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Notes and comments

Introduction: Chris Freeman's "History, Co-Evolution and Economic Growth": an affectionate reappraisal

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Abstract

We maintain that Chris Freeman's approach to the study of the interplay between technical change and economic growth is still a very fertile source of insights. Alas, in much of mainstream research Freeman's contribution is hardly considered. We show that this is a result of the basic assumptions of neoclassical growth theory (both "old" and "new") that prevent a pregnant treatment of technical and institutional change. We conclude that if we want to make real progress with understanding the long-run dynamics of capitalist systems, Freeman's "reasoned history" is an invaluable starting point.

JEL classification: 033, 040, 043

1. Introduction

The first issue of *Industrial and Corporate Change* (2019) features the paper "History, Co-Evolution and Economic Growth" by Chris Freeman (2019). The paper, which in this day and age will probably appear as unusually long, rich and dense to many young readers, was originally written in 1995 as a working paper for the research project *System Analysis of Technological and Economic Dynamics* at the International Institute for Applied Systems Analysis (IIASA) coordinated by one of us (Dosi). Many of the themes touched in the paper were subsequently further elaborated and revised in the classic volume *As Time Goes By* (Freeman and Louçã, 2001).

Together with Richard Nelson, Sidney Winter, and Nathan Rosenberg, Chris Freeman was one of the "founding fathers" of the modern economics of innovation (Mowery *et al.*, 2019). The breadth and depth of his contributions to this field cannot be underestimated, ranging from the development of quantitative indicators for the systematic measurement of scientific and technological activities, to detailed empirical studies of the sources, drivers and effects of technical change in key-industrial sectors, to the formulation of challenging interpretations of the patterns of technical change and their connections with the long-run economic growth both in advanced and developing countries.[1] Besides, Chris Freeman is still universally acknowledged as a wonderfully inspiring scholar by virtue of his unique "human touch" made of kindness, warmth, and generosity with little patience for any form of affectation or posture.

1 For useful assessments of Chris Freeman's contributions, see Dosi. G (2010), Soete and Dosi (2010), and Fagerberg *et al.* (2011).

On these grounds, the decision to publish "History, Co-Evolution and Economic Growth" can be seen simply as an overdue tribute to commemorate one the most important scholars in the field of innovation studies.

Still, Chris' paper continues to present several points of interests touching fundamental analytical and policy challenges that some further reflections are in order. This special section of *Industrial and Corporate Change* contains commentaries to Freeman's paper by Richard Nelson (2020), Jan Fagerberg and Bart Verspagen (2020), Francisco Louçã (2020), and a full article by David Sainsbury (2020). These commentaries all agree in pointing out that the paper will repay careful reading and they discuss the wealth of insight emerging from it. All the commentaries can be read and appreciated in their own right, so we do not think it is necessary to summarize them in detail in this Introduction. Rather, we prefer to provide a further direct commentary to the paper highlighting some issues that we believe are of extreme importance for our understanding of the long-run process of economic growth. We shall start by recalling the major historical issues that any interpretation of "modern economic growth" (Kuznets, 1973) must tackle.[2] Next, we discuss Freeman's interpretation building on his view of technological change. Then, we move to the interplay between technology, institutions, and economic performance. Finally, we consider Freeman's assessment of the British industrial revolution as a testbed for his suggested framework for "reasoned history," also in the light of some recent research on the subject.

2. Modern economic growth: the interpretative challenges

There are at least three fundamental "stylized facts" of "modern economic growth" which also represent major challenges to historians and economists alike[3]:

(SF1) *First*, how and why did we observe*, for the first time in human history* and in a small portion of the entire world, a secular persistent growth in per capita incomes?

Figure 1 provides a snapshot on the beginnings of modern economic growth using the available estimates originally constructed by Angus Maddison (Figure 1a) and the subsequent refinements of the Maddison Project (Figure 1b).[4] Needless to say, both sets of data are fragile and they need to be regarded as tentative conjectures on the comparative contours of long-run economic growth (Nuvolari and Ricci, 2013). Still, they show a picture which is consistent with more qualitative accounts (see among others, Landes, 1969; von Tunzelmann, 1995) and that it is probably reasonably accurate, at least in its broad outlines. For the period, 1500–1700, the estimates are also consistent with Kuznets' view that the maximum long-term growth rate for a pre-industrial economic system could not exceed the 0.2% per year (Kuznets, 1973: 139). Around the second half of the 18th century, there is a marked acceleration in the rate of economic growth, taking place, first in England, and then spreading to other Western countries. This acceleration is, of course, an outcome of the industrial revolution. In this perspective, the industrial revolution appears to be a key turning-point in human history. Before it, economic growth was sluggish and stagnation in living standards was the dominant feature of economic life. The industrial revolution marks the beginning of a new historical phase characterized by sustained economic growth. Accordingly, as aptly noted by Freeman in his paper, the origins of the contemporary world economy are to be found in the fundamental changes it introduced.

(SF2) *Second*, why is modern economic growth associated with a secular divergence in per capita income itself? What accounts for it? Or putting it bluntly, why did some countries get rich and other remain dreadfully poor?

Remarkably, in the period considered in Figure 1a and b (1000–1913) the process of "catching-up" is a prerogative of Western countries. For non-Western countries (Japan, China, and India), catching-up is essentially limited to Japan during the Meiji era. In this case, the fundamental point to emphasize is vividly illustrated in Figure 2 (taken from Allen, 2011: 6). Around 1750, China and India were producing all together >50% world manufacturing output

2 Kuznets defined Modern Economic Growth in these terms: 'The epochal innovation that distinguishes the modern economic epoch is the extended application of science to the problems of economic production.. ...By science we mean the study of observable and testable characteristics of the physical world in accordance with the canons of validity accepted by groups of practitioners called scientists. By science-based technology we mean applied knowledge which rests, in the reliability of its predictions and practices, upon the verified general knowledge in the sciences and upon specific observations on materials and so on' (Kuznets, 1966: 8–9).

3 For a more articulated discussion (see Dosi *et al.*, 1994).

4 The source for the data in Figure 1a is Maddison (2007) and for Figure 1b is Bolt and Van Zanden (2014). The data are available at https://www.rug.nl/ggdc/historicaldevelopment/maddison/ (accessed on March 26, 2020).

