Part II Evolution, technology and institutions: a wider framework for economic analysis

Preface to Part II

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The introductory chapter has outlined the general structure of the book as a whole. But because of the size and complexity of the subject, we shall introduce each section of the book with a brief preface, indicating the scope of the subsequent chapters in that section and drawing out some of the main points which are essential for the flow of ideas in the book as a whole.

In this section Dosi and Orsenigo first introduce the general problem of accounting for the relatively ordered patterns of growth which have been a feature of industrialised capitalist economies for quite long periods—as in the quarter century after the Second World War. They reject the orthodox explanation of this 'dynamic stability' for reasons which have been touched on in the introduction and will be developed at greater length in Part III ('How well does established theory work?'). They are concerned with the inherent uncertainty associated with technical innovation and argue forcefully against any theory which assumes 'hyper-rationality' on the part of representative agents.

How then to account for dynamic stability? They suggest that the problem should be approached in two ways: on the one hand, by studying and understanding the regularities and patterns in the process of technical change itself; and, on the other hand, by recognising the role of institutions (including markets but not *only* markets) in regulating and stabilising the behaviour of the system. These two aspects of long-term dynamic stability are taken up in the two following chapters by Freeman and Perez (Chapter 3) and Boyer (Chapter 4).

Dosi and Orsenigo point out that despite the great diversity in the sources and consequences of technical change, it is not a purely random process. There *are* regularities in the pattern of technical change which have been analysed in empirical studies and which may account in part for the relatively stable patterns of growth. In particular they point to the existence of 'technological trajectories' and 'technological paradigms' which offer opportunities for profitable, innovative investment and growth of new markets over relatively long periods along rather well-defined paths of development and diffusion.

The notion of 'paradigms' and 'paradigm change' is at the heart of the chapter by Freeman and Perez on business cycles and investment behaviour. They observe that Keynes himself and representative neo-Keynesians, such as Samuelson, did not believe in the capacity of the self-adjusting market mechanism to equilibrate investment behaviour, and that a 'climate of confidence', 'animal spirits' and state intervention had to be invoked to achieve a sustained, full employment growth path. Then they examine the influence of technical change in generating a 'climate of confidence' which might sustain expansionary waves of investment, when business only 'pretends to itself' that it believes in the 'rational' *ex ante* calculations of future return on investment.

The Freeman–Perez chapter suggests that some new technologies, after a prolonged period of incubation and crystallisation, offer such a wide range of opportunities for new markets and profitable new investment that, when social and institutional conditions are favourable, entrepreneurs have sufficient confidence to embark on a prolonged wave of expansionary investment. They point out that Keynes himself once acknowledged the validity of this Schumpeterian explanation of major investment booms.

Their analysis is based on the idea of a 'techno-economic paradigm' first advanced by Carlota Perez. This differs from similar ideas advanced by Kuhn, Dosi and others in two ways. Most importantly her concept is one of a '*meta*-paradigm'—a dominant technological style whose 'common sense' and rules of thumb affect the entire economy. It thus corresponds most closely to Nelson and Winter's concept of a 'generalised natural trajectory' or 'technological regime' which dominates engineering and management decisions for several decades.

Secondly, its powerful influence throughout the system derives from a combination of technical *and* economic advantages (hence the expression 'techno-economic' paradigm). This point is an important one since it means that her concept recognises from the outset the influence of the economic selection environment in shaping and crystallising the new technology within the wide realm of the technically feasible. A 'techno-economic paradigm' is a cluster of interrelated technical, organisational and managerial innovations, whose advantages are to be found not only in a new range of products and systems, but most of all in the dynamics of the relative cost structure of all possible inputs to production. In each new paradigm a particular input or set of inputs may be described as the 'key factor' in that paradigm characterised by falling relative costs and universal availability. The contemporary change of paradigm may be seen as a shift from a technology based primarily on cheap inputs of energy to one predominantly based on cheap inputs of information derived from advances in microelectronic and telecommunication technology.

The Freeman–Perez conceptualisation has much in common with Schumpeter's theory of long cycles. It differs from that theory, however, in several ways. In the first place the notion of change of techno-economic paradigm is wider than Schumpeter's key radical innovations introduced at intervals of forty to sixty years. It recognises the pervasive effects of a change of technological style not just in a few motive branches of the economy but throughout the system. The process of structural

change associated with the transition from one paradigm to another affects all industries and services.

Secondly, Perez has offered a more convincing explanation of the periods of deeper depression, which in Schumpeter's model were a pathological phenomenon, but in her model represent periods of 'mismatch' when the established social and institutional framework no longer corresponds to the potential of a new techno-economic paradigm. Structural crises of adjustment are thus periods of experiment and search and of political debate and conflict leading ultimately to a new mode of regulation for the system.

Clearly there are important points of correspondence between the Freeman–Perez model of the role of institutions and that of the French 'regulation' school described in Chapter 4. In this chapter Robert Boyer provides a lucid synthesis of the ideas developed over more than a decade by this group of French economists. (Because this literature is rather scattered and is still inadequately known outside France this chapter also includes a full bibliography of the school's publications.)

In their view it is institutions which provide the 'glue' which holds the system together and enables accumulation to proceed in a relatively ordered manner for quite long periods. Each particular 'regime of regulation' is designed to control and stabilise a particular phase of capitalist growth, differing in important respects from the preceding phase.

They define a 'mode of regulation' as

> any set of rules and individual and collective behaviours which have the three following properties:
>
> - to bring into compatibility possibly conflicting decentralised decisions without the necessity for individuals or even institutions to bear in mind the logic of the whole system;
> - to control and conduct the prevailing accumulation mode;
> - to reproduce the basic social relationships through a system of institutional forms historically determined.

They concentrate their analysis on the institutional forms governing five key features of the mode of regulation: monetary and credit relationships, the wage–labour nexus, the type of competition, the forms of state intervention, and the 'forms of adhesion' to the international regime. They show that all these institutional forms differ considerably between the regimes of early and mature 'competitive regulation' in the nineteenth century and 'monopolistic regulation' in the twentieth century. Their analysis of the 'monopolistic' (or 'Fordist') mode of regulation in the period since the Second World War is particularly well developed and they are able to use it as a basis for formal modelling of the economic system, as illustrated in the second chapter contributed by Robert Boyer to this book (Chapter 7).

To the reader it may appear that the ideas of Perez and of the French Regulation school are sufficiently complementary to offer scope for an original synthesis. The French regulation school, although acknowledging the importance of technical change, have paid relatively little attention to it, whilst Freeman–Perez have not developed so far their analysis of institutional forms or of aggregated formal models of the economy. Both chapters contain tables with suggestive tentative sketches of the historic succession of modes of regulation or paradigm change. But both point to the need for much historical research to flesh out these first approximations.

As Boyer points out in his chapter, historians have too often been reluctant to challenge the prevalent schools in economic theory, whether neo-classical or Marxist, whilst economists have too often tried to impose their theoretical preconceptions in all periods of history (as in the extreme example of 'Robinson Crusoe' theorising). A historical perspective is crucial for any research programme which seeks to understand technical and institutional change, but it must be one which recognises the importance of *qualitative* change in the system.

This conclusion emerges with particular force from the final chapter in Part II by Peter Allen (Chapter 5). He puts the current debate about economic theory in a far wider context, affecting epistemological problems in all the natural and social sciences. This perspective is healthy for economists, since one of the problems, increasingly recognised in the profession, is the need for reintegrating economic theory with the other social sciences, as was considered quite normal by the classical economists. The chapters which have just been discussed and (from an entirely different direction) the work of the 'New Institutional Economics' school are both indications of this need to reconstitute 'Political Economy' with a full recognition of the role of institutions and institutional change. A bridge to the physical sciences in the understanding of technical change is no less important.

Allen points out that all branches of science have been limited in their thinking and ambitions by the prolonged domination of a Newtonian mechanistic perspective, which hinders the analysis of *qualitative* change and evolutionary development. He points to new developments in physics, chemistry and biology, as well as the social sciences which are stimulating the analysis and formal modelling of systems undergoing qualitative change:

> The real message of the new concepts in science is that change and disequilibria are probably more natural than equilibrium and stasis. Those who can adapt and learn will survive. And this will depend on their 'creativity'.

The ideas advanced by Peter Allen in this chapter on 'self-organising evolutionary systems' are of the greatest importance for the subsequent parts of the book dealing with established theory (Part III), the behaviour of firms (Part IV), national systems of innovation (Part V), and formal modelling (Part VII).

2 Coordination and transformation: an overview of structures, behaviours and change in evolutionary environments*

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Introduction

One of the common themes of all contributions to this book is *change*: change not only in the techniques of production and the characteristics of the product but also in the behaviours leading to new discoveries and their economic exploitation; in the general structure of economies and their performance—whether assessed in terms of employment, or income, international competitiveness, productivity, etc.; and, finally, in the mechanisms and institutions through which economies and societies coordinate the economic efforts of their agents, produce change and govern them. Of course, there are micro and macro dimensions to these processes of change. Individuals and/or organisations deviate from the 'normal way' of doing things; adjust to 'external' (environmental) changes; respond in 'creative', new and sometimes unexpected ways to competitive or conflictual challenges; or explore what they believe to be (rightly or wrongly) unexploited opportunities. In turn, individual and organisational behaviours, to different degrees and through different processes, are *selected*, penalised or rewarded. They are selected *ex ante* on the basis of the cognitive structures, 'visions of the world' and competences of individuals, and of the prevailing norms of organisations. They are also selected *ex post*. In contemporary mixed economies, market competition and other forms of more discretionary selection (such as choices by governments, financial institutions, etc.) sort out the behaviours, products, techniques, and organisational forms which—on some economic and/or institutional criteria—are 'preferred'.

* Comments on related papers, on which this work is partly based, by R. Nelson, S. Winter and the participants of the Lewes and Maastricht meetings that led to this book, have been helpful to the present draft.

Finally, the processes of exploration, development, selection and diffusion of new technologies, new 'ways of doing things', organisational structures and institutions, and market interactions, may well often be beyond the control or even the imagination of individual actors.

Of course, processes of change are continuously intertwined with processes of allocation of resources and coordination among agents, which in contemporary mixed economies occur to a good extent via the markets. In fact, the relationship between market signals and market organisation, growth and technical change has long been recognised as one of the central issues in economic analysis. This was one of the major analytical tasks of classical economists, from A. Smith to Ricardo and Marx, who tried to account for the determinants and regularities in the dynamics of industrial economies (the 'laws of transformation . . .') and explain the patterns of allocation and the related coordination of economic activities. The latter appear to produce relatively ordered and efficient outcomes from the multiplicity of decisions by individual agents. One must recognise that the classical economists have not been entirely successful in this task, in that they partly failed to establish a satisfactory link between the properties of price-based allocative mechanisms (with the related competitive process) and the dynamic patterns of growth of the economic system.

Facing the double function of decentralised markets as instruments of allocation of resources and as instruments for the transmission of impulses to change (Kaldor, 1984, 1972), classical economists often considered the second one as by far the most important, without feeling any need to analyse the functional relationship between the two. Fundamental dynamic properties such as the relationship between expansion of markets, division of labour, and productivity growth in Smith, or the 'increasing organic composition of capital' in Marx, are examples of a class of propositions argued on the grounds of the *irreversible transformations* originated by processes of what we could call 'dynamic competition'. Moreover, their neglect of explicit microfoundations was justified on the grounds of what we may term a 'holistic' or 'macroinstitutional' assumption about behaviour: it seemed obvious to them that, for example, given an opportunity, capitalists were ready to seize it, or that their 'institutional' function was to invest and accumulate the surplus.

Conversely, neo-classical economists focused on the problem of allocation of given resources within a context of fixed and freely available technologies. In the neo-classical world the function of the market is only the allocative one: change must be treated either parametrically or reduced to an allocative decision. Correspondingly, the organising principle of the system is the 'economic rationality' of individual agents, taken to be an invariable procedure of maximisation of some known objective function.

The relationship between allocative processes, economic behaviours, innovation and economic change was at the heart of Schumpeter's analysis. Schumpeter stressed the dichotomous role of markets and tried to reconcile them in an uneasy compromise between, first, statics and equilibrium

—to which Walrasian processes were supposed to apply—and, second, dynamics—with the domain of entrepreneurship, disequilibrium and qualitative change of the economic system.

In our view, the contributions to this book should be read in this light: how can we understand *change, coordination and relative dynamic order in environments* characterised by *discovery, learning, selection, evolution and complexity*? Certainly, these contributions do not tell the entire story of these processes. However, several of them can be considered as attempts to tackle, with varying degrees of generality, parts of a big analytical puzzle wherein technological and institutional changes are 'disequilibrating' factors producing non-stationarity in the environment, but, at the same time, emerge in ways which are often rather 'patterned' and—except for major discontinuities—do not yield fundamental breaks in the process of coordination among a multitude of economic agents.

This chapter is meant to suggest a broad interpretation of, and a set of conjectures about the linkages between innovative behaviour, market processes and institutions. In some instances, the argument is backed by references to specific contributions in the economic literature. In other instances it is somewhat more speculative.

Overall, in this essay we try to highlight a broad research programme and some research results on how economic coordination and relative dynamic order may go together, in contemporary economies continuously characterised by technological and institutional change.

Order and change: some preliminary remarks on technology, technical change and the theory of production

Technical change occurs all the time, often endogenously produced within industry by profit-motivated agents who try to appropriate the economic benefits of their innovative success. The institutions that organise production and sales vary, too, both over time and across sectors, ranging from many small producers selling in competitive markets, to oligopolistic firms which can behave strategically in relation to their environment and their future. Technological and institutional change and the varying innovative success of the different agents are part of a continuously changing environment.

We shall ask: are there some mechanisms and processes which can maintain the system on a self-sustained path, however defined?

Let us first consider the characteristics of change—and in particular technical change—as they emerge from the empirical literature. One of us has surveyed them in other works (Dosi, 1986 and Dosi's chapter in this book on the features of innovation). There we conclude that general features of technical progress are (i) sector-specific degrees of appropriability and levels of opportunity of technological advance; (ii) partial tacitness of technological knowledge; (iii) variety in the knowledge-base of and search procedures for innovation; (iv) uncertainty; (v) irreversibility of technological advances (i.e. unequivocal dominance of new processes and products over old ones, irrespective of relative prices); (vi) endogeneity of market structures associated with the dynamics of innovation; (vii) permanent existence of asymmetrics and variety between firms (and countries) in their innovative capabilities, input efficiencies, product technologies, and behavioural and strategic rules.

Under such circumstances, we suggest, a first element which accounts for the emergence of relatively ordered patterns of change stems from the very nature of the *learning process* underlying technological advances. As discussed at greater length elsewhere (Dosi, 1984 and Dosi's chapter in this book), technologies develop along relatively ordered paths shaped by the technical properties, the problem-solving heuristics and the cumulative expertise embodied in *technological paradigms*. Each 'paradigm' entails a definition of the relevant problems that must be tackled, the tasks to be fulfilled, a pattern of inquiry, the material technology to be used, and the types of basic artifacts to be developed and improved. A *technological trajectory* (Nelson and Winter, 1977; Sahal, 1981; Dosi, 1982a; Gordon and Munson, 1981; Saviotti and Metcalfe, 1984) is then the activity of technological progress along the economic and technological trade-offs defined by a paradigm.

In this view, technology is not a free good, but involves specific, often idiosyncratic, partly appropriable knowledge which is accumulated over time through equally specific learning processes, whose directions partly depend on firm-specific knowledge and on the technologies already in use. This view also implies a *theory of production* whose main features are, in the short term, diversity of (relatively fixed) coefficients between firms, and, in the longer run, relatively ordered patterns of accumulation of firm-specific competences (Winter, 1982) and of the development/diffusion of unequivocally superior techniques and products. Relatedly, the local and irreversible nature of technological advances is likely to induce the emergence of strong non-convexities (see Arthur's chapter and Atkinson and Stiglitz, 1969; David, 1975, 1986; Arthur, 1985).

As Arthur (1985) and David (1986) show, cumulative localised and irreversible forms of technical progress yield (i) non-predictability of equilibria; (ii) inflexibility (random walks having absorbing barriers); (iii) non-ergodicity (the past is not 'forgotten' and strong hysteresis effects emerge); and (iv) potential inefficiency (a particular equilibrium or, dynamically, a particular path might be inferior in terms of some welfare measure but the system may still be 'locked' in to it).

Against this background, consider the relationship between market signals and technical change. Technological paradigms and technological trajectories bind to rather narrow limits any process in inter-factoral substitution based on a *given* state-of-the-art of technology, induced by changes in relative prices. However, they provide at the same time relatively ordered 'avenues' of technical progress. With positive technological

opportunities, the economic agents tend to react to (or anticipate) changes in relative prices and demand conditions by searching for new techniques and new products *within* the *boundaries* defined by the nature of each technological paradigm (Nelson and Winter, 1982; Dosi, Pavitt and Soete, 1988). These new techniques and new products, in turn, are likely to be or become superior to the old ones irrespective of relative prices (immediately, as in the case of several microelectronics-based innovations, Soete and Dosi, 1983, or after some learning time as in agricultural machinery, David, 1975). In other words, if they had existed before, they would also have been adopted at the 'old' relative prices. Using a biological metaphor, technological paradigms provide a *relatively coherent source of mutations*, while at the same time constraining the adaptability of the system to optimal allocations for *given* technologies. Conversely, in environments with relatively high technological opportunities and paradigm-bound changes, markets tend to perform as rather powerful stimuli to change, even where they are relatively poorer optimal allocators of given amounts of resources.

Innovation, uncertainty and economic behaviour

Due to the specific characteristics of the innovation process (discussed in Freeman, 1982; Nelson and Winter, 1982; and Dosi, 1986, and Dosi's chapter in this book) one should expect to find innovative environments showing both an *information gap* (i.e. information is necessarily imperfect) and a *competence gap* of every agent (in that the capability of efficiently processing the available information is heavily constrained by the complexity of the causal links characterising the environments to which the information refers).[1] Limits on available information and on the capability of efficiently processing it obviously entail uncertainty in the formation of the expectations on which economic agents base their decisions: the existence of a permanent gap between the 'competence' of the agents and the 'difficulty in selecting the most preferred alternatives' (which is at the core of the very existence of uncertainty) is such that the restriction on the number of allowed alternatives (i.e. the 'routinisation' of behaviour) may well increase 'the chance of "correctly" selecting the action at the right time relative to the chance of "mistakenly" selecting it at the wrong time' (Heiner, 1983, p. 565).

Moreover, one is likely to find another—and even stronger — source of uncertainty which rests on the impossibility of mapping preferences, states-of-the-world, actions and outcomes, even for a notional agent with *infinite* computing capability of all the information that the present can deliver about the future. The nature of this strong uncertainty is twofold. First, the set of outcomes of different courses of action is often unknown (Nelson and Winter, 1982) and might not even be enumerable (which is the *theoretical* condition of computability, let alone the *practical* computability of empirical agents: see Lewis, 1985, 1986.) Almost by definition, trying to do a new thing involves the impossibility of knowing what the new thing will look like, what its economic properties will be, what is the best way of doing it and even what are the feasible ways of achieving the result, if any. Second, the states-of-the-world are at least partly endogenous in that, for example, the future technological advances and the related pay-offs depend in complex and often unpredictable ways on present allocative decisions of a relatively high number of non-collusive agents.

Both phenomena involve *uninsurable* and *unmeasurable* uncertainty (in the sense of Knight, 1965, and Schackle, 1961). Markets may well work efficiently, deliver all the information that they can, and even discount contingencies for future states-of-the-world to which probabilities can notionally be attached (although empirically these markets rarely exist). What markets *cannot* do is to deliver information about or discount the possibility of future states-of-the-world whose occurrence is, to different degrees, the unintentional result of present decisions taken by *heterogeneous agents* characterised by different competences, beliefs and expectations. Whenever these circumstances apply, one may reasonably doubt whether economic agents apply maximisation procedures in their decision-making (e.g. in their allocations to research activities, the directions of search, the choice of products to be developed, etc.), and even whether it is efficient *to try* to do so in environments characterised by environmental complexity, uncertainty and potential surprise. A unique 'rational' behaviour may be hard to define, not only in terms of the information set and computational capabilities of individual agents, but even for a notional external observer who is not God (and thus cannot read in the hearts and minds of the agents) but still knows all the information that markets deliver and also knows that all agents have self-seeking goals; what is 'right' or 'wrong' for any one agent may still depend on uncertain behaviours of all other agents in ways that can hardly be represented in simply game-theoretic frameworks (more on this point is in Winter, 1971; Nelson and Winter, 1982; and Dosi, Orsenigo and Silverberg, 1986).

This is not to say that the agents do not try to be forward-looking and behave strategically in the knowledge that their actions influence the world.[2] However, what acquires a major importance in the description of decisions and behaviours is the actual priors they hold (that is, their actual set of beliefs and *Weltanschauungen*), their problem-solving rules, their specific knowledge, the ways they change them in *non-stationary* systems, and the nature of the environmental selection amongst different classes of agents who hold different beliefs (thus behaving differently even under identical information and incentives from the environment). Putting it another way, in order to discriminate among a very large set of conceivable games, strategies and (possible) equilibria, which the analyst can devise to describe innovative environments, one must introduce also the knowledge of the *actual rules and institutions* governing decisions, learning and adjustment processes.

Uncertainty necessarily implies institutions, in two senses. First, one requires *behaviour-shaping* institutions (which may well be just endogenous developments of organisations, rules, beliefs and *Gestalten* or may also involve external organisations, laws, etc.). Second, uncertainty—even in the weaker form of *imperfect information*—requires institutions to organise the interactions and the coordination between agents who (a) at best have an approximate knowledge of the possible states-of-the-world and of the possible outcomes of their own actions, and (b) operate in an environment where interactions necessarily produce externalities and unintentional outcomes.

