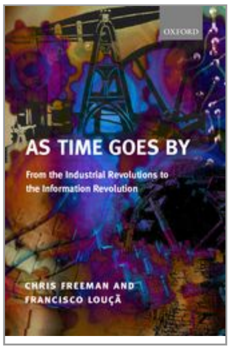

As Time Goes By: From the Industrial Revolutions to the Information Revolution

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Print publication date: 2002
Print ISBN-13: 9780199251056
Published to Oxford Scholarship Online: November 2003
DOI: 10.1093/0199251053.001.0001

(p.137) Part II Successive Industrial Revolutions

(p.138)

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DOI:

In Chapter 1 of the book we have attempted to justify some strong criticism of cliometrics as a method and theory of history. We also criticized some long wave theories, including those of Kondratiev in Chapters 3 and 4, for their attempts to use standard econometrics, rather than a deeper analysis of qualitative change, in their interpretation of long-term fluctuations in the economy. Finally, in Chapter 2 we made some criticisms of Schumpeter for his lack of a consistent approach to the use of history in economics, despite his frequently declared enthusiasm for the subject. Nevertheless, we argued that both Kondratiev and Schumpeter made outstanding contributions to economic history with their long wave theories. In particular, we agree with Schumpeter that any satisfactory explanation of the evolution of capitalist economies must place innovations, their profitability, and their diffusion at the centre of analysis. Such a view is by no means confined to Schumpeter and his followers or to so-called 'evolutionary' economists. Historians and other social scientists have generally accepted a view of technical change as one of the major sources of the qualitative transformation of the economic system. A particularly notable recent example of this recognition of the fundamental importance of innovation in the evolution of social systems is the volume edited by Ziman (2000) on *Technological Innovation as an Evolutionary Process*. Differences emerge not in the recognition of the importance of technical innovations, but in the ways in which they are classified, measured, and analysed and how their relationship with other social and economic phenomena is interpreted.

Some economists take the view that technical change has been and is still today always a slow and gradual process. While accepting the importance of such gradual incremental improvements in many products and processes as those described by Gilfillan (1935) in relation to the ship, or by Hollander (1965) in relation to rayon plants, or by Hughes (1982) for electric power generation and distribution, we share Schumpeter's (1939) view that the appearance and diffusion of innovations is inherently a very uneven process and is sometimes explosive, sometimes very gradual. Furthermore, the clustering of innovations may give rise to phenomena best described as ‘technological revolutions’. Consequently, it is essential to take into account discontinuities as well as continuity, both for individual innovations and for whole families of innovations that are interdependent. The Canadian economist Keirstead (1948) in his book on Schumpeter's economics described (p.140) these changing configurations as ‘constellations’ of innovations, and we shall adopt this expression in our own analysis.

There is some resistance to such an approach. Many economists who appreciate the importance of innovations nevertheless concentrate their attention on specific innovative projects, rather than tackle the huge complexity of attempting to generalize about the entire process. Still others argue that since history, including technological history, is a unique process, and since innovations are so varied, our project is in principle unsound. In particular, some historians and economists reject the concept of ‘technological revolutions’ to describe some of the major changes, such as electrification or computerization.

As we have seen in Chapter 1, some historians even reject the concept of the industrial ‘revolution’ itself. Such attitudes have become rather less common since the widespread application of information technology in every branch of the economy. This led many people to accept some such description of events as the ‘microelectronic revolution’ or the ‘information revolution’. It is hardly possible to pick up a newspaper or a magazine today without some reference to the ‘Internet Revolution’ or the ‘Computer Revolution’. However, there is a serious point behind the objection to the expression ‘revolution’, which it is important to address. Are the major processes of technical change an infinite series of marginal improvements to already established techniques, or are there significant discontinuities which are better described as ‘radical innovations’ or, in the case of combinations of such innovations, as ‘technological revolutions’?

We take the latter view, and, following Schumpeter, we believe that the changes that have occurred in the last two and a half centuries are well described as ‘successive industrial revolutions’. We shall attempt to justify this view in this second part of the book by assembling the evidence for such pervasive and profound changes in industrial structure and technology. These changes, we shall attempt to show, appeared to contemporaries, as well as to ourselves and to competent historians since, to represent major discontinuities and to merit our designation of technological revolutions.

