Working Paper

History, Co-Evolution and Economic Growth

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WP-95-76
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Preface

The research project on *Systems Analysis of Technological and Economic Dynamics* at IIASA is concerned with modeling technological and organisational change; the broader economic developments that are associated with technological change, both as cause and effect; the processes by which economic agents – first of all, business firms – acquire and develop the capabilities to generate, imitate and adopt technological and organisational innovations; and the aggregate dynamics – at the levels of single industries and whole economies – engendered by the interactions among agents which are heterogeneous in their innovative abilities, behavioural rules and expectations. The central purpose is to develop stronger theory and better modeling techniques. However, the basic philosophy is that such theoretical and modeling work is most fruitful when attention is paid to the known empirical details of the phenomena the work aims to address: therefore, a considerable effort is put into a better understanding of the 'stylized facts' concerning corporate organisation routines and strategy; industrial evolution and the 'demography' of firms; patterns of macroeconomic growth and trade.

From a modeling perspective, over the last decade considerable progress has been made on various techniques of dynamic modeling. Some of this work has employed ordinary differential and difference equations, and some of it stochastic equations. A number of efforts have taken advantage of the growing power of simulation techniques. Others have employed more traditional mathematics. As a result of this theoretical work, the toolkit for modeling technological and economic dynamics is significantly richer than it was a decade ago.

During the same period, there have been major advances in the empirical understanding. There are now many more detailed technological histories available. Much more is known about the similarities and differences of technical advance in different fields and industries and there is some understanding of the key variables that lie behind those differences. A number of studies have provided rich information about how industry structure co-evolves with technology. In addition to empirical work at the technology or sector level, the last decade has also seen a great deal of empirical research on productivity growth and measured technical advance at the level of whole economies. A considerable body of empirical research now exists on the facts that seem associated with different rates of productivity growth across the range of nations, with the dynamics of convergence and divergence in the levels and rates of growth of income, with the diverse national institutional arrangements in which technological change is embedded.

As a result of this recent empirical work, the questions that successful theory and useful modeling techniques ought to address now are much more clearly defined. The theoretical work has often been undertaken in appreciation of certain stylized facts that needed to be explained. The list of these 'facts' is indeed very long, ranging from the microeconomic evidence concerning for example dynamic increasing returns in learning activities or the persistence of particular sets of problem-solving routines within business firms; the industry-level evidence on entry, exit and size-distributions – approximately log-normal – all the way to the evidence regarding the time-series properties of major economic aggregates. However, the connection between the theoretical work and the empirical phenomena has so far not been very close. The philosophy of this project is that the chances of developing powerful new theory and useful new analytical techniques can be greatly enhanced by performing the work in an environment where scholars who understand the empirical phenomena provide questions and challenges for the theorists and their work.

In particular, the project is meant to pursue an 'evolutionary' interpretation of technological and economic dynamics modeling, first, the processes by which individual agents and organisations learn, search, adapt; second, the economic analogues of 'natural selection' by which interactive environments – often markets – winnow out a population whose members have different attributes and behavioural traits; and, third, the collective emergence of statistical patterns, regularities and higher-level structures as the aggregate outcomes of the two former processes.

Together with a group of researchers located permanently at IIASA, the project coordinates multiple research efforts undertaken in several institutions around the world, organises workshops and provides a venue of scientific discussion among scholars working on evolutionary modeling, computer simulation and non-linear dynamical systems.

The research focuses upon the following three major areas:

1. Learning Processes and Organisational Competence.
2. Technological and Industrial Dynamics
3. Innovation, Competition and Macrodynamics

HISTORY, CO-EVOLUTION AND ECONOMIC GROWTH

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Abstract

This paper* attempts to present a theory of economic growth. In Section I it discusses the experience of growth modelling over the past 40 years and argues that it fails to capture the most important features of institutional and technical change. Nevertheless as a method for ordering concepts it can be a useful complement to historical research. The problem with history is the almost infinite multitude of events, which have to be classified, described and analysed. A simplifying theoretical framework is essential and inevitable.

Section II tentatively presents such a simplifying classificatory framework. It argues that five historical processes or sub-systems of society have been shown by historical research to be relatively autonomous although interacting major influences on the process of economic growth. These five overlapping sub-systems are science, technology, economy, politics and general culture. Each of these is briefly defined. Humans share with other animals the natural environment which can also powerfully and reciprocally influence economic growth. The other five historical processes each have their own partly autonomous "selection environment" and are uniquely human, which is one reason why biological evolutionary analogies have limited value. Although each of the five has its own distinctive features and relative autonomy, it is their interdependence and interaction which provides major insights into the processes of "forging ahead", "catching up" and "falling behind" in economic growth. Positive congruence and interaction between them provides the most fertile soil for growth, while lack of congruence may prevent growth altogether, or slow it down.

Although a satisfactory theory of economic growth should help us to understand the evolution of the world economy much better, the limits of forecasting and prediction in the social sciences should be clearly recognised. Popper was surely right in maintaining that the most important historical changes are qualitative and non-repetitive. The fact that we can predict eclipses does not mean that we can predict revolutions. Section III discusses the problem of non-recurrence for the social sciences.

Section IV takes a major example to illustrate the theory which has been tentatively advanced - the archetypal example of forging ahead in the British Industrial Revolution in the late 18th Century. It briefly discusses a dozen or so major features of this revolution as identified by historians and suggests that together they justify the notions of confluence and congruence between science, technology, economy, politics and culture as a plausible explanation of the leap ahead in economic growth then achieved for the first time in world history.

Section V then discusses British "falling behind" in the late 19th Century and 20th Century and suggests that this can probably be explained in terms of loss of congruence between the five sub-systems of British society. The rise of new increasingly science-based technologies and of specialised professional management in large corporations fitted ill with some of the older now "traditional" British political and social institutions.

After a brief discussion of the more deliberate processes of "catching up" the paper concludes by pointing out that the theory put forward here resembles many earlier explanations of economic growth. Marx's materialist conception of history stressed the tensions between

* The inordinate length is due to the fact that, if it survives at all, it is destined to become two or three related papers, or possibly a couple of chapters in a book.

"forces of production", "relations of production" and "superstructure" as a source of social and political change or of stagnation in economic growth. Many other historians and economists (e.g. Veblen, Mokyr, von Tunzelmann, Galbraith, Perez) have stressed in particular the inter-action between technical change and organisational change within firms, as well as political and institutional change at other levels in society. This paper differs from most of them and from Marx's theory in two respects. First, it attaches greater importance to science and to general culture. In this it resembles the theories of Needham and Bernal. Secondly, it does not attempt to assign primacy in causal relationships to any one of the five spheres, whereas most other theories assign primacy to technology or the economy or both. It emphasises rather the relative autonomy of each of the five spheres, based on the division of labour and each with its own selection environment. It is this co-evolution which generates the possibility of mis-match between them and periodically of radical institutional innovations which attempt to restore harmonious development. Such harmony however is not necessarily favourable to economic growth, which is not the only objective pursued by human beings. "Congruence" which is favourable to economic growth must be distinguished from other types of congruence.

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HISTORY, CO-EVOLUTION AND ECONOMIC GROWTH

1. Introduction : The Contemporary "Methodenstreit" and the Early Growth Models

A century ago, the German economics profession was split into warring camps in the so-called "Methodenstreit" over the role of history in economics. The historical school led by Gustav Schmoller stressed the uniqueness of human evolution, the difficulty of making broad generalisations and the need to study the specific national and local characteristics of each developing society. The neo-classical school, led by the Austrian Carl Menger, emphasised the necessity to make generalisations based on logical deduction and abstract models which could be tested with empirical data. Schumpeter's attitude to this debate was somewhat equivocal, reflecting his life-long inability to cut the Walrasian umbilical cord and at the same time his recognition of the crucial importance and complexity of evolutionary change. On the whole, he sided with the neo-classical school (Louça, 1995) although in later life he was to emphasise very strongly the necessity to study the history of technical change, the detailed story of individual companies and of the major business cycles (Schumpeter, 1939, 1942) and to recommend to the consternation of his Harvard colleagues that economics should be a post-graduate subject only, for those who had first studied history and mathematics.

The *"Methodenstreit"* ended in almost total victory for the neo-classicals and not only in Germany and Austria but world-wide. However, seen in the longer-term, this has proved to be a pyrrhic victory. Although often marginalised within the mainstream of professional economics, those who stressed the need for an historical approach, the recognition of qualitative change, of institutional diversity and of path dependence for firms, industries, national economies and technologies continued stubbornly to challenge the prevailing orthodoxy. Now, at long last their prolonged efforts are meeting with some success as can easily be seen from any major literature review (Dosi, 1988; Freeman, 1994), as well as from some acknowledgement by leading neo-classical theorists themselves (Hahn, 1987, 1991; Arrow, 1994) of fundamental problems with the mainstream models. Hahn even speaks of the subject returning to its Marshallian evolutionary affinity and facing "the uncertain embrace of history and sociology and biology." (Hodgson, 1995).

As Sidney Winter (1986) remarked it seems so obvious to us "Heracliteans" that you cannot bathe in the same river twice and that evolutionary change is ubiquitous, that we are constantly amazed that our colleagues apparently continue to neglect it. There are, however, genuine intellectual arguments which prevent many economists from accepting the full implications of the evolutionary or institutional critique of mainstream economics. First and foremost among these arguments is the belief that evolutionary theories do not yet offer a satisfactory alternative because of their inability to make useful generalisations. The neo-classical model, with all its faults, is simply retained as an admittedly very crude approximation to real world behaviour, or as an abstract ideal yardstick by which to judge policies and reduce "imperfections".

A similar dilemma confronted economic historians in the 1950s and 1960s when they faced the question of the role of economic theory in the explanation of economic growth, defined here as the growth of output. As Supple (1963) pointed out, many historians complained that much of theoretical economics was "too remote and artificial to be of much use in the study of economic society in the past: that on the whole, its hypotheses and its analytical concepts were abstractions which bore little resemblance to the real world", or were "too restricted in scope to be used in historical investigations without distorting facts to fit them into preconceived theoretical models".

Theorists however were not slow to respond that historians were often mere antiquarians, "gatherers of miscellaneous facts for their own sake" and that they were "too preoccupied with the apparent uniqueness of events" and with case histories to develop systematic explanations. Only with an appropriate theoretical framework would economic history cease to be a collection of unconnected stories and an "interesting but largely useless hobby". (Supple, 1963, page 17).

Supple argues that the truth does not lie midway between these two opposing points of view or with either one but that both are right. It is a question of *good* economic theory and *good* history. Bad theory can indeed be too remote from reality to be of any use or, worse still, can be positively misleading. Good history must aspire to be more than a mass of undifferentiated data.

The theory of economic growth is obviously an area where, as in the *Methodenstreit*, the historical and the abstract theoretical approaches are most likely to clash and where the need for "good" theory and "good" history is most apparent. The tensions inherent in the dialogue between economists and economic historians and the difficulties of resolving these tensions are indeed well illustrated by the development of growth models and growth theories in the second half of this century. Following the *Methodenstreit* mainstream economics paid little attention to growth theory in the first half of the century* but in the 1950s and 1960s it became a fashionable topic. The first Harrod-Domar growth models (Harrod, 1939, 1948; Domar, 1946, 1957) had attempted to demonstrate the (rather narrow) conditions for a dynamically stable full employment growth path in the Keynesian tradition. The later models, following Solow's (1957) pioneering contribution were mainly based on neo-classical assumptions and put the main stress on capital accumulation and increases in the supply of labour, which could be roughly quantified for long periods in the leading industrial countries. All other influences on the rate of growth were subsumed in a so-called "Third Factor" or "Residual Factor" in the aggregate production function.

The growth modellers did not claim that their models provided a satisfactory representation of the complexities of institutional and technical change. Thus, for example, Frank Hahn (1987) was quite explicit:

* Supple even maintains that there was hardly any fresh systematic discussion of the nature of economic development after 1850, with the exception of Marx (Supple, 1963, p. 14).

> "Neo-classical growth theory is not a theory of history. In a sense it is not even a theory of growth. Its aim is to supply an element in an eventual understanding of certain important elements in growth and to provide a way of organising one's thoughts on these matters."
>
> (page 625)

The treatment of all the complexities of technical and institutional change in early growth models came in for heavy criticism both from historians and from many economists, especially as most of the models showed that the "Third Factor" apparently accounted for most of the growth. Balogh (1963) dubbed the "Third Factor" the "Coefficient of Ignorance" while Supple (1963) concluded that "it must surely be clear that any discussion of the relationship between capital formation and economic growth necessarily entails the appraisal of a host of other issues. And these in their turn lead to the conclusion that the accumulation of capital is in itself by no means the central aspect of the process of economic growth" (Supple, 1963, p. 22).

In response to this criticism various attempts were made to disaggregate the residual factor in the aggreate production function, notably by Denison (1962, 1967), who used what Dosi (1988) described as an "entire Kama-Sutra of variables" in his efforts to make systematic comparisons of growth rates. Yet none of these efforts could survive the trenchant criticism of Nelson (1981) and others who pointed to the *complementarity* of all these variables. The contribution of capital accumulation to growth depends not only on its quantity but on its *quality*, on the direction of investment, on the skills of entrepreneurs and the labour force in the exploitation of new investment, on the presence (or absence) of social overhead capital and so forth.

A brave and highly original contribution to the growth modelling debate came from Irma Adelman (1963). She recognised early on that the assumption of constant returns to scale in many models raised big problems and in the so-called "New Growth Theory" this assumption has been dropped in favour of Allyn Young's (1928) increasing returns to scale (Romer, 1986; Grossman and Helpman, 1991).

These models usually also follow her in attempting to assign a specific role to technical change (or as she termed it "the stock of knowledge from applied science and technology"). In her model Irma Adelman also separated "Natural Resources" from other forms of capital in much the same way as the classical economists separated land. This distinction is likely to become increasingly important with the growing recognition of the importance of ecological factors and resource conservation in economic growth. She also separated technical change from other forms of institutional change. Thus she specified the production function as:

$$Y_t = f(K_t N_t L_t S_t U_t)$$

where K_t denotes the amount of the services of the capital stock at time t
N_t stands for the rate of use of natural resources
L_t represents the employment of the labour force
S_t represents "society's fund of applied knowledge"
U_t represents the "social-cultural milieu within which the economy operates "
(Adelman, 1963, page 9)

Adelman was also unusual in her frank recognition of the immense difficulties in the production function approach and of the interdependence of her variables. For example,

> "....... both the quality and the composition of the labour force vary through time and are not independent of the rates of change of the other variables in the system. Specifically, changes in the skills and health of the labour force are directly dependent upon changes in society's applied fund of technical knowledge (S_t)"

Like other modellers, she suggests that the conceptual problems "which arise from the heterogeneity and incommensurability of the production factors may be reduced somewhat if we think of each input as a multi-component vector rather than as a single number".

However this is still not the greatest difficulty with the production function approach. Again, as Irma Adelman so clearly points out:

"Even more difficult than the measurement problems raised by these production factors are those posed by an attempt to quantify our last two variables. S_t and U_t represent heuristic devices introduced primarily for conceptual purposes..... At some time in the future a method may be evolved for the ordinal evaluation of S_t and U_t but such a method does not now exist and accordingly neither variable can be used as an analytical tool."
(pages 11-12)

This situation has scarcely changed since 1963 despite some advances in the measurement of R&D and of education and despite the somewhat greater realism about technical and institutional change in the more recent "new" growth models (Verspagen, 1992).

All of this does not mean that the modelling attempts and developments in growth theory of the past half century have been a complete waste of effort. Adelman's argument for the heuristic value of growth modelling still stands and her own attempt to use her production function to illustrate the differences and similarities in the growth theories respectively of Adam Smith, Ricardo, Marx, Schumpeter, Harrod, Kaldor and the neo-Keynesians is an excellent example of these heuristic advantages. But when all is said and done the main conclusion of the whole debate has been to vindicate the contention of many economic historians and neo-Schumpeterian economists that technical change and institutional change are the key variables to study in the explanation of economic growth.

In his fairly sympathetic treatment of neo-classical growth theory Gomulka (1990) concluded that:

"The cumulative effect of the theoretical and empirical work has been to highlight more sharply and widely than ever before how really central is the role, in long-term economic growth, of the activities producing qualitative change in the economy. Technological changes have assumed the primary role by virtue of their being typically the original impulses which tend to initiate other qualitative changes. By the same token, the work has also helped to delineate the very limited usefulness of the (standard) growth theory based on the assumption that these qualitative changes are cost free and exogenously given." (page 19)

These conclusions are of course wholly unsurprising to neo-Schumpeterian economists and to those economic historians such as Landes (1965, 1969), Rosenberg (1974, 1976, 1982), Rosenberg and Birdzell (1986), Hobsbawm (1968, 1975), David (1975, 1991), Abramovitz (1979, 1986) or von Tunzelmann (1995) who have upheld this interpretation of the historical evidence. The general vindication of their standpoint and indeed its partial recognition in the "new growth theory" can be taken as further supporting evidence for the neo-Schumpeterians in their contemporary "Methodenstreit" with the neo-classicals.