Both the technological and institutional knowledge of *how and what people learn, what are their beliefs and how they change* occupy, in the approach suggested here, a role theoretically analogous to maximising rationality in neo-classical models: they are factors of *behavioural order* which contribute to explain coordination and consistency in uncertain, complex and changing environments.

Institutions, firms and performance

Let us suggest two—complementary—definitions of institutions. A first, more conventional one comprises non-market, non-profit organisations (governments, public agencies, universities, etc.). Their importance in the generation and diffusion of technological innovations is surveyed in Freeman (1982) and Dosi (1986) and discussed analytically in Freeman's and Nelson's chapters in this book. A second, broader definition—nearer to what one finds in sociology—comprises all forms of organisations, conventions and repeated and established behaviours which are not directly mediated through the market.

What has just been said about behaviour in complex and non-stationary environments implies that one might not be able to deduce behaviour, with any reasonable approximation, solely from knowledge of market-delivered information and the self-seeking goal of the agents. In turn, this implies that the institutions which shape 'visions of the world', behavioural conventions, perceptions of opportunities, and interactions between the agents are an important ingredient in the explanation of what the agents actually do, e.g. how much they invest in innovation, what kind of technical progress they expect in the future, what appropriability mechanisms they try to build, how much they cooperate, and to what extent they compete with each other. In this respect, compare, for example, Schumpeter's 'heroic' innovators of the *Theory of Economic Development* with the 'routinised' innovations of *Capitalism, Socialism, Democracy*. These archetypes can be interpreted to represent different institutional patterns which govern different innovative behaviours, even for the same latent opportunities of technical progress.

Institutions, in the broader definition, matter because the 'architecture' of the system affects performance for the same set of underlying incentives. This is so in simple cases of imperfect information (Stiglitz, 1985; Sah and Stiglitz, 1985; Herriott, Levinthal and March, 1985) and institutions matter even in the simplest 'rational expectations' world (Frydman, 1982). *A fortiori*, this applies to all innovative environments which present those strong forms of uncertainty described earlier. Moreover, in general, market processes themselves cannot be adequately understood without reference to the institutions which shape behaviour and adjustment mechanisms (cf. Akerlof, 1984; Okun, 1981).

In fact, even the 'economic agents' which we generally represent as the decision-makers are as such theoretical constructs. What one typically observes are complex institutions—modern corporations—organised around rules, hierarchies and various mechanisms of behaviour of selection and performance assessment (for detailed and conceptually diverse discussions, see Simon, 1957; Cyert and March, 1963; Nelson and Winter, 1982; Marris and Mueller, 1980; Williamson, 1975, 1985; Kay, 1984; Teece, 1982b; and Kay's, Pelikan's, Teece's and Freeman's chapters in this book). There is an important theoretical point here. If richer institutional knowledge is required in order to narrow down the wide set of possible dynamics of any innovative environment consistent with some set of latent technological opportunities, market-delivered information and profit goals, then economic theory faces the task of achieving robust 'stylisations' of different types of firms, the ways they emerge and the influence that these different organisational forms have on firms' behaviour and performance. Relatedly, any theory of the firm must also be a theory of how competences are organised and decisions are taken, and how organisational hierarchies relate to the knowledge base of technological advances (for developments along these lines, see Teece's and Kay's chapters and Nelson, 1981, 1987; Teece, 1982a, 1986; Kay, 1979, 1984; Pavitt, 1984b). In this perspective, the nature of business firms certainly relates to (i) the procedures for coordination, control, and monitoring of the performance of individual members; (ii) an incentive structure; (iii) criteria and procedures for resource allocation; (iv) a (related) information-processing network; but also, at least equally important, to (v) procedures for problem-solving, learning, and storing/reproducing specific competences. The *internal organisation, boundaries and performances* of firms always reveal, we suggest, various combinations *and tensions* between these basic functions (the general issue is discussed in Dosi, Rumelt, Teece and Winter, 1988; see also Aoki, 1986).

Market processes, evolution and performance

We have been discussing so far some technological and institutional properties of non-stationary environments which tend to provide coherence to patterns of change and 'order' behaviour, despite high degrees of uncertainty and problem-solving complexity. These properties, related to the nature of learning and of specific institutional set-ups, operate *ex ante* with respect to market interactions. However, the economic feasibility and success of any one behaviour of economic agents is often ultimately determined by market processes, so that no *a priori* consistency of plans is guaranteed. Thus, one should also investigate the coordinating properties of market mechanisms under non-stationary conditions.

The interaction between institutions which govern innovative activities and market-based patterns of change remains a major theoretical challenge. An understanding of the pattern of change is basic to the understanding of the nature of particular economic institutions (this is increasingly recognised also within the neo-classical tradition: see Arrow and Honkapohja, 1985, p. 22). The converse is also true—the nature of economic institutions contributes to shaping the rates and directions of change. Thus, how does one disentangle the process? How can one model change in economic environments where innovation—with the characteristics outlined earlier—features predominantly?

Whatever specific theoretical representation is chosen, we suggest that these environments present characteristics that are (a) *evolutionary* in the sense that change proceeds also by means of slow or fast, but never instantaneous processes of selection amongst heterogeneous agents who actually compete, make mistakes and (unlike biological evolution) learn over time; (b) *irreversible*, so that past history structures present available options and selection mechanisms; (c) *self-organising* in the sense that the 'order' in the evolution of the system is the *largely unintentional* outcome of the coupled dynamics between technological progress (innovation, learning, etc.), strictly economic activities (investment, pricing, financing, competition for market shares), and the institutions governing decisions and expectations.[3]

Relatedly, a major theoretical challenge concerns the existence and properties of 'equilibrium', however defined, in evolutionary environments with the features briefly described earlier. How can we characterise 'order' in this context? What are the equivalents in an evolutionary environment of the 'existence and stability properties' of more standard equilibrium models?

As introductory remarks, let us suggest two partly complementary definitions. As a first *behavioural* or subjective definition of 'equilibrium', take that notional state of the economy which 'generates messages which do not cause agents to change the theories which they hold or the policies which they pursue' (Hahn, 1984, p. 59). In the framework of this discussion, this 'subjective' definition of an evolutionary equilibrium corresponds to a set of *'structurally' stable strategies*, i.e. the strategies that heterogeneous agents continue to pursue in non-stationary environments which, in turn, fulfil the objectives of these strategies[4].

However, the message-spaces and the action-spaces corresponding to these structurally stable strategies are rather different from those of a Walrasian world of the Arrow–Debreu–Hahn kind in three senses. First, the 'theories' are also about technological developments, market trends, fundamental rules of interaction—in a word, they also embody fundamental and commonly shared *Gestalten* and beliefs about future technological and market contingencies for which there is no forward market and which are indeed the partly endogenous outcome of expectations and individual strategies. Thus, particular sets of 'theories' and beliefs perform in evolutionary equilibria a role vaguely similar to contingency markets in the Walrasian world, in that they provide for the *relative consistency* of expectations of individual agents over time.

Second, the message-space has a much higher dimensionality than in a Walrasian world. However, *theories* and *institutions* simplify it, in the sense that (a) only particular kinds of information trigger attention and behavioural change (cf. also Heiner's contribution to this project). Structurally stable strategies are also likely to embody higher-level rules of selection in the message-space. (Think for example of the computer industry and the complexity of the messages it delivers. It is plausible that several, especially small, firms have a 'theory' that says something like the following: look primarily at IBM, wait six months to see if a new product succeeds, then produce an IBM-clone at lower cost and do not bother with the rest unless major technological or market revolutions occur). These strategies embody problem-solving rules which are sufficiently general and 'redundant' to cope with computational complexity and environmental non-stationarity (Dosi and Egidi, 1987).

Third, the 'policies' also involve (i) rules on 'how much I should adjust prices and quantities and how much I should innovate', on 'innovation versus imitation', on what direction to innovate in, etc.; (ii) beliefs on the origins and effects of change; and (iii) relatively abstract and general strategies on how to cope with and/or *generate* environmental non-stationarity.

Fourth, there might be more than one strategy which is 'stable' over time, without any unequivocal possibility of ranking this as 'better' or 'worse', as compared to others.

In some respects, the 'subjective' definition of a Walrasian equilibrium is a special case of a 'behavioural' one whenever (a) the latter collapses to one specific 'theory' (everyone believes that the world works more or less in a Walrasian way), (b) the world and the theories about it are such as to allow strict separability between some sort of 'short term' about which the agents hold stationary and 'Walrasian' beliefs and a 'longer term' where different (possibly more 'Schumpeterian') beliefs apply.

A second definition of 'evolutionary equilibrium' relates to the *selection mechanisms* at work in the system and the sequence of attractors that they entail. Let us suggest the following definitions. A series of 'evolutionary equilibria' is that path of evolution of the system whereby (a) technical progress proceeds along any one technological trajectory (as defined earlier and discussed in Dosi's chapter); (b) the distribution of firms according to their organizational characeristics and technological asymmetries (that is, their technological lags and leads) is stable; and (c) the distributions of the performance variables (prices, profit rates, productivities, etc.) of the firms in an industry is also stable. Obviously, a steady-state growth is a very special case of an evolutionary path. However, evolutionary equilibria are also, for example, those situations suggested by Nelson (1985) is which two groups of 'innovative' and 'imitative' firms coexist characterised by identical profitabilities and a stable technological lag between 'imitators' and 'innovators'. More generally, evolutionary/self-organisation-type models are likely to generate evolutionary equilibria, in the definition adopted here, for relatively stable combinations of technological *opportunity*, *appropriability* of innovation and *strategic rules* of behaviour.

It is our conjecture that, for established technological paradigms and for given institutions, there exist one or more sequences of evolutionary equilibria (i.e. one or more evolutionary paths) which are stable in the sense that they correspond to the series of attractors which lead the evolution of the system. Actual economic systems may well never be on any sequence of 'evolutionary equilibria'. However, given sufficient stability in technological paradigms and institutional conditions, an evolutionary path, we conjecture, is likely to lead to a relatively stable evolution of the system. For example, it is plausible that any profit for an innovating firm in excess of that level allowed by technological asymmetries *vis-à-vis* imitators will be eroded by mechanisms of both 'stationary adjustment' (i.e. changes in prices and quantities produced by other firms, etc.) and 'Schumpeterian adjustments' (more firms will try to join the 'innovating group', etc.).

A fundamental point, however, is that *in general*, the series of attractors defined by an evolutionary path are *behaviour-dependent* and *path-dependent*. That is to say, it is the very process of approaching any one 'attractor' which may well change the value of the attractor itself: the process of 'getting there', and the ways one tries to get there, influences the 'centre of gravity' itself. Putting it another way, any evolutionary equilibrium implies forces which keep the industry together and forces which keep it moving. However, the two cannot be rigorously separated. Take, for example, that process by which the industry adjusts to, say, 'excess profits' of some innovators. Most likely one will see an expansion of the quantities produced by the other firms and, *ceteris paribus*, a price reduction (this is a 'stationary adjustment'). This same process, however, also implies a change in the average conditions of production of the industry, in average R & D propensity (both due to the change in the distribution of output between innovative and imitative firms), varying 'spill-over' of technical knowledge from 'leading' to 'backward' firms, changes in the average rate of change of production costs, and, ultimately, changes in the 'evolutionary attractor'.

In general, the stability of an evolutionary path, we suggest, is likely to rest upon those technological conditions of opportunity, appropriability and cumulativeness characteristic of each technological paradigm and on the permanence of the institutions governing behaviours and expectation formation.

Conversely, the transition between different evolutionary paths is driven by changes in technological paradigms, forms of organisation, market structures, etc.—often anticipated by relatively small 'deviant behaviours' which, under certain micro and/or macro conditions, become autocatalytic, progressively amplify and may end up being dominant.

An obvious, but extremely difficult, question comes immediately to mind, namely, what is the relationship between the 'subjective' and the 'selective' definitions of 'evolutionary equilibria'? So far, we do not have any robust answer. It seems plausible that a set of evolutionary stable behaviours entails a corresponding 'selective equilibrium' (otherwise people, sooner or later, would change their 'theories' and their 'policies'). However, the converse is not necessarily true: a sequence of selective equilibria could be stable, for example, even at the price of a high rate of mortality of firms, and/or a very high volatility of market shares, productivity, profits (and thus, plausibly, changes in 'visions' and 'policies') of individual firms.

Finally, note that in evolutionary environments, 'theories' and 'policies', on the one hand, and selection mechanisms, on the other, are by no means independent: the selection environment for any one agent is determined by what all others think and do. The endogeneity of selection processes ranges between 'hyperselection' (and thus self-fulfilling prophecy of one or a group of agents) and total counter-intentionality ('if everyone else thinks and behaves like me, my behaviour will be selected out'). The endogeneity of selection rules is, of course, an essential characteristic of *behaviour-dependent* and *path-dependent* evolutionary paths. (More on this and on why these processes cannot generally be reduced to simple game-theoretic concepts is in Silverberg's chapter.)

How does coordination occur and what are the performance characteristics of evolutionary environments? The analysis of these properties is still at a very early stage and here we shall simply suggest some conjectures.

Take, for example, the short-term performance analysis of industries and markets, which is one of the traditional concerns of industrial economics. In another work (Dosi, 1984a) it has been argued that the permanent existence of *asymmetries between firms*, in terms of production costs and product technologies, represents a sort of *factor of order* which (i) limits the set of feasible strategies regarding price/quantity adjustments available in the short term to each firm; and (ii) tends to order them hierarchically (so that, for example, price leadership, under certain conditions, stems from technological leadership). In other words, existence of inter-firm asymmetries reduces the typical indeterminacy of oligopolistic games by introducing hierarchies between the players and asymmetric constraints on their feasible strategies. Technological and organisational asymmetries between firms are likely to be, to a *first approximation*, predictors of short-term performance (in terms of prices, profit rates, etc.). They have a role analogous to those entry- and mobility-barriers upon which the more 'structuralist' tradition in industrial economics has focused (see Bain, 1956; Steindl, 1976; Downie, 1958; Sylos Labini, 1967; moreover on mobility barriers, see Caves and Porter, 1977, 1978). In fact, economies of scale and product differentiation can be considered a sub-set of the asymmetries which tend to arise in innovative environments as a result of learning curves, lead times, cumulativeness in innovative capabilities and internalisation of complementary technologies. Therefore, the proximate determinants of short-term performance are factors directly related to the nature of each technological paradigm (such as the scope for economies of scale, the specific technological opportunities, the degrees of cumulativeness of each technology, etc.) and to the institutions which organise innovative activities (and thus the regimes of appropriability, degrees of corporate internalisation of technological capabilities, established business practices of cooperation versus competition, etc.).

In general, whatever the precise nature of the coordination process, evolutionary environments permanently show an intrinsic tension between a selective pressure toward a 'better' allocation of resources, on the one hand, and the inevitable (indeed, necessary) generation of mistakes, unsuccessful trials, 'wasteful' and partly duplicative processes of search, on the other (Nelson, 1981, and Nelson's chapter in this book). Let us now discuss these properties.

Change and dynamic stability: learning and selection

In standard models coordination among plans and actions of individual agents—and thus the theoretical possibility of economic 'order'—rests on the interaction between a simple behavioural assumption (maximisation) and some sort of scarcity constraint.

Conversely, the 'core' heuristics of the approach suggested here depends on the interaction between exploitable opportunities, present in non-stationary environments, which are too complex and too volatile to be fully mastered or understood by individual agents, and institutions which, to different degrees, simplify and govern behaviour and interactions. As a consequence, 'order in change' is generated by varying combinations of (a) *learning*, (b) *selection mechanisms*, and (c) *institutional structures*.

Figure 2.1 presents an extremely simplified illustration of such an 'evolutionary engine'. In the evolutionary process, asymmetries and diversity among agents are both a functional condition and a necessary outcome of innovation (Eliasson, 1986; Gibbons and Metcalfe, 1986;

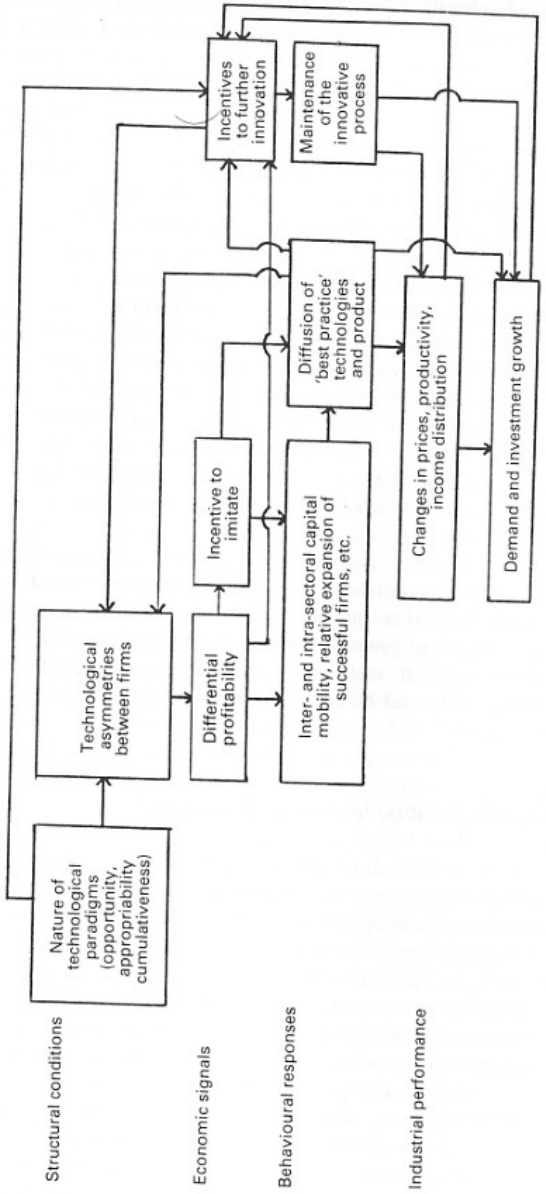

Figure 2.1 Change and dynamic stability: a microeconomic illustration

Nelson and Winter, 1982; Iwai, 1981; Dosi, Orsenigo and Silverberg, 1986). These Schumpeterian features of the system imply continuous 'disequilibrium' features and the dominance of dynamic processes over 'static' allocative mechanisms:[5] technical change is an asymmetry-creating process. Its precondition and outcome are varying degrees of appropriability of the innovation and differential profitabilities. This very process, however, provides both the incentive and the need for other firms to imitate and/or undertake further innovation. While innovation and diversity guarantee dynamism, imitation and market selection of the most successful agents prevent the system from departing too much from 'static' allocative efficiency. The net outcome is a relatively ordered pattern of change in the structure of the system (in terms of rates of innovation, productivity growth, market structures, profit margins, etc.).

The balance between learning and selection involved in each evolutionary process varies with technologies, countries, institutions and historical periods. Moreover, learning is not only (not even primarily) a sort of Bayesian process through which people try to estimate the 'true' coefficients of the world. More basically, people and organisations 'learn' by cumulatively improving on their technological capabilities, by building 'theories' and trying to develop robust rules on 'how to live' in environments where tomorrow never looks quite like yesterday. In other words learning has less to do with computational capabilities and information availability than with Piaget-type development of cognitive structures.

Different combinations of learning modes, selection processes and institutions, of course, yield significantly different environments with different performances and different evolutionary paths. Let us call each group of similar combinations an *evolutionary regime*. Interestingly, these 'regimes', we suggest, closely correspond to what in an important stream of French literature, pioneered by Aglietta (1982), Boyer and Mistral (1983), Coriat (1983), and Lipietz (1984), have called regimes of 'regulation' (*régulation* in French, which Boyer and Mistral translate as 'socio-economic tuning': see Boyer's chapters in this book). Each regime is defined by reference to 'the whole set of institutions, private behaviour and actual functioning of the various markets which channel the long-term dynamics and determine the cyclical properties of the economy during an historical period for a given society' (Boyer and Mistral, 1984, p. 9). We suggest that each 'regime of regulation' represents the aggregate morphology of particular evolutionary/self-organisation processes. Or, to say it the other way round: particular self-organisation processes are the *microfoundation* of particular forms of organisation of the major markets (commodity, labour, financial markets), yielding, under certain conditions, relatively regular patterns of macroeconomic growth and transformation.

The evolving structure of the economy and the patterns of regulation of the system

An important intermediate link—at a level which some writers call 'meso-economic'—between microeconomic behaviours and strictly macroeconmic phenomena are industrail and technological interdependencies between sectors. The standard way of representing the commodity-related aspect of these interdependencies is via input/output analysis. Input/output relations organise the relationship between *industrial* performance variables, the level at which direct interaction between the agents essentially takes place, and the aggregate patterns of investment, demand, employment, etc.[6] Theoretically distinguishable from, although strongly overlapping with input/output flows, one must also consider inter-sectoral technologoical interdependencies, partly made of reciprocal stimuli, bottlenecks, information flows, spillovers of tehnological knowledge, etc.[7] Finally, industries are, to different degrees, behaviourally related via processes of vertical and horizontal integration.[8]

The fundamental aspect of these patterns of interrelation is that they are *heterogeneous and hierarchical*: the sources of technical change are not equally distributed across sectors but depend essentially on technology-specific opportunities.[9] The patterns of production and use of innovation vary as well as sectoral characteristics;[10] there are some sectors which are a fundamental source of technological advances and others that are essentially adopters. Groups of sectors also cluster around internal paterns of interrelation which are stronger than with the rest of the system. Impulses delivered to one particular point of the system may have an aggregate impact, either in terms of overall productivity or demand-generation effects, greater than those delivered at another point.[11] The French tradition of industrial economics tried to capture this aspect of a relatively ordered and hierarchical structure through the concept of *filière*, that is, a cluster of sectors which are connected by strong technological and behavioural input/output interlinkages. The crucial point for the present discussion is that vertically integrated sectors and filières provide a *differentiated and relatively ordered structure of diffusion, transmission and amplification of microeconomic impulses* and *dynamic feedbacks, whose intensity and direction depends on the overall structure of the system and the position of each element in it.*[12] Of course, the input/output structure of an economy at any point in time (or, for that matter, any structural description) is a 'picture' of its functional features (e.g. in terms of aggregate demand, inter-sectoral effects of technical change, etc.). It also shows the kinds of consistency conditions—e.g. between rates of sectoral investment and growth, between income distribution, propensity to invest and inter-sectoral distribution of demand—which must be fulfilled in order to keep the economy on a certain dynamic path. It does not show the *causes* and the *processes* of evolution of the economy. To understand them one must look at 'disequilibrium' behaviours (see the chapters by Allen and

Silverberg). Conversely, if one wants to understand the aggregate ('macro') order which appears in certain historical circumstances, one must look at the institutional and technological structures which constrain and shape the underlying ('micro') evolutionary process.