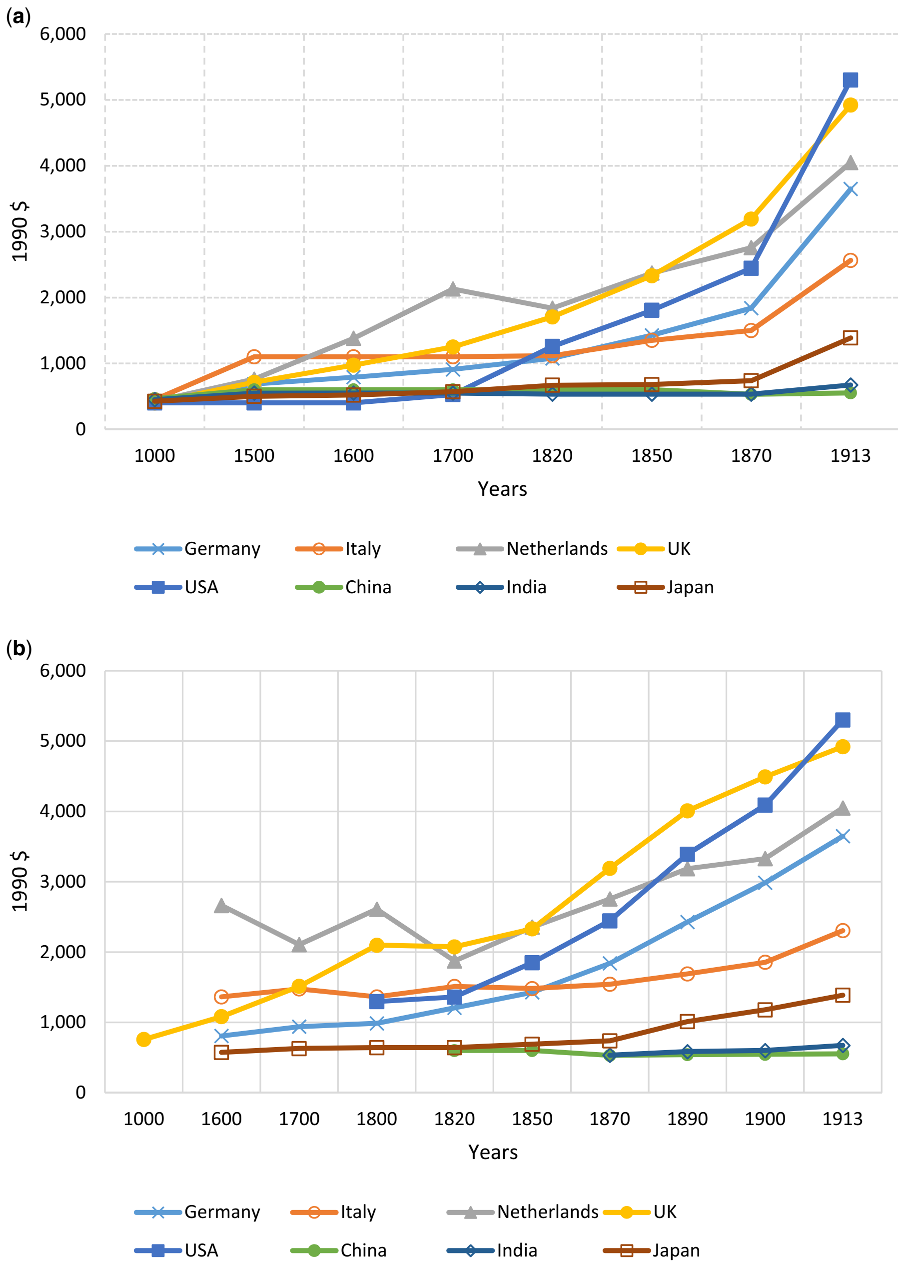

Figure 1. (a) Comparative levels of GDP per capita in selected countries (1990 GK$). *Source*: Maddison (2007). (b) Comparative levels of GDP per capita in selected countries (1990 GK$). *Source*: Bolt and Van Zanden (2014).

(again the underlying data should be considered more as controlled conjectures rather than exact figures). Clearly, Figure 2 shows that the industrial revolution was associated with a major shift in the distribution of global manufacturing output, with industrializing countries increasing dramatically their share, while the shares of non-Western (non-industrializing) countries were progressively shrinking until approximately the early 1950s. This suggests that industrialization, in the sense of the adoption and development of modern technologies for the production of

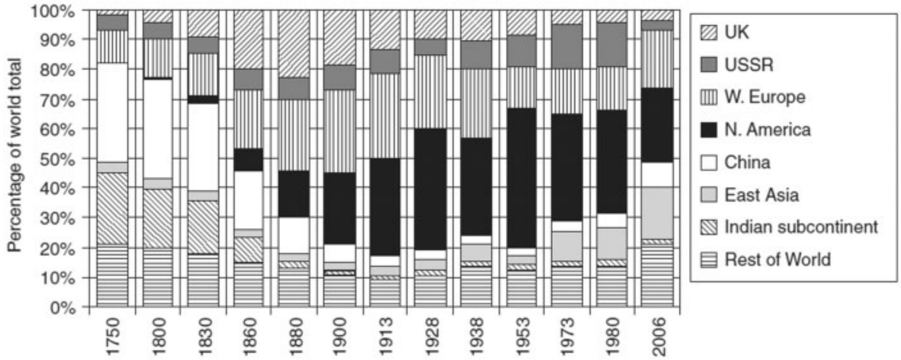

Figure 2. The geographical distribution of world manufacturing output, 1750–2006. *Source*: Allen (2011: 6).

Table 1. Rate of growth of GDP per capita in selected countries (annual average compound growth rates)

	1000–1500	1500–1820	1820–1870	1870–1913	1913–1950	1950–1973	1973–2003
UK	0.12	0.27	1.26	1.01	0.93	2.42	1.93
USA		0.36	1.34	1.82	1.61	2.45	1.86
Italy	0.18	0	0.59	1.26	0.85	4.95	1.72
The Netherlands	0.12	0.28	0.81	0.9	1.07	3.45	1.67
Germany	0.1	0.14	1.08	1.61	0.17	5.02	1.58
China	0.06	0	−0.25	0.1	−0.56	2.76	5.99
India	0.04	−0.01	0	0.54	−0.22	1.4	3.14
Japan	0.03	0.09	0.19	1.48	0.88	8.06	2.08

Source: Maddison (2007: 383).

manufactures, is a major driver of the patterns of convergence and divergence in the world economy during the nineteenth and a large portion of the 20th century.

(SF3) *Third*, what accounts for fluctuations at different frequencies, and for rarer deeper crises, even in the exponential growth of "developed" economies?