Moreover, even though the work of Abramovitz (1986) on "Forging Ahead", "Catching Up", and Falling Behind" is in many respects more illuminating than the early neo-classical models as a tentative explanation of differences in growth rates over the past two centuries, it is nevertheless vulnerable to the pointed critique of Jang-Sup Shin (1995) and others who have criticized the notion of "social capability" as too vague to be operational for development policy-making. The neo-Schumpeterian notion of "technological capability" is no less vulnerable to this type of critique. No-one can really doubt the universal validity of these concepts but partly because they are so universal, they do not tell us very much.

Neo-Schumpeterians may well respond that they have attempted to develop such ideas as the "national systems of innovation" (Nelson, 1993; Lundvall, 1992) precisely in order to inject greater empirical and theoretical content into the notions of "social" and/or "technological" capability. Although the work on national systems of innovation (*Cambridge Journal of Economics*, 1995) has done something to put flesh and bones on the basic ideas of "social" and "technological" capability, it is by no means yet enough to satisfy the critics, who are increasingly uneasy about the neo-classical edifice but do not yet find acceptable the evolutionary alternative. This paper therefore makes a first tentative effort to develop a theoretical framework for "reasoned history" and growth economics. It is experimental rather than definitive and is intended to stimulate critical debate. It attempts to build on the pioneering study of industrialisation by von Tunzelmann (1995).

II. A Theoretical Framework for Reasoned History

A theoretical framework for the history of economic growth should satisfy four main requirements. First, it should provide a plausible explanation and illumination of the stylised facts which summarise the main features of the growth of the world economy, especially for the last two centuries but ideally for a much longer period. Secondly, it should do this for the three main categories identified by Abramovitz (1986): forging ahead, catching up and falling behind. Thirdly, it should identify the major recurrent phenomena in each category to pave the way for generalisations, which should of course be constantly tested against new historical evidence, as well as newly unfolding events. Finally, it should provide a framework for analysing and reconciling the research data, case studies and generalisations emerging from the various sub-disciplines of history: the history of science and of technology, economic history, political history and cultural history.

As a first step in an inevitably ambitious and hazardous undertaking, the following definitions are tentatively proposed for the subject matter which is of interest and from which the evidence is drawn for explanations of economic growth.

1. *The history of science* is the history of those institutions and sub-systems of society which are primarily concerned with the advancement of knowledge about the natural world and the ideas of those individuals (whether working in specialised institutions or not) whose activity is directed towards this objective.

2. *The history of technology* is the history of artefacts and techniques and of the activities of those individuals, groups, institutions and sub-systems of society which are primarily concerned with their design, development and improvement, and with the recording and dissemination of the knowledge used for these activities.

3. *Economic history* is the history of those institutions and sub-systems of society which are primarily concerned with the production, distribution and consumption of goods and

services and of those individuals and institutions concerned with the organisation of these activities.

4. *Political history* is the history of those individuals, institutions and sub-systems of society which are primarily concerned with the governance (legal and political regulation by central, local or international authorities) of society, including its military affairs.

5. *Cultural history* is the history of those ideas, values, artistic creations, traditions, religions and customs which influence the behavioural norms of society and of those individuals and institutions which promote them.

Finally, human beings share with other animals the *natural environment* and this too has its own history and largely independent evolution. Although this is not usually studied by historians but is left to geologists, ecologists, astronomers, meteorologists, physicists and others, it is nevertheless an important influence on human history and is certainly reciprocally influenced by industrialisation and economic growth. Moreover, it is now possible that ecological factors may predominate in determining the rate and direction of economic growth during the course of the 21st Century. However, in view of the special factors involved in this discussion, this aspect of economic growth is not further developed here. A return to the classical tradition of taking "land" seriously is long overdue but for reasons of space it is not tackled here. The present discussion is confined to the five spheres which have been defined above.

This paper will now attempt to justify the use of these five sub-divisions for conceptual and analytical purposes whilst accepting of course that people make only one history and recognising that in real life the five streams intermingle. The same people can be active in several or even all of the five spheres. However the use of sub-divisions is *not* simply a matter of convenience in handling an extremely complicated topic nor is it just a question of following the academic departmentalisation and specialisations which have emerged in the

20th Century. These two factors do play some part and the academic specialisation does provide some indication of the importance of the independent consideration of each sphere. Moreover, the establishment of separate sub-disciplines reflects the sense of dissatisfaction felt especially by scientists, technologists and economists that their special interests were being neglected within the wider rubric in which they were contained. "History" was often felt to be mainly the story of Kings, Queens, Emperors, Empresses, Presidents, Constitutions, Parliaments, Generals, Ministers and other agents of the state (ie. "political history" in terms of the above definitions) or at most political and cultural history. The Editor of the "Encyclopaedia of the History of Technology" was not alone in protesting at the neglect of technology in this approach (McNeil, 1990).

However, these five sub-divisions are proposed here for far more fundamental reasons. In the first place, they are proposed because each one has been shown to have some independent influence on the process of economic growth, varying to be sure in different periods and different parts of the world, but at least sometimes extending over long periods. Finally, and most important of all, it is precisely the *relative* autonomy of each of these five processes which can give rise to problems of lack of synchronicity and harmony or alternatively of harmonious integration and virtuous circle effects on economic growth. It is thus essential to study both the relatively independent development of each stream of history and their interdependencies, their loss of integration and their reintegration.

The study of "out of synch" phenomena and of the positive or negative interaction between our five different streams is essential for the understanding of Abramovitz's (1979, 1994) distinction between "potential" for growth and realised growth as it is too for Leibenstein's (1957) "X" inefficiency. We shall now briefly attempt to justify the separate treatment of each one of the five sub-divisions which have been defined and then discuss in Section III some problems of recurrent phenomena and of the social sciences in general, so that the inherent limitations of all historical studies are recognised.

Anyone who has debated with historians of *science* brought up in the Lakatos tradition must have been impressed by their strong attachment to the "internalist" view of their subject and their resistance to "externalist" ideas about the influence of the economy or of political events on the development of science. For them the "selective environment" which operates for novel scientific hypotheses and theorems consists purely of the criteria and methods of the scientific community itself.

Popper's emphasis on deduction and his narrow rejection of the role of *induction* in the history of science is highly questionable but, whether or not we accept Popperian criteria for the test and survival of scientific ideas and theories, we cannot fail to recognise that the partly autonomous selective environment of the scientific community is a vital element in the history of science.

Similarly, with the history of *technology* studies of the evolution of the ship, of the hammer, of flints for tools and weapons, of the harnessing of the horse, and of the steam engine or the plough emphasise alike the *relative* autonomy of the improvements which were made over the centuries to these artefacts, so essential for human civilisation. The selective environment which interests, inspires and constrains engineers, designers, inventors and mechanics and many historians of technology is primarily the *technical* environment, the criteria of technical efficiency and reliability and of compatibility with existing or future conceivable technology systems.

The reciprocal influence of science and technology upon each other has been demonstrated in numerous studies and is indeed obvious in such fields as computer technology and biotechnology today as well as in earlier developments such as thermo-dynamics and the steam engine. Technology has to take account of the laws of nature and hence of science. Nevertheless, Derek Price (1984), Rosenberg (1969, 1974, 1976, 1982), Pavitt (1995) and many others have produced cogent arguments for recognising the special features of each sub-system precisely in order to understand the nature of their interaction. Nor does this refer only to recent history as the massive contributions of Needham (1954) to the history of Chinese science and technology clearly illustrate.

Historians of technology such as Gille (1978), and Hughes (1982) have amply demonstrated the *systemic* nature of technologies and analysed the interdependencies between different elements in technology systems. Both they and Rosenberg (1969, 1982) have also shown that the technological imperatives derived from these systemic features may serve as focussing devices for new inventive efforts. Such efforts are of course also often powerfully influenced by economic advantages and rewards. Finally, in their seminal paper "In Search of Useful Theory of Innovation" Nelson and Winter (1977) drew attention to the role of *technological trajectories* both specific to particular products or industries and general trajectories, such as electrification or mechanisation affecting a vast number of processes and industries. These ideas were further developed by Dosi (1982) in his work on technological trajectories and technological paradigms, in which he pointed to the relative autonomy of some patterns of technological development by analogy with Kuhn's paradigms in science. Despite the obvious close interdependence between technology and the economy or technology and science, it is essential to take into account these relatively autonomous features in the history of technology.

A satisfactory theory of economic growth and development must certainly take account of these reciprocal interdependencies but it should also recognise that the *relative* autonomy of evolutionary developments in science and technology justifies some independent consideration. In terms of models, there is a strong justification for the procedures adopted by Irma Adelman in separating S_t from U_t and perhaps going even further and separating S_t (science) from T_t (technology).

An essentially similar argument applies to *economic* change. No-one can seriously doubt the importance of capital accumulation, profits, changes in company organisation, the behaviour of firms and of banks for the evolution of industrial societies over the past two centuries.

Economic institutions too have some relative autonomy in the cycles of their development. We may fully accept Supple's critique of the treatment of capital accumulation in growth models but still pay attention to such variables as the share of investment in GDP, business cycles, the trend of the capital/labour ratio, the capital/output ratio and so forth. This also applies to the growth of the labour force, levels of employment and demographic trends, the availability of land and natural resources, although all of these are also influenced by cultural and political trends as well as by technology. Explanations of economic growth must pay especially close attention to the interdependencies between economic history and technological history. It is precisely the need to understand the changing nature of this interdependency which leads us to study "out of synch" phases of development, when, for example, changes in technology may outstrip the institutional forms of the production and market system, which may be slow to change or impervious to change for relatively long periods. The reverse may also occur providing impetus to new technological developments, as with the assembly line or factory production.

Finally, some of these out-of-phase synchronicity problems may be on such a scale that they affect the entire *political* and legal organisation of society. An obvious example was the institution of serfdom in Mediaeval Europe. Most historians and economists would argue that mobility of labour was one of the essential pre-conditions for the emergence of capitalist industry. It would appear on almost all lists of "stylised facts" about the Industrial Revolution. In his six "major characteristics" of modern economic growth Simon Kuznets (1971) points to the rapid shift from agricultural to non-agricultural occupations and most historians agree that the exceptionally early relaxation of the obligations of serfdom in Mediaeval Britain was one of the main factors contributing to Britain's later "forging ahead" in the Industrial Revolution. By the same token the tightening up of the "Second Serfdom" in Eastern Europe and other institutional constraints on the mobility of labour are often advanced as one of the main reasons for the retarded economic growth in Russia and some other East European countries (Dobb, 1947), although there is continuing debate on the sequence of events which led to this retardation.

Further back in history and on a much longer time scale, the influence of slavery on technological and economic development in Ancient Greece and Rome and the more complex problems of Chinese government and cultural institutions and their effects on science and technological development and diffusion of innovations have all been the subject of major historical investigations. The influence of the political and legal system and of the general culture on the economy and on technology was clearly a major factor in all these cases and once more it is essential to recognise that the political system and the general culture did not necessarily change to accommodate new advances in science and technology or in the economy, but had their own dynamic and relative independence (See, for example, Madison, 1995).

The restrictive regulation of trade and industry by the state, by Mediaeval Guilds and by local authorities was held by Adam Smith, as well as by Marx, to be a major hindrance to capitalist growth. Today also the mode of regulation of various industries is often raised as a factor of retardation or acceleration of their growth, notably in the case of telecommunications. The tensions between major changes in technology system, the organisation of firms and political institutions are at the heart of Carlota Perez' (1983) highly original theory of structural changes and long waves in capitalist development.

Finally, *cultural* change is generally accepted as an important influence on economic growth. At the most elementary level, literacy and the quality of general education (as well as purely technical education) are assigned a crucial role in much of the "new growth theory" and in the World Bank (1992) Development Report. Over the longer term the classic work of Max Weber (1930) and RH Tawney (1926) on "Religion and the Rise of Capitalism", although still controversial (see Kitch, 1967), demonstrated that a change in attitudes towards usury, the rate of interest, work, consumption and accumulation was important for the rise of acquisitive entrepreneurial behaviour in Mediaeval Europe. Some Marxist historians might be inclined to treat religious activities as part of the ideological "superstructure" of society, but the relative autonomy of many religious orders and traditions, as well as the conflicts between Church and State, and the role of religion in establishing cultural norms, mean that it cannot be regarded simply as a part of the political system. Nor can politics be denied some independent role, as indeed Engels (1890) himself recognised.

> "Marx and I are ourselves partly to blame for the fact that younger writers sometimes lay more stress on the economic side than is due to it. We had to emphasise this main principle in opposition to our adversaries who denied it and we had not always the time, the place or the opportunity to allow the other elements involved in the interaction to come into their rights."
>
> (page 477)

In his historical studies Marx did indeed discuss with great subtlety and irony the role of political parties and cultural institutions as well as the history of technology and the economy. His materialist conception of history was based on the view that autonomous development of the "productive forces" brought them into conflict with the "relations of production" leading periodically to the revolutionary reconstitution of society and the emergence of new political institutions and a new "superstructure". Clearly there are important points of resemblance as well as difference between the Marxist scheme and that which is proposed here. It tries to avoid some of the rigidities and classification problems of the Marxist scheme whilst recognising his major original contribution to historiography.

This Section has attempted to outline a theoretical framework for the study of economic growth and to provide tentative definitions of five historical processes which are believed to be of the greatest importance for the explanation and understanding of growth. It suggests that each one of these should be studied, both in its own autonomous development within each society and in its reciprocal interactions with the other elements, with a view to identifying and analysing retardation or acceleration phenomena. However, an historical approach to economic growth is unlikely to be acceptable unless it not only tells a story using this type of theoretical framework but is capable of identifying and explaining *recurrent* phenomena, as well as special cases. As Werner Sombart (1929) put it:

> "..... all history and particularly economic history has to deal not only or mainly with the special case, but with events and situations which recur, and, recurring, exhibit some similarity of feature - instances which can be grouped together, given a collective label and treated as a whole."
>
> (Sombart, 1929, page 18)

It is to the question of recurrent phenomena and their interpretation in the natural and social sciences that we turn in the third section of this paper.

III. Recurrent Phenomena in the Social and Natural Sciences

However much we might agree with Sombart about the need to identify recurrent phenomena and make testable generalisations, there are nevertheless genuine difficulties in achieving this aim in the social sciences. Whereas in many of the natural sciences it is possible not only to make repeated observations of natural phenomena but to do so under controlled conditions, often in a laboratory, this is much harder in most of the social sciences and in relation to a theory of history, generally the only recourse is to (often not very reliable) historical records.

It is true that in his "Poverty of Historicism", Karl Popper (1957) upbraided the social sciences for what he maintained was their over emphasis on the differences between the natural and social sciences and gave as one example, the supposed difficulty of conducting experiments in the social sciences. He pointed out that this was even harder for astronomers and geologists than for economists or sociologists. In his view there was far more scope for experimental techniques in the social sciences than was generally imagined. Moreover, generalisations in the social sciences need not be based on ideological preconceptions or political bias, but could be derived, as in the natural sciences, from hypotheses and conjectures which could be tested for "falsifiability". Statements which could not be tested in this way, whether in the natural or the social sciences, were not, in Popper's view scientific statements. "Social engineering", he contended, was also possible in the social sciences, just as applied technology and engineering provided practical tests for theory in the physical sciences.

It may well be that in economics, sociology and psychology, there is more scope for experimental testing and for "social engineering" than is often realised. An example in the sphere of economics is the measurement of elasticity of demand for both new and old products by varying price systematically between different regions of a country. Market research firms do in fact sometimes use this type of data with the cooperation of their clients and more systematic controlled experiments would be possible, given the cooperation of enterprises and ideally also of the media. Stretching imagination to the limits it is possible to envisage some governments with greater power and greater commitment to social science research than any at present visible, conducting large scale experiments with taxes, interest rates and other economic incentives. However, the international complications and the political process within countries would place severe limits on the feasibility and duration of any such experiments. It is hardly conceivable that the process of economic growth itself could be the subject of controlled experiment and comparative study. The longer the time period, the harder it is to imagine the use of such methods. This is no substitute for history.

Even on the relatively short time-scale of the Juglar cycle it has proved extremely difficult to develop econometric models or forecasting methods which are able to take account of institutional or technical change. This does not mean that this modelling work has not yielded valuable results. On the contrary, as in the case of long-run models of economic growth, much has been learnt from this experience. Up to a point models can provide an alternative to controlled experiments both in the natural and the social sciences.

Model-building is indeed one way of testing theories of growth retrospectively with historical empirical data. Even though it has been argued that *aggregate production function* models did not provide a very satisfactory test for theory, something was learned from this experience and as Nelson and Winter (1974) proposed in their discussion of neo-classical versus evolutionary theories of growth, it would be possible to build a whole family of models to test *evolutionary* explanations (page 894). It was their pioneering achievement (1982) to build the first mathematical model of this kind and to show that it provided a possible explanation of the long run growth of the American economy with far more plausible assumptions about technical change and firm behaviour than the neo-classical assumptions embodied in the aggregate production function models.

This does not mean of course that one has to agree with all the assumptions in the Nelson and Winter model, such as on the role of adversity in the innovative behaviour of firms. Clearly, firms do sometimes innovate both when they are expanding fast as well as where they grow slowly or are even contracting (Gomulka, 1990, p. 77). The value of model-building is precisely to provide a framework for testing alternative explanations and debating alternative assumptions.