Indeed, one *does* observe significant aggregate relationships which hold with relatively stable coefficients over certain historical periods while varying from one period to the next. Examples are the relationship between wage growth, on the one hand, and price changes, productivity growth and rates of unemployment, on the other; the link between income and investment (i.e. 'the multiplier'); the relationship between labour productivity growth and output growth ('the Verdoorn–Kaldor law') and some others. These 'stylised facts' are also the main macro relationships in the Keynesian and post-Keynesian traditions. However, their *microfoundation*, we suggest, is to be found in specific classes of evolutionary processes. Moreover, our general conjecture is that the stability of their coefficients and functional form derives from the stability of the fundamental characteristics of the technologies, institutions and market processes which shape them.

At a very general level, let us heroically differentiate three fundamental 'sub-systems': (i) the *technological regime*; (ii) the '*economic machine* (with its inner feedbacks and adjustment mechanisms, related to relative prices, input/output flows, demand generation, investment, etc.); and (iii) the *institutional conditions* (including forms of regulation, prevailing behaviour, forms of organisation of economic activities, political conditions, etc.). We may then describe a *smooth configuration* as one where there are high levels of homeorhesis between these three fundamental 'sub-systems'. Conversely, a low level of homeorhesis is associated with structural *mismatchings* between them. Here, we suggest, is the link between the evolutionary/self-organisation approach to microeconomics, illustrated in this book by Silverberg, Allen, Arthur and Metcalfe, and the macroeconomic interpretations put forward here by Freeman, Perez and Boyer. *What underlies the 'Keynesian machine' linking investment, effective demand and income growth are micro (evolutionary) processes, which in turn are shaped and constrained by the specific characteristics of technologies and institutions.* Thus multiplier/accelerator coefficients will be affected by the amount of 'autonomous' ('Schumpeterian') investment which various technologies trigger. The prevailing 'modes of regulation', in the sense used above, will affect income distribution, the sensitivity of wages to unemployment rates and productivity growth, the propensity to invest and social consumption patterns. The nature of technological paradigms will influence the scope for static and dynamic economies of scale, etc.

Historically, one observes that periods of 'smooth configurations', characterised by efficient macroeconomic adjustment, high rates of growth, etc., are followed by other periods of mismatching, instability, low growth, etc. The substantive hypotheses we want to suggest are (i) there are *critical thresholds* for the variables and coefficients within which a distinguishable configuration is viable and (ii) it is the very process of growth within a configuration which may lead the system toward its critical thresholds.

The second hypothesis is clearly the stronger one and also more difficult to prove. It is somewhat akin to the Marxian–Schumpeterian view that 'it is success which contains the seeds of its own undoing'. Let us divide the argument into three parts, focusing on the institutional, technological and economic levels.

As regards the socio-institutional level, it may well be that there is a long-term unsustainability of high growth and near-full-employment *cum* social stability. The thesis of the long-term incompatibility of capitalism with full employment has been argued in the Marxian tradition by Kalecki (1943) and recently reappraised by Salvati (1983). It is impossible to discuss it here at length. Suffice to say that it may well be that in societies structurally characterised by conflict over income distribution and the conditions of labour, near-full-employment conditions are likely to generate a progressive relaxation of the discipline exerted by market mechanisms upon individual behaviour and induce rising collective expectations (about income and about power) at a rate higher than that at which the system can 'deliver the goods'.

With respect to technology, it is likely—as we argue at greater length in Dosi (1983)—that: (i) the pattern of 'normal' technological progress along the trajectories defined by the prevailing technological paradigm involve non-linear trends in mechanisation/automation of production with a higher rate in the phase of 'maturity' of each paradigm; (ii) the just-mentioned tendency may be accelerated by that part of technical progress which is endogenous to market-inducement mechanisms (cf. the preceding discussion of the impact of growth and relative prices on technical change); (iii) the rate of expansion of demand for new commodities is likely to slow down above a certain level, due to the nature of the prevailing baskets of consumption; (iv) for all the above reasons, the net balance in the dual nature of technical change may progressively shift in favour of its input-saving effect as compared to the demand-creating one.

Finally, as regards the 'economic machine', it should be clear from the foregoing discussion that (i) it does not necessarily embody mechanisms of self-adjustment; (ii) these mechanisms, when they exist, are *bounded* and *limited* in scope; (iii) even more important, rational-expectations models notwithstanding, 'the economic machine' may be a *myopic machine* characterised by high 'holistic effects', self-fulfilling expectations, irreversibilities and positive feedbacks which can guarantee both self-sustained 'vicious' and 'virtuous' circles.

These considerations, taken together, highlight the plausibility of the proposition about 'success which contains the seeds of its own undoing'. The microeconomic (evolutionary) counterpart of this proposition is that

certain kinds of 'fluctuations' and 'non-average' behaviour which emerge within a relatively stable structure (stable in terms of basic technologies, institutions, rules of interaction and expectation formation, etc.), slowly or suddenly, with or without exogenous shocks, become self-reinforcing and destabilise the structure itself (they produce 'qualitative', 'morphological' changes).

One must stress that these fundamental properties of the system such as, first, (limited) homeorhesis, and second, endogenously generated discontinuities and critical thresholds, *do not* depend on rigidities, frictions, etc., in any meaningful sense. The argument so far, for example, implies that the price system *works well* and delivers *all the information it can*. If anything, the system may well reach its 'critical thresholds' *faster* if the microeconomic allocative mechanisms work, since it moves faster toward the exploitation of the technological and consumption possibilities.

In a sense, the great historical discontinuities are also periods of *search* for new consistency conditions and forms of regulation defining new 'smooth configurations' between new technological paradigms, patterns of accumulation, and forms of organisation of the major markets, baskets of consumption, and labour relations. The process of discovery/exploration/development of new technological paradigms during one 'epoch' can be seen from the point of view of the whole society as a slack activity which increases the *number of possible worlds* (i.e. possible configurations) which could be notionally attained in the future. The process of transition and search obviously has a microeconomic dimension, which—as regards technical change in a narrow sense—also involves the emergence and growth of new industries, the slow (or traumatic) adaptation of existing ones, often the emergence and growth of new firms embodying somewhat different 'rationalities', the adoption of new productive techniques, and experimentation with new labour processes.

There is, however, a 'system dimension' of this search process which is crucial as well: the fact that the environmental requirements and processes of selections of microeconomic 'mutations' in one part of the system are likely to depend upon the state and evolution of other *unrelated* parts of it. By way of an illustration, think, for example, of the slow development of the 'consistency condition' involved in the relationship between the mechanisation of American agriculture, the development of the 'technological trajectories' in agricultural machinery, the structure of American land-ownership, and the trends in the relative prices of machines to labour (cf. David, 1975). Or, more recently, think of the socio-institutional requirements notionally demanded by an electronics-related period of high growth, e.g. in terms of work and leisure patterns ('the electronics home', etc.), organisation of the labour process, required infrastructure, etc.

Conclusions

In this highly exploratory discussion, we have tried to investigate the role that both technological change and various kinds of institutions play in the stability and transformation of modern economic systems.

Clearly, the explicit consideration of the properties of technology and technical change introduces irreversible dynamic features, complex inter-dependencies and uncertainty which have consequences somewhat similar to, but far more pervasive than those entailed by indivisibilities, increasing returns and imperfect information in general equilibrium models. In these conditions, it comes certainly as no surprise that the mechanisms conventionally thought of as ensuring stability of the system—simple market processes of the Walrasian type—cannot guarantee the emergence of stable and ordered patterns of change. Conversely, we suggested that the 'principles of order' are to be looked for precisely in those mechanisms and dynamic feedbacks which in stationary neo-classical worlds would most likely yield disequilibrium and instability. Non-stationarity, non-convexities, the absence of a unique principle of rationality defining the behaviour of each agent, behaviour-guiding institutions and unintentional interrelations all contribute to generate paths of dynamic evolution of the economic system. Clearly, the nature of 'order' is in this context radically different from the conventional notion of equilibrium.

At the micro level it refers to the characteristics of learning processes and the properties of a sort of 'Evolutionary Hand'. Like the competitive 'Invisible Hand', it entails a competitive process which relates prices to costs of production and moves resources from low-return to high-return employments. However, the classic 'Invisible Hand', under the conditions of rather fast technical change, increasing returns, environmental complexity, etc., is quite crippled and too weak to keep the system in some sort of order while it grows and changes. Conversely, the 'Evolutionary Hand' also selects and orders the diversity always generated by technological and institutional change. Moreover, it is more powerful because it is not entirely invisible, but is forged within visible (indeed often dominant) technologies and institutions: it not only selects *ex post*, it also teaches and guides *ex ante*.

The emergence of 'order' is contingent on the formation of specific forms of institutional organisation governing the relationship between economic agents, of which markets are an important—but by no means unique—element. The dynamic coherence (homeorhesis) of economic systems in conditions of technical change, we conjecture, is the outcome of particular 'architectures' or forms of 'regulation' which define the functioning and the scope of markets in relation to the specific properties of technological paradigms, the prevailing forms of behaviour and expectation formation of agents, the structure of the interdependencies of the system, and, finally, to nature and interests of the institutions which plan an active role in the economy.

Notes

1. In addition to the classic contributions by Simon, 1955, 1957, see Heiner, 1983, 1985, and Heiner's contribution to this book.
2. In fact, as argued in Dosi and Egidi (1987), powerful problem-solving routines (that is, 'abstract' and robust decision rules which apply to entire classes of, often ill-structured, problems) are the general procedures through which 'intelligent' agents deal with environmental ('substantive') uncertainty and the (related) '*procedural*' uncertainty stemming from problem-solving complexity.
3. These features of evolutionary environments are discussed and formalised in Nelson and Winter, 1982; Iwai, 1981; Eliasson, 1984, 1986; Arthur, 1985; Silverberg, 1987; Dosi, Orsenigo and Silverberg, 1986; Gibbons and Metcalfe, 1986; in this book see the chapters by Allen, Arthur, Metcalfe and Silverberg.
4. Note that these 'stable strategies', which entail specific sets of problem-solving routines of different generality, may or may not correspond to 'evolutionary stable strategies' in the sense currently understood in 'evolutionary games'. See also Silverberg's chapter.
5. An implication is that 'a system—any system, economic or other—that at *every* given point in time fully utilizes its possibilities to the best advantage may yet in the long run be inferior to a system that does so at *no* given point in time, because the latter's failure to do so may be a condition for the level or speed of long-run performance' (Schumpeter, 1943, p. 83, quoted also in Elster, 1983). The point is discussed at greater length in Dosi (1988).
6. In this respect, Pasinetti's concept of vertically integrated sectors is an important theoretical device capable of tracing down the dual nature of technical change (in terms of demand creation and input efficiencies) to all direct and indirect consequences. Cf. Pasinetti (1981).
7. For an historical analysis, cf. Rosenberg (1976) and (1982). For an analysis of the inter-sectoral flows of innovation, cf. Pavitt (1984a) and Scherer (1982).
8. Cf. Teece (1982).
9. For a taxonomy of the patterns of production, use and sector of origin of innovation, see Pavitt (1984a).
10. ibid.
11. On the case of the differentiated productivity effects, cf. Strassman (1959).
12. See Toledano (1978), Perroux (1973), Montfort (1983), Jacquemin and Rainelli (1984), Gazon (1979), Lesage (1984).

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3 Structural crises of adjustment, business cycles and investment behaviour

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Introduction

This chapter discusses the revival of interest in long-term fluctuations in the growth of the world economy and particularly in the Schumpeterian theory of business cycles. After reviewing the common ground in relation to investment behaviour and business cycles, it goes on to discuss the failure of Keynesian economics to come to terms with the influence of technical change. The central theme of the chapter is that certain types of technical change—defined as changes in 'techno-economic paradigm'—have such widespread consequences for all sectors of the economy that their diffusion is accompanied by a major structural crisis of adjustment, in which social and institutional changes are necessary to bring about a better 'match' between the new technology and the system of social management of the economy—or 'regime of regulation'. Once, however, such a good match is achieved a relatively stable pattern of long-term investment behaviour can emerge for two or three decades. This point is illustrated with respect to the rise of information technology. It is argued that this pervasive technology is likely to heighten still further the instability of the system before a new, more stable pattern of growth is attained.

The resurgence of interest in Schumpeter's ideas (e.g. Elliott, 1985) is associated with the slow-down in the growth of the world economy in the last decade. Whereas during the prolonged post-war boom of the 1950s and the 1960s there was some tendency to assume that the general adoption of Keynesian policies would prevent the recurrence of any depression comparable to that of the 1930s and would smooth out smaller fluctuations, this confidence was somewhat undermined by the deeper recessions of the 1970s and 1980s and the return of much higher levels of unemployment. Not surprisingly, this has led to renewed interest in long-cycle or long-wave theories, which make analogies between the 1930s and the 1980s. This chapter concentrates on the explanation of these deeper structural crises of adjustment, without making any assumptions about fixed periodicity or statistical regularity.

We start by looking at the common ground in the analysis of business cycles. We shall quote extensively from Samuelson for several reasons. First of all, he is probably the most authoritative neo-Keynesian economist, and one who commands respect throughout the profession. Secondly, business cycles have always been one of his central professional interests. Thirdly, as the author of the most widely read economics textbook in the Western World, he provides in the successive editions of this book a convenient synthesis of the changing state of the art (Samuelson and Nordhaus in the most recent and thorough revisions, i.e. the 12th edition).

Areas of agreement in business cycle theory

There are of course many different explanations of business cycles and many explanations for the exceptional severity of the 1930s depression and of the recessions of the 1970s and 1980s. But, as Samuelson has pointed out and most textbooks on the business cycle confirm, there *is* actually a measure of agreement on *some* of the central issues.

Most importantly there is virtually universal agreement that one of the main sources of cyclical fluctuations in the economy is the instability of investment. All empirical studies of business cycles show much greater fluctuations in the capital goods industries than in consumer products, as in the extreme example of the Great Depression of the 1930s, when GNP fell by 30 per cent in the United States but output of producers' durable equipment fell by 75 per cent.

Samuelson (1980) comments:

> Ordinarily, consumption movements seem the *effect* rather than the *cause* of the business cycle. In contrast, there is reason to believe that the movements of *durable* goods represent key causes in a more fundamental sense. [p. 242]

The wording is slightly changed in the 1985 edition but the emphasis on investment remains and indeed virtually all schools of economic theory would accept the empirical evidence on the relative amplitude of fluctuations in different sectors of the economy. Moreover, they would also agree that there are certain aspects of investment in plant and equipment which make some fluctuations almost inevitable: 'postponability' on the one hand and competitive pressures to expand capacity on the other; the uneven development in the relative growth rate and capital intensity of various sectors of the economy; indivisibilities in many large investments ('lumpiness') and the 'accelerator' principle tending to amplify investment in upswings and diminish it in downswings. On a smaller scale some similar considerations apply to inventories and to consumer durables. These 'endogenous' factors are in themselves sufficient to account for fluctuations in the system.

However, Samuelson (1980) points out in his 'synthesis' that 'external' factors also play an important part:

Most economists today believe in a combination of external and internal theories. To explain major cycles, they place crucial emphasis on fluctuations in *investment* or *capital* goods. Primary causes of these capricious and volatile investment fluctuations are found in such external factors as (1) technological innovation, (2) dynamic growth of population and of territory, and even in some economists' view, (3) fluctuations in business confidence and 'animal spirits'.

With these external factors we must combine the internal factors that cause any initial change in investment to be *amplified* in a cumulative multiplied fashion—as people who are given work in the capital goods industries respend part of their new income on consumption goods, and as an air of optimism begins to pervade the business community, causing firms to go to the banks and the securities market for new credit accommodation.

Also, it is necessary to point out that the general business situation definitely reacts in turn on investment. If high consumption sales make business owners optimistic, they are more likely to embark upon venturesome investment programmes. Inventions or scientific discoveries may occur independently of the business cycle, but their appreciable economic introduction will most certainly depend on business conditions.

Therefore especially in the short run, investment is in part an *effect* as well as a cause of income movements. [p. 246]

As Samuelson points out, essentially similar logic applies, of course, in the reverse direction leading to the danger of a cumulative downward spiral. Temporary over-capacity as a result of bunching of investment, perceived lack of sufficient new markets, the saturation of some existing markets, major instabilities in the international economy, over-restrictive monetary policies, uncertainties about technology, protectionism and general lack of business confidence are among the many influences which may trigger or accelerate a vicious circle of declining investment and national income. All of them have been identified as important influences in the severe depression of the 1930s.

Thus far, then, is an area of general agreement about the causes of business cycles and the problems of 'virtuous' and 'vicious' spirals in economic activity. However, a gulf still remains between those economists who, despite what has been said above, still look to the self-regulating private market mechanism, the rate of interest, capital-labour substitution, and monetary policy as the main stabilising forces governing investment behaviour and consequently the fluctuations in the system as a whole, and those who, like Keynes and Samuelson, lack faith in this mechanism to sustain long-term stable growth. The central issue is the possibility of rational optimising behaviour at the micro level of the firm. It will be argued in Part IV of this book that this model of entrepreneurial behaviour is fundamentally flawed. This means that periods of stable growth depend more on a general climate of confidence, including widespread belief in the future potential benefits from technical change, than on an unbelievable set of assumptions about perfect information and accurate calculations on

the future rate of return of a wide variety of investments with uncertain outcomes.

Keynes

It is often said that Keynes was deeply rooted in the neo-classical tradition of economics and this is no doubt true. Nevertheless, even in his earliest writings, it is possible to trace his awareness of these limitations of the self-regulating market mechanism. Moggridge (1976) points out that already in 1913 in his book on *Indian Currency and Finance* he insisted on '. . . the essential fragility of the economic order which others took to be natural and automatic and emphasized the need for conscious management'.

This already foreshadowed his more general onslaught on *laissez-faire* in the 1920s:

The world is *not* so governed from above that private and social interest always coincide. It is *not* so managed here below that in practice they coincide. It is *not* a correct deduction from the Principles of economics that enlightened self-interest generally *is* enlightened; more often individuals seeking separately to promote their ends are too ignorant or too weak to attain even these.

In 1934 in one of his broadcasts on the BBC, he was even more explicit (quoted in Eatwell, 1982):

On the one side are those who believe that the existing economic system is, in the long run, a self-adjusting mechanism, though with creaks and groans and jerks and interrupted by the time lags, outside interference and mistakes . . . on the other side of the gulf are those who reject the idea that the existing economic system is, in any significant sense, self-adjusting . . . The strength of the self-adjusting school depends on its having behind it almost the whole body of organised economic thinking and doctrine of the last hundred years. This is a formidable power . . . For it lies behind the education and the habitual modes of thought, not only of economists, but of bankers and businessmen and civil servants and politicians of all parties . . . thus if the heretics on the other side of the gulf are to demolish the forces of 19th century orthodoxy . . . they must attack them in their citadel. No successful attack has yet been made . . . I range myself with the heretics.

This broadcast foreshadowed the publication of his *General Theory of Employment, Interest and Money*, which at least temporarily was indeed a fairly successful attack (Keynes, 1936) on the 'citadel', and which argued that '. . . the duty of ordering the current volume of investment cannot safely be left in private hands' and advocated the 'socialisation of investment'. By this he meant, of course, not public ownership or socialism, but public responsibility for the overall level of investment and employment. He insisted that if private decisions to invest were inadequate to overcome a depression, then it was the responsibility of government to compensate for this deficiency. Interest rate policy probably would not be in itself a

An inadequate level of private investment might arise from many causes; in a famous and often-quoted passage Keynes stressed the impossibility of purely rational calculations about the future rate of return from new investment and compared it with an expedition to the South Pole. He stressed the crucial importance of a climate of confidence and the role of 'animal spirits'. He pointed to the problem of excess capacity even in some industries which had grown rapidly in the previous boom and the problem of temporary saturation of particular markets. He stressed ironically the good fortune of Ancient Egypt in having pyramids and large-scale investment which did not 'stale with abundance' and of the Middle Ages in having cathedrals: 'Two pyramids, two Masses for the dead are twice as good as one, but not so two railways from London to York.'

From the time of the publication of the *General Theory*, orthodox economics mounted a counter-attack mainly on the issues of monetary policy, fiscal policy, and wage flexibility. However, there has been no comparable counter-attack on his theory of private investment behaviour. Indeed, Siegenthaler (1986), quoting Shackle's (1967) essay on 'Keynes' Ultimate Meaning', argues that this is Keynes' most lasting and fundamental contribution to economic theory.