Table 1 shows the average growth rates in GDP per capita taken from the original Maddison dataset. Two points emerging from the table merit attention. The first is again the dramatic discontinuity brought about by the industrial revolution. The second is that after the industrial revolution there have been significant changes in the rate of economic growth. Interestingly enough, some of these historical phases have clearly an international coverage. For example, the period 1913–1950 appears to be a phase of relatively weak economic performance in all the countries of the table, while, on the other hand, the period 1950–1973 is a period of buoyant economic growth on a world scale. For a long time, economists have addressed the issues of economic growth without paying much attention to these major historical discontinuities that marked the long-run evolution of the world economy, which are not easily accommodated in steady-state growth models. As clearly emerging from Freeman's paper, a proper understanding of the process of economic growth requires the development of an interpretative framework that can account in a plausible way for the different and variable growth rates experienced by the different countries. Freeman's insight was that such a framework ought to be based on a careful investigation on the interaction between patterns of technical change and the evolution of the socio-institutional set-ups.

3. Technical change and long-run aggregate fluctuations

The debate about SF1 and SF2 has traditionally been largely left to economic historians, until damages done recently by economists in their imperialist drive to claim large territories of economic history as a testbed for growth models.

In retrospect, economists, cared, if they cared at all, about SF3, but indeed, after Marx and Schumpeter, very few addressed it in a systematic manner. And they cared even less about the relevant role of technological change.[5]

Freeman (1982) laments this state of affairs. In fact, the systematic investigation of the drivers of long-term economic growth came mostly with the aggregate analyses by Moe Abramovitz (1956) and Bob Solow (1957) essentially *by default*. Up to the early 1980s, in the predominant view epitomized by the Solow model economic growth proceeded smoothly at a stable growth rate. In the Solow model technical change was reckoned as the key driver of economic growth, but it was considered to be the outcome of autonomous developments in science and technology and, accordingly, treated as an exogenous factor, which could, for many purposes, be approximated by a constant time drift in the production function. In this framework, as any economics-trained student knows, one starts with the description of aggregate income with a formula like:

$$Y(t) = A(t) * F[L(t) + K(t) + \ldots]$$

where Y is income at time t, L, K are labor, capital, and whatever else are the inputs at that same time t. And, $A(t)$ is a time dependent shift parameter. Finally, the F[.] function is meant to capture the impact of the accumulation of inputs upon output.

It turns out that no matter the "Kamasutra" of stock variables one puts within the F[.] function, in time-series estimations of the dynamics of Y, its contribution is relatively small as compared with $A(t)$—which economists mostly take for "total factor productivity growth," while, more pointedly, Abramovitz (1956: 11) originally dubbed it the "measure of our ignorance about the causes of economic growth."

Given such a theoretical formulation and such evidence, there have basically three types of responses.

A *first* one addressed the theory and the implications of the way the F-function has been written down. Of course, nobody denies that, in general, in order to have some output you need some input. But, the largely preferred functional form—a degree-one homogeneous function—does not hold:

1. Even under very demanding equilibrium assumption it is simply logically inconsistent: recall the "capital controversy" (for an overview, see Harcourt, 1969).
2. With (nearly) constant distributive shares it is a sheer algebraic tautology (Shaikh, 1974)
   Add to that:
3. From all we know now from the empirical evidence on technology, such representation of technology itself is simply caricatural (as if, given the appropriate relative prices one could produce one million tons of steel with one kilowatt of electricity but one billion people breathing on iron oxide! More on this issue in Dosi and Nelson, 2010).

A *second* stream of responses has led to efforts to "look inside the residual," which Nate Rosenberg called "opening up the black box" (Rosenberg, 1982). A great deal of such investigations has gone on since, but, we are sure, the Abramovitz's and Solow's did not disagree with the Nelson, Winter, Rosenberg and, indeed, outstandingly, Freeman that the movement of the clumsily detected "residual" was due, to a good extent, to the movements of the *endless frontier of scientific and technological knowledge* (Bush,1945). This stream basically did not dwell on the conceptualization of the process of economic growth in terms of a production function (indeed much too little), but, basically studied in detail at the sources and procedures of innovation, as radically distinct activities from sheer allocation processes. In our view, this is basically what the all *economics of innovation* is (or at least was at its inception) about. And, it has enormous ramifications in several domains of economic analysis, including theories of the firm and of industrial dynamics driven by *heterogeneous capabilities* of firms and other non-market organizations, and their evolution. Indeed, as Nelson (2020) and Sainsbury (2020) argue in this volume, the evolution of knowledge and capabilities is at the core of the explanation of the development patterns of different nations (Dosi *et al.*, 2009).

A *third* stream of research has followed fundamentally the opposite route, trying to explain away the "residual" and "endogenize" it. One drive was mainly empirical at least at the beginning, adding further variables to the Kamasutra of factors comprised in the production function, from capital to human capital, social capital, natural resources, and climate. Despite all these efforts, success in squeezing the size of the "residual" has not been so high. Another drive to the same end, much more successful in academic terms, starting from the theory with much smaller attention to the empirics, has been the "new growth revolution." Building on the, *correct*, acknowledgment that a

5 This section draws partially on Nuvolari (2019).

good deal of technological search is undertaken by business firms, it assumed also that the search can be reduced to an allocative activity similar to the one postulated for whatever goes on within the *F*-function (so, now the billion workers may either breath on iron oxide or on "ideas," which in turn enters into the productivity of either the kilowatt of energy or the breathing on the iron . . .).

There is indeed a major recognition in Freeman's work of the importance of firms' search activities. But neither he nor, for that matter, any other founding father of the economics of innovation could have ever imagined in their worst nightmares that such activities could be squeezed back into the standard theory of optimal allocation of resources by forward looking agents, perhaps with "rational technological expectations" (?!).

As we have suggested, in Freeman's world one did not care much about the strictures of the *F*-function. Dosi in his team cared more, being familiar with the "Cambridge controversy," whereas on the other side of the Atlantic did not care at all, perhaps unjustly fearing to disappoint the Arrow and Solow of this world (see Dosi's comments, in Teece, 2019). In any case, we were all busy in understanding what was going on within the "black box," discovering indeed lots of regularities and properties. When most of us realized, if at all, the import of the *Counter-Reformation* coming along in the form of endogenous growth theory, it was far too late.

Moreover, on the other side of the Atlantic our friends were looking inside the micro box, never moving to the macro (Dick Nelson was an exception, albeit mainly on the institutional side, see below). In this, Chris Freeman was bold and tried head-on to launch a research program that could connect explicitly the effects of technological change with macro dynamics. In this task, Chris Freeman and his associates (Luc Soete, J. Clark, Luc Soete, and Carlota Perez) argued for a revisitation of Schumpeter's perspective of long waves of economic development driven by technical change (Freeman *et al.*, 1982; Freeman and Perez, 1988, Freeman and Louçã, 2001; Fagerberg and Verspagen, 2020; Louçã, 2020, this volume).