However, even though, whether by modelling or other methods, we may achieve a considerable improvement in our understanding of economic growth, this does not mean that this will permit *predictive* forecasting in the way that prediction is possible in some of the natural sciences. The ubiquity of qualitative change, the uncertainty inherent in the growth of science and technology, as well as political and cultural change, rule this out. Indeed, no-one insisted on this more strongly than Popper (1963) himself.

> "Society is changing, developing. This development is not in the main repetitive. True in so far as it is repetitive, we may perhaps make certain prophecies. For example, there is undoubtedly some repetitiveness in the manner in which new religions arise, or new tyrannies; and a student of history may find that he can foresee such developments to a limited degree by comparing them with earlier instances, i.e. by studying the conditions under which they arise. But this application of the method of conditional prediction does not take us very far. For the most striking aspects of historical development are non-repetitive. Conditions are changing, and situations arise (for example, in consequence of new scientific discoveries) which are very different from anything that ever happened before. The fact that we can predict eclipses does not, therefore, provide a valid reason for expecting that we can predict revolutions."
>
> (Popper, 1963, page 341)

Even though we may rate the recurrence of repetitive events as rather more common than Popper allows, it is hard to refute his fundamental point. A theory of history must start from a realistic recognition of the limited role of historical recurrence. This does not mean however that we cannot learn a great deal from even this limited recurrence as well as from unique events. Both meteorology and seismology are natural sciences which have difficulty with long-term prediction but provide probabilistic forecasts useful for policy-making. In fact, since the entire universe is evolving, even those long-term predictions in which we have great confidence, such as the date of the next eclipse are really no more than conditional probabilistic forecasts with a very high degree of probability attached.

It is in this context that Sidney Winter's recollection of the Heraclitean standpoint that "we cannot bathe in the same river twice" is so thought-provoking. There is no doubt that Heraclites (and Sidney Winter) were right that whatever river we may choose to bathe in tomorrow, it will not be the same as the one we bathed in yesterday or today, even though it may have the same name and look the same to all outward appearance. This is also true of the entire physical universe. It is indeed evolving all the time and no part of it is exactly the same today as it was yesterday. Nevertheless there are sufficient relatively stable characteristics of most rivers for a sufficiently long time (centuries if not millennia) that we can use the knowledge of these characteristics and of recurrent patterns of change to navigate some and to use them or others for irrigation. Useful generalisations can be made about rivers even though they will certainly not be valid for all time. For example, one of the earliest great human civilisations was based on such scientific observations and identification of recurrent patterns in the behaviour of the Nile and the use of this knowledge for large-scale irrigation of agriculture. Models can be made of the silting of estuaries or of the influence of rainfall on the rate of flow, which may be useful both for the advance of science and for technology. Of course, it would be foolish to ignore processes of change, such as erosion or pollution, which may affect the behaviour of those who might wish to drink the water or bathe in it but the regularity of recurrence has been sufficient for many practical human purposes.

Thus, despite the validity of Heraclites' statement we can nevertheless agree with Popper that we can make limited conditional generalisations both about the recurrent behaviour of rivers, as well as the human institutions which can make use of this knowledge, although the latter statement is subject to greater qualifications. The questions for historical research are: how much similarity persists and over what periods, what brings an end to the identifiable recurrent patterns and how do new patterns emerge?

These are indeed the questions which have preoccupied economists in the study of business cycles, whether these are inventory cycles (Kitchin cycles), the (now "traditional") business cycles (Juglars) or long (Kondratieff and Kuznets) cycles. Analysis of economic growth must certainly be concerned with cyclical behaviour, whether in modern capitalist economies or older civilisations. Although there have been many irregularities in these cycles there has also been sufficient recurrence, at least in recent times, as to provide some useful indications for generalisation and for policy-making. The work of Carlota Perez (1983, 1985, 1988) on long cycles has shown that even if *identical* behaviour is ruled out, as it must be, there may still be striking (or hidden) similarities or dissimilarities, which are helpful in understanding the phenomena and even in making probabilistic forecasts and indications for policy. The comparative method of establishing differences, as well as similarities, can be especially helpful, as was demonstrated on a small scale in Project SAPPHO in relation to innovation performance in firms. Plant breeders who study the growth of plants make widespread and very effective use of this method of paired comparison.

The study of recurrent events is likely to be most fruitful when it is possible to identify instances of *non-recurrence*, (or *non-happening*) in certain countries or over certain periods, as well as instances of recurrence but with some varying characteristics. Why does a river sometimes stop flowing, whether seasonally (the Winterbourne phenomenon) or for longer periods? Why do some rivers change their course or become more polluted than others? Why do industries grow fast in some countries but not in others? Why do some countries catch up rapidly at some periods and others more slowly or not at all? These are the kind of questions which may yield benefits from comparative studies of recurrence even though we cannot bathe in the same river twice and even though history is a unique series of events.

It will be argued in Section V that Gerschenkron (1962, 1963, 1968) in particular proposed an interesting technique for the study of recurrent phenomena in the "catch-up" process of various countries. Far more difficult is the case of "forging ahead" because by definition this implies the emergence of many new features in the world economy. But before turning to the consideration of catching up and forging ahead in economic growth we first conclude the discussion of method in the natural and social sciences.

We may concede to Popper that the differences between natural and social sciences can easily be exaggerated and that the social sciences have much to learn from the successes of the natural sciences. It is tempting for social scientists, in their anxiety to obtain results comparable to the more spectacular achievements of their colleagues, to try and imitate their methods and make analogies with one or other of the natural sciences in developing their own models and theories. In particular, it is tempting for evolutionary economists, as the very name implies to make analogies with biological evolution in their efforts to break away from mechanistic models. (For a recent selection of papers in this tradition, see Hodgson, 1995).

Such analogies can provide valuable insights and the use of metaphor and analogy generally is often helpful in stimulating imaginative thinking and breaking the "mind-forged manacles" (to use a poet's metaphor) of obsolete theories and behaviour. The biological analogy concentrates attention on the process of change and on the interaction between organisms and their environment in selecting certain types of change. This focus is certainly helpful in the study of economic growth but as with all analogies, it is essential to recognise its limitations as well as its validity. One of the main differences between biological evolution and the process of economic growth is that there are several different selection environments in the evolution of human social systems. The natural environment is common to both but that is where the similarity ends. As we have argued in Section I, it is essential to understand the distinct human selection environment within various sub-systems as for example, the science sub-system. The accumulation of scientific knowledge and of technological knowledge and artefacts are uniquely human processes even though they may have originated, as with other animals, in the search for food and shelter and the communication associated with this search.

In the case of technology too, there are birds and mammals which do make use of "tools" in the sense of twigs, branches or stones, but the systematic *design* and *improvement* of tools and other artefacts are also uniquely purposeful human activities, with their own partly autonomous selection environment. Economists often use a biological analogy to analyse the competitive behaviour of firms in a capitalist economy and the survival of the supposedly "fittest" firms. This is a case of the borrowing back of an analogy which Darwinian theory originally took over from economics. But again the selection environment which confronts firms in their competitive struggle is actually very different from the natural environment confronting animals and plants and this economic environment is itself rapidly changing in ways which are unique. Finally, the political system and the cultural milieu are again uniquely human and powerfully influence the evolution of the economy, as they also reciprocally influence the evolution of science and technology. Evolutionary theories which deal *only* with the survival of *firms* (Alchian, 1951) or *only* with the survival of artefacts or of nations are inadequate for the study of economic growth (Freeman, 1992).

We have no alternative but to confront the unique features of human history, even though we may quite legitimately search for patterns of recurrence and for explanations of recurrence and of non-recurrence. One of the most obvious unique features is the rate of knowledge accumulation in human societies and the varying modes of disseminating this knowledge between individuals and groups. These are rivers which are sufficiently deep and persistent as to justify continuous attention by historians of economic growth, searching both for regular patterns as well as for the emergence of new features of flow. The search for recurrent patterns should inform the special consideration, which is given to the five historical processes which have been identified.

There are some characteristics of the evolution of human societies which have endured for millennia, although their *manifestations* may have varied very much. Such characteristics would be those which primarily distinguish human behaviour from animal behaviour. These have been enduring characteristics of all human societies from a very early period of differentiation of humans from higher apes and they depend on *learning* in various ways, so that the analysis of changes in the *modes* of learning should be a central feature in the study of economic growth.

In the earliest times the learning of humans probably closely resembled that of the foraging animals from which we are descended. It was essentially a search and observation process based on trial and error and the accumulation of knowledge about edible and poisonous, potential and actual sources of food. With the domestication of other animals, the use of fire and above all with settled agriculture the learning and dissemination became far more complex, but still based essentially on search, experiment, language, communication and of course serendipity. Contrary to many theories of history it would therefore be possible to date the origins of science not in the Middle Ages but in Palaeolithic times or even earlier. What has changed is not the search, observation and learning but the modes of conducting and organising search, re-search, learning, accumulating, validating and disseminating knowledge about the natural world (science) and about ways of producing, using and improving tools and artefacts (technology). As the division of labour proceeded within families and tribes and varying in different geographical environments, learning about production and exchange systems (economics) became increasingly important. As some knowledge became routinised in customs and traditions (culture) and in forms of regulating social behaviour (politics, war, slavery), so the separate streams of knowledge became increasingly important as well as their intermingling in general culture.

Consequently, the distinction we have made at the outset between the various historical processes is not something which emerged only in very recent times, or in the Middle Ages, but has been a feature of human history for millennia. What have been changing are the ways of learning and accumulating knowledge and passing it on, interacting with changing ways of organising production, regulating economic activities and social behaviour. Learning by doing, even if it was once mainly learning by gathering and eating, has always been with us. Learning by producing and using have been with us since the early use of tools of various kinds. Learning by inter-acting has always been with us. These are persistent human activities across all civilisations. What have changed are the modes of learning, of recording and disseminating what has been learnt and the ways in which different modes of learning have interacted with each other. The British industrial revolution was remarkable for these novel modes of learning and interacting.

Another unique but related feature of human evolution is the extent and nature of the division of labour in human societies at least for several millennia. It is true that some animal species, such as ants and bees also exhibit a fairly complex pattern of social organisation. In the study of these animal societies too it is essential to pay close attention to the patterns of communication and control, as well as to hierarchical patterns of organisation (Marais, 1975; Fabre, 1885). The division of labour in human societies, however, is unique both because of its complexity and because of the speed of emergence of new specialisations, associated with the rate of knowledge accumulation, the rate and direction of change in techniques and the associated changes in the patterns of communication and hierarchical organisation. The behavioural routines of colonies of ants and bees have of course evolved over biological time but they are so stable that relatively firm predictions can be made, which may be useful to bee-keepers. The behavioural routines which also affect human behaviour are less predictable and stable.

Nevertheless, here too there are some deep and very persistent rivers even though modes of navigation may appear to change beyond recognition. We have already argued that the search for new knowledge, inventive behaviour in relation to techniques, innovation as well as routine behaviour in relation to economic and political organisations are four relatively autonomous but persistent streams or historical processes. Analogies with the behaviour of bees or ants break down above all because of the role of imagination and changing purpose in these activities. As Marx so cogently pointed out: what distinguishes the worst of architects from the best of bees is that the architect first of all constructs a building in the imagination.

The role of imaginative, conscious, purposeful activity is important in all spheres of social life and is undoubtedly one of the most important distinctive features of the evolution of human societies. There are of course some scientists and theologians who believe that there is a purposeful element in the evolution of the universe in general or of this planet or of a chosen nation in particular (for example, Gaia theories). Still others believe that the mode of evolution is itself sufficient to impart the appearance of purpose without its actual presence ("blind watchmakers", some versions of chaos theory, etc). Whatever may be the truth in any of these theories the element of purpose is overtly present in human history in the conscious activities of human beings in a way which is manifestly not the case either in the evolution of other animal species or geological evolution.

Of course, there are some similarities with the animals from which we have evolved, even in the purposeful use of tools on a very small scale, or in language, communication and forms of social organisation. But at least for the last 5000 years the differences have become so great that it would be absurd simply to follow biology (or any other natural science) as a model for a theory of human history.

It is for this reason that we cannot accept Popper's restrictive approach to the purposeful action of social groups, as well as individuals. Popper tends to dismiss the effectiveness of purposive action by groups of people, maintaining that "groups, nations, classes, societies, civilisations, etc." are "very largely postulates of popular social theories rather than empirical objects". (Popper, 1963, page 341). He emphasises that "the best laid schemes of mice and men gang oft agley" and lead to pain and tears rather than to promised joys. He is very wary of "conspiracy theories" which attribute social purpose to entities which can have no such collective purpose and formulates "the main task of theoretical social sciences" as to "to trace the unintended social repercussions of intentional human actions." (page 342) This type of analysis has certainly played an important part in economic theory, especially Keynesian theory and it is obviously important in considering the unintended environmental consequences of the widespread application of some new technologies. However, sometimes groups do achieve at least some of the objectives which they set out to achieve just as individuals do, even if they are involved in conflicts. Therefore, historical analysis cannot restrict itself to analysis of "unintended consequences" but should also take account of "intended consequences". The possibility for individuals to imagine a desirable future and to associate with other individuals to achieve a variety of collective purposes, such as catching up in standards of living or improving the environment is surely an important difference between human beings and other animals and an essential part of the study of economic growth. Certainly this study should include unintended as well as intended consequences, as for example, falling behind rather than catching up may be the actual outcome of some policies designed to accelerate economic growth. But in spite of Popper's well justified aversion to conspiracy theory we cannot rule out the study of purposeful actions both by individuals and by groups as well as both their intended and their unintended consequences. In this study, comparisons between success and failure in achieving intended objectives may be especially fruitful. Even though human beings may often not attain the ends which they seek or may even court disaster by persisting with conflicting or irreconceivable objectives, or because the outcome of many different purposes may be quite different from each taken separately, nevertheless, the role of purposeful activity cannot be ignored. Its role is particularly evident in the case of "catching up" to which we turn in Section V.

In this paper it is possible to give only brief illustrative examples and to show only in a very condensed form that they are consistent with the stylised facts as they have emerged from historical research. In line with the objectives set out in Section I, we shall take these examples from the Abramowitz taxonomy of forging ahead, catching up and falling behind. Here, however, we shall concentrate mainly on one example - of forging ahead. We have argued that forging ahead is the more difficult phenomenon to explain since although intentionality is present in some senses, it cannot be so clear as in the case of catch-up. We have therefore given the most attention to the archetypal case for industrial capitalism - the British industrial revolution. For catch-up we discuss far more briefly various approaches, notably the theories of List, of Gerschenkron and of Perez and Soete (Section V). Even more briefly we mention a few features of British "falling behind" in the 20th Century.

We have taken these examples from the last two centuries because this is the period in which we are most interested and we shall argue that there was a discontinuity in economic growth starting with the British industrial revolution. Some generalisations which can be made about economic growth after the 18th Century may not be valid before that period.

The Section which follows discusses the main explanations which have been advanced by historians for the British Industrial Revolution. It necessarily contains a certain amount of detail in each of a dozen sub-sections. Some fairly extensive quotes are included, especially where there are controversial interpretations and where the authors convey a point with particular emphasis. Those who are already familiar with the historical literature or who are bored with the detail may wish to proceed directly to the summary and analysis in sub-section (xii) of Section IV.

IV. Forging Ahead: the British Industrial Revolution

Historians (Ashton, 1948; Deane, 1965; Hobsbawm, 1968; Habbakuk, 1963; (Eds) Floud and McCloskey, 1981; Rostow, 1960; Mathias, 1969; Landes, 1969; von Tunzelmann, 1978, 1995; Supple, 1963; (Eds.) Hoppit and Wrigley, 1994) differ in their interpretation of the main features of the British industrial revolution. Some put the main emphasis on entrepreneurship, some on inventions and innovations, some on transport, communications and trade, and some on the growth and composition of market demand. However, almost all agree that single factor explanations are inadequate and almost all mention most or all of these together with the changes in agriculture and of course the accumulation of capital and mobility of labour.

The picture which emerges from a dozen or so major studies of the industrial revolution and most notably from the recent (1994) eleven-volume history of the industrial revolution published by the Economic History Society (Eds. R Church and EA Wrigley) may be summarised as follows:

i) *Acceleration of growth from 1780s*

Economic historians appear to agree that there was a fairly sharp acceleration of British industrial output, investment and trade in the last two decades of the eighteenth century. Hoffmann calculated the rate of growth of British industrial output from 1700 to 1780 as between half and one per cent per annum, but from 1780 to 1870 at more than 3 per cent. More recent estimates (Crafts, 1994) have reduced the estimated growth rates for the later period but do not change the fundamental picture (Table 1). Supple (1963) sums up the consensus as follows:

> "..... economic change did not experience a steady acceleration, rather there was a more or less precise point (which most historians place in the 1780s) after which innovation, investment, output, trade and so forth all seemed to leap forward ".
>
> (page 35)

Although it was the surge of growth in industry in the late 18th Century which was the principal component of the acceleration in British economic growth, Phyllis Deane (1962) estimated that the rate of growth in national income over the period from 1800 to 1860 was twice as high as the rate from 1740 to 1800. Again, new estimates by Crafts (1994) show somewhat slower growth for the period 1780-1800 than some of the earlier estimates. He estimates national income growth at 0.7 per cent per annum from 1760 to 1780, 1.32 per cent from 1780 to 1800 and 1.97 per cent from 1801 to 1834 (page 196). However, this did mark a transition to a sustained rate of economic growth over a long period greater than any which had ever been previously achieved. It is for this reason that the British industrial revolution merits intense study, even though the growth rate has since been surpassed.