According to Shackle:

> Keynes' whole theory of unemployment is ultimately the simple statement that, rational expectation being unattainable, we substitute for it first one and then another kind of irrational expectation; and the shift from one arbitrary basis to another gives us from time to time a moment of truth, when our artificial confidence is for the time being dissolved, and we, as business men, are afraid to invest and so fail to provide enough demand to match our society's desire to produce.

Siegenthaler comments on this passage:

> This interpretation of Keynes calls for interpretation itself, but at least three things are made very clear by Shackle. First, confidence enters the scene in a context in which rational expectations cannot be formed on the basis of adequate knowledge, so that confidence must be 'artificial'; subjective certainty which encourages an actor to invest is grounded not in a true model of economic reality, but in an arbitrary one for which sufficient evidence fails to be available; in very particular situations confidence gets dissolved and actors become aware of objective uncertainty, of their inability to know the future and it is only in those 'moments of truth' that subjective uncertainty governs the behaviour of the actor . . . Actors get confident not on the basis of adequate knowledge, not as a result of procedures leading to objectively superior forecasting methods, not as an outcome of individual optimising strategies of selecting and handling information . . . But they do get confident despite uncertainty . . . Confidence, albeit an artificial one, prevails except on rare occasions.

Solow (Klamer, 1984) has scornfully dismissed the attempt of the new school of 'rational expectations' to argue that actors, whether consumers, wage earners or entrepreneurs, can indeed form rational, long-term expectations about such future events as the impact of electronic technology on the economy. And indeed few would attempt to deny the force of Solow's argument or that of Keynes, with respect to major technical innovations.

Nevertheless, because of the crucial importance of technical change for investment behaviour, which is acknowledged by all schools of economic thought, it is essential to examine in more depth the question of the influence of technical change, on the state of confidence and vice versa. At certain times technical change appears to undermine confidence and stability, while at others it has the opposite effect. At the level of the individual innovative investment, the findings of empirical studies of investment and evaluation in R & D are clear-cut and virtually unanimous: they strongly support the view of Shackle and Schumpeter that investment in new products and processes has an element of true uncertainty: by definition the outcome cannot be known (Freeman, 1982, Chapter 7).

However, the analysis cannot be restricted to the level of the individual innovation or to counting innovations; the qualitative aspects and the systems interrelatedness of innovations must be taken into account. Under favourable conditions, the Schumpeterian bandwagons roll and business confidence improves, leading to an atmosphere of 'boom' in which, although there are still risks and uncertainties attached to all investment decisions, animal spirits rise. Such favourable conditions include complementarities between innovations and the emergence of an appropriate infrastructure as well as some degree of political stability and institutions which do not hinder too much the diffusion of new technologies. In these favourable circumstances the growth of new markets and the profitability of new investments appear to offer a fairly stable prospect of future growth, despite the uncertainties.

But there are also circumstances when technical change could have the opposite effect and could destabilise investment by undermining confidence in the future prospects for the growth of some firms, industries or economies. Moreover, as technologies and industries mature over a long period, diminishing returns and declining profitability may set in, leading to sluggish investment behaviour. If this is at all widespread it may take major social and political changes to restore confidence in the future growth of the system on the basis of new technologies. In the section on 'Diffusion of new techno-economic paradigms and institutional changes' we shall discuss the circumstances in which this can occur.

Here we wish only to make the point that in the early stages of radical technical innovation uncertainty prevails, so that Schumpeterian entrepreneurship and Keynesian animal spirits are necessary for the first steps. Once diffusion is under way, even though diffusion itself involves further innovation, the excitement generated by rapid growth of markets and/or exceptional profits of innovations may generate rising confidence and waves of imitation, provided the social and institutional framework and the infrastructure favour these developments.

Keynes himself once acknowledged the dominant influence of technical change on investment behaviour in his *Treatise on Money* (1930):

> In the case of fixed capital, it is easy to understand why fluctuations should occur in the rate of investment. Entrepreneurs are induced to embark on the production of fixed capital or deterred from doing so by their expectations of the profit to be made. Apart from the many minor reasons why these should fluctuate in a changing world, Professor Schumpeter's explanation of the major movements may be unreservedly accepted . . .
> It is only necessary to add to this that the pace at which the innovating entrepreneurs will be able to carry their projects into execution at a cost in interest which is not deterrent to them will depend on the degree of complaisance of those responsible for the banking system. Thus while the stimulus to a credit inflation comes from outside the banking system, it remains a monetary phenomenon in the sense that it only occurs if the monetary machine is allowed to respond to the stimulus. [Vol. 2, p. 86].

This passage is remarkable not only for its unequivocal acceptance of Schumpeter's explanation of the major surges of investment in capitalist societies but also its emphasis on the enabling role of monetary policy. It is all the more surprising that neither Keynes nor the Keynesians followed up this recognition of the crucial role of technical innovation. In fact, in the *General Theory* Keynes regressed to a position of neglect of technology when he introduced the largely artificial concept of a secular decline in the marginal efficiency of capital unrelated to the actual changes in techniques or in the capital stock. Schumpeter was therefore justified in one of the main points of his critique of the *General Theory*:

> it limits applicability of this analysis to a few years at most – perhaps the duration of the '40 months cycle'—and in terms of phenomena, to the factors that *would* govern the greater or the smaller utilisation of an industrial apparatus *if* the latter remains unchanged. *All* the phenomena incident to the creation and change in this apparatus, that is to say the phenomena that dominate the capitalist process, are thus excluded from consideration. [1952, p. 282]

For the Keynesians it became a matter of relative indifference *which* were the new technologies and the fast-growing industries. We shall argue that it does matter very much *which* are the important new technological systems, because they are unique and their effects on private and public R & D and investment strategies, and the government policies, and institutional changes, which are required to advance them, may be very different. We shall argue that Keynesian analysis and policies were and are deficient with respect to long-term changes in technology, their effects on business confidence and structural change in the economy and the specifics of infrastructural investment. Almost all neo-Keynesian (and much other) macroeconomic analysis and modelling is restricted to purely *quantitative* aspects of investment and employment, whereas Schumpeter rightly insisted on the crucial importance of *qualitative* aspects.

Clearly, this criticism of Keynesian theory rests on a particular view of the relationship between technical change and business cycles which is usually associated with Schumpeter's long-wave theory. It sees the major booms, such as those of the 1950s and 1960s or the 1850s and 1860s as based on the diffusion of major new 'techno-economic paradigms' into the world economy and the deeper depressions as periods of structural adjustment, when the social and institutional framework is adapting to the rise of major new technologies.

Interestingly enough, even though Samuelson (1981) has dismissed the likelihood of another major depression, he did stress the probability of a prolonged downturn in the rate of economic growth:

> It is my considered guess that the final quarter of the 20th century will fall far short of the third quarter in its achieved rate of economic progress. The dark horoscope of my old teacher Joseph Schumpeter may have particular relevance here.

Samuelson's reference to Schumpeter clearly implies that the major long-term fluctuations in economic development cannot be explained simply in terms of conventional short- and medium-term business-cycle theory but require an additional dimension of analysis. This involves the rise of new technologies, the rise and decline of entire industries, major infrastructural investments, changes in the international location of industry and technological leadership and other related structural changes, for example, in the skills and composition of the labour force and the management structure of enterprises.

A taxonomy of innovations

It has been argued that a weakness of most neo-classical and Keynesian theories of technical change and economic growth is that they fail to take account of the *specifics* of changing technology in each historical period.

One reason that economists do not attempt this daunting task is, of course, the sheer complexity of technical change. How can the thousands of inventions and innovations which are introduced every month and every year be reduced to some kind of pattern amenable to generalisation and analysis? In this section we shall suggest a taxonomy of innovation, based on empirical work at the Science Policy Research Unit. We shall distinguish between (1) Incremental innovation; (2) Radical innovation; (3) New technology systems; (4) Changes of techno-economic paradigms. (See also the introductory discussion on paradigms and trajectories in Chapter 2).

(i) *Incremental innovations*: These types of innovation occur more or less continuously in any industry or service activity although at differing rates in different industries and different countries, depending upon a combination of demand pressures, socio-cultural factors, technological opportunities and trajectories. They may often occur, not so much as the result of any deliberate research and development activity, but as the outcome of inventions and improvements suggested by engineers and other directly engaged in the production process, or as a result of initiatives and proposals by users ('learning by doing and 'learning by using'). Many empirical studies have confirmed their great importance in improving the efficiency in use of all factors of production, for example, Hollander's (1965) study of productivity gains in Du Pont rayon plants or Townsend's (1976) study of the Anderton shearer-loader in the British coal-mining industry. They are frequently associated with the scaling-up of plant and equipment and quality improvements to products and services for a variety of specific applications. Although their combined effect is extremely important in the growth of productivity, no single incremental innovation has dramatic effects, and they may sometimes pass unnoticed and unrecorded. However, their effects are apparent in the steady growth of productivity, which is reflected in input–output tables over time by changes in the coefficients for the existing array of products and services.

(ii) *Radical innovations*: These are discontinuous events and in recent times are usually the result of a deliberate research and development activity in enterprises and/or in university and government laboratories. There is no way in which nylon could have emerged from improving the production process in rayon plants or the woollen industry. Nor could nuclear power have emerged from incremental improvements to coal or oil-fired power stations. Radical innovations are unevenly distributed over sectors and over time, but our research did not support the view of Mensch (1975) that their appearance is concentrated particularly in periods of deep recessions in response to the collapse or decline of established markets (Freeman, Clark and Soete, 1982). But we would agree with Mensch that, whenever they may occur, they are important as the potential springboard for the growth of new markets, and for the surges of new investment associated with booms. They may often involve a combined product, process and organisational innovation. Over a period of decades radical innovations, such as nylon or 'the pill', may have fairly dramatic effects, i.e., they *do* bring about structural change but in terms of their aggregate economic impact they are relatively small and localised, unless a whole cluster of radical innovations are linked together in the rise of new industries and services, such as the synthetic materials industry or the semiconductor industry.

(iii) *Changes of 'technology system'*: These are far-reaching changes in technology, affecting several branches of the economy, as well as giving rise to entirely new sectors. They are based on a combination of radical and incremental innovations, together with *organisational* and *managerial* innovations affecting more than one or a few firms. Keirstead (1948), in his exposition of a Schumpeterian theory of economic development, introduced the concept of 'constellations' of innovations, which were technically and economically interrelated. An obvious example is the cluster of synthetic materials innovations, petro-chemical innovations, machinery innovations in injection moulding and extrusion, and innumerable application innovations introduced in the 1920s, 1930s, 1940s and 1950s (Freeman, Clark and Soete, 1982).

(iv) *Changes in 'techno-economic paradigm' ('technological revolutions')*: Some changes in technology systems are so far-reaching in their effects that they have a major influence on the behaviour of the entire economy. A change of this kind carries with it many clusters of radical and incremental innovations, and may eventually embody a number of new technology systems. A vital characteristic of this fourth type of technical change is that it has *pervasive* effects throughout the economy, i.e. it not only leads to the emergence of a new range of products, services, systems and industries in its own right; it also affects directly or indirectly almost every other branch of the economy, i.e. it is a 'meta-paradigm'. We use the expression 'techno-economic' (Perez, 1983) rather than 'technological paradigm' (Dosi, 1982) because the changes involved go beyond engineering trajectories for specific product or process technologies and affect the input cost structure and conditions of production and distribution throughout the system. This fourth category corresponds to Nelson and Winter's concept of 'general natural trajectories' and, once established as the dominant influence on engineers, designers and managers, becomes a 'technological regime' for several decades. From this it is evident that we view Schumpeter's long cycles and 'creative gales of destruction' as a succession of 'techno-economic paradigms' associated with a characteristic institutional framework, which, however, only emerges after a painful process of structural change.

We now turn to an elaboration of the main characteristics of 'techno-economic' paradigms and their patterns of diffusion through long waves of economic development. As the following sections will attempt to show, a new techno-economic paradigm develops initially within the old, showing its decisive advantages during the 'downswing' phase of the previous Kondratiev cycle. However, it becomes established as a dominant technological regime only after a crisis of structural adjustment, involving deep social and institutional changes, as well as the replacement of the motive branches of the economy (Table 3.1).

'Key factor' inputs and change of techno-economic paradigm

As the last section has made clear, our conception of 'techno-economic paradigm' is much wider than 'clusters' of innovations or even of 'technology systems'. We are referring to a combination of interrelated product and process, technical, organisational and managerial innovations, embodying a quantum jump in potential productivity for all or most of the economy and opening up an unusually wide range of investment and profit opportunities. Such a paradigm change implies a unique new combination of decisive technical *and* economic advantages.

Clearly one major characteristic of the diffusion pattern of a new techno-economic paradigm is its spread from the initial industries or areas of application to a much wider range of industries and services and the economy as a whole (Table 3.1). By 'paradigm' change we mean precisely a radical transformation of the prevailing engineering and managerial *common sense* for best productivity and most profitable practice, which is applicable in almost any industry (i.e. we are talking about a 'meta-paradigm').

The organising principle of each successive paradigm and the justification for the expression 'techno-economic paradigm' is to be found not only in a new range of products and systems, but most of all in the dynamics of the relative *cost* structure of all possible inputs to production. In each new techno-economic paradigm, a particular input or set of inputs, which may be described as the 'key factor' of that paradigm, fulfils the following conditions:

(i) Clearly perceived low and rapidly falling relative cost. As Rosenberg (1975) and other economists have pointed out, small changes in the relative input cost structure have little or no effect on the behaviour of engineers, designers and researchers. Only major and persistent changes have the power to transform the decision rules and 'common sense' procedures for engineers and managers (Perez, 1985; Freeman and Soete, 1987).

(ii) Apparently almost unlimited availability of supply over long periods. Temporary shortages may of course occur in a period of rapid buildup in demand for the new key factor, but the prospect must be clear that there are no major barriers to an enormous long-term increase in supply. This is an essential condition for the confidence to take major investment decisions which depend on this long-term availability.

(iii) Clear potential for the use or incorporation of the new key factor or factors in many products and processes throughout the economic system; either directly or (more commonly) through a set of related innovations, which both reduce the cost and change the quality of capital equipment, labour inputs, and other inputs to the system.

We would maintain that this combination of characteristics holds today for microelectronics and we discuss this further in the section below on the 'information technology paradigm'. It held until recently for oil, which underlay the post-war boom (the 'fourth Kondratiev' upswing). Before that, and more tentatively, we would suggest that the role of key factor was played by low-cost steel in the third Kondratiev wave, by low-cost and

steam-powered transport in the 'Victorian' boom of the nineteenth century (Table 3.1, column 5—'Key factor industries. . .').

Clearly, every one of these inputs identified as 'key factors' existed (and was in use) long before the new paradigm developed. However, its full potential is only recognised and made capable of fulfilling the above conditions when the previous key factor and its related constellation of technologies give strong signals of diminishing returns and of approaching limits to their potential for further increasing productivity or for new profitable investment. (In quite different types of society and different historical circumstances, archaeologists have also recognised the crucial importance of 'key factors' in economic development in their classification of the 'Stone Age', 'Bronze Age' and 'Iron Age'.)

From a purely technical point of view, the explosive surge of interrelated innovations involved in a technological revolution could probably have occurred earlier and in a more gradual manner. But, there are strong economic and social factors at play that serve as prolonged containment first and as unleashing forces later. The massive externalities created to favour the diffusion and generalisation of the prevailing paradigm act as a powerful deterrent to change for a prolonged period (see Chapter 26 by Brian Arthur). It is only when productivity along the old trajectories shows persistent limits to growth and future profits are seriously threatened that the high risks and costs of trying the new technologies appear as clearly justified. And it is only after many of these trials have been obviously successful that further applications become easier and less risky investment choices.

The new key factor does not appear as an isolated input, but rather at the core of a rapidly growing system of technical, social and managerial innovations, some related to the production of the key factor itself and others to its utilisation. At first these innovations may appear (and may be in fact pursued) as a means for overcoming the specific bottlenecks of the old technologies, but the new key factor soon acquires its own dynamics and successive innovations take place through an intensive interactive process, spurred by the limits to growth which are increasingly apparent under the old paradigm (Table 3.1, column 7—'Limitations of previous techno-economic paradigm . . .'). In this way the most successful new technology systems gradually crystallise as a new 'ideal' type of production organisation which becomes the common sense of management and design, embodying new 'rules of thumb' and restoring confidence to investment decision-makers after a long period of hesitation.

Clearly, this approach differs radically from the dominant conceptualisation of changing factor costs in neo-classical economic theory, although it has points of contact, such as the persistent search for least-cost combinations of factor inputs to sustain or increase profitability. Most formulations of neo-classical theory put the main emphasis on varying combinations of labour and capital and on substitution between them, and implicitly or explicitly assume responsiveness even to small changes in

Table 3.1 A tentative sketch of some of the main characteristics of successive long waves (modes of growth)

1	2	3	4	5	6	7	8
Number	Approx. periodisation Upswing Downswing	Description	Main 'carrier branches' and induced growth sectors infra-structure	Key factor industries offering abundant supply at descending price	Other sectors growing rapidly from small base	Limitations of previous techno-economic paradigm and ways in which new paradigm offers some solutions	Organisation of firms and forms of cooperation and competition
First	1770s & 1780s to 1830s & 1840s 'Industrial revolution' 'Hard times'	Early mechanisation Kondratieff	Textiles Textile chemicals Textile machinery Iron-working and iron castings Water power Potteries Trunk canals Turnpike roads	Cotton Pig iron	Steam engines Machinery	Limitations of scale, process control and mechanisation in domestic 'putting out' system. Limitations of hand-operated tools and processes. Solutions offering prospects of greater productivity and profitability through mechanisation and factory organisation in leading industries.	Individual entrepreneurs and small firms (< 100 employees) competition. Partnership structure facilitates co-operation of technical innovators and financial managers. Local capital and individual wealth.
Second	1830s & 1840s to 1880s & 1890s Victorian prosperity 'Great depression'	Steam power and railway Kondratieff	Steam engines Steamships Machine tools Iron Railway equipment Railways World Shipping	Coal Transport	Steel Electricity Gas Synthetic dyestuffs Heavy engineering	Limitations of water power in terms of inflexibility of location, scale of production, reliability and range of applications, restricting further development of mechanisation and factory production to the economy as a whole. Largely overcome by steam engine and new transport system.	High noon of small-firm competition, but larger firms now employing thousands, rather than hundreds. As firms and markets grow, limited liability and joint stock company permit new pattern of investment, risk-taking and ownership.
Third	1880s & 1890s to 1930s & 1940s *'Belle epoque'* 'Great depression'	Electrical and heavy engineering Kondratieff	Electrical engineering Electrical machinery Cable and wire Heavy engineering Heavy armaments Steel ships Heavy chemicals Synthetic dyestuffs Electricity supply and distribution	Steel	Automobiles Aircraft Telecommunications Radio Aluminium Consumer durables Oil Plastics	Limitations of iron as an engineering material in terms of strength, durability, precision, etc., partly overcome by universal availability of cheap steel and of alloys. Limitations of inflexible belts, pulleys, etc., driven by one large steam engine overcome by unit and group drive for electrical machinery, overhead cranes, power tools permitting vastly improved layout and capital saving. Standardisation facilitating world-wide operations	Emergence of giant firms, cartels, trusts and mergers. Monopoly and oligopoly became typical. 'Regulation' or state ownership of 'natural' monopolies and 'public utilities'. Concentration of banking and 'finance-capital'. Emergence of specialised 'middle management' in large firms.

Table 3.1—*cont.*

1	2	3	4	5	6	7	8
Number	Approx. periodisation Upswing Downswing	Description	Main 'carrier branches' and induced growth sectors infra-structure	Key factor industries offering abundant supply at descending price	Other sectors growing rapidly from small base	Limitations of previous techno-economic paradigm and ways in which new paradigm offers some solutions	Organisation of firms and forms of cooperation and competition
Fourth	1930s & 1940s to 1980s & 1990s Golden age of growth and Keynesian full employment Crisis of structural adjustment	Fordist mass production Kondratieff	Automobiles Trucks Tractors Tanks Armaments for motorised warfare Aircraft Consumer durables Process plant Synthetic materials Petro-chemicals Highways Airports Airlines	Energy (especially oil)	Computers Radar NC machine tools Drugs Nuclear weapons and power Missiles Micro-electronics Software	Limitations of scale of batch production overcome by flow processes and assembly-line production techniques, full standardisation of components and materials and abundant cheap energy. New patterns of industrial location and urban development through speed and flexibility of automobile and air transport. Further cheapening of mass consumption products	Oligopolistic competition. Multinational corporations based on direct foreign investment and multi-plant locations. Competitive subcontracting on 'arms length' basis or vertical integration. Increasing concentration, divisionalisaton and hierarchical control. 'Techno-structure' in large corporations.
Fifth*	1980s & 1990s to ?	Information and communication Kondratieff	Computers Electronic capital goods Software Tele-communications equipment Optical fibres Robotics FMS Ceramics Data banks Information services Digital tele-communications network Satellites	'Chips' (micro-electronics)	'Third generation' biotechnology products and processes Space activities Fine chemicals SDI	Diseconomies of scale and inflexibility of dedicated assembly-line and process plant partly overcome by flexible manufacturing systems, 'networking' and 'economies of scope'. Limitations of energy intensity and materials intensity partly overcome by electronic control systems and components. Limitations of hierarchical departmentalisation overcome by 'systemation', 'networking' and integration of design, production and marketing.	'Networks' of large and small firms based increasingly on computer networks and close co-operation in technology, quality control, training, investment planning and production planning ('just-in-time') etc. 'Keiretsu' and similar structures offering internal capital markets.