We shall quote at some length the comments of contemporary observers, including novelists and artists, to illustrate the point that these clusters of innovations had a dramatic impact at the time, even though, as time goes by, their novelty is blurred and they may become just part of the landscape. In Table 1, for each great technological revolution we cite a few contemporary events that were especially conspicuous and that clearly demonstrated not only the technical feasibility of major new products or processes, but also their huge potential profitability. Andrew Tylecote (1992) originally used this method, and we follow him in believing that such dramatic 'demonstration effects' were extremely important in establishing for a wide public the likelihood and the dawning reality of a technological 'revolution'. Many people began to jump on the Schumpeterian bandwagon after these events. In part, whether or not the expression 'revolution' is used to describe them is simply (p.141)

Table II.1. Condensed Summary of the Kondratiev Waves

Constellation of technical and organizational innovations	Examples of highly visible, technically successful, and profitable innovations	'Carrier' branch and other leading branches of the economy	Core input and other key inputs	Transport and communication infrastructure	Managerial and organizational changes	Approx. timing of the 'upswing' (boom) 'downswing' (crisis of adjustment)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1. Water-powered	Arkwright's Cromford	Cotton spinning	Iron	Canals	Factory systems	
mechanization of	mill (1771)	Iron products	Raw cotton	Turnpike roads	Entrepreneurs	1780s–1815
industry		Water wheels	Coal	Sailing ships	Partnerships	
	Henry Cort's 'puddling'	Bleach				1815–1848
	process (1784)					
2. Steam-powered	Liverpool–Manchester	Railways and	Iron	Railways	Joint stock companies	
mechanization of	Railway (1831)	railway equipment	Coal	Telegraph	Subcontracting to	1848–1873
industry and		Steam engines		Steam ships	responsible craft	
transport	Brunel's 'Great Western'	Machine tools			workers	1873–1895
	Atlantic steamship (1838)	Alkali industry				
3. Electrification of	Carnegie's Bessemer steel	Electrical equipment	Steel	Steel railways	Specialized professional	
industry, transport,	rail plant (1875)	Heavy engineering	Copper	Steel ships	management systems	1895–1918
and the home		Heavy chemicals	Metal alloys	Telephone	'Taylorism'	
		Steel products			Giant firms	1918–1940

	Edison's Pearl St. New					
	York Electric Power					
	Station (1882)					
4. Motorization of	Ford's Highland Park	Automobiles	Oil	Radio	Mass production and	
transport, civil	assembly line (1913)	Trucks	Gas	Motorways	consumption	1941–1973
economy, and war		Tractors, tanks	Synthetic materials	Airports	‘Fordism’	
	Burton process for	Diesel engines		Airlines	Hierarchies	1973–
	cracking heavy oil (1913)	Aircraft				
		Refineries				
5. Computerization	IBM 1401 and 360 series	Computers	‘Chips’ (integrated	‘Information	Networks; internal,	
of entire economy	(1960s)	Software	circuits)	Highways’	local, and global	??
	Intel microprocessor	Telecommunication		(Internet)		
	(1972)	equipment				
		Biotechnology				

(p.142) a question of semantics. Whereas meteorologists can reach agreement about which wind force should be designated as a 'storm', a 'gale', or a 'hurricane', it has proved more difficult for historians and economists to agree on what constitutes a 'revolution'. Some observers regard the diffusion of electronic computers as the gradual extension of the use of other calculating and measuring devices, such as slide rules, tabulating machines, and the abacus; others find no problem in regarding the events of the late twentieth century as the 'computer revolution'.

It was, of course, true that some of those industries, which later became most characteristic of the Industrial Revolution, were already growing in the sixteenth or seventeenth or even earlier centuries—many innovations in textile machinery, for example, were being made in the Middle Ages, and some of the major social and cultural changes that are often regarded as part of the climate of the Industrial Revolution began much earlier. Nevertheless, we would maintain that the acceleration of the rate of growth of several key industries in the late eighteenth century, the wave of inventions and innovations that made such acceleration possible, and the shift from domestic to factory production did constitute a set of events which legitimate the use of the expression 'revolution'. We shall attempt to justify this view with supporting evidence in Chapter 5.

Even though the critics rightly insist that the new products and industrial techniques were initially confined to a few sectors, they nevertheless comprised new modes of developing, producing, transporting, and distributing a widening range of goods and services. Such discontinuities have long been familiar to archaeologists with their taxonomies of 'Stone Age', 'Bronze Age', 'Iron Age', etc. We shall argue that there is a justification for a similar approach to the far more rapidly changing and complex technologies of industrial societies. In this second part of the book we hope to provide convincing evidence to justify this approach.