This "post-Schumpeterian view" (the term "neo" being now hijacked by the orthodox "new" growth theories) is based on the notion of "technological system." With this term Freeman and his co-authors defined a "constellation" of innovations endowed with strong technological and economic linkages. As a case in point, one can think at the complementarities between steam engines, machine tools and machinery, and iron production techniques during the first industrial revolution. One of the salient features of some "technological systems" is their degree of pervasiveness, in the sense that they are suitable of being adopted in a wide range of industrial activities.[6] According to Freeman and his colleagues, the long-term evolution of capitalist economies has been characterized by the deployment of a sequence of these pervasive technological systems. In this perspective, the economic history of capitalist economies is not characterized by a stable steady-state growth path, but by long-run waves of development, namely historical phases in which economic growth is rather robust and sustained, intertwined with periods in which the growth process is relatively sluggish and the overall economic performance (in terms of productivity growth, output growth, unemployment, etc.) of the system is bleak.

As mentioned, the second half of the 1980s witnessed also the emergence of the "new (neoclassical) growth theory." In this approach, technical progress was not only regarded as the (endogenous) driving force of economic growth, but it was claimed that its dynamics could be finally explained using conventional economic analysis.

There is an interesting and little-noticed difference between the "old" and the "new" version of neoclassical growth theory, in addition to what was discussed above, which Freeman in his paper points out. The "old" neoclassical growth theory did not pretend to be a theory of economic history (Hahn and Matthews, 1964; see also Hahn, 1988). The more circumspect and less ambitious aim of many of the "old" neoclassical growth models was to illustrate the behavior of a set of critical variables assuming that a number of very restrictive assumptions were satisfied. Of course, it was reasonable to hope that an improved understanding of the mechanics of growth in these imaginary situations—"golden ages" (using an expression coined by Joan Robinson) more likely to belong to some mythical

6 "Changes in technological systems. . .are far-reaching changes in technology, affecting several branches of the economy, as well as giving rise to entirely new sectors. They are based on a combination of radical and incremental innovations, together with *organizational* and *managerial* innovations. . .some changes in technological systems are so far-reaching in their effects that they. . .have *pervasive* effects throughout the economy. . .the changes involved go beyond engineering trajectories for specific product or process technologies and affect the input cost structure and conditions of production and distribution throughout the system" (Freeman and Perez, 1988: 46–47). Freeman and Perez term these technological systems (or combination of technological systems) capable of exerting these major reverberations on the economic systems as "techno-economic paradigms."

lost world rather than to the actual course of history of mankind—could contribute to shed some light on the growth record of capitalist economies. However, at least among the most attentive contributors to the neoclassical approach as Hahn himself, claims laid in this direction were particularly modest. As Hahn and Matthews stated in their survey, it was rather clear that historical patterns of economic growth could not be adequately described by means of steady-state growth models (Hahn and Matthews, 1964).

This seemed to have changed in the new growth theory and well as in the "neo-institutionalist" models which we shall discuss later on. Not only is there the claim that the new models can finally provide an adequate picture of the endogenous process of technical change. A number of contributions have also contended that endogenous growth models may be applied in a rather straightforward way to the study of economic history (Romer, 1996).

In particular, this claim seems to characterize a particular stream of breed of endogenous growth theory, the so-called general purpose technologies (GPTs) growth models which emerged during the mid-1990s. This class of models is essentially a "domestication" in the ambit of endogeneous growth theory of a number of key-ideas that were originally expounded by Freeman and his associates. Sadly, in most cases this endeavor has been carried out without a proper acknowledgment of Freeman's contributions.[7] In the original formulation proposed by Bresnahan and Trajtenberg (1995), GPTs, which represent a counterpart of the concepts of "technological systems" and of "techno-economic paradigm," are defined as technologies endowed with three salient characteristics: (i) they perform some general function, so they can be employed in a wide range of possible application sectors, (ii) they have a high technological dynamism, so that the efficiency with which they perform their function is susceptible of being continuously improved, and (iii) they generate "innovation complementarities," that is to say that their adoption stimulates further rapid technical progress in the application sectors. Steam power, electricity, and information and communication technologies (ICTs) are most frequently put forward as clear-cut examples of GPTs. Although changing the assumptions concerning the structure of technical change, these models retain the traditional neoclassical micro-foundations based on perfectly rational agents and market equilibrium.

The innovative aspect of this class of endogenous growth models is that they generate patterns of growth that are also characterized by alternating phases of acceleration and deceleration determined by the implementation of successive GPTs, producing, on a long time scale, a Schumpeterian wave-like profile, even if this is the effect of rather mechanic properties of the models. More specifically, these models assume that each new GPT requires a rather long period of "acclimatization" in the economic system. Hence, the initial impact of GPT on productivity growth is limited. This phase of sluggish dynamics of productivity concludes when the GPT is finally fully "acclimatized" in the economic system and it can exert its full potential. In that instance, the rapid rate of technological change in the GPT and in the application sectors (due to the innovation complementarities of the GPT) produces an acceleration in the rate of overall productivity growth. Finally, as the scope for further improvements in the GPT is progressively exhausted, this phase of rapid productivity growth will gradually peter out.

GPT models are appealing because they hold the promise of providing a simple, albeit insightful account in which the long-term dynamic of productivity growth is driven by the diffusion of radical innovations following the well-known S-shaped paths.[8] However, when moving from the models to their application to economic history, the matter becomes immediately thorny. The first note of skepticism toward GPT models has been voiced in an important contribution by Field (2011). According to Field, the three criteria used for assessing whether a technology deserves the accolade of "GPT" when looked closely, are far from straightforward. In fact, one of the main directions of the evolution of the GPT literature has consisted in the "discovery" of more and more GPTs, besides steam, electricity, and ICT (from other technologies such as the internal combustion engine and the water wheel to organizational innovations such as the factory system and mass production, to bodies of engineering knowledge such as chemical engineering). This is rather disquieting since it probably indicates that, at least so far, that the GPT framework is not really equipped for properly

7 For surveys of this stream of literature see Jovanovic and Rousseau (2005) and Bresnahan (2010). Neither of them mentions Freeman's contributions.