Table 1. Sectoral Growth of Real Industrial Output (Per Cent per Annum) in Britain

Years	Cotton	Iron	Building	Weighted Average*
1700-1760	1.37	0.60	0.74	0.71
1770-1780	6.20	4.47	4.24	1.79
1780-1790	12.76	3.79	3.22	1.60
1790-1801	6.73	6.48	2.01	2.49
1801-1811	4.49	7.45	2.05	2.70
1811-1821	5.59	-0.28	3.61	2.42

*1700-1790 based on 1770 Weights
1790-1821 based on 1801 Weights
Including other industries

Source: Crafts (1994)

ii) *Exceptional growth and falling prices of cotton textiles*

The surge of growth in British industry was not simply "balanced reproduction" ("balanced" growth of all industries simultaneously) but was characterised by the exceptionally rapid growth of a few leading sectors, above all the cotton industry and to a lesser extent, iron (Table 1). The share of cotton in total value added of industry grew from 2.6 per cent in 1770 to 17 per cent in 1801.

> ".... in the initial decades of the British industrial revolution it was the cotton textile industry which experienced the most spectacular expansion. Subsequently, after 1840 railroad investment and the spread of a transportation network seemed to dominate the economy and in the third quarter of the century, the steel industry and steamship construction leapt ahead"
>
> (Supple, 1963, page 37).

The backward and forward linkages to other industries (Hirschman, 1958) were of course also important but the exceptional role of the cotton textile industry is generally acknowledged both by contemporaries and by historians ever since. Imports of raw cotton grew from an average of 16m. lbs p.a. in 1783-1787 to 29m. lbs in 1787-92 and 56m. lbs in 1800 as the source changed from the West Indies to the United States slave plantations. The rate of increase in imports was described by a 19th Century historian (Baines, 1835) as "rapid and steady far beyond all precedent in any other manufacture".

He attributed the extraordinary rise in the 1770s and 1780s directly to the effects of technical inventions and their diffusion: "from 1771 to 1781, owing to the invention of the jenny and the water-frame, a rapid increase took place; in the ten years from 1781 to 1791, being those which immediately followed the invention of the mule and the expiration of Arkwright's patent, the rate of advancement was prodigiously accelerated."

It was on the basis of a whole series of inventions and improvements (Hills, 1994; Mann, 1958; von Tunzelmann, 1995) that big increases in productivity became possible, based increasingly on their exploitation in the new system of factory (mill) based production. These improvements in process technology made possible the rapidly falling prices which in turn provided the competitive strength for British exports to undercut Indian and other Asian textiles and indeed all other producers. Exports of cotton textiles reached 60 per cent of output by 1820 and became the biggest single commodity in 19th Century trade accounting still for over 30 per cent of British exports of manufactures in 1899, when Britain was still by far the biggest exporter.

Carlota Perez has pointed especially to the role of rapidly falling prices of key production factors in successive industrial transformations or long waves of economic development, as with steel in the late 19th Century, or oil in the 20th. The most obvious case is of course the contemporary orders of magnitude reduction in the price of chips for a myriad of micro-electronic devices, and especially for computing. Whilst not quite so spectacular, the fall in the price of cotton yarn was certainly remarkable, occurring as it did in the inflationary period of the Napoleonic Wars. The price of No. 100 Cotton Yarn fell from 38/- in 1786 to 6/9d in 1807. Landes (1965) estimates that the price of cotton yarn fell by 1837 to one twentieth of its level in 1760 (p. 109). This fall cannot be mainly attributed to a sharp fall in the price of the raw material (Table 2), but must be ascribed to innovations.

iii) *Invention and Innovation*

Virtually all accounts, whether contemporary or otherwise, agree on the importance of inventions, both in the cotton industry and in other industries for the spurt in economic growth. Indeed they were often given pride of place in the older textbooks on English history. Like Adam Smith (1776) recent studies stress the continuous improvement of processes in the factory or work-place, as well as the original major inventions. They also stress the speed with which inventions became innovations and were then rapidly diffused. The number of patents sealed had been about 80 in the period 1740-49 but increased to over 100 in 1750-59 and to nearly 300 in 1770-79. Patents are an imperfect indicator but there were no changes in this period which might invalidate the series (Eversley, 1994).

Table 2 Raw Cotton Prices - Great Britain, 1782-1820

NOTES TO PART A

[1] SOURCE: Thomas Tooke, *A History of Prices* (London, 1838–58), vol. II, pp. 401–2. These prices are stated to be drawn from *Prince's Price Current*.

[2] According to T. Ellison, *The Cotton Trade of Great Britain* (London, 1886), the price range of West Indian cotton in the following periods was:

1771–5	9½ to 14d
1776–80	16d to 25d
1781	19d to 48d

[3] E. Baines, *A History of the Cotton Manufacture* (London, 1835) gives a different series of prices, taken from circulars of Messrs George Holt & Co. of Liverpool, from 1806 for Bowed Georgia and Pernambuco:

	Upland (i.e. Bowed Georgia)	Pernambuco		Upland (i.e. Bowed Georgia)	Pernambuco
1806	15 to 21½	23½ to 29	1814	23 to 37	28¼ to 41
1807	15½ to 19	24½ to 26½	1815	18 to 25½	25½ to 37
1808	15½ to 36	25½ to 42	1816	15 to 21	23 to 30
1809	14 to 34	22½ to 38	1817	16¼ to 23¼	22 to 27¾
1810	14½ to 22½	23 to 29	1818	16½ to 22	22 to 27
1811	12¼ to 16	18 to 23½	1819	10 to 19¾	16 to 23½
1812	13 to 23½	19 to 27½	1820	8 to 13¾	11½ to 18¾
1813	21 to 30	24 to 34			

A. Highest and Lowest Prices in Each Year, West Indies, American and Brazilian, 1782–1820

pence per lb.

	West Indies, Surinam and Berbice	Bowed Georgia	Pernambuco		West Indies, Surinam and Berbice	Bowed Georgia	Pernambuco
1782	20 to 42	—	—	1802	15 to 33	12 to 38	24 to 35
1783	13 to 36	—	—	1803	14 to 27	8 to 15	24 to 29
1784	12 to 25	—	—	1804	12 to 28	10 to 18	21 to 30
1785	14 to 28	—	—	1805	17 to 28	14 to 19	23 to 30
1786	22 to 42	—	—	1806	14 to 26	12 to 15	20 to 24
1787	19 to 34	—	—	1807	14 to 22	10 to 14	21 to 23
1788	14 to 33	—	18 to 31	1808	14 to 33	9 to 30	21 to 33
1789	12 to 22	—	16 to 22	1809	14 to 36	10 to 18	20 to 34
1790	12 to 21	—	19 to 22	1810	17 to 27	10 to 19	21 to 27
1791	13 to 30	—	18 to 31	1811	9 to 21	7 to 14	14 to 22
1792	20 to 30	—	22 to 30	1812	11 to 18	11 to 14	17 to 20
1793	12 to 27	13 to 22	21 to 27	1813	12 to 30	16 to 26	23 to 34
1794	13 to 26	12 to 18	18 to 25	1814	22 to 34	22 to 30	26 to 36
1795	15 to 30	15 to 27	21 to 30	1815	18 to 32	14 to 23	22 to 33
1796	19 to 30	12 to 29	22 to 30	1816	16 to 24	15 to 20	22 to 29
1797	17 to 40	12 to 37	23 to 41	1817	18 to 25	17 to 22	21 to 25
1798	25 to 40	22 to 45	37 to 41	1818	15 to 26	16 to 22	21½ to 26
1799	18 to 55	17 to 60	29 to 52	1819	11 to 23	11 to 19	16½ to 23
1800	20 to 38	16 to 36	33 to 37	1820	8 to 17	8 to 14	12 to 18
1801	21 to 30	17 to 38	32 to 36				

There is some disagreement on the nature of the major inventions of the 18th Century. Some authors argue that they were typically very simple, they "leave the impression that the inventions were the work of obscure millwrights, carpenters or clock-makers, untutored in principles, who stumbled by chance on some device."

Whilst not emphasising the role of accidents, Hobsbawm (1968) makes the point that

> "The early Industrial Revolution was technically rather primitive not because no better science or technology was available, or because men took no interest in it, or could not be persuaded to use it. It was simply because, by and large, the application of simpler ideas and devices, often of ideas available for centuries, often by no means expensive, could produce striking results. The novelty lay not in the innovations, but in the readiness of practical men to put their minds to using the science and technology which had long been available and within reach; and in the wide market which lay open to goods as prices and costs fell rapidly. It lay not in the following of individual inventive genius but in the political situation which turned men's thoughts to soluble problems.
>
> This situation was very fortunate for it gave the pioneer Industrial Revolution an immense, perhaps an essential, push forward. It put it within the reach of an enterprising, not particularly well-educated or subtle, not particularly wealthy body of business-men and skilled artisans..... In other words, it minimised the basic requirements of skill, of capital of large-scale business or government organisation and planning."
>
> (page 44)
>
> Furthermore, "this relatively unsophisticated type of technology meant that the higher grades of technology could be readily recruited from among the men with practical workshop experience. Britain could even manage to do without a system of state elementary education until 1870, of state secondary education until after 1902."
>
> (page 45)

Ashton, however, argues that "such accounts have done harm by obscuring the fact that systematic thought lay behind most of the innovations in industrial practice" and overstressed the part played by chance (Ashton, p 154). Further, "Many involve two or more previously independent ideas or processes, which brought together in the mind of the inventor issue in a more or less complex and efficient mechanism. In this way, for example, the principle of the jenny was united by Crompton with that of spinning by rollers to produce the mule ......"

Landes (1965) also stresses the high skills of the mechanics, smiths, millwrights and tool-cutters of the Industrial Revolution:

> "Even more striking is the theoretical knowledge of these men. They were not on the whole, the unlettered tinkers of historical mythology. Even the ordinary millwright, as Fairbairn notes, was usually a fair arithmetician, knew something of geometry, levelling and mensuration, and in some cases possessed a very competent knowledge of practical mathematics. He could also calculate the velocities, strength and power of machines, could draw in plan and section."
>
> (page 296)

At the opposite extreme some accounts give the impression that the inventions were the result of individual genius or scientific brilliance, rather than the outcome of a continuous social process. In part, these differences of interpretation arise from the fact that (as still today) there is a very wide spectrum of inventions and innovations. The vast majority, then and now, are incremental improvements to existing processes and products and, as Adam Smith observed, are often made by workers who use machines in different types of work-place. They may be facilitated by specialisation based on division of labour, but again, as Adam Smith observed, still other inventions result from the work of scientists whose skill is to observe dissimilar processes. Hills (1994) basing his comments on experience of actually running the machines in the North Western Museum of Science and Industry, stresses the trajectory of improvement exploited by Hargreaves and Arkwright:

> "As with most inventions, their work must not be taken in isolation since it was dependent on what had been done before..... the various methods of spinning by hand .... are more closely linked than has hitherto been realised to the ways of spinning used by Hargreaves, Arkwright and their predecessors, Paul and Wyatt ."
>
> (Hills, page 112)

Nevertheless, the combined effect of the inventions of Hargreaves, Arkwright, Crompton and their predecessors and successors was revolutionary rather than gradual (Table 3). The leap in productivity at the end of the 18th Century reduced the number of operative hours to process (OHP) 100 lbs of cotton by much more than an order of magnitude. This again confirms the

Table 3 Labour Productivity in Cotton: Operative Hours to Process 100 lbs of Cotton

	OHP
Indian Hand Spinners (18th Century)	50,000
Crompton's Mule (1780)	2,000
100-Spindle Mule (c. 1790)	1,000
Power-assisted Mules (c. 1795)	300
Roberts' automatic Mule (c. 1825)	135
Most efficient machines today (1990)	40

Source: Jenkins (1994) p. xix.

Perez theory of "quantum leaps" in technological revolutions. The power required to operate the later innovations meant that machinery had to be installed in purpose-built premises (factories). Even though Arkwright limited his licenses to machines of a thousand spindles, human muscle and horse power were rapidly succeeded by water power and later by steam (Jenkins, 1994).

The smelting of iron ore with coke and Cort's process for the conversion of pig iron into malleable (wrought) iron by "puddling" were decisive inventions for the metal-working industries in the eighteenth century. Together they made possible a big increase in the supply of relatively cheap iron which took place between 1780 and 1840 (from about 60,000 tons p.a. to about 2 million tons p.a.).

In a highly original analysis of innovations in the cotton industry in the Industrial Revolution, von Tunzelmann (1995) provides strong evidence that the main inducement for innovators was *time*-saving and that the savings in fixed and working capital, in labour and in land were the indirect result of this time-saving objective, pursued within a general paradigm of relatively straight-forward mechanisation. He also brings out the role of focussing devices and coordination in the whole production system. "Replication of the particular components which represented the most constrictive bottlenecks was often carried out in addition to speeding them up. The cylinder for block printing could thus be replicated by up to five times" (Baines, 1835, page 236). "The same innovation strategy underlay the jenny, which multiplied the traditional spinning wheel initially to 8 and eventually to sometimes 120 within the one machine". (page 15). Von Tunzelmann also quotes Baines on the productivity increases brought about by "a series of splendid innovations and discoveries, by the combined effect of which a spinner now produces as much yarn in a day as by the old processes he [*sic*] could have produced in a year, and cloth which formerly required six or eight months to bleach, is now bleached in a few hours". (von Tunzelmann, page 8).

Hobsbawm over-simplifies the situation with respect to science, to skills, and the linkages between science and technology. The case of bleaching is very different from the case of spinning and the chemical, metal and gas industries owed more to the interaction between science and technology. The cotton industry itself, as metal machinery was substituted for wooden, also became increasingly dependent on the technical advances in the metal-working industries and on the skills of tool-makers. Even if, by today's standards, now judged "primitive", the skills and the science of that time were crucial for successful invention and innovation, nevertheless, Hobsbawm's point is an important one in understanding *diffusion* and links closely to the related issues of capital accumulation, factory organisation and entrepreneurship.

iv) *Capital Accumulation*

The classical economists (and as we have seen, the early neo-classical growth models) put the accumulation of capital centre stage in their analysis of economic growth. Whilst certainly not denying its importance, economic historians tend to reduce their estimates of its rate of increase in the early stages of the Industrial Revolution. Whereas Rostow (1960) had argued that "take-off" into "self-sustained" growth required a rise in productive investment from 5 per cent of NNP to 10 per cent and that Britain had met this condition at the end of the 18th Century, Crofts (1994) estimates Gross Domestic Investment as still only 7.9% of GDP in 1801 (Table 4).

However, this slower rate of increase is still quite consistent with the very small size of firms at this time, the relatively low cost of the new machines and the very low rate of interest. Ashton (1948) attaches great significance to the low rate of interest from the mid-18th Century onwards (the rate on Consols was 3% from 1757).

> "If we seek - it would be wrong to do so - for a single reason why the pace of economic development quickened about the middle of the 18th Century, it is to this we must look. The deep mines, solidly built factories, well-constructed

Table 4 **Gross Domestic Investment as a Percentage of GDP**

	"New" (Crafts) Estimate	"Old" (Feinstein) Estimates	
1700	4.0	1761-1770	8
1760	5.7	1771-1780	9
1780	7.0	1781-1790	12
1801	7.9	1791-1800	13
1811	8.5	1801-1810	11
1821	11.2	1811-1820	11

Source: Crafts (1994)

canals and substantial houses of the Industrial Revolution were the products of relatively cheap capital."

(page 152)

Accumulation of itself of course does not necessarily lead to productive investment. Attitudes towards investment had been changing since the Reformation and the broadening of the capital market from trade, agriculture and Government debt to fixed capital for the new factories should not have been so difficult when the rate of profit in the new industries was often high. Hobsbawm (1968) however suggests that the major investors (defined by him as "the great landlords, mercantile and financial interests") did not yet invest, at least in the early stages of the Industrial Revolution in the new industries to a substantial extent. "The cotton masters and other budding industrialists" had to acquire their capital from local sources - family, friends, country banks and ploughed back profits.

This view is supported also by Postan (1994), who gives examples of many firms, including Boulton and Watt, which obtained loans from family and friends to tide them through.

> "The financial history of most other industrial enterprises of the late eighteenth and early nineteenth century is very similar. When the burdens were too heavy for the resources of a single man the financing would be undertaken by a partnership, which was actually a combination of a few friends or relatives. Even the most high-sounding companies of the time, such as the famous Carron Company, were composed of small and intimate groups of partners. Joint stock publicly subscribed was a very rare exception."
>
> (page 278)

However, he states that by 1830 the new joint stock banks and private banks in the country and industrial areas were well able to meet the industrial need for short-term capital, although not for long-term investment.

v) *Entrepreneurship*

Even though artisans or inventor-entrepreneurs and their partners or families often had to struggle to raise the capital for the numerous new firms starting up in cotton and other industries, this highly de-centralised pattern imparted great flexibility to the newly emerging industries. Many historians (e.g. Ashton, 1948; Wilson, 1955) stress that social mobility was much greater in Britain than in other countries. The entrepreneurs came from very diverse backgrounds and the role of "dissenters" (Quakers and adherents of other unorthodox religious denominations) is frequently mentioned. Ashton states that it is not easy to distinguish inventors, "contrivers", industrialists and entrepreneurs and that they came from every social class and from all parts of the country. Aristocrats like Coke of Holkham Hall innovated in agriculture, or like the Duke of Bridgewater in canals. Clergymen and parsons, such as Cartwright and Dawson innovated in new ways of weaving cloth and smelting iron. Doctors of medicine, such as John Roebuck and James Keir took to chemical research and became industrialists. "Lawyers, soldiers, public servants and men of humbler station than these found in manufacturing possibilities of advancement far greater than those offered in their original callings. A barber, Richard Arkwright, became the wealthiest and most influential of the cotton-spinners; an inn-keeper, Peter Stubbs built up a highly esteemed concern in the tile trade; a schoolmaster, Samuel Walker, became the leading figure in the North of England iron industry.