*All columns dealing with the "fifth Kondratieff" are necessarily speculative

Table 3.1—*cont.*

9	10	11	12	13	14	15	16	17
Number	Techno-logical leaders	Other industrial and newly industrial-ising countries	Some features of national regimes of regulation	Aspects of the international regulatory regime	Main features of the national system of innovation	Some features of tertiary sector development	Representative innovative entrepreneurs engineers	Political economists and philosophers
First	Britain France Belgium	German states Nether-lands	Breakdown and dissolution of feudal and medieval monopolies, guilds, tolls, privileges and restrictions on trade, industry and competition. Repression of unions. Laissez-faire established as dominant principle.	Emergence of British supremacy in trade and international finance with the defeat of Napoleon.	Encouragement of science through National Academies, Royal Society, etc. Engineer and inventor-entrepreneurs and partnerships. Local scientific and engineering societies. Part-time training and on-the-job training. Reform and strengthening of national patent systems. Transfer of technology by migration of skilled workers. British Institution of Civil Engineers. Learning by doing, using and interacting	Rapid expansion of retail and wholesale trade in new urban centres. Very small state apparatus. Merchants as source of capital	Arkwright Boulton Wedgwood Owen Bramah Maudslay	Smith Say Owen
Second	Britain France Belgium Germany USA	Italy Nether-lands Switzerland Austria–Hungary	High noon of laissez-faire. 'Nightwatchman state' with minimal regulatory functions except protection of property and legal framework for production and trade. Acceptance of craft unions. Early social legislation and pollution control.	'Pax Britannica'. British naval, financial and trade dominance. International free trade. Gold standard.	Establishment of Institution of Mechanical Engineers and development of UK Mechanics' Institutes. More rapid development of professional education and training of engineers and skilled workers elsewhere in Europe. Growing specialisation. Internationalisation of patent system. Learning by doing, using and interacting	Rapid growth of domestic service for new middle class to largest service occupation. Continued rapid growth of transport and distribution. Universal postal and communication services. Growth of financial services	Stephenson Whitworth Brunel Armstrong Whitney Singer	Ricardo List Marx
Third	Germany USA Britain France Belgium Switzer-land Nether-lands	Italy Austria–Hungary Canada Sweden Denmark Japan Russia	Nationalist and imperialist state regulation or state ownership of basic infrastructure (public utilities). Arms race. Much social legislation. Rapid growth of state bureaucracy.	Imperialism and colonisation. 'Pax Britannica' comes to an end with First World War. Destabilisa-tion of international financial and trade system leading to world crisis and Second World War.	'In-house' R and D departments established in German and US chemical and electrical engineering industries. Recruitment of university scientists and engineers and graduates of the new Technische Hochschulen and equivalent Institutes of Technology. National Standard Institutions and national laboratories. Universal elementary education. Learning by doing, using and interacting	Peak of domestic service industry. Rapid growth of state and local bureaucracies. Department stores and chain stores. Education, tourism and entertainment expanding rapidly. Corresponding take-off of white-collar employment pyramid. London as centre for major world commodity markets.	Siemens Carnegie Nobel Edison Krupp Bosch	Marshall Pareto Lenin Veblen

Table 3.1—*cont.*

9	10	11	12	13	14	15	16	17
Number	Techno-logical leaders	Other industrial and newly industrial-ising countries	Some features of national regimes of regulation	Aspects of the international regulatory regime	Main features of the national system of innovation	Some features of tertiary sector development	Representative innovative entrepreneurs engineers	Political economists and philosophers
Fourth	USA Germany Other EEC Japan Sweden Switzer-land USSR Other EFTA Canada Australia	Other Eastern European Korea Brazil Mexico Venezuela Argentina China India Taiwan	'Welfare state' and 'warfare state'. Attempted state regulation of investment, growth and employment by Keynesian techniques. High levels of state expenditure and involvement. 'Social partnership' with unions after collapse of fascism. "Roll-back" of welfare state deregulation and privatisation during crisis of adjustment	'Pax Americana' US economic and military dominance. Decolonisa-tion. Arms race and cold war with USSR. US-dominated international financial and trade regime (GATT, IMF, World Bank) Destabilisation of Bretton Woods regime in 1970s	Spread of specialised R and D departments to most industries. Large-scale state involvement in military R and D through contracts and national laboratories. Increasing state involvement in civil science and technology. Rapid expansion of secondary and higher education and of industrial training. Transfer of technology through extensive licensing and know-how agreements and investment by multinational corporations. Learning by doing using and interacting.	Sharp decline of domestic service. Self-service fast food and growth of super-markets and hypermarkets, petrol service stations. Continued growth of state bureaucracy, armed forces and social services. Rapid growth of research and professions and financial services, packaged tourism and air travel on very large scale.	Sloan McNamara Ford Agnelli Nordhoff Matsushita	Keynes Schumpeter Kalecki
Fifth*	Japan USA Germany Sweden Other EEC EFTA USSR and other Eastern European Taiwan Korea Canada Australia	Brazil Mexico Argentina Venezuela China India Indonesia Turkey Egypt Pakistan Nigeria Algeria Tunisia Other Latin American	'Regulation' of strategic ICT infrastructure. 'Big Brother' or 'Big Sister' state. Deregulation and reregulation of national financial institutions and capital markets. Possible emergence of new-style participatory decentralised welfare state based on ICT and red–green alliance.	'Multi-polarity'. Regional blocs. Problems of developing appropriate international institutions capable of regulating global finance, capital, ICT and transnational companies.	Horizontal integration of R and D, design, production and process engineering and marketing. Integration of process design with multi-skill training. Computer networking and collaborative research. State support for generic technologies and university–industry collaboration. New types of proprietary regime for software and biotechnology. 'Factory as laboratory'.	Rapid growth of new information services, data banks and software industries. Integration of services and manufacturing in such industries as printing and publishing. Rapid growth of professional consultancy. New forms of craft production linked to distribution.	Kobayashi Uenohara Barron Benneton Noyce	Schumacher Aoki Bertalanffy

*All columns dealing with the "fifth Kondratieff" are necessarily speculative

Source: based on Freeman (1987)

these relative factor prices in either direction, i.e. 'reversibility'. Our approach stresses the system's response to *major* changes in the price of *new* inputs, and *new* technologies which exploit their potential to reduce costs of both labour and capital, as a result of new total factor input combinations and organisational–managerial innovations. Such major changes are the result of an active and prolonged search in response to perceived limits, not on the basis of perfect information but on the basis of trial and error, i.e. the historical learning process stressed by Hahn (see Chapter 1). Once the new technology is widely adopted, the change is generally irreversible (i.e. the principal actors became 'locked in' by the pervasive economic and technical advantages and complementarities; (see Chapter 26).

We have stressed the role of a key factor or factors in creating widening investment opportunities and creating the potential for big increases in productivity and profits. We turn now to consider the wider societal problems involved in the transition from one 'techno-economic paradigm' to another.

Diffusion of new techno-economic paradigms and institutional change

It is a clear implication of our mode of conceptualising successive 'techno-economic paradigms' that a new paradigm emerges in a world still dominated by an old paradigm and begins to demonstrate its comparative advantages at first only in one or a few sectors. The fastest-growing new sectors are thus *not* those which are the motive branches of an established, technological regime (Table 3.1, columns 5—'Main "carrier branches" and 6—'Other sectors growing rapidly'). There is no possibility of a new paradigm displacing an old one until it has first clearly demonstrated such advantages and until the supply of the new key factor or factors already satisfies the three conditions described above: falling costs, rapidly increasing supply, and pervasive applications. Thus a period of rapid growth in the supply of the key factor(s) occurs already *before* the new paradigm is established as the dominant one, and continues when it is the prevailing regime.

A new techno-economic paradigm emerges only gradually as a new 'ideal type' of productive organisation, to take full advantage of the key factor(s) which are becoming more and more visible in the relative cost structure. The new paradigm discloses the potential for a quantum jump in total factor productivity and opens up an unprecedented range of new investment opportunities. It is for these reasons that it brings about a radical shift in engineering and managerial 'common sense' and that it tends to diffuse as rapidly as conditions allow, replacing the investment pattern of the old paradigm.

The full constellation—once crystallised—goes far beyond the key factor(s) and beyond technical change itself. It brings with it a restructuring of the whole productive system.

Among other things as it crystallises, the new techno-economic paradigm involves:

(a) a new 'best-practice' form of organisation in the firm and at the plant level;
(b) a new skill profile in the labour force, affecting both quality and quantity of labour and corresponding patterns of income distribution;
(c) a new product mix in the sense that those products which make intensive use of the low-cost key factor will be the preferred choice for investment and will represent therefore a growing proportion of GNP;
(d) new trends in both radical and incremental innovation geared to substituting more intensive use of the new key factor(s) for other relatively high-cost elements;
(e) a new pattern in the location of investment both nationally and internationally as the change in the relative cost structure transforms comparative advantages;
(f) a particular wave of infra-structural investment designed to provide appropriate externalities throughout the system and facilitate the use of the new products and processes everywhere;
(g) a tendency for new innovator-entrepreneur-type small firms also to enter the new rapidly expanding branches of the economy and in some cases to initiate entirely new sectors of production;
(h) a tendency for large firms to concentrate, whether by growth or diversification, in those branches of the economy where the key factor is produced and most intensively used, which results in there being distinctly different branches acting as the engines of growth in each successive Kondratiev upswing;
(i) a new pattern of consumption of goods and services and new types of distribution and consumer behaviour.

From this it is evident that the period of transition—the downswing and depression of the long wave—is characterised by deep structural change in the economy and such changes require an equally profound transformation of the institutional and social framework. The onset of prolonged recessionary trends indicates the increasing degree of mismatch between the techno-economic sub-system and the old socio-institutional framework. It shows the need for a full-scale reaccommodation of social behaviour and institutions to suit the requirements and the potential of a shift which has already taken place to a considerable extent in some areas of the techno-economic sphere. This reaccommodation occurs as a result of a process of political search, experimentation and adaptation, but when it has been achieved, by a variety of social and political changes at the national and international level, the resulting good 'match' facilitates the upswing phase of the long wave. A climate of confidence for a surge of new investment is created through an appropriate combination of regulatory mechanisms which foster the full deployment of the new paradigm. Since the achievement of a 'good match' is a conflict-ridden process and proceeds very unevenly in differing national political and cultural contexts, this may exert a considerable influence on the changing pattern of international technological leadership and international patterns of diffusion (Table 3.1 and Chapter 23).

Schumpeter's (1939) theory of depression was rather narrowly 'economic' and strangely, for someone who was so much aware of social and organisational aspects of technical innovation, tended to ignore the institutional aspects of recovery policies. This was one of the main reasons for the relative neglect of his ideas compared with those of Keynes.

The information technology paradigm

The technological regime, which predominated in the post-war boom, was one based on low-cost oil and energy-intensive materials (especially petrochemicals and synthetics), and was led by giant oil, chemical, automobile and other mass durable goods producers. Its 'ideal' type of productive organisation at the plant level was the continuous-flow assembly-line turning out massive quantities of identical units. The 'ideal' type of firm was the 'corporation' with a separate and complex hierarchical managerial and administrative structure, including in-house R & D and operating in oligopolistic markets in which advertising and marketing activities played a major role. It required large numbers of middle-range skills in both the blue- and white-collar areas, leading to a characteristic pattern of occupations and income distribution. The massive expansion of the market for consumer durables was facilitated by this pattern, as well as by social changes and adaptation of the financial system, which permitted the growth of 'hire purchase' and other types of consumer credit. The paradigm required a vast infrastructural network of motorways, service stations, airports, oil and petrol distribution systems, which was promoted by public investment on a large scale already in the 1930s, but more massively in the post-war period. At various times in different countries both civil and military expenditures of governments played a very important part in stimulating aggregate demand, and a specific pattern of demand for automobiles, weapons, consumer durables, synthetic materials and petroleum products.

Today, with cheap microelectronics widely available, with prices expected to fall still further and with related new developments in computers and telecommunications, it is no longer 'common sense' to continue along the (now expensive) path of energy and materials-intensive inflexible mass production.

The 'ideal' information-intensive productive organisation now increasingly links design, management, production and marketing into one integrated system—a process which may be described as 'systemation' and which goes far beyond the earlier concepts of mechanisation and automation. Firms organised on this new basis, whether in the computer industry

such as IBM, or in the clothing industry such as Benneton, can produce a flexible and rapidly changing mix of products and services. Growth tends increasingly to be led by the electronics and information sectors, taking advantage of the growing externalities provided by an all-encompassing telecommunications infrastructure, which will ultimately bring down to extremely low levels the costs of access to the system for both producers and users of information.

The skill profile associated with the new techno-economic paradigm appears to change from the concentration on middle-range craft and supervisory skills to increasingly high- and low-range qualifications, and from narrow specialisation to broader, multi-purpose basic skills for information handling. Diversity and flexibility at all levels substitute for homogeneity and dedicated systems.

The transformation of the profile of capital equipment is no less radical. Computers are increasingly associated with all types of productive equipment as in CNC machine tools, robotics, and process control instruments as well as with the design process through CAD, and with administrative functions through data processing systems, all linked by data transmission equipment. According to some estimates computer-based capital equipment already accounts for nearly half of all new fixed investment in plant and equipment in the United States.

The deep structural problems involved in this change of paradigm are now evident in all parts of the world. Among the manifestations are the acute and persistent shortage of the high-level skills associated with the new paradigm, even in countries with high levels of general unemployment, and the persistent surplus capacity in the older 'smokestack', energy-intensive industries such as steel, oil and petrochemicals.

As a result there is a growing search for new social and political solutions in such areas as flexible working time, shorter working hours, re-education and retraining systems, regional policies based on creating favourable conditions for information technology (rather than tax incentives to capital-intensive mass production industries), new financial systems, possible decentralisation of management and government, and access to data banks and networks at all levels and new telecommunication systems. But so far, these seem still to be partial and relatively minor changes. If the Keynesian revolution and the profound transformation of social institutions in the Second World War and its aftermath were required to unleash the fourth Kondratiev upswing, then social innovations on an equally significant scale are likely to be needed now. This applies especially to the international dimension of world economic development.

The structural crisis of the 1980s

From this brief summary of some of the characteristics of the new paradigm it will have become apparent that the widespread diffusion of the new technology throughout the economic system is not just a matter of incremental improvements, nor just a question of the extension of existing capacity in a few new industries. It involves a major upheaval in *all* sectors of the economy and changes in the skill profile and capital stock throughout the system. It is for this reason that periods like the 1930s and the 1980s cannot be treated in the same way as the minor recessions of the 1950s and 1960s.

The structural crisis involved in the transition from one technological regime to another increases the instability of investment behaviour for a number of reasons. The leading-edge industries of the new paradigm are growing so rapidly that they constantly tend to outstrip the supply of skilled labour. However, the headlong rush to increase capacity as bandwagons get rolling also leads to periodic crises of over-capacity, as there is no way in which the supply can precisely anticipate and match smoothly the growth of market demand (in Hahn's terminology, the 'true' demand function cannot be known). Moreover the technology is still changing so rapidly that successive generations of equipment and products rapidly become obsolete. The tempestuous growth of the chip industry and the computer industry in the 1970s and 1980s has also been marked by periodic, though short-lived, crises of over-supply (Ernst, 1983, 1987). There were similar problems with the leading-edge industries of the 1920s and the 1930s—automobiles, consumer durables and organic chemicals.

The problems in the other sectors of the economy are even more severe. Some industries which have previously been at the heart of the (now superseded) paradigms now experience much slower rates of growth or absolute decline. They may also have problems of over-capacity and rationalisation which are prolonged, as has been the case in some of the energy-intensive industries in the 1970s and 1980s, such as steel, petrochemicals and synthetic fibres. Similar problems were encountered by the railways and railway equipment industries as well as by coal and textiles in previous structural crises.

There are also severe problems in those manufacturing and service sectors which still have ample growth potential but are confronted with the need to change their production processes, their product mix, their management systems, their skill profiles and their marketing to accomplish the shift to an entirely new technological paradigm. This is a painful and difficult process of adjustment, involving, as we have seen, a kind of cultural revolution as well as the need for major re-equipment. These problems can be seen very clearly today in such industries as printing, vehicles and machine tools, as well as in services such as insurance, distribution and transport. They were equally apparent in many industrial sectors adapting in the 1920s and 1930s to the new energy-intensive mass and flow production systems which at that time represented the leading edge of the new techno-economic paradigm.

The depression of the 1930s was certainly one of extraordinary severity, especially in the leading industrialised countries—the United States and Germany. Between 1929 and 1933 GNP fell by 30 per cent in the United States, industrial production by nearly 50 per cent, output of durable producers' equipment by 75 per cent and new construction by 85 per cent. It is hardly surprising that Keynesian economists, such as Samuelson (1980), discount the likelihood of the recurrence of such a catastrophe:

> Although nothing is impossible in an inexact science like economics, the probability of a great depression—a prolonged cumulative chronic slump like that of the 1930s, 1890s or 1870s—has been reduced to a negligible figure. No one should pay an appreciable insurance premium to be protected against the risk of a total breakdown in our banking system and of massive unemployment in which 25 per cent of workers are jobless. The reason for the virtual disappearance of great depressions is the new attitude of the electorate . . . The electorate in a mixed economy insists that any political party which is in power—be it Republican or Democratic, the Tory or Labour Party—take the expansionary actions that can prevent lasting depressions. [p. 251]

This may be an over-optimistic view. Whilst not dissenting from Samuelson's description of economics as an inexact science, this chapter suggests that it is quite possible for the world economy to experience a depression, which, even if not so severe in all respects as that of the 1930s, could be more severe than the earlier recessions of the 1870s and the 1890s.

This somewhat pessimistic view is based on the observation that the main sources of instability which gave rise to the depression of the 1930s are also present today, albeit in a somewhat different form: the international debt situation, extreme imbalances in international payments, weakness in agricultural prices, instability in exchange rates, creeping protectionism, the absence of an adequate system of regulating the international economy and in particular the absence of an adequate international lender of last resort, disarray in the economics profession, and lack of long-term vision in policy-making. The present wave of technical change sweeping through the world economy is likely to exacerbate the problems of instability in investment, and of structural change at the national and international level and the associated disequilibria in the international economy.

It is notable that Samuelson's argument that severe depressions can be averted rests not on any faith in the self-regulating powers of the market, but unequivocally on the belief that *political* factors, principally the level of unemployment, will put pressure on governments to adopt expansionary policies, which are assumed to be available and applicable. We share with him and other Keynesians their scepticism that the rate of interest and monetary policy are in themselves sufficient to achieve an equilibrium growth path.

But for his argument to carry conviction it would be necessary not only for governments to adopt *national* policies to counteract tendencies toward depression, but also at least for the leading countries to act in a co-ordinated manner at the *international* level. Recent experience must cast some doubt on both these assumptions. It is no doubt true that the experience of recession and stagnation does induce a search for expansionary policies at the political level. But, as in the 1930s, this search may lead to nationalistic, protectionist and even militaristic policies as well as to neo-Keynesian policies and other as yet untried solutions. It may also be hindered by the extreme divergence of views from the economics profession on such questions as the feasibility and desirability of a return to fixed exchange rates.

The uneven and varied response of governments, firms and industries to the threats and opportunities posed by information technology tends to accentuate the uneven process of development. Typically in the past, major changes in techno-economic paradigm have been associated with shifts in the international division of labour and international technological leadership. Newcomers are sometimes more able to make the necessary social and institutional innovations than the more arthritic social structures of established leaders. Erstwhile leading countries such as the United Kingdom or the United States may become the victims of their own earlier success. On the other hand, countries lacking the necessary minimal educational, managerial, R & D and design capability may be even more seriously disadvantaged in international competition.

This means that changes of paradigm are likely to be associated with the temporary aggravation of instability problems in relation to the flow of international investment, trade and payments. The enormous Japanese trade surplus and the US trade deficit reflect not merely exchange rate problems, but also the more successful Japanese exploitation and application of IT outside the leading-edge industries, and the introduction of many institutional innovations facilitating this process (Chapter 23). The US economy leads in military applications of IT but lags in other areas. There is thus a major 'structural' component in the international trade imbalances, as there was in the 'technological gap' which the United States opened up between the 1920s and the 1950s (Freeman, 1987).

The same is even more true of the problems of Third World countries. A report of the Inter-American Development Bank has highlighted these critical problems confronting the world economy and has warned that the IMF measures to deal with the crisis have been short-term palliatives, not long-term solutions. Albert Fishlow (1985) points out that Latin America faces a burden of debt service repayments greater than the level of reparations that Germany found impossible after the First World War. Only a widespread recovery of productive investment and technical innovation in Latin America could sustain the growth needed to finance even a much lower level of debt repayment and interest payments. It is not without interest that Samuelson and Nordhaus in the 12th edition of *Economics* (1985) do introduce a sentence or two suggesting that 'default of major heavily indebted countries' could lead to a Great Depression.

The Third World countries are experiencing difficulties in developing the new information technology industries to sustain their competitive power, but the new technologies do actually offer some major advantages to them, provided they modify their trade, industrial and technology policies, as indicated in Chapter 21 by Perez and Soete.

However, these 'catching up' efforts of Third World countries also require some resolution of the basic structural problems confronting the entire world economy. This implies new measures to facilitate the international transfer of technology as well as a resolution of the debt problem. Thus the greatest problem of institutional adaptation lies in the sphere of international financial and economic institutions, to take account of these long-term structural adaptation difficulties. The development of new national and international 'regimes of regulation' is discussed in the following chapter by Boyer.

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4 Technical change and the theory of 'Régulation'

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Mixing technology with economics: a difficult task

The economist has many problems in dealing with technical change, for at least three interrelated reasons.