8 For an example of this approach see Jovanovic and Rousseau (2005).

Table 2. Pavitt taxonomy and long waves of capitalist development

Period	Techno-economic paradigm	Industrial organization	Typical industries	Pavitt's category of firms
1770–1830	Early mechanization	Independent small manufacturing firms	Textiles and Pottery	Supplier dominated
1840–1880	Steam engines and railways	Separation between producers of capital and consumer goods (Rosenberg)	Mechanical engineering, and machine tools	Specialized suppliers
1890–1930	Emergence of science-based technology	Corporate R&D and large-firms	Chemicals and electricity	Science based
1940–1980	Fordism	Large corporations MNC (Chandler), mass consumption	Cars, synthetic products, and consumer durables	Scale intensive
1990–....	ICTs	Large corporations, network of firms	Microelectronics, Software, and Internet	Information intensive

Source: based on Archibugi (2001).

identifying what are the genuine key-technological developments that are underlying the process of long-run economic growth.[9]

However, even if we limit ourselves to the three most obvious suspects, namely steam, electricity, and ICT, the application of GPT growth models to the historical record remains fraught with difficulties. This because it is difficult to summarize the development of these technologies by means of a simple S-shaped diffusion path. The development of these technologies is characterized by discontinuities and ruptures. In this context, identifying an initial and final moment and tracing a precise path for the diffusion process becomes an exercise involving a large degree of arbitrariness (see Nuvolari, 2019, for a discussion of this issue in the case of steam power). In other words, the GPT approach features an overly simplified chronology of technical diffusion that is not really effective in accounting for the observed dynamics of economic growth. So far, economic historians who have attempted to apply the GPT framework to economic history have been disappointed (Crafts and Mills, 2004; Ristuccia and Solomou, 2014).[10] The main conclusion emerging from this line of research is that the focus on a few key technologies such as the steam, electricity, and ICT seems to be much too narrow a perspective for the study of the connection between the long-term evolution of 7technology and economic growth.

In comparison, Freeman's notion of "technological systems" and of "techno-economic paradigm" is characterized by a broader "coverage"—both longitudinally (as it includes a number of interlinked technologies) and temporally (as it acknowledges the possibility of a sequence of radical innovations within the same technological system). As such it is more in tune with received accounts of history of technology and economic history.

Yet, even considering the broad concept of "technological system," it must be recognized that the task of thoroughly tracing a connection between the deployment and demise of particular technological systems and "waves" of

9 Also David and Wright (1999: 10) have put forward a similar concern with respect to the increasing number of GPTs identified in the literature: "One has only to consider the length of such proposed lists of GPTs to begin to worry that the concept may be getting out of hand. History may not have been long enough to contain this many separate and distinct revolutionary changes. . .. On closer inspection, it may be that some of these sweeping innovations should better be viewed as sub-categories of deeper conceptual breakthrough in a hierarchical structure. Alternatively, particular historical episodes may be fruitfully understood in terms of interactions of one or more GPTs on previously separate historical paths." Interestingly enough, the revision to the concept of GPT proposed by David and Wright is stretching it towards the notion of technological systems originally suggested by Freeman.

10 It is worth citing the conclusions of Crafts and Mills (2004: 170) who have attempted, from a broadly sympathetic point of view, to interpret British 19th century productivity trends in terms of the diffusion of steam power as a GPT: "seeking to base an account of 19th century British growth primarily on the implications of steam is surely misconceived. The newfound enthusiasm for General Purpose Technology models as a way of conceptualizing long run growth processes should not be taken too far."

economic growth is still largely unfulfilled (and maybe unfulfillable!). Freeman and his associates (see, in particular, Freeman and Louçã, 2001) in their appreciative accounts have assembled some highly suggestive evidence in this direction. They have also suggested the existence of a number of mechanisms such as backward and forward linkages, technological spillovers, investment multipliers of particular technologies, etc. that might indeed account for the economy-wide repercussions of the diffusion of these technological systems. However, a precise assessment of the economic impact of technological systems based on the available historical data on the adoption of various technology and on productivity growth is still lacking,[11] and, as Louçã (2020) suggests, might be statistically unattainable even in principle if one abandons any naïve notion that "cycles" repeat themselves with the same features and same regularities. Indeed, as noted by Perez (2015), the chronology of technological systems proposed by Freeman and Louçã was only partially consistent with the traditional Kondratiev chronology of long waves. Accordingly, Perez (2015) has recently proposed a reformulation of the original framework in which "technological systems" are related to "great surges of development," each characterized by an "installation period" and a "deployment period." Perez's surges of development are not to be interpreted as coherent economic phases in terms of macro-economic indicators, but rather as phases in which the broad production system is rearticulated around the newly emerging technological system. It is worth noting that Perez's (2015) framework still posits a connection between technical change and economic outcomes in the form of major financial crises that characterize the "exuberance" of investment in the early installation period of the new technological system.

When the notion of "technological system" is used in such a way as to encompass the entire life-cycle of a broad constellation of technologies (i.e. steam power, machinery, iron production techniques) the long-term evolution of capitalist economies seems to be better captured by a different chronological scheme, based on the more traditional distinction between the "first industrial revolution," "second industrial revolution," and "third industrial revolution," than by the one based on Kondratiev waves (von Tunzelmann, 1995: 97–100). The virtues of this alternative periodization are explicitly discussed by Freeman and Louça (2001: 145). In particular, they are very explicit in recognizing that "the *entire* life-cycle of a technology system will usually be much more than a century" (Freeman and Louçã, 2001: 145). Still, they maintain that there is the possibility of establishing some link between technical change and economic performance in terms of the particular phases in the development of each technological system. Be this as it may, it is clear that the more flexible and broad periodization in terms of the classic three industrial revolutions (with a possible Fourth one in its earliest phase, see Fagerberg and Verspagen, 2020) may represent a useful framework for interpreting the historical record, while still keeping many of the insights of Freeman's approach (Nuvolari, 2019).

Interestingly enough, the perspective outlined so far can be connected with another fundamental "work horse" of the economics of innovation literature: the Pavitt taxonomy of patterns of innovative activities (Archibugi, 2001). In this perspective, the taxonomy should be interpreted in a dynamic rather than in the conventional static-descriptive fashion. According to Archibugi, each Schumpeterian wave described by Freeman and his associates, may be linked with the emergence of a new type of firms whose patterns of innovative activities are described by a specific category of the Pavitt taxonomy (see Table 2).