One reason that Dissenters were so prominent in entrepreneurship may well have been their non-conformist outlook and often their rationalism. However, Ashton also points out that the exclusion of Dissenters from the universities and from office in government forced many to make their careers in industry. Moreover, the non-conformist zeal for education led them to establish their own schools and the non-conformists "constituted the better educated section of the middle classes. Presbyterian Scotland provided an unusually high proportion of the leading inventors (Watt and most of his assistants, Sinclair, Telford, Macadam, Neilson and many others) at a time when Scotland had by far the best primary education system in Europe and some of the best universities. "It was not from Oxford or Cambridge, where the torch burnt dim, but from Glasgow and Edinburgh, that the impulse to scientific enquiry and its practical application came." (page 157). The dissenters' academies established in English towns, such as Bristol, Manchester, Warrington, Northampton, etc. did for England what the Universities did for Scotland.

Ashton's discussion provides some corrective to Hobsbawm's rather exclusive emphasis on the less well educated and his neglect of the role of science. Not only were a significant minority of the most successful entrepreneurs well acquainted with recent science, they often took the trouble to keep up these contacts.

vi) *Agriculture*

It is remarkable that whilst studying the Industrial Revolution, almost all historians feel impelled to pay considerable attention to agriculture. British agriculture had several unique features in the 18th Century. In the first place, as already mentioned, Britain was one of the first countries, if not the first, to loosen the obligations of serfdom and it had indeed virtually disappeared centuries before the Industrial Revolution. Secondly, a class of tenant farmers had grown up who, as a result of the Enclosures, had large enough holdings to introduce many reforms in their systems of cultivation and treatment of livestock. Thirdly, a significant number of landlords after the English Civil War of the 1640s invested quite heavily in the improvement of their estates, as well as in other local projects, government bonds and even industry.

Britain was thus almost alone among European countries in entering the Industrial Revolution, neither with a large number of small-holder peasants, nor with the remains of serfdom, but with a relatively progressive capitalist style of agricultural production geared to the market and characterised by quite rapid growth in labour productivity. According to Allen (1986) between the Middle Ages and 1800 English grain yields approximately doubled but the yield per *acre* was no higher than in other European countries. What was distinctive about British agriculture was the much higher *labour* productivity as shown in Bairoch's estimates (Table 5) and those of Wrigley (Table 6). Allen's research shows that the rise in English labour productivity was due in about equal measure to higher crop yields (this was common to all NW Europe) and (uniquely) the shift to large capitalist farmers and the reduction of employment per acre.

Table 5 **Agricultural Labour Productivity, 1840**

Country	Output*
United Kingdom	17.5
France	11.5
Belgium	10.0
Germany	7.5
Sweden	7.5
Switzerland	5.0
Italy	4.0
Russia	7.0

Source: Bairoch (1965), p. 1096, cited in Allen (1994)

* Net output in millions of calories per male worker

Table 6 **English and French Agricultural Labour "Productivity"***

Year	England	France
1500	1.32	1.38
1600	1.43	1.45
1700	1.82	1.58
1750	2.19	1.63
1800	2.48	1.70

Source: Wrigley (1985) cited in Allen (1994)

* "Productivity" calculated as ratio of total population to agricultural population

These unique institutional changes in Britain also facilitated another major social change which was essential for the rise of urban industrialisation: mobility of labour. Large farms operated with wage labour paved the way for factories operated with wage labour. The 18th Century witnessed a great increase in farm size and release of agricultural labour, especially women and children. However, labour did not move so easily to the new towns and the pressures for surplus agricultural labour to move out of the countryside did not reach their peak until the New Poor Law of 1832, which introduced the deterrent system of Workhouses to prevent "outdoor relief" of the rural poor.

vii) *Mobility of Labour and Work Organisation*

Whereas earlier accounts (e.g. Dobb, 1947; Marx, 1867) had stressed the Enclosures as a major factor in the recruitment of an urban proletariat, more recent research (e.g. Chambers, 1994) has put the emphasis also on the acceleration in population growth in the 18th Century. This research has shown that employment often continued to grow in *rural* areas despite the effects of the Enclosures. The creation of new employment in these areas was indeed already emphasised by contemporaries, such as Arthur Young (1770) and Adam Smith (1776). This new employment was partly in village industries, partly in construction including canals, ditching and other public works and partly in agriculture itself through exploitation of hitherto unused land.

The demographic revolution in England again appears to have unique features (Goldstone, 1994). It arose not so much because of reduction in mortality as through increased fertility associated with proletarianisation, earlier age of marriage and more stable employment than was offered by "casual labour in field or cottage". Earlier family formation was therefore the major factor in the accelerated population growth of the late 18th Century. Goldstone's hypothesis is that:

> "The increase in fertility after 1750 does not appear linked to a broad change in living standards or nuptiality. The fall in age at marriage did not result from a general shift of the age distribution of marriages towards younger ages but

> from a sudden concentration of first marriages at very young ages by a limited fraction, roughly 20 per cent of the marrying population."
>
> (Goldstone, 1994, page 377)

The rise of the industrial proletariat therefore was not simply a question of landless agricultural labour obliged to seek work in towns, but was a much more complex process. The removal of constraints on mobility from very early times was certainly a unique and important feature of English industrialisation, as was the early rise of wage labour relationships in rural areas as well as in towns. In addition, the special features of the demographic revolution must be taken into account as well as immigration. The demographic changes were also very important in the growth of the home market in the late 18th Century, as per capita incomes apparently did not increase by much between 1780 and 1820, if at all.

The increased supply of labour for the industrial revolution was not simply a question of men, women and children going to work in factories, but also of course of hours of work and work organisation and discipline. Indeed, some theorists (notably Marglin, 1974) explain the rise of factory work mainly in terms of the maintenance of labour discipline rather than economic or technical factors. The techno-economic explanation of Landes still appears the more plausible but whatever the explanation, once the factory system was established it had its own dynamic in terms of the shift in investment from working capital to fixed capital, the coordination of many operations, and the organisation of shifts and division of labour (von Tunzelmann, 1995).

The importance of *time* in this context of work discipline has been brilliantly illustrated by Edward Thompson (1967, 1994). He starts his paper with a quote from the 19th Century novel of Thomas Hardy, "*Tess of the D'Urbevilles*".

> "Tess .... started on her way up the dark and crooked lane or street not made for hasty progress; a street laid out before inches of land had value and when one-handed clocks sufficiently sub-divided the day."

The metaphor of "one-handed clocks" serves to introduce a beautiful account of the way in which notions of time changed over the centuries and how older concepts of time based on the seasons, the sun, the cockerel and even the direction of the wind, gave way to the tyrannical two-handed clock, the waker-up (knocker-up) and later the alarm clock, the second hand, the stop-watch, time and motion study, "clocking on" (and later the micro-seconds of contemporary computer technology). "In 17th Century Chile time was often measured in "credos"; an earthquake was described in 1647 as lasting for the period of two credos; while the cooking time of an egg could be judged by an Ave Maria said aloud." The attitude of Algerian peasants towards time was described by Bordieu as one of "nonchalant indifference to the passage of time which no-one dreams of mastering, using up or saving ..... Haste is seen as a lack of decorum combined with diabolical ambition," and the clock is sometimes known as "the devil's mill" (Quoted in Thompson, 1994, page 59).

In the domestic industries, based on the putting out system, time of course did matter but hours of work were very irregular and work-intensity fluctuated enormously; Monday was often a day for drinking rather than working. The degree of synchronisation was slight and work was task-oriented. Earnings were almost always based on piece-rates. Finally, Thompson observes:

> "the irregularity of the working day and week were framed, until the first decades of the 19th Century within the larger irregularity of the working year, punctuated by its traditional holidays and fairs."
>
> (page 468)

In view of the prevalence of these "pre-industrial" attitudes towards time, it is hardly surprising that the growth of factory industry was accompanied by acute social conflicts about working hours. In the 18th Century complaints about the licentiousness, drunkenness, laziness, ill-discipline, and debauchery of the English "lower class" were commonplace and schools were seen as one of the main ways of inculcating time discipline in addition to factory penalties.

The pressures to increase working hours were strong in the early period of industrialisation and early in the 19th Century gas lighting was one of the technical inventions which facilitated the use of longer hours and shift-work in factories but the resistance of the new factory proletariat was also strong and led to the prolonged efforts of the unions to reduce working hours. These efforts at reform were resisted by Senior and other classical economists on the grounds that profit depended on the "last hour" of the working day.

However, it was not only the new trade unions and reformers, such as Lord Shaftesbury, who were appalled by the long hours of work but also more enlightened industrialists such as Robert Owen, Josiah Wedgwood and Samuel Whitbread. These entrepreneurs, who were among the most successful, argued that technical and organisational innovations, together with improved education and training, and paternalistic reforms in the enterprise would raise productivity more than the crude lengthening of the working day.

The conflicts over working hours and factory discipline serve to remind us that the industrial revolution was by no means a conflict-free consensual transition. The resistance of those who suffered most reached a peak in the 1830s when numerous riots, the first General Strike, and actual insurrections in several towns in England and Wales brought Britain quite close to social revolution.

A profound cultural and social change in attitudes towards time was an essential feature of the Industrial Revolution. The combination of von Tunzelmann's work on time-saving technical change with Thompson's work on attitudes towards time in pre-industrial and industrial societies brings out one of its most crucial features. Thompson concludes:

> "Mature industrial societies of all varieties are marked by time-thrift and by a clear demarcation between 'work' and 'life'....... The point at issue is not that of the 'standard of living'. If the theorists of growth wish us to say so, then we may agree that the older popular culture was in many ways, otiose, intellectually vacant, devoid of quickening and plain bloody poor. Without time-discipline we could not have the insistent energies of industrial man; and

> whether this discipline comes in the form of Methodism, or of Stalinism, or of nationalism, it will come to the developing world. What needs to be said is not that one way of life is better than the other; but that this is a place of the most far-reaching conflict; that the historical record is not a single one of neutral and inevitable technological change, but is also one of exploitation and of resistance to exploitation; and that values stand to be lost as well as gained."
>
> (pages 93-94)

Finally, it is necessary to keep in mind that although factory production became the norm for the most rapidly growing leading sectors of the economy, such as cotton, these still accounted for a relatively small minority of *total* employment until well into the 19th Century.

Nevertheless, the social innovation of factory production was one of the most fundamental changes of the Industrial Revolution. Landes (1965) stresses that neither the workers nor the older class of merchant capitalists, who organised cottage production systems, welcomed this change. It was a radical leap made possible by an exceptional combination of favourable circumstances in 18th Century England, sufficient to overcome the inertia and active resistance of older institutions and attitudes. Landes maintains that the adoption of the factory system of production was driven not only by its much greater profitability but also by a crisis of the cottage-based system. It was a clear example of the interdependence of technical, organisational, economic and cultural change.

viii) *Market Demand*

The role of demand in the Industrial Revolution is one of the issues where there are still quite serious differences of opinion among historians. The controversy is analogous to that among economists about the relative importance of "demand-pull" and "technology push" in stimulating innovations after the Second World War (Mowery and Rosenberg, 1979; Freeman, 1994). Like that controversy it is leading away from linear models to a more systemic approach which accepts that there is a continuous interplay between demand and supply.

A very influential piece of work was that of Elizabeth Gilboy, first published in 1932 and reprinted in three other independently edited collections of papers since (Eds. Church and Wrigley, 1994). She argued that the role of demand had been neglected and pointed to contemporary accounts of the role of fashion, imitation and change of taste in stimulating demand for new goods, as well as old ones. These might at first be described as 'luxuries' but would come to be accepted later as 'necessities'. She summed up her position in these words:

> "Theoretically, then, it is possible to conclude that far-reaching and widespread industrial changes cannot occur except in a society in which demand and consumption standards are undergoing swift and radical readjustment. Such a society is characterised by mobility between classes, the introduction of new commodities leading to the development of new wants, and a rise in real income of the people as a whole."
>
> (page 631)

Her argument about the role of "keeping up with the Joneses" has been generally accepted by many authors since, notably by Eversley (1994) and Landes (1969). (For other references to the reiteration of her theory, see Mokyr, 1994). However, it has been very heavily criticised by Mokyr (1994) in rather the same manner that Mowery and Rosenberg demolished the exaggerated claims for demand-led innovation in the 1960s.

It should be noted, however, that Elizabeth Gilboy's own argument for stressing the role of demand was modestly presented and did not deny the Schumpeterian view that in the early stages of radical innovation, entrepreneurs must create their own market demand, since consumers can have no prior knowledge of the product. She did not attempt to use statistical sources to justify her position with empirical evidence; but Eversley (1994) did so, stressing especially the expansion of *home* market demand in the period from 1750 to 1780, based on rising population and rising living standards. He gave various examples of contemporary descriptions of changing tastes and evidence of a more varied pattern of consumption, facilitated by big developments in the infrastructure, especially canals.

> ".... we can cite a mass of contemporary sources alleging the prevalence of 'luxurious habits' amongst the 'poor'; a complaint shorn of its moralising

> overtones, means nothing more than that some labourers liked tea with sugar even when both were heavily taxed; that women decked themselves out in clothes considered too good for them; and that in some cottages you might find a bit of carpet or even a piano. What seems necessary for growth is that the very exceptional expenditure should become a little less so, that articles described by Nassan Senior as 'decencies', half-way between luxuries and necessities, should spread through some more of the 'middling sorts of people' and that some labourers should take it into their heads (according to their betters) as to go short of food and put themselves into debt for a looking glass or a pair of gilt buckles for their Sunday shoes."
>
> (page 294)

As an example of the kind of goods he is talking about, Eversley quotes the example of the inventory of goods for the cottage of Richard Wainwright, a nailer who as early as August 1739 possessed a fine shovel, a coal hammer, a toasting iron, bellows, a copper can, wooden furniture, scissors, a warming pan, two iron pots, a brass kettle, a pail, two barrels, two bedsteads, a sieve, candlesticks, a rug, a blanket, a kneading tub, a brass skimmer and basting spoon, linen, glass bottles and various other kitchen utensils (page 319).

Eversley believed that the construction of the Midlands canal network and the Lancashire canals in the third quarter of the eighteenth century brought down the price of food as well as coal and other commodities in many towns, especially Birmingham. The improvements in regularity and speed of mail and passenger travel on the coaches in the 1770s also facilitated the creation of larger regional markets for new goods, especially simple metal products.

Many authors, including of course Adam Smith, based on his extensive travels in Europe, maintained that standards of living in 18th Century Britain were well above other European countries. In particular, this was held to be true for a larger and wealthier middle class. Habbakuk (1963) advances this as one of the main explanations of the British industrial revolution:

> "..... average per capita incomes were higher than on the continent. There were larger numbers of people with a reasonable margin of subsistence for the consumption of manufactured goods. The inducement to expand an individual

industry was not therefore impeded by the very inelastic demand which faces an industry in the poorer countries of the modern world."

(page 115)

Mokyr, however, argues that the simple demand leadership thesis is based on circular reasoning:

"It is transparent that if a shift in the demand curve for industrial goods is to be used for the explanation of the rise of industrial output, the shift in the demand curve must be caused by factors other than the rise of output itself."

(page 38)

He dismisses all of Eversley's explanations, and concludes:

"The intention of this paper has been to examine the Gilboy hypothesis in every possible interpretation and to decide whether we can assign an important role to demand factors in the explanation of the industrial revolution. Few of the various alternative interpretations withstand the scrutiny of *a priori* reasoning or empirical tests. The old schoolboy view of the industrial revolution as a 'wave of gadgets' may be not so far off the mark after all, provided we allow for 'more' as well as for 'better' gadgets and we include abstract improvements such as organisational change, changes in workers' attitudes ....."

(page 411)

ix) *Infrastructure*

Whilst generally suspicious of the role of scale economies in relation to expansion of demand, Mokyr concedes that these were important in relation to infrastructural investment in canals and roads. Transport infrastructure is surprisingly neglected in many studies of the industrial revolution, including the otherwise comprehensive Volumes 2 and 3 of the recent Economic History Society set of papers. However, in his chapter on the supply of raw materials, Wrigley (1994) refers to the supply of coal and minerals as being the main driving force for canal building in the late 18th Century. This view is supported by the role of landlords as investors (Table 7) as well as the value of freight carried and the geographical pattern of canal construction.