If technological systems are supposed to evolve smoothly and continuously in response to mainly *external factors* (such as advances in pure and applied science), their only effect would be to shift the long-run equilibrium path of the economy. This results in the usual method of injecting technological trends into a given macroeconomic model, and neglects any feedback from the economic side to the technological one. The really big problem is to combine economics with technology *in the very long run*, in the Marshallian sense, i.e. with industrial structures and labour both adapting to technological paradigms.

A second difficulty lies in the temptation to relapse into *technological determinism* according to which economic growth as well as most social institutions derive from purely technical matters. If this kind of statement was not made by Schumpeter himself, it turned out to be a salient feature of the present recovery of neo-Schumpeterian ideas. This is not so much surprising, since standard theory usually does not deal with *social forms of organization*, either supposing them to be given by history, or totally ignoring them. Hence a major challenge is to see if one can distinguish clearly between two dynamics—one concerning institutional forms, and the other the technological system—and then to investigate their *ex post* compatibility.

But the problem is made still more complex by another puzzling finding: neither innovations nor growth exhibit steady trends in the long run, since, on the contrary, the so-called *Kondratiev waves*—i.e. the succession of a long-lasting boom and then stagnation over a period of half a century—are once again considered as a true problem for economic historians. Theoreticians are mainly interested in equilibrium path growth models, and only a few of them have tried to formalize Kondratiev-style cycles. To my knowledge, very few successful examples are available on this last topic. Similarly, economists have a lot of problems in analysing why the same technological trajectory might have positive effects upon employment and stability during some periods, but negative ones during others (see Chapter 3). The traditional theories point to an invariant impact—usually positive in neo-classical models, negative in the pure Keynesian closed-economy framework—whereas the issue at stake is to understand *changing patterns through time*.

Clearly, many economists are now trying to cope with these problems, since numerous national or international projects have been launched, especially during the last decade. This chapter intends to suggest a tentative theoretical approach, the aims of which are precisely the same, even though initially at least the question of technological change was not at the forefront. This approach, called '*régulation*' in French, is not easily translated into English, since the English word 'regulation' is usually associated with the much narrower problem of regulation of the behaviour of public utilities, whilst the expression '*socio-economic tuning*' brings a connotation of a conscious and sophisticated adjustment mechanism. Actually the process of fitting production and social demand in a given set of structures and institutions is always an uneven, unbalanced and usually contradictory consequence of very partial rationalities and strategies, however integrated modern corporate economies may seem. For this reason we simply use the word 'régulation' in the French sense of the word. This approach is far from being a fully-fledged theory, but its interest is precisely its implications for these three puzzles.

Contrary to the usual approach in economics, the focus is not on short- or medium-term issues but on the *long run and structural change* in advanced capitalist countries. For example, the US and French economies have been studied over nearly two centuries. Over such a period technology, industrial structures, labour force composition and institutions cannot be assumed given or constant.

Similarly, technology cannot be dealt with in isolation from the rest of *the economic and social system*. The major question is, then, the coherence and compatibility of a given technical system with a pattern of accumulation, itself defined by a complex set of economic regularities and mechanisms affecting competition, demand, the labour market, credit and state intervention. The major finding is the following: there are several different modes of development and 'régulation' observed in history—there is no single universal mode.

Within each mode of development the very factors which account for a successful, long-lasting boom also explain the reversal of economic dynamics *from growth to crisis*. Once totally mature, a socio-technical system gives rise to new economic imbalances and social conflicts. Hence possible obstacles arise during the process of accumulation itself, leading to a major, i.e. a structural, crisis, characterized by quasi-stagnation and large instabilities. Therefore the same ongoing technical change—crudely measured by average productivity growth—might have negative effects upon employment, in complete opposition to the situation during periods of high and stable growth.

This chapter first presents the major concepts of the 'régulation' approach. Then a summary is given of the main findings on the relationship between technology and long-run economic dynamics.

A method for the analysis of structural change: the 'régulation' approach

Between economic history and theory

In fact, most of the problems previously stressed derive from very unsatisfactory links between two departments of the social sciences: economic and social history on the one hand, economic analysis on the other. Most *historians* are fond of assessing the validity of accounts of events, sources and data. When they do dare to propose and test causal mechanisms, they mainly refer to the state of the art of other social sciences, especially economics, but sociology and anthropology as well. The New Economic History is a clear example of such a strategy, which has led to very mixed controversies among scholars: sometimes interesting, often provocative but in other cases, quite dubious! If the French 'Annales' school is excluded, almost no historian challenges existing economic theories, whether neo-classical, Keynesian or even Marxian! Implicitly, at least, historical facts are supposed to fit into a given general theory, already available.

In contrast, the *economist* is rarely as modest. Whatever the precise contents of his theory, his aim is to derive general results from very basic principles and as few as possible (the principle of maximization for neo-classicists, the law of value for Marxists, and so on). While testing his models the economist is strongly induced to interpret any discrepancy as a purely casual phenomenon, more or less related to historical or sociological peculiarities, and thus without any theoretical importance. Just to give an example, most monetary histories are no more than stubborn attempts to prove the truth of one variant or another of the quantity theory of money. Even completely perverse evolutions of income velocity are interpreted as a minor phenomenon. Why bother with reality and history, since the basic theory is necessarily true according to first principles!

Paradoxically, such a caricature is not absent from many Marxist analyses: has not Marx said everything about the laws of capitalism in the long run? In a capitalist system production is undertaken solely in order to obtain a profit on commodities as exchange value, and not just to satisfy direct individual or social needs, i.e. according to their use value! Therefore there appears a tendency to make accumulation an end in itself, an absolute novelty with respect to all previous production modes. Labour itself becomes a commodity, but a very special one which brings a surplus value, the root of profit. Hence, a propensity exists to exploit more and more workers according to new production methods obtained by applying science and techniques to economic activity. Marx is thought to have proved a fundamental dynamic law of capitalism: its necessary collapse due to the famous tendency for the rate of profit to fall. Since this has not been the case until now, the followers of Marx stress the succession of transitory counterbalancing forces. When used indiscriminately, such a device can interpret any discrepancy, whatever the size of the gap between the prediction of the theory and observed historical events. Just to give an example, some Marxists in the 1960s contended that since the First World War productive forces have been continuously declining, and others that the unprecedented growth observed from 1945 to 1973 was the strongest evidence of the deepening of the structural crisis of the inter-war years!

From a methodological point of view such severe shortcomings derive largely from insufficient links between theory and empirical analysis on the one hand, and from purely deductive or inductive methods on the other. Would it not be surprising, for example, for physicists to wait until the basic concepts of mechanics (the notion of forces, weight, acceleration) had been completely elaborated before attacking the evolution of particular complex systems? In fact, the successful method has been to build a series of intermediate models which use the general laws of mechanics in order to analyse the exact composition of forces, and then to check if the expectations derived from the model fit the facts. *Mutatis mutandis*, the economist faces the same problem and should adopt a similar strategy: try to work out intermediate notions and models in order finally to organize an appropriate and careful comparison with observed facts.

In this respect, the 'régulation' approach is an attempt to elaborate a *continuum of concepts* from the more abstract ones (for example, that of production modes) to the observed regularities in the behaviour of economic agents (as part of the 'régulation' mechanisms). Some of these intermediate notions are accumulation regime, structural or institutional form, wage-labour nexus, and so on. They benefit from the conclusions of long-run historical studies and point in the direction of a new theoretical framework which would combine a critique of Marxian orthodoxy, and an extension of Kaleckian and Keynesian macroeconomic ideas, in order to rejuvenate a variant of earlier institutional or historical theory. Let us now present these different topics.

The notion of accumulation regime

The 'régulation' approach, progressively elaborated in France since the early 1970s, is basically built upon a critique of mechanical and catastrophic interpretations of Marx. The logic of accumulation is certainly central to capitalist economies. Of course, the spreading of the market relationship introduces into the system the possibility of crises, while all the conflicts based upon exploitation of workers and competition among capitalists make these crises more and more likely, at least during particular periods. But actual historical records suggest that the inherent contradictions of the system can be contained at least partially and for a time. Then minor crises are sufficient to promote a recovery within a cumulative growth pattern. Such episodes need not be characterized as pure accident but as possible *stable configurations of the economy*. This is the basic idea and the reason why the concept of *regime of accumulation* is so important.

In order to analyse the possibility of such a process in the long run, the economist has to find out what are the various technological, social and economic regularities which allows it. Let us mention five of them:

a pattern of *productive organization* within firms, defining the way wage-earners work with the means of production;

a *time horizon* for capital formation decisions, within which managers can use a given set of rules and criteria;

income shares between wages, profits and taxes, which reproduce the various social classes or groups;

a *volume and composition of effective demand* validating the trends in productive capacity;

a particular set of relationships between capitalist and *non-capitalist modes* of production.

Hence a regime of accumulation is defined by the whole set of regularities which allow a general and more or less consistent evolution for capital formation, i.e. which dampen and spread over time the imbalances which permanently arise from the process itself. The five features previously defined are sufficient to build either a macro model with two departments (producing respectively consumption and production goods) or an aggregated model, for simplicity's sake (final section, 'A research agenda'). Given the evolution of the technical coefficients, income shares, composition of demand, transfers to other social groups, and the time lags involved, it is possible to close the dynamic model (Boyer, 1975; Bertrand, 1983; Fagerberg, 1984).

Of course, the method is not brand new and has a long historical tradition. Nevertheless, this approach tries to overcome some major shortcomings of previous attempts. First, the game is not purely mathematical—the key parameters are chosen according to statistical and econometric studies as detailed as possible. Second, the technological determinants are combined with economic and social mechanisms, thus preventing capital from being reduced merely to a question of reproduction in a quasi-technical sense: for example, workers are not a special productive commodity but part of the social relationships defining their place in society. Third, the regime of accumulation is by no means the end of the analysis, since it seems to be a very abstract concept, largely unobserved by economic units. But then, why do capitalists, workers and other social groups behave in such a way as to substantiate this regime?

The importance of institutional forms

This notion of institutional forms illuminates the basis of social regularities which channel economic reproduction. Basically, a structural or institutional form denotes a codification of a main social relationship. Here again the idea is that the same invariant and abstract relationship might have very different realizations either for a given country over time or for different countries during the same period. In some sense, the 'régulation' approach tries to extend to organizational forms what technological theorists have done for *technological systems or paradigms*. Is it not clear that the characteristics of the first industrial revolution are not those of the present one? Similarly, all forms of labour organization, state intervention, monetary creation and so on are not at all equivalent as far as economic dynamics is concerned.

Monetary and credit relationships are essential in defining the mode of interaction between separate economic units. This abstract form can take several configurations according to the direction of causality between money and credit on the one hand and the degree of sophistication of national and international financial systems on the other. At first sight this form might seem quite removed from the question of technological change. But after all, Schumpeter in his *Theory of Economic Development* attributed credit to a major role in shifting resources from old industries and products to new ones. Furthermore, many contemporary analysts see some links between technological change (i.e. the mix between product and process innovations) and the tendency towards inflation or deflation, whether associated with a *Kondratiev* style of reasoning or not (Freeman, 1978, Mensch, 1978).

Historical studies do confirm significant changes in the forms of the monetary constraint. In the nineteenth century, under the so-called gold standard, inflows or outflows of currencies continually controlled the evolution of domestic credit. Hence a very typical business cycle resulted, associating bankruptcies with declining prices and production. In contrast, after the Second World War the volume of credit given by banks to firms and households became the key determinant of the money supply. External capital flows exerted only transitory constraints, usually overcome by a once-for-all devaluation in the late Bretton-Woods system. Therefore a cumulative expansion of credit money with permanent inflation became possible, at least until the 1970s. Consequently, one observes a very specific pattern of investment in industrial structures and of research and development.

The wage–labour nexus defines a second and a crucial institutional form, since it characterizes the relationship between capital and labour, management and employees. Broadly speaking, it involves all problems relating to work organization and the standard of living of wage-earners. A form of the wage–labour nexus is defined by a coherent system encompassing the following five components: the type of means of production and control over workers; the technical and social division of labour and its implications for skilling/deskilling; the degree of stability of the employment relation, measured, for example, by the speed of employment or work duration adjustments; the determinants of direct and social wages in relation to the functioning of labour market and state welfare services;

the standard of living of wage-earners in terms of the volume and origin of the commodities they consume.

Empirical investigations have revealed very different forms through history or across countries at a given period of time. To be brief, a *competitive wage–labour nexus* used to prevail in the last century: most of the consumption of the workers came from non-capitalist modes of production, and few collective organizations existed to oppose business strategies and market forces. Hence there was a high responsiveness of wages to employment fluctuations and no indexing. In contrast, since the First World War, collective bargaining and the emergence of the welfare state have introduced a new wage–labour nexus, called *Fordist*. In this system, wages are not only a cost but also a key determinant of consumption and hence effective demand. Implicitly, or by explicit agreement, nominal wages become indexed to consumer prices and to expected productivity gains, and thus have a very low sensitivity to unemployment. This point is of interest for technological change analysis, since the concept of Fordism closely relates mass production to mass consumption, therefore defining a new stage of capitalist development (see p. 84, for more details).

The *type of competition* is a third component introduced into the analysis. The concept of accumulation regime assumes completely homogeneous capital, whereas in fact many separate private units compete to get higher profits via production cost reductions and/or product differentiation. This competition expresses itself through various price mechanisms, which may have quite opposite effects upon the direction and intensity of technological change. It is necessary to make a clear distinction between purely static approaches (market power as a source of extra profits via oligopolistic pricing) and dynamic analyses (the issue is then whether more concentration spurs product and process innovation).

In this respect, historical analysis yields interesting results by contrasting at least two different types of competition. In the nineteenth century, even if financial concentration was not negligible, price variation was the only way to adjust for discrepancies between demand and productive capacity. The logic was very myopic and operated only *ex post*. The closure of plants, bankruptcies and redundancies were the usual way for providing a new equilibrium in the system. This is *traditional price competition*. From 1945 to the 1970s, the 'régulation' has been quite different. A much higher centralization of financial assets and concentration of markets led to *oligopolistic competition*. In this system, firms compete through advertising, and more generally through product differentiation, while prices are derived from a mark-up applied to average costs. Basically this is associated with a form of internal planning, in which firms try to expand capacity in step with expected demand. To the extent that real wage income increases with productivity (the Fordist wage–labour nexus), cumulative growth is then possible, with *ex post* adjustments only between minor discrepancies in growth rates rather than production levels themselves. This is the distinguishing feature of the Fordist development in contrast to that of the last century. Finally, the canvas has to be completed by examining two other components.

The mode of adhesion to the international regime plays a pre-eminent role when one passes from a purely abstract analysis to the study of a given national economy. This concept is defined by the set of rules and conventions which organize the exchange of commodities, the location of production units (via direct foreign investment) and the financing of external disequilibria. This conception is quite at odds with traditional discussions which contrast open to closed economy, free trade to protectionism, fixed to flexible exchange rate systems, etc. In fact, the 'régulation' approach is developing a series of intermediate concepts which relate the international growth regime (i.e. the division of economic space and their linkages) to the existence of strategic areas and, ultimately, to the opportunities and constraints imposed or offered to each nation by the world system (Mistral, 1986).

The issue is quite important as far as technical change is concerned. The advances in abstract knowledge as well as in applied technology are mainly defined at the international level, not separately in each country. Nevertheless, countries are not equally able to take advantage of these general opportunities and translate them into profitable production to be sold at home and abroad. Hence various countries occupy different places in the international regime of growth, due both to their mastering of new technology and to their access to world finance. This explains, for example, why the rate of growth in Japan is not equal to that of the United States, and why German and UK macroeconomic achievements differ. Similarly, the international regime may change in the long run, due to a combination of technological domination, financial intermediation and political hegemony. Historical evidence suggests that contrasted periods do alternate during the domination of the same country, be it the United Kingdom during the last century or the United States after the Second World War. Relative stability and cumulative growth take place when all the factors of domination are simultaneously mastered by the leading country, but large instabilities and slow growth or even stagnation occur when technological and economic hegemony, but not necessarily financial intermediation, are declining.

The forms of state intervention are the last institutional configuration. In some respects, this is related to the previous configuration, since it has always been an attribute of the state to organize the relations with the world economy. Basically, the state operates in a different way from pure market relationships: coercion by law replaces mutually profitable exchanges, whereby the power to tax is clearly at odds with the free exchange of commodities. Hence, contrary to an old Marxist view, the state does not necessarily originate in purely capitalist relations. Rather, it seems to express a nexus of linkages between social classes and groups, qualitatively through laws and regulation, quantitatively through public spending (André and Delorme, 1983).

The attraction of this concept is to allow very different patterns of state interventions. For a long period of time a *bounded state* prevailed, the role of which was mainly to enforce private contracts and laws about property and to guarantee internal and external security. Nevertheless, the economic role of this limited state was not nil, since it helped a great deal to preserve the existing social order. After the First World War (and still more the Second), all advanced capitalist countries have evolved towards an *interventionist and large state*. Its role is now crucial in organizing the production of public services, financing infrastructure and productive investment, and managing the social wage within the so-called welfare state. Of course, one should add the intervention in science and technology by means of education, the tax system, defence programmes, general regulation about technical norms, etc. Both qualitatively and quantitatively, these two types of state are not at all equivalent as far as economic dynamics and social reproduction are concerned.

Modes of regulation and crisis types

It is now necessary to pass from these limited and partial regularities involving numerous economic agents and their behaviour to the possibility of a consistent dynamic system. Standard economic theory uses the general concept of equilibrium and assumes that for a broad category of 'tatonnement' processes, the model converges towards a stable and unique equilibrium. Of course, in more sophisticated mathematical economic theory many equilibria can exist, but such a result is rarely related to any real world economic problems. In contrast, the 'régulation' approach stresses the possibility of *several modes* of adjusting production to demand, credit to money, income distribution to demand formation. More basically, each wage–labour nexus, firm organization and competition type, public institution and monetary rule may—or may not—induce a coherent adjustment process for the economy as a whole. This institutional and structural setting is not set against market mechanisms but rather may enable it to function efficiently. In this framework institutions and markets, state and private units, jointly determine economic and social dynamics.

The analysis is hence converging towards the notion of *mode of régulation*, a partial and modest alternative to the overwhelming tyranny of static equilibrium. Consequently, we use this expression to designate any set of rules and individual and collective behaviours which have the three following properties:

- they make possible conflicting *decentralized decisions* compatible without the necessity for individuals or even institutions to comprehend the logic of the whole system;
- they control and regulate the prevailing *accumulation mode*;
- they reproduce *basic social relationships* through a system of historically determined institutional forms.

The trick is now to show that this notion is not an empty box, but can be filled with several different examples of systems of regulation, that is precisely the aim of the next section (p. 77). Note, too, that technology is present in many places in this scheme, but integrated into industrial organization, the wage–labour relations, standard of consumption, etc. However, a final definition and typology first has to be presented.

The concept of 'régulation' has to be complemented by its twin, that of crisis. In common language, as well as in most economic theory, this notion has either a specific narrow meaning (the oil, debt, welfare state, Keynesian economic policy crisis) or none at all (except perhaps a lasting under-employment equilibrium or a breakdown in growth trends). Our approach attributes a very central place to it and proposes a clear distinction between two broad categories of crisis.

According to the first definition, *cyclical crises* are the usual feature of any stabilized mode of 'régulation'. Since the accumulation of capital drives economic dynamics, disequilibria frequently occur within the system as a result of the necessary lags between the demand and capacity effects of investment or the discrepancy between stocks and flows in financial decisions. Therefore, after a period of boom, the economy adjusts to the previous imbalances by a downwards movement of inventories, production, investment, employment, etc. This type of crisis is part of the system's self-equilibration, and does not destroy it. Thus it might be misleading to speak of a crisis, since this expression lends an image of catastrophe and drama to what is *the usual business cycle*.

Nevertheless, two qualifications have to be made. First, from cycle to cycle the various institutional forms and industrial structures change slowly, so that some drift in the 'régulation' mode occurs. Qualitatively, however, it remains the same, and the question of new institutions does not arise. Second, economic policy rules do not have to be changed to promote the recovery: without discretionary intervention by the state, growth can resume as soon as the previous disequilibria have been eliminated by the 'régulation' process.

A second and quite opposite definition deals with *structural crises*. We shall use this designation for any episode during which the very functioning of regulation comes into contradiction with existing institutional forms, which are then abandoned, destroyed or bypassed. In other words, the limits to the 'régulation' mode and regime of accumulation—the combination of which defines a *mode of development*—become obvious in every sphere of social and economic life. One is now well justified to speak about the existence of a crisis, since the system can no longer reproduce itself in the long run, at least on the same institutional and technological basis.

At least three criteria allow us to distinguish a cyclical crisis from a structural one. First, the social and economic conflicts are such that, within the given mode of 'régulation', no self-correcting mechanism for profits exist. Second, most—if not all—of the institutional forms are questioned by the spreading of the crisis from its local and seemingly accidental origin to the whole system. Third, the way out of the trouble is not attained by letting the economic mechanisms play out their role, since they are precisely at odds with each other. Thus strategic choices made by leading firms, unions and governments are necessary to promote a new mode of development. In other words, the system is no longer totally deterministic; rather, political and social choices have to play a role in shaping and restructuring the economy.

Such a distinction is not purely semantic. If the mild recessions of the 1960s belonged to the first category, the period which opened in the early 1970s is clearly of a different nature, more or less of the second category. The consequences as regards economic policy are far-reaching. This central conclusion of the 'régulation' approach will now be elaborated in detail.

