patents and in all patents.

these factors interact, and the way in which core problems, such as those related to climate change, may emerge in this process. It also provides at least a starting point for thinking about solutions to such problems, as is clear from the various references to policy in the paper.

Since the publication of Freeman and Louçã (2001), this line of inquiry has no longer been a central part of economics, although, at least we would argue, it is a key ingredient in the transition literature (as summarized by, e.g. Laestadius, 2015). With the climate problem more pressing than ever, and global leaders in dire need of potent policies to initiate and sustain an effective policy against it, Freeman's approach has the potential of greatly increasing the relevance of the economics discipline for policymaking. The approach is also relevant for analyzing other major technological developments, such as the so-called 4IR that is expected to have large effects on employment and the income distribution, and for the interaction between this and other macro-scale technological changes. Indeed, following Freeman's approach, one might argue that with the right vision and policy, the 4IR may be of great help in solving the climate crisis, putting the global economy on an equitable and green trajectory.

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