It has been common parlance for a long time among historians to use such expressions as 'the age of steam' or the 'age of electricity', even if only for convenient descriptive periodization. As we have argued in Part I, this type of taxonomy is needed not just for convenience, but because it enables us to develop a better understanding of the successive patterns of change in technology, in industrial structure, and, indeed, in the wider economic and social system. Most historians of technology have recognized and emphasized the importance of the *systemic* features of technology (Gille 1978; Hughes 1982). The innovation and diffusion of new products and new processes are not isolated events, but are always and necessarily related to the availability of materials, energy supply, components, skills, infrastructure, and so forth. Very often, again as Schumpeter observed, innovations appear in clusters and are rarely, if ever, evenly distributed over time or in space. There are obvious reasons why this should be so, such as scientific discoveries which open the gates to whole families of new products, as for example, with biotechnology or macro-molecular chemistry. A new or rapidly growing (p.143) source of energy or materials may have similar effects, as with oil and electricity. Rikard Stankiewicz (2000) has described this as the opening up of new ‘design space’ for engineers and entrepreneurs, while Bresnahan and Trajtenberg (1995) coined the expression ‘General Purpose Technologies’ (GPTs) to describe those changes that have very pervasive effects. Much earlier, Nelson and Winter (1977) used the expression ‘generalized natural trajectories’ to describe this phenomenon.

While recognizing that scientific discoveries may have a major influence on the development of general purpose technologies, this does not of course mean that we subscribe to the much-abused ‘linear model of innovation’. The relationship between science and technology is an interactive one and, as we hope to show in the following chapters, new constellations of innovations depend on advances in both.

This second part of the book is about how such new constellations emerge, spread, and ultimately come to dominate an industrial society for a few decades before giving way, after a period of several decades of great turbulence, to the next such combination. We suggest that these phenomena underlie the ‘long waves’ of capitalist development that have been identified and studied by many economists as shown in Chapters 2–4. The denial of the existence of these long waves is based mainly on the formal use of simplistic econometric techniques for the measurement of ‘trends’ in aggregates such as GDP, industrial production, and so forth. But, as Schumpeter already insisted, such aggregates conceal as much as they reveal, since they ignore those structural and qualitative changes in the economy that are at the heart of the process of economic growth. In Part I we argued that it is not just the *aggregate* growth of the GDP that is important, but the emergence of new industries and the adoption of those new technologies, which make growth possible. Louçã (1997) has written a critique of the purely econometric approach to business cycles, and the first part of this book has further developed this critique. Part II has an additional purpose: to analyse in some depth those processes of technological, structural, and social change that give rise to long waves of development. The next chapter attempts such an analysis for the first Kondratiev wave, while the following chapters (6, 7, 8, and 9) attempt it for the later waves.

Schumpeter was, of course, the principal economist to build his theory of cycles primarily on innovations and their diffusion, and our approach owes much to his pioneering work. However, as Chapter 2 has shown, it differs from his in some important respects. He exhorted later writers to amend his work in the light of new evidence and ideas, and we have followed his advice.

Kuznets, Rosenberg, and other critics of Schumpeter have argued that:

1. no innovations are big enough to give rise to major cyclical fluctuations in profitability, investment, employment, and growth throughout the economy;

2. even if innovations combine together, no one has shown how such combinations could form and develop together to give rise to such fluctuations over periods of roughly half a century.

In the 1980s and 1990s an answer to these critics began to emerge. Schumpeter's notion of the clustering of innovations is now well established among historians and theorists of innovation. Many economists have explored this concept, and in the long wave debate it was developed especially by Freeman *et al.* (1982) and by Perez (1983). They used the expression ‘New Technology Systems’ to analyse these constellations, taking in particular the examples of electronics and synthetic materials to demonstrate the pervasive nature of some processes of technical change, the discontinuities that they entailed, the structural changes in the economic system, and patterns of employment and the long time scales involved in these processes of *system* diffusion.