Notably, if we take this approach, it becomes clear that perhaps in many Schumpeterian accounts, too much emphasis has been put on the notion of "creative destruction." In fact, the constellation of innovations that are at the origins of the three industrial revolutions have led to the emergence of new types of firms characterized by different innovation behaviors. However, this does not imply that pre-existing firms have been completely superseded, but, more plausibly, that the structure of the economic system is becoming more articulated and complex. In other words, the current production system is constituted by an overlap of layers of the technological systems of the first, second and third industrial revolutions. As noted by Pavitt himself in an early appraisal of the economy-wide impact of ICT technologies, when assessing newly emerging technological trends, it is crucial to take properly into account "the differentiated and cumulative nature of technical change" (Pavitt, 1986: 45). In particular, he noted that improvements in information technologies were going to be clearly affected by the existing technological trajectories. Rather than "creative destruction" the penetration of information technologies across application sectors was going to determine processes of "creative accumulation" with information technologies being integrated into the existing "local" procedures of innovation.

11 To date, the only systematic attempts to assess the contribution of steam power technology to productivity growth (in Britain) are represented by von Tunzelmann (1978) and Crafts (2004).

4. Structural crises and institutional transformations

As important as technology is for the process of development, it can hardly be the sole driver of it. It might well be *a necessary conditio, a primus inter pares*. Witness the fact that quite a few of the inventions with major importance for the first industrial revolution had their origins outside England, where the revolution actually happened (MacLeod, 2004). Indeed, a fundamental point emerging from Freeman's paper is the fundamental socio-institutional embeddedness of economic processes. Accordingly, in Freeman and Perez (1988), the deployment of a new "techno-economic" paradigm involves a major restructuring of the whole production system. This process of restructuring involves, in its turn, a deep transformation of the social and institutional framework (Freeman and Louçã, 2001; Louçã, 2020).

The notion of socio-institutional framework refers to the social-arrangements that ensure a broad consistency among the dynamics of productivity and key macro-economic aggregates, including patterns of consumption and investment, income distribution, capacity utilization, etc. The approach of Freeman and Perez introduces a characterization of the economic system which is embedded in a set of socio-institutional arrangements that works as homeostatic mechanisms (Dosi, 1984). The "downswing phase" of the long wave is the outcome of a mismatch between the newly emerging techno-economic paradigm and the delayed adjustment of the socio-institutional framework. In these phases, the macroeconomic system becomes particularly fragile with sluggish growth and increased volatility (Dosi and Virgillito, 2020). Interestingly enough, this vision of the growth process is very close to that put forward by that of the French "Regulation School" (Boyer, 1988, 1990).[12] This approach considers the phases of relatively successful capitalist development such as the so-called Golden Age (1945–1975) of Western capitalism as the outcome of a well-tuned congruence between an underlying "regime of accumulation" and a "mode of regulation" which is a specific ensemble of institutional forms ensuring the reproduction of capitalist property relations by stabilizing the prevailing regime of accumulation. Both the Freeman and the Regulation School approaches point to the existence of social institutional arrangements that provide mechanisms of adjustment of economic processes, well beyond the simple functioning of any price-driven allocation system. In doing so, it is straightforward that a detailed depiction of the configuration of the institutional set-ups is necessary in order to account for the ways the social-institutional framework is regulating the evolution of the techno-economic paradigms.

Notably, Freeman's perspective on institutions is not only focused on the issue of coordination that is, the role of the socio-institutional framework in coordinating the material reproduction of the system, but it also considers explicitly the issue of the distribution of power and exploitation, as is explicit in his account of the British industrial revolution. Hence, in Freeman's framework institutional forms are to be understood as genuine *constitutive social relations* rather than simply as *rules of the game* à la North (North, 1991).

Accordingly, Freeman (2019) and Freeman and Louçã (2001) introduce new dimensions shaping the patterns of economic change with the five relatively autonomous, but *co-evolving* domains, namely,

- scientific knowledge,
- technology,
- the "economic system,"
- the political set-ups,
- the "cultural system."

The central methodological tenet of Freeman's "reasoned history" is that a proper understanding of the interplay between institutional set-ups and technical change should be rooted in this broader interpretative frame in which all the elements above are considered.

It is instructive to compare Freeman's approach with the neo-institutionalist approaches that are practiced today in many areas of mainstream economics. The mentioned view of institutions is that of "rules of game" (North, 1991) which provide the set of incentives with which fully rational agents are confronted. In this perspective, power, and socially determined beliefs and preferences are completely ruled out of the analysis. It seems appropriate, therefore, to term the current neo-institutionalist vogue as a form of "weak-institutionalism," in the sense that institutions are merely a scaffold in which the interactions among rational economic agents take place. Interestingly enough, if one

12 For a discussion of the overlaps between evolutionary perspectives and the French School of Regulation see Coriat and Dosi (2002).

looks beyond economics, considering other domains of the social sciences, an alternative perspective on institutions was there since the classics (just think e.g. of Weber, Dewey, Durkheim, Commons, Marx). In this latter view, which we can label as "strong-institutionalism" institutions do not play simply a parametric role, but they inform the very choices and behavior of the agents. In other words, in this approach it is not possible anymore to neatly separate the decision-process of the individual agents from the institutional context, since the institutional context may shape the very preferences of the agents (Dosi *et al.*, 2020).

Interestingly enough, most of the recent research on institutions has tried to document the connection between different institutional forms and economic performance by means of econometric exercises. In this vein, most of the efforts have been devoted to the elaboration of identification strategies that could tackle effectively the issue of the potential endogeneity of the institutional variable of interest with respect to economic performance (Acemoglu *et al.*, 2005). Although the emphasis has been laid on the issue of endogeneity, the quantitative characterization of institutional variables has been approached with very crude methods. As a result, the main research finding emerging from this strand of research consists in very reductionists accounts that point to the virtues of very broad notions of institutional forms such as "secure property rights" or "inclusive institutions." When considered in this perspective, it seems that the recent research agenda on institutions prevailing in economics is not really able to break interesting new ground, despite its econometric sophistication (Dosi *et al.*, 2020).

Freeman's approach is completely antithetical to these neo-institutionalist accounts of growth. In Freeman one finds an explicit consideration of the complexity of institutional forms and their co-evolutionary dynamics with the other sub-systems. This is clearly a much more sophisticated and nuanced approach to the study of institutions. And it does not neglect the paramount importance of technological change discussed above. Again, also in this respect, Freeman and Louçã (2001) can be regarded as a starting point for a challenging research agenda, which will certainly *not* yield some "institution-augmented" growth accounting exercise (contribution of property right institutions x%, contribution of capital accumulation y%, contribution of "social capital" z% ...), but rather as an interpretative thread able to dissect the varied historical experiences and to provide compelling interpretations of long-run growth paths.