Table 7 __Investments in Transport Systems (percentages of nominal capital invested)__

	Canals 1755-1815 (1)	Railways 1820-1844 (2)	Canals 1755-1780 (3)	Railways 'early years' (4)	Canals 1780-1815 (5)	Railways 'later years' (6)
1. Peers, gentry, 'gentlemen', etc.	22	28	41	22	22	37
2. Land: farmers, graziers, etc.	2	-	1	-	2	-
3. Commerce: merchants, traders, tradesmen, etc.	39	45	27	52	40	38
4. Manufacturers	15	11	8	15	15	7
5. Professions, including clergymen	16	9	16	8	16	10
6. Women	6	5	8	2	6	8
	100	100	100	100	100	100

Source: Hawke and Higgins (1981)

The sea transport of coal from Newcastle to London was established long before the Industrial Revolution but the wave of canal and turnpike road construction from the 1760s onwards (Figure 1) linked the North and Irish Seas with the navigable reaches of the major rivers - the Mersey, the Ouse, the Severn, the Thames, the Trent, the Clyde and the Forth - and the growing centres of population in the Midlands, the North and Scotland. The cost of transporting coal was reduced by about 50 per cent as a result of the establishment of the canal network. From 1700 to 1750 Parliament had been passing Turnpike Acts at the rate of eight a year but in the 1760s and 1770s this increased to a rate of forty per annum.

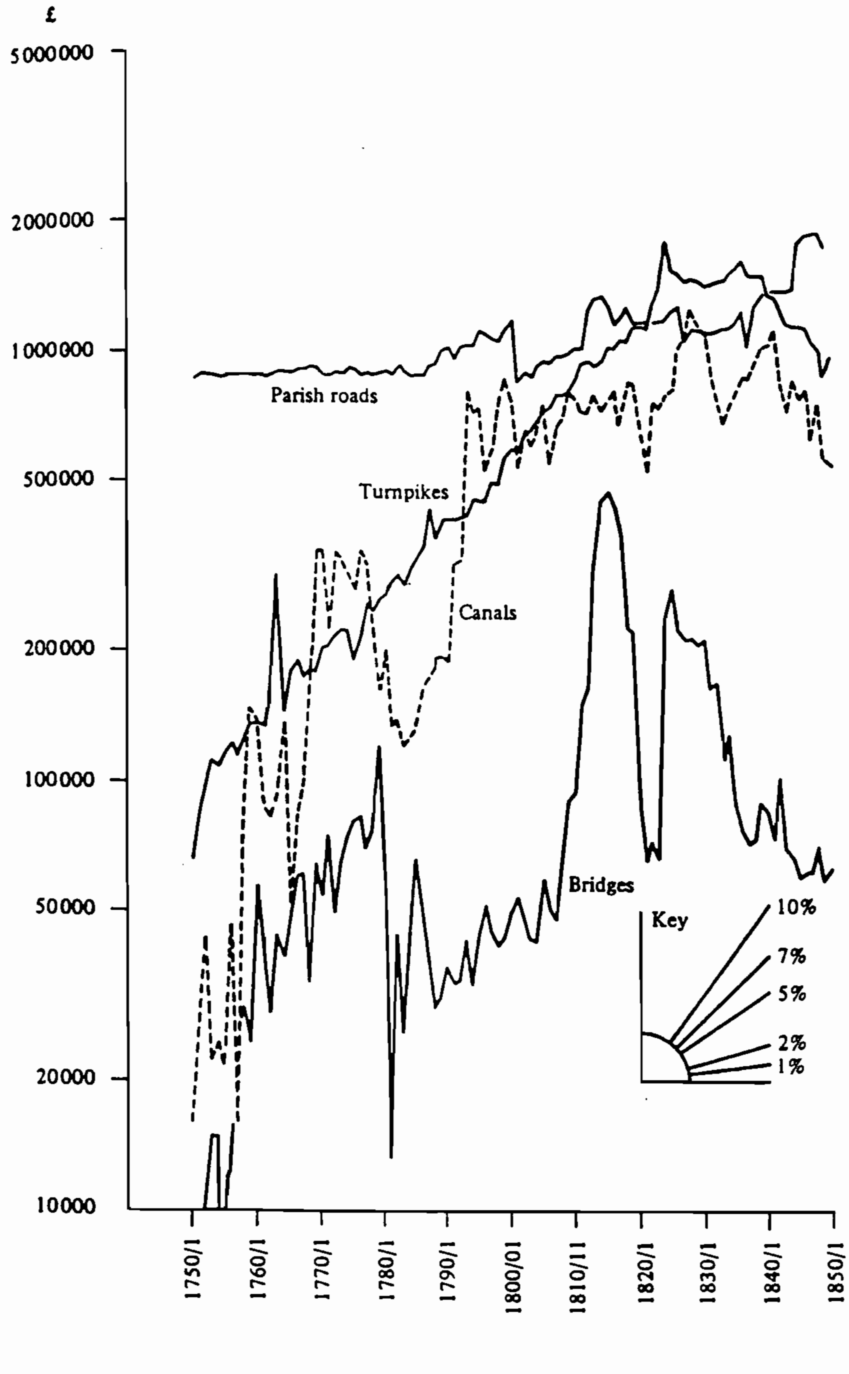
Although canal construction was a relatively small fraction of total investment (von Tunzelmann, 1981), Hobsbawm points out that the "wide scattering" of British industry through the countryside, based on the putting out system, the coal-mining regions, the new industrial textile regions, the "village industries" and London as a huge centre of population, trade and services (the largest in Europe) had two major consequences:

> "It gave the politically decisive class of landlords a direct interest in the mines which happened to lie under their lands, (and from which, unlike the Continent, they rather than the King, drew royalties) and the manufactures in their villages. The very marked interest of the local nobility and gentry in such investments as canals and turnpike roads was due not merely to the hope of opening wider markets to local agricultural produce, but to the anticipated advantages of better and cheaper transport for local mines and manufactures".
>
> (page 16)

The second consequence was that manufacturing interests could already determine government policy, unlike other European countries and even the Netherlands where merchant and landed interests were still dominant. The oligarchy of landed aristocrats was unlike the feudal hierarchies of other European countries in several ways. They were a "bourgeois" aristocracy.

Their contribution to investment in the new transport infrastructure was remarkable (Table 7) but the contribution of merchants, manufacturers and professional people showed that by the

Figure 1 **Transport and Social Overhead Capital**



Expenditure on creating, improving and maintaining canals and roads, etc. 1750-1850 (current prices). The immediate source is Higgins (1971). The estimates result from the Sheffield - SSRC project into capital formation and are discussed in Higgins & Pollard (1971) and Feinstein (1978)

Source: Hawke and Higgins (1981)

mid 18th Century Britain already had a capital market capable of financing quite large investments in social overhead capital, essential for the rapid growth of industry and trade in the last quarter of the century. Foreign trade through London, Liverpool, Cardiff, Newcastle, Edinburgh, Hull, Bristol and many smaller ports kept pace with the growth of GDP from 1760 to 1820 despite the disruption of the Napoleonic Wars. Although exports did not lead the Industrial Revolution, being fairly constant at about 15 per cent of output, they were disproportionately important for the fastest growing industries.

x) *The Invisible Hand*

The high degree of consensus between landlords, manufacturers, and merchants on the main lines of economic policy in the late 18th Century facilitated the rapid growth of manufacturing industry and trade at a rate unequalled before in history and unparallelled in any other European country. The acute 19th Century conflicts between landlords and industrialists over agricultural protection which culminated in the Repeal of the Corn Laws still lay ahead. Many of the old merchant monopolies and guild restrictions had disappeared already in the 17th Century and the early 18th Century. When Adam Smith made his onslaught on all these restrictions in 1776, he was in many respects knocking on an open door.

The basic idea of the "Invisible Hand" was also widely anticipated, for example, by Mandeville in his Fable of the Bees in 1714 with its sub-title: Private Vices, Public Benefits" and by Pope in his couplet equating self-love with social benefit. Many of Smith's ideas were also anticipated by the Physiocrats in France and by James Steuart in Scotland. Nevertheless, his book on "The Wealth of Nations" was by far the most influential and important book on economics of the 18th Century.

It was so, not only because it established "Political Economy" as a reputable discipline in its own right but even more because of its influence far beyond those interested in economics as an academic subject. It would be hard to imagine a stronger expression of the congruence of political aims with economic theory than the statement of the Prime Minister, William Pitt, "We are all your pupils now." Smith's extraordinary influence was due to the fact that it provided an almost perfect rationalisation for the profit-seeking activities of the new industrialists and merchants. They could with a good conscience believe that what they were doing was serving the community through the pursuit of their own self-interest.

The very title and main theme of his book shifted the focus of economic enquiry from trade to growth and from agriculture to productive industry. It meant that the pursuit of growth, capital accumulation, and national prosperity became to a great extent, the shared objective of the State, the industrialists, the aristocracy and the merchants. Thus it was that despite the fact that the landlords wee still by far the most wealthy and politically influential class, economic policies were followed which promoted the interests of the rapidly growing but still small new industries. Gerschenkron has distinguished "positive" from "negative" state policies for industrialisation and somewhat confusingly defined "negative" policies as non-intervention by the state, whereas in his terminology "positive" policies are interventionist. However, in the late 18th Century the non-interventionist laissez-faire policy reducing state involvement with industry and trade was certainly a positive policy in the normal meaning of the word. Small firm competition was a reality in late 18th Century Britain and the opening of domestic and foreign markets did indeed promote technical and organisational change and productive investment in the way that Smith advocated. He was very close to the actual changes taking place in workshops, markets, banks and governments, as the example of the workshop manufacturing pins so clearly demonstrates and his language was not so far removed from the general culture of society as to make it unintelligible to a broad readership, as is often not the case with economics today.

The broad social consensus exemplified by Smith's "Wealth of Nations" did not of course amount to unanimity. It expressed a rationalisation above all of the interests of the "productive" classes of society. However, the rent income of landlords was justified by Smith in a way which it certainly never was 40 years later by Ricardo. Smith attacked monopoly "conspiracies" against the public interests whether by unions to raise wages or merchants to raise prices, yet he was very much concerned with the improvement of the living standards of the poor. In his day, laissez-faire doctrine did not yet carry the uncaring stigma which it acquired as a result of a half-century of intensive urbanisation and industrialisation, the social critique of two generations of poets and novelists and the resistance of many workers to inhuman conditions of work. The "collective intentionality" which emerged in 18th Century Britain was a consensus which did not embrace the still illiterate and poor majority, but their acquiescence could be obtained with rather a small amount of violent repression, despite the fact that living standards for many of them improved little, if at all.

xi) General Culture

The consensus necessary to harmonise many differing individual purposes was of course not exclusively dependent on the widespread acceptance of a particular type of economic theory or rationalisation. It was far more broadly based in the general culture of the time. The Renaissance, the Scientific Revolution and the Reformation of the 16th and 17th Centuries all contributed directly or indirectly to the prevalence of a pragmatic, individualistic, empiricism hard to measure, but widely recognised as characteristic of 18th Century Britain. Moreover, although the English Civil War of the 1640s ended with the Restoration of the Monarchy and no other monarch suffered the fate of Charles I, the 18th Century monarchy was very different from that of the 16th Century or the absolutist monarchies still strongly entrenched on the Continent of Europe. De facto parliamentary sovereignty without a written constitution was firmly established from 1688 onwards. The tradition of parliamentary government with the give and take of political debate and the toleration extended to organised opposition set the example for many other institutions, high and low. Trial by jury, the Common Law, the establishment of national newspapers, the philosophic tradition of Bacon, Locke and Hume, the "Dissenting Academies", and the non-Conformist sects were among the many institutions, which if not entirely unique to England, were in combination impressive evidence of a democratic culture providing a fertile soil for the flowering of local initiatives in all parts of the country.

This general culture both contributed to and was strongly influenced by the Scientific Revolution of the 17th and 18th Centuries. The influence of science is underestimated by many historians in much the same way as economists still today have often underestimated the contribution of science to contemporary innovation. Some Marxist historians, including Engels, have been inclined to overstate the contribution of technology to economic growth by comparison with science, although others, such as Needham, did not do so. Eighteenth Century science was, of course, very different from 20th Century science. Nevertheless, even though the expression "scientist" had not been coined in his time and even though men of science or natural philosophers were very few in number, Adam Smith was well aware of their great importance and emphasised it in the opening pages of "The Wealth of Nations":

> "All the improvements in machinery, however, have by no means been the inventions of those who had occasion to use the machines. Many improvements have been made by the ingenuity of the makers of the machines, when to make them became the business of a peculiar trade; and some by that of those who are called philosophers or men of speculation, whose trade is not to do anything but to observe everything; and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects. In the progress of society, philosophy or speculation becomes like every other employment, the principal or sole trade and occupation of a particular class of citizens. Like every other employment too, it is subdivided into a great number of different branches, each of which affords occupation to a peculiar tribe or class of philosophers; and this subdivision of employment in philosophy, as well as in every other business, improves dexterity and saves time. Each individual becomes more expert in his own peculiar branch, more work is done upon the whole, and the quantity of science is considerably increased by it."
>
> (Smith, 1776, page 8)

It would be hard to devise a more concise statement of the role of science in the Industrial Revolution together with the role of the capital goods industry and users of machinery in the advance of technology. However, Smith's comments on the division of labour draw attention away from another of the ways in which science influenced technology *and* economic growth albeit indirectly and that is its influence on the general culture and on the education and training of engineers and inventors themselves.

Ashton (1958), Musson and Robinson (1979) are among the historians who have done most to demonstrate both the direct (especially Musson) and the indirect (especially Ashton) contribution of science to technology and the general culture of English and Scottish society. Whilst von Tunzelmann (1981) may be right in emphasising that French science was ahead of British science and that much science everywhere was "wrong-headed", this does not undermine the basic argument that an experimental, enquiring, rational spirit and approach was a necessary condition for the work of scientists and inventors alike, as was an elementary awareness of what was known and believed at the time, whether later shown to be "wrong-headed" or not. In fact, von Tunzelmann points out that "the scientific revolution, dated either at the foundation of the Royal Society in 1660 or earlier in the century (Webster, 1975) preceded the financial revolution, the commercial revolution, the transport revolution and the industrial revolution, as these overlapping changes are conveniently dated." (page 148). Furthermore, he also stresses the positive influence of science on the general climate of ideas, within which inventors worked. Ashton insists that:

> "The stream of English scientific thought, issuing from the teaching of Francis Bacon, and enlarged by the genius of Boyle and Newton was one of the main tributaries of the Industrial Revolution. Newton indeed was too good a philosopher and scholar to care whether or not the ideas he gave to the world were immediately "useful" but the belief in the possibility of achieving industrial progress by the method of observation and experiment came to the eighteenth century largely through him."
>
> (page 155)

Like Musson and Robinson he gives numerous examples of the ways in which the leading physicists, chemists and geologists of the day were in intimate contact with the leading figures in British industry: there was much coming and going between the laboratory and the workshop and men like James Watt, Josiah Wedgwood, William Reynolds and James Keir were at home in the one as in the other. The various scientific societies of the day, including especially those in Manchester and Birmingham, but also the Royal Society in London, were another forum for contact between scientists and inventors, although there were certainly periods when these links were minimal. As Ashton points out, even taking into account the growth of scientific specialisation which Adam Smith observed, the language of science had not yet become so esoteric as to preclude contact with the language, culture and practice of ordinary people.

Thus, despite the fact that science had its own institutions, procedures and publications as well as its own "wrong-headed ideas" it certainly influenced both technology and the general culture of society in ways highly favourable to technical change and innovation.

It is often said today that United States culture has been especially favourable to innovation and a contrast is often made between this intellectual and business environment and that of contemporary Britain, supposedly now far more conservative and unreceptive to innovation. Whilst these attitudes are extraordinarily hard to measure, it should be noted that many 18th Century observers believed that British Society was at that time exceptionally favourable to innovation. With typical caustic wit, Dr. Johnson gave the bizarre example of techniques of hanging to illustrate this point:

> "The age is running mad after innovation..... all the business of the world is to be done in a new way; men are to be hanged in a new way. Tyburn [the site at which executions were held] itself is not safe from the fury of innovation..."

A later American equivalent of Dr. Johnson could have cited the electric chair as an equally gruesome example of the spirit of innovation which pervaded the United States, as it became the next major example of a country "forging ahead" in the late 19th Century.

xii) "*This Precious Stone set in a Silver Sea*"

Poets such as Shakespeare have shown far greater awareness of Britain's natural good fortune as an island, than economists and historians who have been inclined recently to dismiss geographical factors, climate and natural resourse endowment as trivial compared with "constructed advantage" (e.g. Hobsbawm, 1968).

Not only did Britain's island condition favour the early development of navigation, ship-building, and world-wide trade, it also offered protection "against infection and the hand of war." Historians still debate the influence of the Napoleonic Wars on British trade and industry, but it was surely remarkable that the industrial revolution continued apace throughout the period from 1789 to 1815. While some branches of industry were slowed down, others such as iron received a considerable stimulus (Table 1). The fact that Britain was not an actual theatre of war must surely also have been a source of comparative advantage, as it was to an even greater extent to the United States during the First and Second World Wars. To be a supplier of weapons and equipment and derive whatever technical inducements may be derived from this, whilst at the same time to be a combatant on other peoples' territories cannot have been wholly disadvantageous to economic development.