Such concepts as the *systemic* nature of innovation and the range of *pervasive* applications have found very general acceptance. This applies also to some economic theorists who have not been directly involved in the long wave debate at all. For example, Helpman (1998) and his colleagues adopted the expression ‘General Purpose Technologies’ from Bresnahan and Trajtenberg's paper in the *Journal of Econometrics* (1995). Helpman accepts the important distinction between incremental innovations and those that he describes as ‘drastic’ or major innovations. In his model it is the drastic innovations that drive the GPTs because of their ‘innovational complementarities’ and their ‘generality of purpose’: ‘When these effects are particularly strong, as for example, in the case of electricity, they lead to monumental changes in economic organizations. Sometimes they also affect the organization of society through working hours, constraints in family life, social stratification and the like’(Helpman 1998: 4).

The use of the expression ‘monumental’ and the inclusion of organizational and social changes are particularly notable and bring this analysis in the ‘new growth theory’ closer to the work of those economists who have been studying innovation systems and participating in the long wave debate, especially the work of Carlota Perez (1983). She was particularly notable for her emphasis on institutional as well as on technical changes. As she has consistently argued, *system* changes cannot take place except through a combination of profound social and organizational, as well as technical, innovations, and this necessarily takes a long time.

As already noted in Chapter 3, at the end of the nineteenth century one of the founders of the American Economics Association, John Bateson Clark, detected a period of forty-five years for the maturation of new methods of production, based on his empirical observations in Germany and the United States (Clark 1899: 429). The type of systemic changes that we discuss in this part of the book took even longer. Indeed, it is for this very reason that the irregular periodization we are postulating is a matter of ‘half-centuries’ (p.145) rather than the five to thirteen years of the ‘ordinary’ (Juglar) business cycle. As we have seen in

Chapters 3 and 4, many long wave theorists, including Kondratiev himself, explained the long waves partly in terms of the long life of infrastructural investments and their ‘echo’ replacement every half-century or so. We rejected this explanation, but we certainly do accept that the emergence, crystallization, and diffusion of new technology systems is a matter of decades, not just years. These new constellations *do* include new infrastructures, as well as new industries, new services, and management systems, but it is not the ‘echo’ replacement of the older infrastructures that leads to the long wave. It is the prolonged process of emergence and diffusion of the new technology through the economy. Many empirical studies of innovation have concentrated on individual products or processes and have found market saturation occurring more quickly, for example after ten or twenty years; the diffusion of an entire technology *system* is a different matter. Indeed, as Carlota Perez (2000) has pointed out, the rate of diffusion of individual products will often depend on the maturity (or otherwise) of a related system. Obviously, new electrical products could diffuse much more rapidly when a new infrastructure was in place, when the appropriate skills of electricians and engineers were generally available, and when consumer attitudes and the legislative environment were more favourable to the new technology. In the early days of a new constellation, all these things may present barriers and cause delays to diffusion, if indeed the new products can be imagined or designed at all.

Some historians who, like ourselves, fully endorse the importance of periodization and of the role of technology (for example von Tunzelmann, Chandler) nevertheless prefer a classificatory scheme that brings together the first and second Kondratiev waves as the ‘First Industrial Revolution’. In their scheme, the third and fourth waves become a ‘Second Industrial Revolution’ and the present change a ‘Third’. This second part of the book will make clear why we prefer the ‘Kondratiev’ wave classification, even though we are not entirely happy with the ‘wave’ metaphor for reasons explained in Chapter 4.

The *entire* life cycle of a technology system will usually be much more than a century. Railway systems originating in the middle of the nineteenth century are still very important today. Electrical technology is the essential foundation for electronic systems and the automobile has certainly not disappeared. But the entire life of a technology system goes through several phases. In the very earliest days it may still be mainly or entirely a laboratory phenomenon and apparently unconnected scientific discoveries may be the most important events. Only after successful demonstration of technical and commercial feasibility can large-scale diffusion begin.

The selection environment in capitalist economies means that the most profitable innovations will probably experience a phase of explosive growth, following the first successful applications. As the technology finds an increasing range of applications, the macroeconomic effects may be very (p.146) substantial, as is obvious today from the example of the Internet and information technology. However, exponential growth cannot continue indefinitely, so that a mature stage ensues when profitability is eroded and growth slows down. More new technologies compete for a place in the sun but the erstwhile dominant technologies do not disappear but co-exist in a multi-technology world.

Thus, in a simplified and schematic way, the following phases in the life cycle of a technology system may be distinguished:

1. the laboratory-invention phase, with early prototypes, patents, small-scale demonstrations and early applications;
2. decisive demonstrations of technical and commercial feasibility, with widespread potential applications;
3. explosive take-off and growth during a turbulent phase of structural crisis in the economy and a political crisis of coordination as a new regime of regulation is established;
4. continued high growth, with the system now accepted as common sense and as the dominant technological regime in the leading countries of the world economy; application in a still wider range of industries and services;
5. slow-down and erosion of profitability as the system matures and is challenged by newer technologies, leading to a new crisis of structural adjustment;
6. maturity, with some 'renaissance' effects possible from fruitful coexistence with newer technologies, but also the possibility of slow disappearance.