5. Co-evolution and the British Industrial Revolution

The wealth of insight emerging from this approach is evident in its application to the case of the British Industrial Revolution. Remarkably, even if a considerable amount of research on this crucial historical episode has been carried out since Freeman's paper was written, the paper still provides a fresh and compelling synthesis. In particular, it is worth emphasizing that most recent and influential contributions on the British Industrial Revolution such as that of Allen (2009) and Mokyr (2009) have been trying to identify an ultimate trigger of the industrial revolution. In Allen's view, the trigger is represented by the "high wage economy" of pre-industrial Britain, while in Mokyr's case, the trigger is the "industrial enlightenment." To be sure, in both Allen's and Mokyr's contributions the overall account of the process takes place against the background of a complex pattern of historical transformation in which there is an interplay between multiple factors. Still, in Freeman's perspective, the emphasis of co-evolution and congruence or mis-matchings seems to be able to highlight a number of critical issues that in monocausal explanations may become blurred.[13] For example, while in Allen's account the role played by military success and aggressive mercantilism as a critical factor for the emergence of the "high wage economy" remains somewhat implicit (Allen, 2009: 110), in Freeman's synthesis the point is given a very explicit consideration.

Relatedly, Freeman's inquiry on the British Industrial Revolution, even if focusing on the dominant trajectories of "mechanization" and the development of steam power technologies, remains alert to the variety in the patterns of technical change. In this perspective, the industrial revolution should be interpreted as a process of co-evolution among scientific development, technical advancement, economic change, political transformation, and cultural evolution leading to the emergence and consolidation of an effective and "pluralistic" national innovation system (Freeman and Louçã, 2001: 153–174). The key point is that technological change and economic transformation proceeded on a broad front. The 18th-century British economy and society provided a nurturing environment for the

13 Freeman's interpretation is here in tune with Roy Porter's account 18th-century English social history: "Naturally, rapid industrialization did not have just one single cause: it depended on the felicitous chemistry of many disposing elements" (Porter, 1990: 312).

increasing interactions between inventors, entrepreneurs and financial backers, scientists, engineers, skilled workmen, and users. In these context, inventive activities were organized using different organizational set-ups and they also differed in terms of the approaches adopted in search activities (ranging from those who practiced a scientific approach such as James Watt, to those who adopted systematic engineering procedures of trial and error and parameter variation such as John Smeaton and Josiah Wedgwood, to inspired tinkerers such as James Hargreaves). In this way, Freeman's paper clearly points to the importance of encompassing the inquiry on long-run economic growth in a broad narrative frame in which political, cultural, and social dimensions are also considered.

6. Conclusions

Our discussion of Freeman's paper has been carried out with a focus on some key methodological issues emerging from it. The main lesson, in our view, is that the paper shows that "there is another way." This is important because more and more scholars seem to share the belief that, despite its methodological sophistication, the current treatment of technological and institutional change in mainstream economics is not really yielding much in terms of genuine new insights. Of course, we must be aware that the richness of Freeman's paper depends also, to a large extent, on his talent as a scholar able to span different social sciences and combining them with historical research. It would be wrong, therefore, to consider the Freeman's framework for reasoned history as a blueprint or a recipe that can be simply taken off the shelf and applied to specific empirical cases. This would amount to a much too rigid interpretation of the approach. Rather, the framework should be probably better understood as a list of ingredients or in terms of very broad guidelines. The actual application will naturally require much creative ingenuity in the handling of the different sources and in the integration of quantitative and qualitative evidence. But, on reflection, this is actually one further reason for embarking in the direction blazed by the paper.

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References

Abramovitz, M. (1956), 'Resource and Output Trends in the United States since 1870,' *American Economic Review*, **46**, 5–23.

Acemoglu, D., Johnson S. and Robinson J. (2005), 'Institutions as a fundamental cause of long run economic growth,' in P. Aghion and S. Durlauf (eds), *Handbook of Economic Growth*. Elsevier: Dordrecht, The Netherlands.

Allen, R. C. (2009), *The British Industrial Revolution in Global Perspective*. Cambridge University Press: Cambridge, UK.

Allen, R.C. (2011), 'The spread of manufacturing,' in Neal, L. and Williamson, J. (eds.), *The Cambridge History of Capitalism*, Volume II. Cambridge University Press: Cambridge.

Archibugi, D. (2001), 'Pavitt's taxonomy sixteen years on: a review article,' *Economics of Innovation and New Technology*, **10**(5), 415–425.

Bolt, J. and Van Zanden J. L. (2014), 'The Maddison Project: collaborative research on historical national accounts,' *Economic History Review*, **67**, 627–651.

Boyer, R. (1988), 'Technical change and the theory of "Régulation"' in Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds.), *Technical Change and Economic Theory*. Pinter: London.

Boyer, R. (1990), *The Regulation School: A Critical Introduction*. Columbia University Press: New York, NY.

Bresnahan, T. (2010), "General Purpose Technologies," in B. Hall and N. Rosenberg (eds), *Handbook of the Economics of Innovation. Volume II*. Elsevier: Amsterdam, The Netherlands.

Bresnahan, T. and Trajtenberg M. (1995), 'General Purpose Technologies: "engines of growth"?,' *Journal of Econometrics*, **65**(1), 83–108.

Bush, V. (1945), *Science, the Endless Frontier: A Report to the President*. U.S. Government Printing Office; Washington, DC.

Coriat, B. and Dosi G. (2002), 'Evolution and *regulationary* theories: similarities and differences,' in R. Boyer and Y. Saillard (eds), *Regulation Theory. The State of the Art*. Routledge: London, UK.

Crafts, N. F. R. (2004), 'Steam as a general purpose technology: a growth accounting perspective,' *Economic Journal*, **114**(495), 338–351.

Crafts, N. F. R. and Mills T. (2004), 'Was the 19th century British growth steam powered?: the climacteric reconsidered,' *Explorations in Economic History*, **41**(2), 156–171.

David, P. and Wright G.. (1999), 'General Purpose Technologies and surges in Productivity growth: Historical reflections on the future of the ICT Revolution,' University of Oxford. *Discussion Papers in Economic and Social History no*. 31.

Dosi, G. (1984), 'Technology and conditions of macroeconomic development: some notes on adjustment mechanisms and discontinuities in the transformation of capitalist economies,' in C. Freeman (ed.), *Innovation, Design and Long Cycles of Economic Development*. Royal College of Arts: London, UK.

Dosi, G. (2010), 'Christopher Freeman: a social scientist and a progressive intellectual,' *Science and Public Policy*, **37**(8), 631–635.

Dosi, G., Cimoli M. and Stiglitz J. (2009), *Industrial Policy and Development: The Political Economy of Capabilities Accumulation*. Oxford University Press: Oxford, UK.