Economists too are often rather coy about the role of military power, and especially of naval power, in sustaining supremacy in trade, foreign investment and control over raw material supplies, whether for Britain in the 18th and 19th Centuries or the United States in the 20th Century. It may also well be true, as Kennedy (1988) has proposed, that military and political hegemony, at one time both the cause and effect of economic leadership, becomes increasingly an economic burden as the cost of sustaining military supremacy increases. The anti-colonial views of Adam Smith and the general anti-imperialist standpoint of classical economics have also tended to minimise the possible contribution of naval power to economic growth. But again the poets were probably more realistic. The "mariners of England who guard our native seas, whose flag has braved a thousand years the battle and the breeze" did have something to do with British prosperity. The defeat of the Spanish Armada and later of the Dutch fleet and Napoleon's defeat at Trafalgar, were only the major episodes in the preservation of the national integrity and political stability of Britain, which were essential conditions for economic progress. Piracy and the plunder of colonial territories also played their part, even though again colonialism may later have become a burden rather than an advantage.

xiii) *Summary and Analysis*

Supple (1963) provides an admirably terse summary of the main points which have been discussed above in Sub-sections (i) to (xii):

> "Britain's economic, social and political experience before the late 18th Century explains with relatively little difficulty why she should have been an industrial pioneer. For better than any of her contemporaries Great Britain exemplified a combination of potentially growth-inducing characteristics. The development of enterprise, her access to rich sources of supply and large overseas markets within the framework of a dominant trading system, the accumulation of capital, the core of industrial techniques, her geographical position and the relative ease of transportation in an island economy with abundant rivers, a scientific and pragmatic heritage, a stable political and relatively flexible social system, an ideology favourable to business and innovation - all bore witness to the historical trends of two hundred years and more, and provided much easier access to economic change in Britain than in any other European country."
>
> (page 14)

Returning now to the theoretical framework tentatively advanced in Section II above we may re-classify and develop the main points which have emerged as follows:

(a) **Science**

Bacon's advocacy of scientific methods and his proposals for what amounted to a national network of R&D laboratories already in the early 17th Century were at that time unique in Europe. Also unique was his clear intention to promote both science and invention by their close interaction. Already as a precocious youngster at Trinity College, Cambridge between the ages of 12 and 15, he had written a critique of Aristotelian abstract logic and a defence of experimental techniques. Although later disgraced, his status as a Lord Chancellor and the other high offices that he held contributed to the influence of his ideas, and to the high prestige of science in Britain ever since. The establishment of the Royal Society in 1660 (note the "Royal" in the year of the restoration of the monarchy), although followed by similar national institutions in other European countries indicated that science had already achieved in Britain a high status in the general culture of the country, despite the very small number of active "scientists". The various scientific societies which flourished in the 18th and early 19th Century, like the Royal Society itself, varied in the degree of their involvement with technology but there were certainly periods when they provided a forum for intense interaction. It was from the middle of the 17th Century that Derek Price (1963) dates his "take-off" for the exponential growth of science, with its characteristic methods, publications, open critical debate and other institutions (see also Merton, 1938). The work of Newton in the late 17th Century, more than that of any other scientist confirmed the already high prestige of science in Britain, and its crucial importance for mechanical engineering and for navigation, both vital to the future trade and industry of the country. Newton was accorded the same type of respect, bordering on adulation, as Adam Smith a century later. Poets brought him into their work both as an object of admiration (Pope) and shame (Blake).

Thus, although historians differ on the contribution of science to the specific inventions of the late 18th Century (e.g. von Tunzelmann, 1981; Landes, 1965; Musson, 1972; Mathias, 1969; Hobsbawm, 1968) scarcely any of them deny the contribution of science to the general culture of the time. The science of that time has to be seen in the light of contemporary standards, not those of today. It is possible, although difficult, to maintain, as some Marxist historians did (e.g. Hessen *et al.*, 1930) that Newton's *Principia* was a response to the economic imperatives of the day and to the technological problems of navigation. What, however, is not possible to deny is that at least from the 17th Century onwards, science in Britain had its traditions and institutions, which reciprocally influenced technology, even though it was often the case, as with the steam engine and thermodynamics that technology led the way and science followed. The relatively free movement between laboratory and workshop, the existence of scientist-entrepreneurs as well as inventor-entrepreneurs and the participation of inventors and entrepreneurs in the activities of scientific societies in Manchester, Birmingham, and other industrial centres are further evidence of the fruitful interactions between science and technology in the British Industrial Revolution. Mathias (1969) quotes an amusing small illustration of the growing prestige of science. In 1788 John Richardson entitled his book

"Philosophical Principles of the Art of Brewing". For the new edition in 1798, the title was changed to "Philosophical Principles of the Science of Brewing".

Strength in basic science was not a unique feature of Britain's development but it was a very important one. Relatively unique features were the intimacy of the interaction between science, invention and entrepreneurship and the strong influence of science on the general culture of society. Babbage in 1835 concluded that "it is impossible not to perceive that the arts and manufactures of the country are intimately connected with the progress of the severer sciences (Quoted in Mathias, 1969).

b) **Technology**

Most historians place invention and innovation at the heart of their explanations of the British Industrial Revolution; indeed for a long time it was *the* explanation. As we have seen there are some historians (Mokyr, 1977, 1994; Ashton, 1948) who are at least half inclined to return to the "schoolboy" explanation: "a wave of gadgets" spread over England in the second half of the 18th Century. Questions which are still debated are whether this can still stand as a single factor "trigger" explanation which set the whole vast process in motion and why such a spurt of inventions occurred at this time. That there was a stream of radical and continuous improvement inventions for techniques, machines and products in many different industries, including agriculture during the 18th Century is nowhere denied.

Although they were widely spread, however, the innovations which had the most dramatic and rapid effects on productivity were those in the cotton industry and to a lesser extent in other textile industries and in iron. That the cotton machinery innovations induced such a quantum leap in output and exports was in turn due to a radical organisational innovation - the shift to factory production from the domestic "putting out" cottage industry system. It was this juxtaposition of organisational, social and technical innovations, at first using water power and later steam power, that made it possible to exploit the potential of that combination of inventions by makers and uses of machinery which Adam Smith had already identified as so fruitful. The substitution of iron and other metals for wood in the new machines opened up a trajectory of mechanical improvements which culminated in the mechanisation of most industrial processes in the 19th Century.

The use of water power in small workshops was of course nothing new. It had been exploited by the cutlery industry in Sheffield for centuries and was one of the reasons that the Industrial Revolution took off in the North, with its mountain streams, rather than the South, with its greater wealth and commerce. But the substitution of water power and steam power for human muscle-power on a larger scale was characteristic for the factory system of production, and in the first place the cotton industry.

As von Tunzelmann (1978) has clearly demonstrated, the widespread application of steam power outside a few industries came later in the mid-19th Century, coinciding with the railway boom. The Boulton and Watt steam engine, although a remarkable advance on the earlier designs used in the mining industry, and owing something to science as well as to technology was nevertheless not sufficiently cheap or efficient to find really wide application. Still better engines were developed in the Cornish mining industry before steam power was widely used.

That "dissimilar" specialised streams of knowledge (as Adam Smith described them), could be brought together under one roof depended on entrepreneurship as well as the social mobility of scientists and inventors and their informal contacts. The "partnership" form of company organisation facilitated the emergence of numerous inventor-entrepeneurs as well as scientist-entrepreneurs. Boulton and Watt were the archetypal example of this marriage of financial and management skills with inventive skills, enabling these small new companies to mobilise sufficient capital to move from invention to innovation and to diffusion in a growing market.

The particular importance of technology was evident from the comments of foreign observers and more clearly from the determined efforts of other countries to catch up with Britain by the acquisition and transfer of British technology. Perhaps even more conclusive and showing the contemporary British awareness, were the tough restrictions and penalties imposed to discourage the export of British technology. These efforts were however largely unavailing. Even though it was illegal to take out the plans, Samuel Slater emigrated from Derbyshire in 1789 to Rhode Island and built a replica of Arkwright's machine, thus becoming the founder of the American power textile industry. The Cockerill brothers, who had already been transforming the Belgian textile industry at the end of the 18th Century, built one of the largest engineering works in Europe at Seraing to manufacture pumps, steam engines and hydraulic presses and boasted of easy access to British inventions. Even in Vienna, the directors and foremen of cotton mills were British emigrants. Nevertheless, Britain had by then opened up a gap in living standards, and productivity which was not to be closed by catching up countries until nearly a century later.

Although the links between technology and the economy were at the very heart of the Industrial Revolution and the successful conversion of many inventions to profitable innovations in numerous small but growing firms made possible the acceleration of productivity growth in the leading sectors, this was not a linear process any more than it is today. Feedback and interaction within industries, between industries, between technologies and from the market all played a part and this process was facilitated by the general culture of society, as well as the huge improvements in communications and transport.

(c) **Economy**

Although the growth of capital investment was apparently at a rather lower rate than earlier estimates had assumed, the British capital market had several unique features highly favourable to productive investment in the late 18th Century. A money-based market economy, including also agricultural transactions was already firmly established well before the Industrial Revolution. Habits of saving and investment had developed in various social classes, the relatively prosperous middle class, the professions, and notably the aristocracy, as well as traders and industrialists. This, together with the low rate of interest made possible by these unique features of the British capital market facilitated a rise in investment to about 10 per cent of GDP. There was some reluctance to finance the new fixed investment in factories but local sources of finance, including family and friends enabled the new industrial entrepreneurs to obtain the small amounts of capital they needed to finance the investment in machinery and other fixed capital embodying their technical innovations. The relatively small scale of these early investments meant that capital shortage was not a constraining factor.

Indeed in the early days, labour shortage was if anything more of a problem, despite the uniquely high mobility of British labour and the wave of enclosures of agricultural land. The influence of demographic trends is still disputed but the combination of a sharp rise in population in the late 18th Century, the delayed effects of rural social change and immigration combined to swell the ranks of the urban proletariat. A little later, the ruin of the hand-loom weavers and the decline of other cottage industries, although causing acute social distress and many local riots, reinforced the industrial working class, so that the earlier reluctance to accept factory discipline, longer hours of work and other features of capitalist industrial civilisation were overcome by the stark alternatives to wage labour and the incentive to try and earn a small margin above subsistence, whenever possible, to finance the purchase of the new consumer goods.

Technical and institutional change were inextricably linked to the processes of capital accumulation and the growth of the labour force. Although the classical economists from Adam Smith onwards put capital accumulation at the centre of their analysis of the capitalist mode of growth, they were very well aware of these other influences. The "entrepreneur" was more than the "representative agent" of later abstract models. Although driven by the profit motive and to some degree compelled to innovate by the competitive process, the separation of ownership, control and management had not yet gone so far as to deprive these early entrepreneurs of unique individual innovative qualities of leadership and coordination, as well as the ruthless desire to succeed in accumulation.

Capital accumulation, mobility of labour and capital were all essential features of the industrial revolution as traditional economic theory, as well as Marxist and Schumpeterian theory have always maintained. But the Marxist/Schumpeterian view of embodied technical change, of the role of new products in competition and of innovative entrepreneurship conforms still better to the story told by almost all historians, albeit with minor variations.

d) **Politics**

A little more controversy surrounds the role of cultural and political change but none deny their significance altogether. Because they are not amenable to measurement in the way that science, technology and the economy can be (to some extent) measured, it is all too easy simply to omit them from models and analysis. This would be a very grave mistake.

The reception accorded to Adam Smith's "*Wealth of Nations*" illustrates this perhaps better than anything else. The British political system, alone in Europe at that time, was uniquely receptive to the message of Adam Smith. Despite his support for the American War of Independence, his unequivocal condemnation of monopolies as conspiracies against the public and his strong reservations about the powers and conduct of governments, he became a revered public figure whose authority was regarded as essential validation for new departures in economic and social policy.

Several unique features of British political life combined to produce this concordance. One of these was the development of a "bourgeois aristocracy" with a strong interest in infrastructural investment and other forms of commercial investment. The political dominance of this class did not block the advance of industry and economic reforms in the way that it did in so many other European countries, although not of course in the United States.

Another unique feature was the continuity of a relatively stable form of parliamentary government for a long period after the Civil War. Even though dissenters (and Catholics) were deprived of some civil rights, a tradition of toleration had developed which enabled educated and talented non-conformists and other minorities to play a very active role in society and especially in entrepreneurship and local politics.

Finally, the island position of Britain coupled with the long naval tradition, meant that even though Britain was involved in numerous wars throughout the 18th Century, culminating in the Napoleonic Wars, these were not fought on her own territory. This further reinforced her political stability, and probably also her economic strength, despite occasional periods of panic repression.

A unique political tradition combined with many restraints on the exercise of arbitrary power combined to give a uniquely favourable reception to the doctrine of "laissez-faire" in economic policy, low taxation and removal of institutional barriers to trade and industry. Working class resistance was kept in check by legislation against unions (the Combination Acts), by the restricted franchise and (more rarely) by outright repression of Luddite riots and strike movements.

e) General Culture

The influence of science and of religious toleration in British culture were not entirely unique. There were of course parallel developments in other European countries, especially in France and in the Netherlands. Descartes, Voltaire and the Encyclopaedists did perhaps even more than Bacon, Locke and Hume to weaken the hold of dogmatic religion on popular culture. Nevertheless, it is notable that Voltaire believed England to be ahead in Europe in matters of free speech and publication and a pragmatic approach to politics, and believed these to be closely related to her commercial success.

Illiteracy was still widely prevalent in Britain in the 18th Century and it would be a mistake to attribute the Industrial Revolution to any big advance in the general level of education, whether primary, secondary or tertiary. It was the existence of a fairly substantial educated middle class, partly the result of the efforts of non-conformist minorities, which made possible the cultural changes associated with the Industrial Revolution.

Nor was formal technical education a major feature of the early days of the Industrial Revolution. It was mainly a question of learning by doing and apprenticeship on the job. There was considerable flexibility in the conversion of older skills and, as the pace of the revolution quickened, part-time night school type of training for "mechanics" became increasingly important. It was not until much later that the various "Institutes" of Engineering for Civil and Mechanical Engineers were established (1820s). The relatively small part played by changes in the formal education system is not altogether surprising. As Hobsbawm (1968) in particular insisted, much of the technology which was being diffused depended more on mechanical ingenuity and practical experience than on book learning. This does not mean that "learning" was not important but only that learning by doing and by using were the predominant methods for the greater part of the work force. Indeed, British engineers took great pride in their practical experience and their "hands-on" approach to problem-solving. It stood them in good stead during the period when mechanisation was the dominant technological trajectory but raised some problems as electric power and other more complex, more "theoretical" technologies became increasingly important.

Although extraordinarily hard to measure, changes in attitudes towards accumulation, hours of work, consumption, and leisure were all important in the 18th Century. Perhaps most important of all was the spread of a pragmatic, experimental attitude and fairly open-minded readiness to discuss, entertain and apply new ideas in the work-place.

From this summary of five main streams of history: science, technology, economy, politics and culture, we may conclude that each contributed to the "Forging Ahead" of Britain in the 1780s and 1790s. Most of all, however, it was their relatively harmonious confluence which was the basis for British success. The interdependence of technology, capital accumulation and new forms of work organisation is especially striking; less obvious but no less important were the dependence of all of these on cultural and political changes. Finally, science interacted not only or even mainly with technology or the economy but indirectly through the general culture of society. It remains to discuss the questions of recurrence and of intentionality. The presence of many unique features in the British "forging ahead" vindicates Popper's view that the most important events in the social sciences are non-recurrent. When it comes to catching up, however, or even to later forging ahead, recurrence becomes a key issue as we shall see in Section V.

V. Falling Behind and Catching Up

Falling Behind

Success in pioneering the first industrial revolution enabled Britain to stay ahead of most of the competition for the greater part of the nineteenth century. Only in the United States, the next country to "forge ahead" did per capita incomes surpass those of Britain towards the end of the century. Britain had become "the workshop of the world" with by far the dominant share in world exports. Even by 1899 Britain still accounted for nearly 40 per cent of world exports of manufactures, compared with about 20 per cent for Germany and 10 per cent for the United States. Her share of manufacturing *production* was still greater than any other country except the United States (Maizels, 1963).

The mechanical industrial and transport technologies of the mid 19th Century (railways, machine tools and the applications of steam power in a wide range of industries) were those in which Britain already had a lead in the 1830s, and in which she continued to dominate world trade. Nevertheless, by the 1880s the end of British industrial and technological supremacy was already foreshadowed. The harmony between the five main streams of change which had been so characteristic of the early stages of the Industrial Revolution was undermined in the late 19th Century and still more in the 20th Century, when the forging ahead of the United

States and the catching up of numerous other countries, especially in Europe became the dominant features of the growth of the world economy.