In this part of the book we shall try to show that it is phases 2–5 that are associated with those wavelike movements in the economic and social system that have been designated since Schumpeter as 'Kondratiev waves' or cycles. In phase 6 the system no longer has the huge effects on the economy that we are postulating for phases 2–5. In phase 1, the *economic* effects are scarcely perceptible although this phase may last a very long time.

The prolonged gestation and diffusion periods are obvious today from the example of information technology and the Internet. As Chapter 9 will attempt to show, the origins of this technology go back for much more than half a century in terms of science and invention, but in terms of the *macro*- economic effects of diffusion these were felt especially in the final quarter of the twentieth century. They may be even greater in the first quarter of the twenty-first century, when the world-wide diffusion of information and communications technology (ICT) affects all countries and all sectors of the economy. The rate of diffusion may slow a little below the tempestuous early days, but the weight of the new technology systems in the aggregate economy is now far greater, so that the macroeconomic effects are enormous. We shall attempt to show in the chapters that follow that each successive (p.147) industrial revolution showed this kind of pattern, although each had its own unique features too.

It was Carlota Perez (1983) who first suggested that some technology systems, such as ICT, were so pervasive that they dominated the behaviour of the whole economy for several decades in this way and reciprocally influenced major social and political changes. She proposed several crucial original ideas which we have used in the analysis that follows.

1. For each long wave, Perez suggested that one or more ‘key factors’ (iron, coal, steel, oil, electronic chips) became so cheap and universally available that they gave rise to a potentially vast array of new factor combinations (what Stankiewicz later called a vast new ‘design space’). The producers of key factors she called ‘motive branches’; these became major industries with each successive wave. In this book we use the expression ‘core inputs’ rather than ‘key factors’ because the word ‘factor’ is used in so many different senses and the word ‘input’ conveys more precisely what we have in mind.
2. Perez suggested further that new products based on the availability of these core inputs and some complementary inputs could stimulate the rise of other new industries, whose rapid growth and great market potential (‘carrier branches’) would give a major impetus to the growth of the entire economy (cotton textiles, steam engines, railways, electrical products, automobiles, computers, etc.). A new infrastructure would serve the needs of the new industries and would reciprocally both stimulate and facilitate the rapid growth of both carrier and motive branches (Table 1). Perez's concept resembles that of historians such as Rostow (1963), who used the expression ‘leading sectors’ to describe these new fast-growing industries. We also use the expression ‘leading sectors’ to embrace ‘carrier branches’, ‘motive branches’, and new infrastructures. Still other branches of the economy follow in the wake of the leading sectors (‘induced branches’), for example service stations, repair shops, garages, and distributors in the case of automobiles, and the later development of mass tourism and ‘fast food’ restaurants.
3. The structural transformation arising from these new industries, services, products, and technologies is inevitably associated with the combination of organizational innovations needed to design, use, produce, and distribute them. Gradually new ‘common-sense’ rules of managing and organizing the new technology emerge through trial and error, which could prove effective in older industries as well as the new ones. Factory-based production could be used for other textiles as well as cottons; mass and flow production techniques could be applied in the food industry and the catering industry as well as in automobiles and oil; computer systems could be used in almost any industry or service. This new approach to management and organization Perez described variously as a ‘new technological style’ and a ‘new techno-economic paradigm’. Once it had emerged and demonstrated its effectiveness, she suggested that it had a wider influence in society, affecting government and the general culture as well as business firms.

4. Such a widespread process of structural and organizational change could hardly take place in a smooth and gradual way. The new 'techno-economic paradigm' would not be easily and universally accepted despite its evident superiority and profitability in many applications, because there would be strong vested interests associated with the previous dominant paradigm and the regulatory regime and cultural norms associated with that older paradigm. Thus, what had often been described as the 'downswing' of the long wave would be a period of great turbulence characterized by the rapid growth and high profitability of some newer firms and industries, side by side with slower growth, declining trends, or stagnation in others, and by political conflict over the appropriate regulatory regime. Monetary disorder, relatively high levels of unemployment, and tariff disputes would be typical phenomena of these transitional periods of structural adjustment. The 'mismatch' between the old institutional framework and the new constellation of technologies could be resolved in various ways in different countries and different industries.