The place of technology in long-run dynamics: the main results of the 'régulation' approach

Three 'régulation' modes: old, competitive, monopolist

A historical analysis of the French economy since the end of the eighteenth century gives many hints about such changes. In order to substantiate them, the method tries to combine various tools which are usually disconnected. This begins with a precise characterization of the institutional setting (using available syntheses and monographs by historians). The next step is to formulate a hypothesis about the logic of economic regularities associated with each institutional form. The third stage consists of statistical and econometric tests of the derived hypotheses in each area (price and wage formation, credit and money, etc.). Fourth, the components are synthesised in order to check the coherence and viability of the whole 'régulation' system. Finally, when possible, models are constructed in order to assess the exact properties of each mode of 'régulation'.

A very brief synthesis of such a study is given in Table 4.1 to give some idea of the method, which has been kept at a high level of generality in the preceding presentation. One significant piece of evidence is that, over two centuries, the cyclical pattern of the French economy has been changing rather drastically:

In the old 'régulation' ('régulation a l'ancienne'), the agricultural sector plays a dominant role, since modern capitalist industry is only emerging. This produces a unique cyclical pattern: every bad harvest leads to soaring prices of corn and more generally agricultural prices; hence peasants cannot buy industrial goods and the industrial sector is hit by the second round of the crisis; then workers are fired and the nominal wage is lowered, even if the general price level is climbing. The 'régulation' is by nature *stagflationnist*, since it associates unemployment with inflation (Figure 4.1).

Table 4.1 A brief summary of a histroical study of French capitalism (the major institutional forms have experienced a transformation)

INSTITUTIONAL FORMS / PERIODS	1789	1848	1873	1896	1914 - 1918	1929	1929	1939 - 1952	1967	1973	1980'
• WAGE LABOUR NEXUS											
. Work organization	Manufactures replace craftmen	Work duration is extended but reaches crisis levels	Limitations of malleability of work rules	Early Scientific Management	Massive use of taylorian methods.....	.....Implemented for civilian goods.....	.....but workers oppose to it	Industrial disruption and recovery	Fordism becomes dominant.....	but hits some limits	The search for new forms
. Lifestyle	Basically out of the capitalist sector	slight evolution in consumption norms		Slow insertion of wage earners in society		Social wage is recognized as a principle		Launching of a complete . Welfare system . Workers benefit from mass consumption			The slowing down shakes Welfare State financial stability
• COMPETITION											
. Concentration and centralisation	Large plants are emerging.....	....Tendency towards concentration		Finance capital is strenghtening	Cooperation large firms/ State	Industrial cartels and financial holdings		Basis for national planning	Concentration of markets.....	.....French holdings become international...	...a new balance between home and international strategy
. Price formation	Controled by guilds	Principle of free market	Prices clear the market	Early monopolistic pricing	State price controls	First example of mark-up pricing		State controls	. Administred prices, public control . medium term strategy in pricing decisions		...the return to more price competition
• STATE											
. Budget and taxes	Limited to general functions.....	.....even if regulations are important	Significant economic interventions (railways)	Small size of budget/ GDP	Unprecedented surge	Budgetary cuts.....	relative growth in the depression	New and high levels for public spending /GDP	Slow growth.....stabilization of the size of State.....growth		...tentative to curb down public regulations
. Money and credit	Metallic reserves limit money creation	Credit is checked by external balance and interest rate variations			The war is financed by pure money credit.....	.....so is the postwar boom	Return to gold standard		Credit money has now a leading role..... .....periodic devaluations.....	...tentative monetary controls	...crisis of economic policy
• INTERNATIONAL REGIME											
. Hegemonic country	England is the core of industrial revolution......		......and the banker of the world United States and Germany are challenging British hegemony		British decline is reinforced	.....surge of US might		US are now hegemonic, organize and stabilize the international regime.....		.....which is challenged by new competitors	underlying crisis of US leadership
. Cohesive forces	Exchange of manufactured goods versus primary commodities		The relative stability derives from the position of England		The loss of competitiveness	.....destabilizes the system		A new international order.....	.....allows OECD growth.....	.....till the crisis of the Bretton Woods system	a very unstable system

Source: CEPREMAP–CORDES (1977).

In competitive 'régulation' ('régulation concurrentielle'), the pattern changes very significantly. Now the industrial sector imposes more and more its logic on to the whole system. The crisis derives from over-production in industry rather than from under-production. Even in agriculture social and economic relationships are transformed in such a way that more productivity is obtained. So during the nineteenth century the scarcity of food is replaced by abundance. Therefore the *modern industrial business cycles* emerge: the boom is slightly inflationary, the crisis deflationary. Most of the macroeconomic variables now behave pro-cyclically. The difference from the previous 'régulation' is therefore large and clear-cut (Figure 4.1).

In monopolist 'régulation' ('régulation monopoliste'), the distribution of income is significantly socialized through a series of compromises between capital and labour (Fordist wage formation along with inflation and productivity), between firms (mark-up pricing), between the state, citizens and capital (welfare state, pattern of public spending and tax system). Therefore the pure price adjustment mechanism bears only a minor part of the burden in adjusting social demand and production. To a larger extent, a complex set of institutions, conventions and rules constantly aims at developing effective demand at the same rate as production capacity, which in turn is partially linked to the intensity and direction of technical change via the accumulation process.

The economic dynamics are now fairly different: growth is faster since the increasing returns to scale associated with Fordist industries can be reaped via a steady demand evolution, easy to forecast. The business cycle becomes milder and milder and inflation does not stop even during recessions. Hence a *new stagflationist pattern* emerges, very characteristic of monopolistic 'régulation', if not toally unique in long-run history (recall the old 'régulation'). So the central approach stresses the specificities of modern economies, which bear little resemblance even to the inter-war period. The conclusion is further strengthened by an analysis of accumulation regimes.

Very constrasted modes of development

It turns out that the two last 'régulation' systems were associated with different accumulation regimes, and this is another reason for diverging patterns of crisis in 1929 and today (see below). More generally, since the middle of the last century, three major patterns of growth have been observed. In this characterization, the interplay between technology and economic and social factors is decisive.

Extensive accumulation exhibits a significant use of science and technology in production processes, but firms mainly try to apply existing knowledge

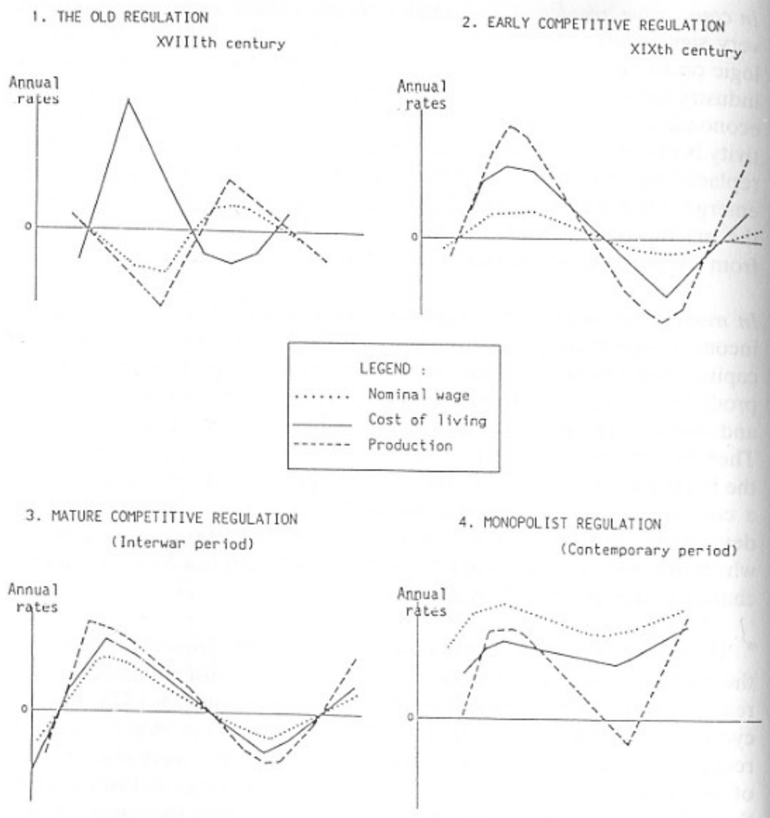

Figure 4.1 Changing regulation modes over two centuries: some stylized diagrams about the French experience

Source: Boyer (1978).

to their business and do not strive to improve them continuously. Similarly, the time horizon of firms is generally rather short, whereas the wage-earners in industry are mainly producers of commodities, and not so much consumers of them. Thus from 1895 to 1920, average productivity is quasi-stagnating, as are real wages, while growth is only obtained by a lengthening of working hours or by the hiring of more workers (Table 4.2). This quasi-stagnation may be related to numerous factors: lack of technological opportunities, limitations of the home and world markets, consequences of

Table 4.2 A brief statistical survey of development modes in France, 1856–1985
After the Second World War production norms and wage-earners consumption norms run parallel.

A. Real wage and productivity in the long run

(average annual rates in per cent)

INDEXES / PERIODS	Industrial Employment	Weekly Hours	Total Hours	Productivity per Employee	Real Wage	Accumulation Regime
1856-1870	- 1,0	- 0,8	- 1,8	2,4	1,4	Intensive
1870-1895	0,8	- 1,0	- 0,2	2,3	2,0	Intensive and its crisis
1895-1913	0,8	- 0,3	0,5	0,3	+ ε	Extensive
1913-1920	0,3	1,2	1,5	- 1,8	- 3,0	Extensive
1920-1930	1,2	- 2,8	- 1,6	5,8	2,2	Intensive without mass consumption
1930-1937	- 3,1	- 2.8	- 6,0	2,8	1,5	....and its crisis
1937-1949	1,0	0,9	1,9	- 0,3	- 0,5	Extensive
1949-1959	1,1	0,2	1,3	4,9	3,9	Intensive
1959-1973	0,8	- 0,4	0,4	4,8	4,1	...with mass consumption..
1973-1985	- 2,0	- 0,9	- 2,9	3,5	1,5	...and its crisis

Sources: CEPPREMAP–CORDES (1977): Insee vol II pp. 59–90 (1986).
Wage-labour is the dominant form of activity

B. The place of wage earners in the whole economy

(Figures in percent)

SHARES OF	1913	1929	1938	1949	1959	1969	1979	1985
Wage earners in total labour force	57,9	60,4	56,6	61,8	69,4	78,4	83,8	84,4
Direct wage in household disposable income	38,3	43,2	43,1	41,4	46,7	47,3	47,1	44,5
Direct wage and social benefits in household disposable income	39,4	45,7	48,0	57,3	67,2	72,3	78,3	86,0
. Food in total consumption	47,7	47,7	44,7	47,9	39,7	28,4	20,4	19,3
. Industrial goods in total consumption	27,4	29,9	29,4	28,1	29,1	29,9	34,3	33,6

Computed on the basis of the following data: L.A. Vincent (1972) pp. 322–325; A. Sauvy (1967) p. 496; INSEE (1986) vol. 3
From competitive to Fordist regulation of wages
C. Estimates for the relation $W = \varepsilon \cdot p + \theta_0 \cdot N + \theta_1$ with W: nominal wage; p: consumer price; N: employment (annual wage rates); ( ): t of student.

	ε	θ_0	θ_1	R^2	D^W
1923-1938	0.47 (3.37)	1.49 (2.99)	3.1 (2.8)	0.81	1.82
1953-1969	0.59 (4.4)	0.91 (2.56)	4.65 (6.1)	0.66	1.64
1959-1977	0.96 (8.0)	0.39 (1.17)	4.44 (4.49)	0.81	1.64

Source: Basle, M., Bautier, P., Mazier, J., Vidal, J.F. 'Emploi, revenu salarial prix et profit'. Economie et Prévision 1982.

competitive regulation upon the boldness of investment in brand new industries, ruinous impact of the war.

Intensive accumulation without mass consumption is a second ideal type. After the Second World War, industrial organization undergoes drastic transformations under the pressure of Scientific Management, and not only because the wrecked economies have to be rebuilt. Many new production processes are available, while some products cross the barrier of mass consumption. Along with authors like Braverman and Coriat, the 'régulation' approach insists upon the so-called Taylorian revolution. During the 1920s, productivity speeds up, more than usual after such an episode. But this period is relatively short and most of the positive effects are reversed after 1930 (Table 4.2). Basically, mass production is technically possible but cannot be sustained since the prevailing 'régulation' strongly moderates real wage increases, at the same time as wage-earners become a dominant fraction of the total labour force. It turns out that such intensive accumulation is highly contradictory (the profit rate is too high to permit an adequate effective demand) and unstable (look at inter-war production statistics). Therefore this is not a viable mode of development in the long run.

Intensive accumulation with mass consumption has been observed since the 1950s and defines a third configuration. Not only does scientific management continue to advance (diffusion of the assembly line as the key configuration of industrial organization) and new products are launched (radio and TV sets, electrical appliances for the home), but a *new social compromise* between capital and labour ensures that workers will benefit from economic and technological progress. Workers are now both *producers and consumers* of capitalist new goods. Similarly, wages are a cost but also a key determinant of consumption and hence aggregate demand (via an investment accelerator effect). The shift away from a purely competitive mechanism towards an administered 'régulation' of Fordist-Keynesian flavour facilitates such a move towards a new mode of development. In this respect, the period 1945–73 is without any historical precedent: stable and high growth, propelled by a simultaneous evolution of productivity and real wages (Table 4.2).

One sees clearly that this interpretation differs from the traditional long-wave interpretation 'à la Kondratiev'. Of course, each of the three accumulation regimes witness a long boom and then a period of decline, stagnation and crisis. But beneath these rough macroeconomic regularities, the underlying mechanisms and the factors explaining the downswing are quite different: exhaustion of the reserve army of wage-earners in extensive accumulation, lack of demand linked to the capacity dynamics in intensive accumulation, and adverse evolution of profit rates in intensive accumulation with mass consumption.

Technological change but no new wage–labour nexus: the inter-war crisis

To recapitulate the previous discussion, there is no doubt that technology and industrial organization play very important roles in long-run economic change. But the 'régulation' approach does not adopt a purely deterministic view of technological factors: everything depends on the compatibility with the basic institutional forms and the ability of the mode of 'régulation' to deal with the kind of disequilibria or conflicts that accompany accumulation. One can give no better evidence of this general proposition than the inter-war period.

Technological change but no new wage–labour nexus: the inter-war crisis

Many empirical studies converge towards the general conclusion that the technical system underwent a drastic change after the Second World War: dissemination of electrical power and new mechanical devices (for example, the assembly line), emerging new goods such as cars, home appliances, not to mention dwellings and buildings. The war had made mass production possible, first of weapons and products for the army but, later on, of civilian goods. Thus the same organizational system, called either Scientific Management or Taylorism, is extended to new branches when the economy has to be rebuilt after the war.

It is no accident that this period has been called the 'Roaring Twenties': lagged consumption has to be met while investment is rising to keep pace with modernization and demand. But the long-term viability of such an accumulation regime is not evident: one observes either over-accumulation and the appearance of adverse trends in profit rates, or a discrepancy between production capacity and demand. For some period of time, selling to small and medium bourgeoisie, peasants and foreign countries softens this imbalance. But as wage-earners now constitute the most significant part of the total labour force (remember the euthanasia of the *rentiers* due to inflation or debt repudiation), their consumption plays a key role in determining effective demand.

But after a while the system becomes increasingly troubled. In spite of some new features of collective bargaining (for example, regarding wage indexation), the regulation of the labour market remains basically competitive. The nominal wage is fairly sensitive to ups and downs in employment, whereas Taylorism generates very important productivity increases (see Table 4.2). Hence a very slow growth of the real unit wage results in spite of the boom of the 1920s. Then comes the 1929 crisis, resulting from the diverging trends between real wages and productivity, consumer demand and investment. The paradox can be summarized in one sentence: when wage formation is mainly competitive, a new industrial revolution leads to such a high profit rate that it cannot be sustained in the long run because of a lack of appropriate total demand (Figure 4.2).

Therefore a still more general conclusion can be proposed: *the effects*

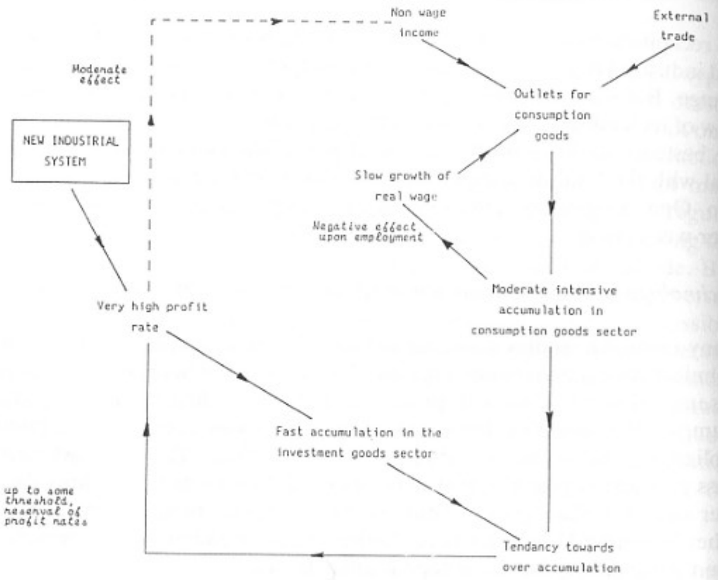

Figure 4.2 The vicious spiral of intensive accumulation without mass consumption

of any new technological system cannot be assessed independently of the existing or emerging mode of 'régulation'.

Compatibility between the technical system and the capital/labour compromise: the post Second-World War Fordist regime .

More or less the same technological basis is extended to new sectors after 1945. As a first approximation, the 1920s and the 1960s can be said to belong to the same technological paradigm. But, then, how do we explain why growth replaced stagnation as a long-run tendency, and that, contrary to contemporary fears, the collapse of 1929 did not repeat itself in the 1950s? The answer of the 'régulation' approach is simple enough: due to drastic social and political transformations, a new 'régulation' replaced the old one and made rapid technological change, quasi-full employment and sustained growth compatible.

The more drastic shift is in the wage–labour nexus. On the one hand, workers and unions accept capitalist modernization and do not oppose Scientific Management and Taylorist methods. On the other, managers agree to share productivity gains with wage-earners, so that the wage norm now permits employees to benefit from economic progress, regardless of sector, size of firm, location and skills. Thus, this new form of collective

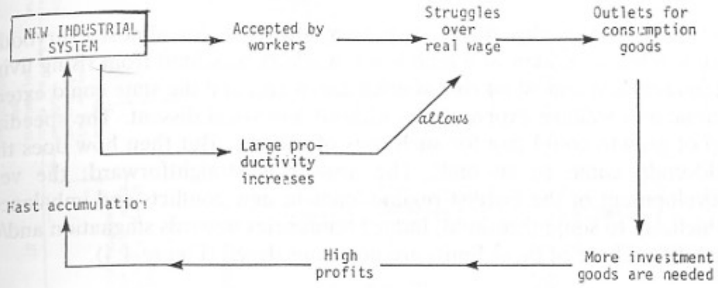

Figure 4.3 The virtuous spiral of monopolist growth

bargaining diffuses through the whole system and generates a *permanent improvement in consumption norms*. Since simultaneously investments are creating new modern capacity, the process now becomes self-sustaining. More demand for consumption goods induces investment opportunities in related sectors; hence outlets for equipment goods producers, who earn high profit. Thus a virtuous circle emerges in which the monopolist 'régulation' mode both stabilizes growth and promotes it (Figure 4.3).

According to this view, the major difference from the inter-war period lies in the *'régulation mode'* and not that much in the technological system. Of course, other institutional changes help in passing from one mode to another, or in some cases are made possible by the shift towards Fordist wage–labour relationships. *Oligopolistic competition* thus moderates possible struggles between firms by eliminating price cuts as the usual tool for obtaining market shares. Early US hegemony guarantees an international regime in which the various OECD countries can jointly grow without strong competitive pressure: when the state of business is good in the United States, everybody benefits from it. Finally, *Keynesian counter-cyclical policies* give the final touch to the Fordist regime: money and public spending are conceived as means for preventing departures from full employment or for reducing inflationary pressures.

Interestingly enough, this conclusion approaches the thinking of most of the specialists of technical progress: the success of Keynesian policy was based on a *coherent and dynamic technical system*. If the latter enters into crisis, so does the former. To risk a metaphor: Keynesian policies were the accelerator and the brake, not necessarily the engine of growth. Now a fourth result will be discussed.

The limits of Fordism as a social, economic and technical regime: the present crisis

Needless to say, this regime was very attractive for almost everybody: profit rates were kept at a high level, workers benefited from rising living standards and almost no risk of unemployment, and the state could extend public and welfare expenditures without any vocal dissent. The speeding up of growth could pay for such uses of income. But then how does this Eldorado come to an end? The answer is straightforward: the very development of the Fordist regime leads to new conflicts and imbalances which, up to some threshold, induce tendencies towards stagnation and/or stability. Three of these limits are now considered (Figure 4.4).

Fordism becomes counter-productive

From a technical point of view, the search for increasing returns to scale leads to larger and larger manufacturing plants, which produce a significant part of total output. It then becomes increasingly more difficult to balance the output of the assembly line with demand, both qualitatively (changes in models) and quantitatively (adaptation to short-run shocks). According to another arguement, Fordism is fairly efficient as regards labour and capital productivity when it replaces older systems, but it becomes harder and harder to get the same results when the issue is to deepen—and no longer to extend—the same organizational methods. Hence a possible decline in productivity growth rates sets in (in the United States during the mid-1960s) and/or in capital efficiency (in almost all OECD countries during the same period). But a third factor can also play a role: blue-collar workers revolt against Taylorist and Fordist methods through turnover, absenteeism, and a slacking of work intensity. In many cases they convert their protest into wage demands (recall May 1968 or autumn 1969). This leads to a possible profit squeeze to the extent that firms cannot pass on their cost increases because of strong external competition. Let us now examine two other limits.