British "falling behind" has been discussed by many historians and Walker (1993) distinguishes three main explanations:

(i) The spread of industrialisation was bound to undermine British economic hegemony and the world geographical factors which had favoured Britain so much in the 17th and 18th Centuries no longer favoured her now. Railways opened up Europe and other continents to trade and travel and the relative importance of the North Atlantic area declined.
(ii) Success which initially breeds more success ultimately breeds failure. British imperial power became over-extended and a rentier mentality developed. "Failure developed its own pathology." Industries became defensive and less enterprising.
(iii) "....... the culture and institutions that sustained industrial development in the period of expansion proved inappropriate to the new industries that emerged in the 1880s and 1890s..... As Nelson and Rosenberg described ..... the chemical and electrical industries required a greater and more systematic engagement in science and education, and the automobile industry a more scientific approach to industrial management than had hitherto been practised." (page 158)

All of these explanations, but especially the third are consistent with the theory of history which has been developed here. The loss of congruence was particularly notable in five main areas:
(1) The system of industrial training and technological education which had served Britain fairly well in the 18th and early 19th Century, was less suited to the needs of the new technologies and industries. Countries which were catching up in the second half of the 19th Century, especially the United States and Germany, developed a far more thorough and systematic approach to technological education than Britain and, in the case of Germany and some other European countries, a more thorough and extensive system of training skilled

workers. It was some time before British public opinion became aware of the lag; recognition was retarded by a belief that the old approach was still the best and some resistance to institutional change and social innovation from complacent interest groups.

(2) What later came to be regarded as a rather amateurish British style of industrial management not only in small firms but in the larger ones, which were now developing, was not well suited to the new technologies and scale of production. "Muddling through" was a source of flexibility and innovative behaviour in the circumstances of the early industrial revolution with very small production units, but this was no longer the case with the large corporations and much larger fixed investments of the 20th Century. Characteristic of the most successful catching up countries, such as USA, Germany, Japan and Korea has been a rather thorough and systematic management approach to design, production engineering and marketing. The comparisons made by Peter Lawrence of the way in which British and German engineers *in the same industries* spent their working day was especially revealing. The main activities of the German engineers were planning the purchase of new capital goods and studying the possibilities of new technology; the main activities of their British counterparts could best be described as "fire brigade" operations dealing with a variety of unforeseen crises in the plant.

(3) Whereas the main thrust of British investment during the industrial revolution was in the new industries and infrastructure, by the early years of the 20th Century the focus had shifted to portfolio and utility investment overseas. The British capital market financed infrastructural investment all over the world but to a diminishing extent in Britain itself.

(4) Whereas the prestige, status and remuneration of *engineers* was apparently rising in a number of industrial countries and especially Germany and the United States, it suffered some relative decline in Britain. In the universities, the prestige of *science* was high and British scientists continued to make major contributions to world science. This was far less true of *technology* (Ashby, 1968).

(5) Whereas the *laissez-faire* approach of government had been in many ways suited to the early stages of the industrial revolution, its limitations became increasingly apparent, with the new technologies and scale of industry. This was well exemplified by the regulatory regime

for electric power generation and distribution. Hughes (1982) has shown that Berlin and Chicago forged ahead of London in the applications of electric power in part because of the multiplicity of standards in Britain and mis-management of the new infrastructure.

All of these points indicate that various "out of synch" phenomena had emerged towards the close of the 19th Century in Britain - between technology and culture, technology and politics, technology and the economy and even between technology and science. Very few people foresaw this relative British decline at mid-nineteenth century. Even Friedrich List, the outstanding exponent of catch-up theory on the Continent of Europe, died believing that Germany could never overtake Britain. Much later on, in the 1960s, the "Dependency" theorists were so impressed by the advantages of the United States and Western Europe that they though it impossible for countries in Asia, Latin America or Africa ever to catch up. Even today, writers such as Ernst and O'Connor (1989) find it hard to believe that the East Asian countries can continue with their catch-up.

The advantages of fore-runners may indeed appear overwhelming at first to late-comers. Not only do they apparently command an unassailable lead in technology, but they enjoy many static and dynamic economies of scale and privileged prestigious positions in world markets. It is for this reason that successful catch-up is often referred to as a "miracle" (The German and Japanese "miracles" of the 1950s, 1960s and 1970s; the Korean and Taiwanese "miracles" of the 1980s and 1990s). But if any process is to be regarded as a "miracle" it should be "forging ahead" rather than catching up.

Catch-up

Catching-up countries have previous models so that intentionality is far more clearly present as the very name implies. To be sure, political and cultural institutions are extremely varied and sometimes impossible to imitate but even in this case, they provide models and lessons. In the area of technology and science, catch-up is far more straightforward. Moreover, the desire to catch up, once awakened in various social groups and in at least some political institutions, can provide a rather powerful unifying national ideology, amounting to a form of collective intentionality. This is certainly not to deny the enormous obstacles which latecomers do face, nor the intensity of the social conflicts which they experience in attempting to develop appropriate catch-up strategies. The fact that so few Third World countries have been successful is evidence enough for this. Nor is catch-up ever simply a question of imitation, it always involves institutional and technical innovation for the catching-up countries. Nevertheless, the element of imitation, especially in relation to technology and economic organisation, means that recurrent phenomena are much more frequently evident. It is possible here only to give the briefest indication of these characteristics of catch-up processes, citing only a few examples, which may serve to illustrate the controversies about catch-up among historians and economists.

German Catch-up in the 19th Century

Friedrich List differed from Jean-Baptiste Say not only in his advocacy of tariff protection for infant industries in catch-up countries but in his entire approach to the role of science and technology in economic development. Say also contributed several completely original ideas to economic theory but is known mainly for his untiring advocacy of classical theories of free trade and competition. List on the other hand, developed an entire theory of catch-up. Interestingly enough he is often remembered in Germany as a strong advocate of *railway* construction, which he saw as essential to unify the scattered German states and provide the infrastructure for a modern economy. This, however, was only one feature of a much wider approach to economic development. His book on "The National System of Political

Economy" might indeed have been entitled "The National System of Innovation" since this was its main focus. Far more than the classical economists he recognised the crucial role of knowledge accumulation (as opposed to capital accumulation) in economic growth:

> The present state of the nations is the result of the accumulation of all discoveries, inventions, improvements, perfections and exertions of all generations which have lived before us: they form the intellectual** capital of the present human race, and every separate nation is productive only in the proportion in which it has known how to appropriate those attainments of former generations and to increase them by its own acquirements."
>
> (page 113)

List's clear recognition of the interdependence of tangible and intangible investment has a decidedly modern ring. He saw too that industry should be linked to the formal institutions of science and of education:

> "There scarcely exists a manufacturing business which has not relation to physics, mechanics, chemistry, mathematics or to the art of design, etc. No progress, no new discoveries and inventions can be made in these sciences by which a hundred industries and processes could not be improved or altered. In the manufacturing State, therefore, sciences and arts must necessarily become popular."
>
> (page 162)

It was thanks to the advocacy of List and like-minded economists as well as the long-established Prussian system, that Germany developed one of the best technical education and training systems in the world. This system not only was, according to many historians, (e.g. Landes, 1969; Barnett, 1988; Hobsbawm, 1968) one of the main factors in Germany overtaking Britain in the latter half of the 19th Century, but to this day, is the foundation for the superior skills and higher productivity of the German labour force (Prais, 1981) in many industries. Many British policies for education and training for over a century can be realistically viewed as spasmodic, belated and never wholly successful attempts to catch up with German technological education and training systems.

** I have used the expression "intellectual capital" rather than "mental capital" used in the early English Edition, C.F.

Not only did List anticipate these essential features of current work on national systems of innovation, he also recognised the interdependence of the import of foreign technology and domestic technical development. Nations should not only acquire the achievements of other more advanced nations, they should increase them by their own efforts. Again, there was already a good model for this approach to technological learning in Prussia: the acquisition of machine tool technology. It was British engineers (especially Maudslay) and mechanics who were responsible for the key innovations in machine tool technology in the first quarter of the 19th Century. This technology was described by Paulinyi (1982) as the "Alpha and Omega of modern machine-building" because it enabled the design and construction of metal-working precision machinery for all other industries. Those involved attempted to maintain a considerable degree of secrecy, but its importance was recognised by the Prussian government, who took decisive steps to acquire the technology, despite the fact that the British government was attempting to ban the export of machine tools (with the imposition of heavy fines for contravention).

The Prussian government which had set up Technical Training Institutes (Gewerbe-Institut) made sure that they received imported British machine tools for reverse engineering and for training German craftsmen, who then disseminated the technology in Germany industry (Paulinyi, 1982). British craftsmen were also attracted to Prussia as much of the technology depended on tacit knowledge. (Three out of four of the leading machine tool entrepreneurs in Britain at that time had themselves spent years with Maudslay in his workshop). The transfer of technology promoted and coordinated by the Prussian state was highly successful: the German machine tool industry proved capable of designing and manufacturing the machinery necessary to make steam locomotives in the 1840s and 1850s. This set Prussia (later Imperial Germany) well on the road to overtaking Britain. Although he did not cite this particular example, List therefore was not talking in a purely abstract way about industrialisation and technology transfer but about a process which was unfolding before his eyes. It was summed up by Landes (1969):

"..... Only the government could afford to send officials on costly tours of inspection as far away as the United States; provide the necessary buildings and equipment; feed, clothe, house, and in some cases pay students for a period of years. Moreover, these pedagogical institutions were only part - though the most important part - of a larger educational system designed to introduce the new techniques and diffuse them through the economy; there were also non-teaching academies, museums, and, most important perhaps, expositions."

"......... Finally, the government provided technical advice and assistance, awarded subventions to inventors and immigrant entrepreneurs, bestowed gifts of machinery, allowed rebates and exemptions of duties on imports of industrial equipment. Some of this was simply a continuation of the past - a heritage of the strong tradition of direct state interest in economic development. Much of it, in Germany particularly, was symptomatic of a passionate desire to organize and hasten the process of catching up".

"In so far as this promotional effort stressed the establishment of rational standards of research and industrial performance, it was of the greatest significance for the future." (page 151)

Here clearly there is a set of recurrent phenomena which have been characteristic of catch-up countries. Not only did List analyse many features of the national system of innovation which are at the heart of contemporary studies (education and training institutions, science, technical institutes, user-producer interactive learning, knowledge accumulation, adapting imported technology, promotion of strategic industries, etc.) he also put great emphasis on the role of the state in coordinating and carrying through longterm policies for industry and the economy. Here, as often, he took issue with Jean-Baptiste Say, his favourite target in his polemics with the classical school, who had argued that governments did not make much difference, except in a negative way.

The United States was of course even more successful than Germany in overtaking Britain in the second half of the 19th Century and List had learnt a great deal from his residence in the United States and especially from Hamilton's (1791) *Report on Manufactures*. The widespread promotion of education (though not of industrial training) was even more remarkable in the United States than in Germany. However, the abundance of cheap, accessible materials, energy and land together with successive waves of immigration, and the total absence of feudal institutions, imparted to the United States national system some specific characteristics without parallel in Europe, which facilitated not only catch-up but forging ahead (Abramovitz and David, 1994; David, 1995). The pro-active role of the state was greater in Germany whilst foreign investment played a greater role in the United States.

Catch-up at the Sectoral Level

This discussion of some of the outstanding features of catch-up strategy at the *national* level may be complemented by a brief reference to catch-up at the *industry* level. Sectoral development is always an extremely uneven process and typically catch-up too is very uneven. Gerschenkron (1962) and Jang-Sup Shin (1995) concentrated in their analysis on the sectoral level of catch-up, taking the example of iron and steel for Germany and Russia in the 19th Century (Gerschenkron) and Japan and Korea in the 20th Century (Jang-Sup Shin).

They point out that although late-comers have a model to aim for and the knowledge that it can be achieved, catch-up cannot follow an *identical* path simply because the world has changed both for fore-runners and for late-comers. The followers have to face international competition which the pioneers did not face by definition, but they can also interact with the fore-runners and even cooperate with them. In any case the technologies which they acquire have already been tested and proved and already reached a significant scale of development. Furthermore, Gerschenkron argued that sometimes *late* late-comers (i.e. very backward countries) could close a technology gap without all the "social capability" conditions being present:

> 'One thing is obvious. Illiteracy and low standards of education, and the resulting difficulty in training skilled labor and efficient engineers, can be overcome to some extent by immigration from more advanced countries and to some extent by using the training facilities of those countries. The same is true, even more importantly, of the lack of store of technical knowledge. It can be imported from abroad. In this sense, however, one can say that in a backward country there exists a 'prerequisite' to industrial development which 'the' advanced country did not have at its disposal, that is, the existence of the more advanced countries as sources of technical assistance, skilled labor, and capital goods'.
>
> (pages 46-47)

Following Gerschenkron, Shin developed the argument for *institutional* innovations in late-comer countries:

> Here the substitution of missing prerequisites, or the utilisation of existing prerequisites, and catching-up is more of a simultaneous than of a sequential process in late-comers. Gerschenkron therefore argues in several places that those prerequisites are created 'not before, but *in the very course of* - and as a consequence of - a spurt of industrialization'.

However, this process is not automatic. Hence his emphasis on institutions:

> '.... industrialization processes [of late-comers] .... showed considerable differences, as compared with more advanced countries, not only with regard to the speed of the development ... but also with regard to the productive and organizational structure of industry which emerged from those processes. Furthermore, these differences in the speed and character of industrial development were to a considerable extent the result of application of institutional instruments for which there was little or no counterpart in an established industrial country.'
>
> The central focus of Gerschenkron's analysis of late industrialisation is therefore placed on the question as to how those often 'missing' prerequisites in late-comers are created or substituted for through specific institutional responses, rather than on that of whether some prerequisites exist sufficiently in particular late-comers at the beginning of their development."
>
> (Jang-Sup Shin, 1995, page 29)

This leads to one of the most interesting features of the Gerschenkron/Shin analysis. They point to the fact that both in the case of the steel industry and the much later case of the semi-conductor industry, some late-comers endeavoured to exploit *scale* economies which the leaders had not yet achieved. Germany and Russia both built steel plants in the late 19th Century and 20th Century with a much larger capacity than the largest British steel plants of the time. They could only do this of course because a rapidly growing world market was already established. The substitution of cheaper and better steel rails for iron rails in the world's railway systems was one major source of this rapidly expanding demand but there were many others, such as ship-building and construction. The innovation which the late-comers successfully made was to exploit one of the technological trajectories which Nelson and Winter (1977) identified. Both Gerschenkron and Jang-Sup Shin are careful to emphasise that each catching-up process has some unique features, both in terms of the industry and the catching-up country. Moreover, increasing returns to scale at plant level cannot always be relied upon as the example of the steel industry itself demonstrates. Whereas the Korean steel industry did indeed profit from building what was then the largest steel plant in the world in the 1960s, late-comers in the 1990s confront an entirely different situation. The Malaysians have to catch up with mini-plants (Bell, 1995) because of the changes in steel industry technology.

Capital intensity and massive scale economies were a key feature of process industries such as oil, bulk chemicals, steel and to some extent of mass production industries, such as automobiles and consumer durables. They are also a feature of some, but by no means all, electronic products, and notably of memory chips for computers. Jang-Sup Shin is therefore justified in pointing to some recurrence of leap-frogging in scale of plant in the very different industries of steel and semi-conductors. He is also justified in recalling Gerschenkron's hypothesis that even though leap-frogging in scale could be a recurrent phenomenon in catch-up, the method of *financing* these huge investments in what were hitherto backward countries would vary greatly depending on specific national circumstances, institutional innovations and independent developments in the banking system. Thus, some of the early 19th Century developments in the Prussian steel industry (in Silesia) were financed by the state, but later on the German banks were fully capable of sustained long-term investment in industry. This was not the case with the Russian banks at the end of the 19th Century, so that the state was again the main source of credit for the new large plants.

Thus, in Gerschenkron's *schema* the main role of institutions in the late-comer countries was to mobilise resources and concentrate them on large capital-intensive projects. Catch-up countries could invest in large *individual* plants even though overall capital-intensity might be low. This is a much more limited *schema* than that of List or of Perez and Soete (1988), as Jang-Sup Shin clearly recognises. However, he justifies this admittedly limited analysis of specific capital-intensive sectors just because it is intermediate between "descriptive history" and the universal propositions of Abramowitz or of Perez and Soete (page 32). He justifies his critique of Abramowitz and Rostow with the Gerschenkronian argument that all the "pre-conditions" for "take-off" do not have to be present and that social capability is acquired *at the same time* as technological capability, not in advance of it.

His critique of Perez and Soete is more complex. A justifiable criticism which they would surely accept is that they do not provide the empirical evidence to support their theory beyond the case of information and communication technology (ICT). There is certainly an enormous need for research on historical experience of catch-up at the level of the firm, the industry, the country and the technology. Paradoxically, however, Shin's own research provides some support for their analysis. The German catch-up in steel was most successful precisely as Perez and Soete suggested, when a "window of opportunity" was opened by the diffusion of major new technologies (Bessemer, Siemens, Gilchrist, Thomas, etc.) and by the numerous applications of high quality but cheap steel in electrical engineering, armaments and construction as well as in railways and ship-building (Freeman,). The Gerschenkron/Shin approach misses the main point of the Perez and Soete theory - the *pervasiveness* of major new technology systems and their linkages throughout the economy.

His other main critique of Perez and Soete - that of "technological determinism" may also be partly justified in terms of the theory which has been advanced here and which ascribes some relative autonomy to processes of political and cultural change. However, their theory was not advanced as a universal theory of history but as an analysis of growth and catch-up in the capitalist world economy of the past two centuries or so. It thus assumes the existence of a Capitalist economy and the related political institutions and culture. It is difficult to deny that in this period, within a complex system of interdependent relationships between science, technology, economy, politics, and culture, many of the changes in politics and the economy have been in the nature of a response to changes in technology.

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