There has been in the past, and will continue to be, a wide variety of institutional changes in response to the pervasive effects of the new technologies. Autonomous and semi-autonomous processes of social and institutional change in various countries will influence the diffusion process. The spread of the new paradigm will be very uneven by firms and by industries as well as by countries. Some will be deeply and immediately affected, others affected only after a long time-lag, still others hardly at all. The Perez concept of paradigm change certainly did not mean that all firms in all countries could adopt the same organizational model, only that such processes as electrification or computerization would have a world-wide influence on the evolution of the behaviour of firms, albeit mediated through great local variety of adaptation, experiment, and previous local historical experience. Following a turbulent period of structural change and the general acceptance of the new paradigm, a period of greater stability would ensue, corresponding roughly to the 'boom' or upswing phase of the long wave.

These ideas have aroused considerable interest and some acceptance (see e.g. Tylecote 1992; Lloyd-Jones and Lewis 1998, and the three volumes containing selections of key papers on the history of the long wave debate edited respectively by Freeman 1996 and by Louçã and Reijnders 1999). In this second part of the book we shall attempt to test and clarify them more systematically. This will require:

1. assembling and analysing the empirical and historical data for each wave to see whether they do indeed support or refute the above propositions; this will involve both quantitative and qualitative analysis at the level of firms, industries, technologies, and countries;
2. developing an 'appreciative' historical description which takes account of the unique features of each wave and demonstrates how each new

> ‘constellation’ of innovations was developed and was promoted (or (p.149) hindered) by the technological, scientific, economic, political, and cultural environment through its rise to dominance and its maturity. Such historical narrative will be based on our conclusions about reasoned history in Chapter 4. It is necessary both for plausibility and to avoid those teleological interpretations that assume the pre-existence of a paradigm and portray its diffusion in idealistic rather than evolutionary terms. It recognizes that each new paradigm may have a very different combination of favourable influences and that its diffusion is an untidy and uncertain historical process.

The analysis begins with the British Industrial Revolution, and most of the next chapter is concerned with the British case. This is because the ‘catch-up’ process of industrialization did not begin in earnest until the second half of the nineteenth century so that the necessary data for the first Kondratiev wave are available only for Britain. In the second Kondratiev wave, the United States and Germany were catching up in many industries and technologies and were beginning to draw ahead in some. Therefore, while continuing to concentrate on the British case, we also analyse some other countries, particularly the United States. Later chapters (7, 8, and 9) take up the story of the third and fourth Kondratiev waves in several countries and the emerging characteristics of a fifth Kondratiev wave based on information and communications technologies. We recognize that it is a weakness of our book that we deal with only a few leading countries. Although we do believe that their role has been exceptionally important, we would certainly accept that the relationship with the rest of the world is and always was important, as Tylecote rightly insisted. We hope that future work will overcome this shortcoming of our book.

It will be useful also at this stage to indicate two of the ways in which our approach differs from Schumpeter's. In particular, we place far more emphasis on the diffusion of innovation than he did. In our view, the earlier inventions and innovations have very little perceptible effect on macroeconomic behaviour, essential though they are for technological development (phase 1 of the system evolution outlined above). The big surges of investment, output, and trade depend on diffusion and scale economies. Thus, whereas Schumpeter classifies the steel industry in the upswing of the *second* Kondratiev wave, we classify it to the third wave (Chapter 7) when the Bessemer and other new steel manufacturing processes became widely diffused. Small quantities of steel were of course used long before either the second or the third wave, but in our view it was the huge expansion of the steel industry in the third Kondratiev wave that was the important phenomenon from a *macro*economic perspective. The upswing of the economy during the Industrial Revolution itself was based mainly on iron, not steel. Second, whereas Schumpeter constantly stressed the role of the ‘heroic’ entrepreneur (thus inviting Kuznets's jibe: did they get tired every fifty years?), we stress rather the (p.150) changes in management systems that accompanied each technological revolution (column (6), Table 1).

We would maintain that the evidence of rapid growth of the ‘motive branches’ producing the core inputs, and of the ‘carrier branches’, acting as exemplars for an entire historical period, is quite strong and indeed is supported by most historians. So, too, we believe is the evidence of falling relative prices, multiple applications, and universal availability of the core inputs. On the role of physical infrastructures, the evidence is also, in our view rather compelling and has been well marshalled and presented by Nakicenovic and Grübler (1991).