Dosi, G., Freeman C. and Fabiani S. (1994), 'The process of economic development: introducing some stylized facts and theories on technologies, firms and institutions,' *Industrial and Corporate Change*, **3**(1), 1–45.

Dosi, G., Marengo L. and Nuvolari A. (2020), 'Institutions and economic change: some notes on self-organization, power and learning in human organizations,' *Eurasian Business Review*, **10**(1), 1–22.

Dosi, G. and Nelson R. (2010), 'Technical change and industrial dynamics as evolutionary processes,' in B. Hall and N. Rosenberg (eds), *Handbook of Economics of Innovation*. Elsevier: Amsterdam, The Netherlands.

Dosi, G. and Virgillito M. (2020), 'In order to stand up you must keep cycling: change and coordination in complex evolving economies,' *Structural Change and Economic Dynamics*, forthcoming.

Fagerberg, J., Fosaas M., Bell M. and Martin B. (2011), 'Christopher Freeman: social science entrepreneur,' *Research Policy*, **40**(7), 897–916.

Fagerberg, J. and Verspagen B. (2020), 'Innovation-diffusion, the economy & contemporary challenges: a comment,' *Industrial and Corporate Change*, **29**(4).

Field, A. (2011), *A Great Leap Forward. 1930s Depression and US Economic Growth*. Yale University Press: New Haven, CT,

Freeman, C. (1982), *The Economics of Industrial Innovation*. Frances Pinter: London, UK.

Freeman, C. (2019), 'History Co-evolution and economic growth,' *Industrial and Corporate Change*, **28**(1), 1–44.

Freeman, C., Clark J. and Soete L. (1982), *Unemployment and Technical Innovation*. London. Pinter.

Freeman, C. and Loucã F. (2001), *As Time Goes by: From the Industrial Revolutions to the Information Revolution*. Oxford University Press: Oxford, UK.

Freeman, C. and Perez C. (1988), 'Structural crises of adjustment, business cycles and investment behavior,' in G. Dosi. (eds.), *Technical Change and Economic Theory*. Pinter: London, UK.

Hahn, F. H. (1988), 'Neoclassical Growth Theory,' in J. Eatwell, M. Milgate and P. Newman (eds), *The New Palgrave: A Dictionary of Economics*. Macmillan: London, UK.

Hahn, F. H. and Matthews R. C. O. (1964), 'The theory of economic growth: a survey,' *Economic Journal*, **74**(296), 779–902.

Harcourt, G. (1969), 'Some Cambridge controversies in the theory of capital,' *Journal of Economic Literature*, **7**, 369–405.

Jovanovic, B. and Rousseau P. (2005), 'General Purpose Technologies,' in P. Aghion and S. Durlauf (eds), *Handbook of Economic Growth. Volume IB*. Elsevier: Amsterdam. The Netherlands.

Kuznets, S. (1966), *Modern Economic Growth, Rate, Structure and Spread*. Yale University Press: New Haven, CT.

Kuznets, S. (1973), 'Modern economic growth: findings and reflections,' *American Economic Review*, **63**, 247–258.

Landes, D. S. (1969), *The Unbound Prometheus. Technological Change and Industrial Development in Western Europe from 1750 to the Present*. Cambridge University Press: Cambridge, UK.

Louçã, F. (2020), 'Chris Freeman forging the evolution of evolutionary economics,' *Industrial and Corporate Change*, **29**(4).

MacLeod, C. (2004), 'The European origins of British technological predominance,' in L. Prados de la Escosura (ed.), *Exceptionalism and Industrialisation. Britain and Its European Rivals*. Cambridge University Press: Cambridge. UK.

Maddison, A. (2007), *Contours of the World Economy, 1-2030 AD*. Oxford University Press: Oxford, UK.

Mokyr, J. (2009), *The Enlightened Economy. An Economic History of Britain, 1700-1850*. Yale University Press: New Haven, CT.

Mowery, D., Malerba F., Dosi G. and Teece D. (2019), 'Introduction: Nathan Rosenberg as a founding father of the economics of innovation,' *Industrial and Corporate Change*, **28**(2), 283–288.

Nelson, R. (2020), 'On reasoned history,' *Industrial and Corporate Change*, **29**(4).

North, D. (1991), 'Institutions,' *Journal of Economic Perspectives*, **5**(1), 97–112.

Nuvolari, A. (2019), 'Understanding successive industrial revolution: a "development block" approach,' *Environmental Innovation and Societal Transitions*, **32**, 33–44.

Nuvolari, A. and Ricci M. (2013), 'Economic growth in England, 1250-1850: some new estimates using a demand side approach,' *Rivista di Storia Economica*, **29**, 31–54.

Pavitt, K. (1986), '"Chips" and "Trajectories": how does the semiconductor influence the sources and directions of technical change?,' in R.M. MacLeod (ed.), *Technology and the Human Prospect*. Pinter: London, UK.

Perez, C. (2015), 'From "long waves" to "great surges": continuing in the direction of Chris Freeman's 1997 lecture on Schumpeter's business cycles,' *European Journal of Economic and Social Systems*, **27**, 69–79.

Porter, R. (1990), *English Society in the Eighteenth Century*. Penguin: Harmondsworth, UK.

Rosenberg, N. (1982), *Inside the Black Box: Technology and the Economy*. Cambridge University Press: Cambridge, UK.

Ristuccia, C. and Solomou S. (2014), 'Can general purpose technology theory explain economic growth?: electrical power as a case study,' *European Review of Economic History*, **18**(3), 227–247.

Romer, P. (1996), 'Why, indeed, in America?: theory, history and the origins of modern economic growth,' *American Economic Review*, **86**, 202–206.

Sainsbury, D. (2020), 'Towards a dynamic capability theory of economic growth,' *Industrial and Corporate Chang*, **29**(4).

Shaikh, A. (1974), 'Laws of production and laws of algebra: the humbug production function,' *Review of Economics and Statistics*, **56**(1), 115–120.

Soete, L. and Dosi G. (2010), 'Chris Freeman: the person,' *Science and Public Policy*, **37**(8), 629–630.

Solow, R. (1957), 'Technical change and the aggregate production function,' *Review of Economics and Statistics*, **39**(3), 312–320.

Teece, D. (2019), 'Roundtable discussion Nathan Rosenberg Memorial issue,' *Industrial and Corporate Change*, **28**(2), 409–417.

von Tunzelmann, G. N. (1978), *Steam Power and British Industrialization to 1860*. Clarendon: Oxford, UK.

von Tunzelmann, G. N. (1995), *Technology and Industrial Progress. The Foundations of Economic Growth*. Edward Elgar: Aldershot, UK.