Of course, every technological revolution is uneven in its effects, whether we are talking about information technology or the earlier pervasive technologies. For this reason, we postulate an irregular periodization of the long waves (only *approximately* half a century). For this reason, too, we believe that the wave metaphor itself is not the most suitable, as explained in the concluding part of Chapter 4. The wave metaphor may give an impression of a smoothness and regularity that is certainly not characteristic of the turbulent processes we are describing. Some key industries and services are undoubtedly profoundly affected, others only to a small extent, and the speed with which these changes occur will also vary considerably. Some products and industries will begin to be affected soon after the first emergence and crystallization of a new constellation, others only decades later. In Table 1, as already indicated, column (2) gives a more precise indication of a few decisive events, which first clearly demonstrated to a very wide public both the technical *and* the economic advantages and potential of a new system. In his book, Tylecote (1992) gives a similar presentation of this point, showing a period of several years which he describes as a period of ‘crystallization’ during which a new paradigm demonstrates ‘clear-cut superiority’.

The speed with which a new technological style becomes dominant after it first demonstrates clear-cut superiority and widespread (international) potential (Tylecote 1992: 68) depends to a considerable extent on the new infrastructures that are needed for its diffusion. These infrastructures are of two kinds. On the one hand are the physical infrastructures for communication and transport, as shown in Table 1; but there are also other very important infrastructures, which are needed for training and educating people in the new skills and for designing and developing a new range of products and services (the science–technology infrastructure). Investment in both types of infrastructure always requires political initiatives and changes in the regulatory regime, and these are normally the subject of intense political debate and conflict. Here the fourth point in the Perez model outlined above is highly relevant, and here too she has made an important original contribution with her suggestion that in the ‘downswing’ periods the growth of the new constellation may be retarded in various ways by the old institutional and social framework, which is more resistant to change than the (p.151) technology itself. It is also plausible that a period of political, social, and cultural change may lead to the development of a framework that offers greater scope and support to the new constellation—a new ‘regime of regulation’. These ideas are reminiscent of Marx's notion of tension between the ‘productive forces’ and ‘relations of production’, but, whereas Marx applied his theory to capitalist social relations in general, and to earlier social formations, the Perez theory was developed in relation to successive changes within the framework of a predominantly capitalist economy.

It is an extraordinarily difficult and challenging task to disentangle the interplay of technical and organizational changes within the economy with wider political, cultural, and social changes in a variety of different countries. However, we have been encouraged by the pioneering work of Tylecote (1992) and by the recent work of Lloyd-Jones and Lewis (1998), and have attempted in the chapters that follow to address some of these fundamental problems, albeit only briefly. We agree with Helpman (1998) that the diffusion of major new technologies does indeed lead to ‘monumental’ organizational and institutional changes, which co-evolve with the technology. The expression ‘structural crisis of adjustment’ has been very widely used recently to characterize some of these problems that arise in the turbulent periods of transition from an old technological regime to a new one. While the account that follows concentrates on the change in technology and in the structure of the economy, the concluding sections in each chapter do introduce some of these wider social problems, which, as we have insisted in Chapter 4, are an essential part of the historical narrative (Hodgson 1999). Some of these issues are further developed in the Conclusions to Part II.

In these conclusions we shall discuss some of the *recurrent* features of each Kondratiev wave, which we believe justify the use of the expression ‘Kondratiev waves’, rather than a simple scheme of periodization. We fully accept that each wave has unique characteristics and, despite the limitations of space, we try to describe some of the unique features of each wave in the chapters that follow. Nevertheless, there are also recurrent features to which we return; they include the phenomenon of pervasive and interdependent constellations of innovations, and the role of core inputs, of carrier branches and new infrastructures, and of new management styles. Finally, profound structural changes can come about only through a crisis of adjustment in each wave, which necessitates many changes in the institutional and social framework. The political system of a country and its local culture have their own dynamic also. The theory that we are advancing does indeed lay great stress on technical change and on changes in the structure of the economy, but this does not mean that it can be fairly classified as ‘technological determinism’. Technical change is itself partly the outcome of social, political, and cultural influences. In the concluding chapter, we return to these fundamental questions of co-evolution, which face and perplex all historians and which we have introduced in Chapter 4 and the Conclusions to Part I. (p.152)