From national complementarities to the struggle for external competitiveness

Fordism is just as much a socio-economic principle of organization as a technological one. Since the larger plants are usually more efficient, once national monopolies are set up, they tend to compete with one another at the world level. Thus, oligopolistic pricing, which has stabilised at home, turns into competitive pressures for external markets such that the previous price formation mechanism weakens or even breaks down. In a sense, if competition had led to monopoly, now monopoly turns back into competition! This change is far-reaching, since it destabilizes mark-up pricing and consequently the previous mechanisms governing wage formation. National economies are no longer the boundaries within which

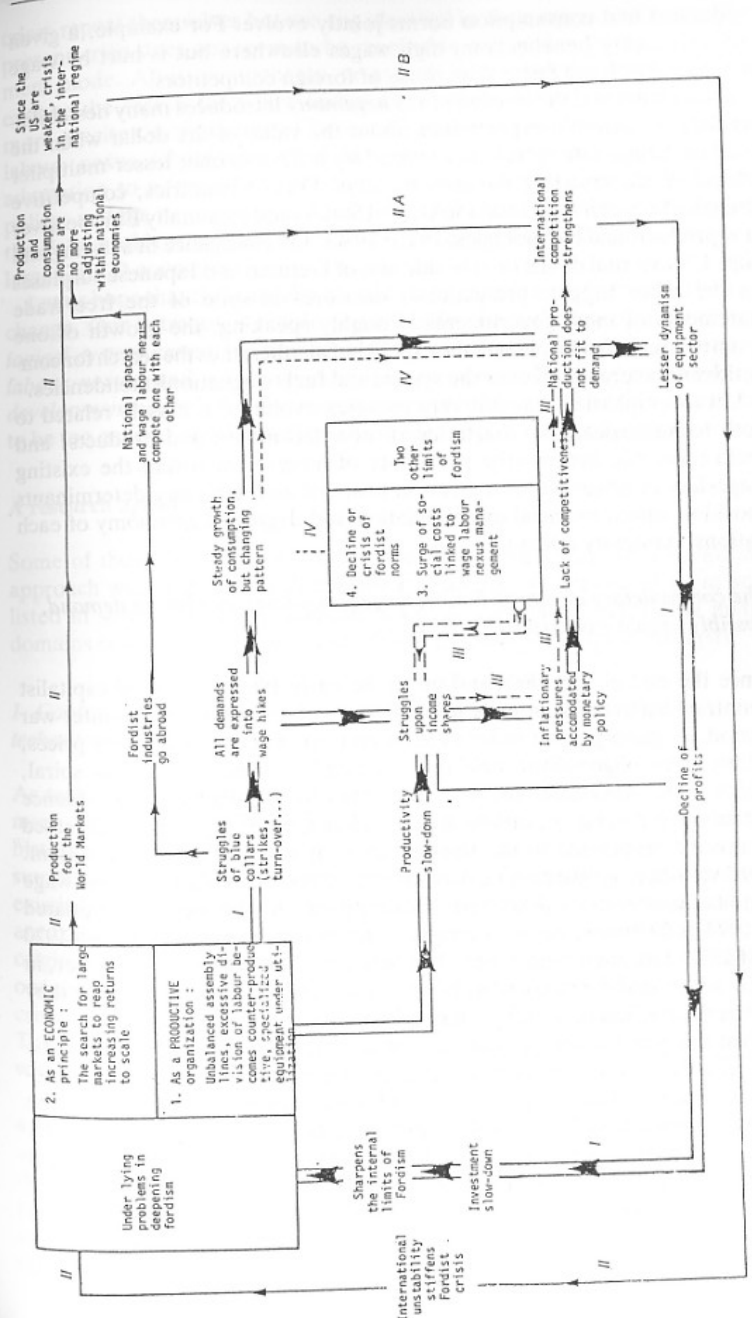

Figure 4.4 From growth to crisis: a simplified analysis

production and consumption norms jointly evolve. For example, a given firm or country benefits from high wages elsewhere but is hurt by wage increases which are faster than those of foreign competitors.

Simultaneously, the *erosion of US hegemony* introduces many destabilizing factors: unstable expectations about the value of the dollar when the fixed exchange rate system is replaced by a flexible one; lesser multiplier effects of US growth compared to other OECD countries; competitive struggles between Japan and the United States, and eventually Europe, over new products and technologies. In the 1980s, the emergence of a lasting and huge US external deficit on one side and of German and Japanese surpluses on the other triggers protectionist measures in spite of the free trade statements of most governments. Roughly speaking, the growth of one country is seen to take place at the expense of another; thus the search for competitiveness spreads all over the system and fuels stagnationist tendencies.

Let us emphasize that this very complex evolution is closely related to both technological (the mastering of new techniques and products) and socio-economic factors (the possibility of adjustment within the existing wage–labour nexus), not to mention financial and monetary determinants (position within financial intermediation and degree of autonomy of each national monetary policy).

The contradictory effects of Fordist wage formation: positive on demand, possibly negative on profits

Since the end of the 1960s and up to the early 1980s, advanced capitalist countries suffered from evils quite different from those of the inter-war period. A quasi-perfect indexation of nominal wages to consumer prices, jointly with oligopolistic pricing, generated a wage–price–profit spiral, which culminated after the two oil shocks in two-digit inflation. Hence pressures to reverse previously accommodating monetary policies increased in inverse proportion to the strength of each nation's productive system. Fordist collective bargaining sustained demand via a form of real wage rigidity, as previously described. This explains why the recessions initiated in 1973 or 1979 were not a repetition of the collapse observed between 1920 and 1932. Moreover, the speed of adjustment of employment was lower, in such a way that firms hoarded labour as a quasi-fixed factor; at least they did at the beginning of the present crisis!

But this process has an evident drawback: if the shock is mainly about a deterioration in the terms of trade, and if the national economy is a price-taker at the world level, then the profit rate is squeezed. Furthermore, the existing monopolistic 'régulation' is unable to recover its previous level, since that kind of perturbation never occurred in the past. Thus investment slackens, which leads to less capacity and lower productivity growth, since a slower embodiment of technical progress and diffusion of new production processes take place. So in contrast to the inter-war crisis, the *profit rate is now too low* compared to the growth in demand. The major structural

crises repeat themselves but are not identical in their origin and form. The present crisis does not seem to be resolvable within the existing development mode. All its components, or at least a large part of them, have to evolve: the search for a new technical paradigm (post-Fordist, but for a more precise description see Chapter 27); the reorganization of the wage–labour nexus (short-term flexibility of wages and employment and/or adaptation to a 'new' New Deal); the basic principles guiding economic policy; and the negotiation of a new international regime in order to solve the debt problem as well as to moderate competitive struggles between large OECD countries.

Let us hope that these results are of some interest to students of technical change. Our leitmotiv is simple, even a little naïve; *the fate of any technological system cannot be disentangled from social (particularly the wage–labour nexus) and economic determinants (the evolution of the mode of development as a whole)*. But the reader may rightly consider this statement to be too general and demand more detailed hypotheses and analyses.

A research agenda

Some of these investigations of the role of technology in the 'régulation' approach were carried out during the last decade. A number of them are listed in section II of the references. Let us summarize briefly the main domains covered and present possible extensions of this line of analysis.

1. Confronting the basic hypotheses with the findings of science and technology research

As technology is not the only point of entry in the 'régulation' approach, more detailed analysis is needed to substantiate the succession of the three historical stages: extensive, intensive without and then with a mass consumption accumulation regime. It would be interesting to survey the existing literature and check if the features attributed to technology are confirmed. To give an example, Hounshell (1984) shows that Ford's original model of industrial organization was replaced by a more flexible one during the 1920s and 1930s. Contrary to a now common belief, the first crisis of the pure Fordist model takes place during the inter-war period. Thus the present one would be the second, so that product differentiation within mass consumption would not be totally new.

At a more conceptual level, it would be stimulating to compare this approach with the notions elaborated by SPRU to interpret the vast amount of case studies, sectoral and global analyses made over one or two decades. In particular, the concepts of technological system and technological paradigm (Dosi, 1982) display the same features as the 'régulation' approach for institutional forms. *A priori*, one could imagine a marriage of these two lines of analysis. The convergences are already very significant:

in a sense the mismatch between technology and institutions (Perez, 1983) is closely related to what has been said about structural crisis ('The place of technology in long-run dynamics' in this chapter).

2. Formalizing various accumulation regimes besides the Fordist one

A second agenda concerns macroeconomic theory. All the previous hypotheses have been kept fairly general, without any analysis of their coherence. For such a purpose, a minimum of formalization is called for, especially in order to check under which conditions a regime is structurally stable or runs into a major crisis. Prototypes of such models have already been proposed and even submitted to various econometric tests. For example, a cross-section and medium-term Kaldorian model seems to confirm the role of increasing returns in post-Second World War growth (Boyer and Petit, 1981b) and the breakdown of this model since the early or mid-1970s (Boyer and Ralle, 1986b). Similarly, the significance of the Fordist model for the US economy has been investigated by Caussat (1981).

Nevertheless, many points remain rather obscure and call for new analysis. First, a minimal and very simplified model of Fordism has to be agreed upon by the 'régulationists' themselves. The interested reader will find such an attempt in a recent paper (Boyer and Coriat, 1987), which in a sense synthethizes some previous work (Aglietta, 1974; Billaudot, 1976; Bertrand, 1978, 1983). Second, a more general approach has to address the extreme variablility across countries and historical periods of accumulation regimes and 'régulation' modes. Hence a vast research programme is called for, which ideally would combine different productivity regimes—linked, amongst other things, to the precise technological system—and various demand regimes associated with given mechanisms for income distribution and demand generation (see my Chapter 27 in this volume). More generally, theoreticians should work on *macroeconomics of technological change*.

3. Searching for the roots of the present crisis: what role does technology play?

The analysis, however, should not be restricted to the study of equilibrium growth paths, i.e. to self-stabilizing processes, as most macroeconomic theory does. We need to understand the causes of crises considered as periods of stagnation and/or large instabilities. As mentioned earlier, the very success of a 'régulation' mode might lead to a slow shift in structural parameters, such that the system becomes globally unstable. This might offer a possible explanation of this aspect of long waves and a way to analyse their underlying social and economic determinants. In this respect

the 'régulation' approach converges with other recent analyses (Screpanti, 1986; Hanappi, 1986; Goodwin, 1986).

Furthermore, special attention should be devoted to the origins of the present crisis. Combining a theoretical Fordist model with some estimates of the key parameters would allow us to answer a difficult but central question: would the exhaustion of the technological system have led to another form of crisis, quite apart from the changes affecting the distribution of income and the dynamics of the world economy (Bertrand, 1983)? Similarly, are the so-called Fordist rigidities a major cause or only the unintended consequences of a crisis originating in economic and social factors? Subsequent work should check the validity of very preliminary work already available (Boyer and Coriat, 1987). A more confident answer should help to resolve the puzzle about the exact role of technology during the present crisis.

4. What could the next accumulation regime and technological system look like?

The previous analysis, if correct, has important consequences. One may no longer rely upon cyclical regularities (the Kondratiev waves) to assess the date and the conditions of a way out of the present disorder. The underlying complex process is of course dependent upon past conditions, but not totally, since social struggles, political choices, favourable (or dramatic) innovations, as well as chance, shape the final outcome. Therefore a major challenge for economic analysis is to discard the ambition to forecast the long-term future, but nevertheless attempt to assess the viability of a set of changes in institutional forms and technology.

Of course, this exercise in 'macroeconomic fiction' is tricky indeed, but seems worthwhile. It would allow us to discuss the long-run consequences of economic and social policies. The usual debates too frequently focus upon short- or medium-term issues. The first tentative steps in this direction seem promising, if not conclusive (Boyer and Coriat, 1987, and Chapter 27 of this book). These analyses provide two major hints. First, measures encouraging technological change and policies of market return seem to be rather contradictory as far as economic stability and the fight against mass unemployment are concerned. Second, contrary to a now widely held view, public and private cooperation might help a good deal in promoting a new growth regime.

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5 Evolution, innovation and economics

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Introduction

Technical change and innovation are the subject of this book, and the forum of most of the discussion will be that of economic theory. But really, economic change is just one aspect of the more general question of evolution. The parallel has already been recognized by several authors who have argued convincingly for the idea that economies should be understood on the basis of the 'evolutionary paradigm', rather than that of the more traditional assumptions of equilibrium, or of deterministic mechanics.[1–4]

But this seems to be only the first step in the recognition of the fact that it is our lack of understanding of creative processes, adaptation and evolution itself which is the core of the problem. What we are really faced with is an evolving complex system, and the creation, acceptance, rejection, diffusion or suppression of 'innovations and technical changes' cannot be considered in terms of 'economics', separated from history, culture, social structure, the ecological system and so on. That we should have ever attempted to do so is a symptom of our past unwillingness to 'grasp the nettle' of the holistic, dynamic, 'more than mechanical' nature of the real world.[5]

The very idea that areas of study can be hived off into separate domains in which 'closed' sciences can be constructed seems to be based only on organizational convenience, not on reality. Economics is only one aspect of a human system. Cultural habits and rituals, music, technology, beliefs, psychological and biological needs are others. Ultimately all 'economic' decisions must be based in this wider reality and will both reflect and affect these broader areas. Human values underlie 'prices', and either as individuals, or in measures of collective welfare, the monetary and the non-monetary must meet and interact. Any action will have effects on many different aspects, and these in turn will influence others, and so in a complex chain of responses which defy simply, intuitive evaluation.

It is not enough that we should try to understand economics in 'evolutionary' terms (though apparently this alone is considered dangerously radical by most economists), but rather that economics should be seen as

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just one aspect of evolving, complex systems. And if this is the case, then a proper understanding of innovation and technical change can only come from improved knowledge about the general problem.

What therefore is the science of evolution?

What basis does it offer for discussing the discovery and diffusion of improvement and adaptation and what 'laws' can possibly apply?

Newtonian clocks and Darwinian watches

Until recently, the only answer to such a question would have been that offered by theories of evolution based on the ideas of Charles Darwin.[6] But these ideas, although certainly correct as far as they go in biology, present evolution simply as the fruit of 'selective' forces acting on randomly occurring mutations. The theory is not really predictive, but instead is a plausible explanation of whatever is observed. If some animals are observed to behave in a certain way, then it must be because a mutant arose who did so, and whose innovation was advantageous. Because of this, the behaviour must have been selected for, and that it why we see it . . . While Darwin's theory represented a tremendous step forward for the biological sciences, its connection to physics was tenuous, and it was simply assumed that they applied to different, and separate, domains.

In Newtonian science, understanding of a system was to be obtained by identifying its 'parts' together with the causal connections between them. The resulting assemblage of mechanisms then constituted a 'model' of the system, and provided a tool for understanding observations and making predictions.

This idea reflected and confirmed the notion of the universe as a kind of giant 'clockwork' mechanism, conceived of and set in motion by God, and running according to immutable laws. Science was about discovering these 'laws of nature', and hence revealing the intricacy and power of the creator's work. And science succeeded in this quite brilliantly. Two basic situations were found. In the absence of friction (planetary motion, for example), the movement was unchecked, going on for ever. There was no 'net effect' from such movements, and there would be no way of telling whether a film of such events was being shown forwards or backwards. The movement was 'reversible'.

But with dissipative processes such as friction, any initial concerted motion would eventually be damped until the system reached thermodynamic equilibrium and all its initially high-grade energy had been dissipated into random, thermal motion. This was an irreversible, deterministic progression to equilibrium, and this final state could be predicted as the maximum of the appropriate thermodynamic potential. The image here is of a universe gradually 'winding down' as it uses its initial potential for creativity.

However, evolution in biology or the human sciences, and more specifically the understanding of the birth and diffusion of innovations in the modern world, is about creative forces. It does not concern so much the simple functioning of the existing system, although this is interesting. Instead, it is primarily concerned with how the system became what it is, and how it will evolve in the future. In other words, if the world is viewed as some kind of 'machine' made up of component parts which influence each other through causal connections, then instead of simply asking how it 'works', evolutionary theory is concerned with how it got to be as it is. It is fundamentally about the origins of qualitative change in things, and how the 'parts' of a system came into being, and are maintained.

The Newtonian paradigm was not about this. It was about mechanical systems either just running, or just running down. At best, existing structure was maintained, while usually it was eroded during the approach to equilibrium, as entropy increased. Any representation of 'creative processes' was entirely absent.

Despite this obvious shortcoming, the extraordinary success of Newtonian physics, and of thermodynamics, vindicated every day in calculations concerning industrial processes, made it a tempting theoretical framework to apply to *all* complex systems. Because of this, in fields such as economics, biology, ecology, anthropology, etc., theories appeared in which 'understanding' was based on assumptions of 'equilibrium' and a search for the 'appropriate' potential function which *governed* the evolution of these systems—utility, fitness, efficiency, etc.

But the real difference in approach between this Newtonian–Darwinian view and the new perspective today lies in whether we think of evolution as being over, or as still continuing. The key issue is centred on the passage between detailed microscopic complexity of the real world, which clearly can evolve, and any aggregate, macroscopic 'model' of this. In economics, the passage from micro to macroeconomics is 'achieved' by simply supposing that the system is always at economic equilibrium. In this way the particular actions of individuals and entrepreneurs are assumed to be such that equilibrium relationships always hold between macro variables. Two timescales are supposed. A very short one, for the approach to price equilibrium where all markets clear, and a longer one which describes the displacement over time of this equilibrium as a result of changing 'parameters'. Change is then always exogenous to the model, being driven by imposed changes of the relevant parameters. In other words, this corresponds merely to a 'description' of change (and not an accurate one), mechanically impacting on a system of fixed structure, imposed changes in parameter values. Indeed, calibrating any such model becomes simply a task of finding changing values of parameters such that it reproduces the observed time variations of variables. And this amounts to a 'curve fitting' exercise with no real content. It explains only the economists' obsession with simultaneous equations, regressions and static curves, and denies the importance of history, of time delay, of anticipation, and indeed of consciousness.

The real sources of economic change are in the system. They are due to the creative actions of entrepreneurs and consumers. These are rooted in the perception of changes in technology, the distribution of available consumers, and changing tastes. To a physicist (or even an ex-physicist) causality relates the change that occurs at a particular moment to the state of the system as specified by the values of variables, for given parameters. So, for example, after a period of over-supply of some good, the quantity of the stock can only be 'explained' in historical terms, as the result of a previous period of over-zealous production. What cannot be done is to 'explain' the size of this stock in terms of the existing situation as given by the values of the other factors. This would only be possible at equilibrium when the over-supply had been 'corrected', and the perfect information of actors had been used to adjust prices, and through them supply and demand, so that all markets cleared. In reality, though, the actual behaviour of the system will in fact be described by the series of actions and changes which correspond to the state of previous over-supply. What will happen is described by differential equations relating to change to state, and not by simultaneous equations relating between themselves the values of different variables.

However, the equilibrium hypothesis is tenacious, mainly because it avoids all the real difficulties of life, and can lead to elegant theorems and lemmas, which are the very stuff of Ph.D.s, professorial appointments and honorary degrees. Despite the fact that it flies in the face of everyday experience, it has therefore been the foundation on which the whole edifice of economic theory has been built.[7]

Although in retrospect the acceptance and adoption of such an assumption may seem a little extraordinary, the underlying reason for its adoption was simple—there was no alternative. Microeconomics might discuss individuals' and firms' behaviour, Schumpeter[8] might base his thinking on entrepreneurs, and Simon[9] might show the importance of limited information and computation time, but somehow the illusion was still clung to that, whatever these details were, their 'sum' was necessarily controlled by the competitive forces underlying economic equilibrium, and even that this latter expressed some kind of 'optimal' use of resources, some 'maximum economic activity'.

The image that this presents is one of evolution as a 'blind watchmaker',[10] where the intricate machinery of the world is comparable to that of a watch, whose cogs and bearings are the fruit of the selection, in the past, of unspecified trials. Behind this is the idea of evolution as an optimizing 'force', which has led to the retention of the individuals and organizations we see because of their functional superiority. In this way, the classical theories of economics, of evolutionary biology and of anthropological interpretation have been permeated by the materialist ideas of the mechanical paradigm of classical physics. Carried deep within this is the idea of 'progress', of the rightful 'survival of the fittest', and of a natural 'justice' which must characterize the long-term evolution of a complex system.

However, equilibrium models based on these ideas have proved in practice to be quite unsatisfactory as a basis for decision-making. Despite an enormous investment in research into economic, ecological and social systems, these concepts have failed to provide satisfactory models, and our understanding of the evolution that we observe remains essentially based on 'experience'. The fundamental reason for this is that the basic paradigm—our whole way of thinking about such things—is wrong. The systems which we see around us are neither at nor on their way, necessarily, to thermodynamic equilibrium. The sunlight which is incident upon the earth makes sure that this is not the case. All living things have evolved in a situation of *non-equilibrium*! And for such systems evolution can lead to the emergence of structure and form, and to qualitative change even in relatively simple physical systems.

Self-organizing systems: the new evolutionary synthesis

The central question which arises is that in order even to think about reality, to invent words and concepts with which to discuss it, we are forced to reduce its complexity. We cannot think of the trillions of molecules, living cells, organisms, individuals and events that surround us, each in its own place and with its own history. We must first make a taxonomic classification, and we must also make a spatial aggregation. This is shown in Figure 5.1. On the left we represent the cloudy, confused complexity of the real world. Each part is special, each point unique. On the right is a 'model' of that reality, in terms of 'typical elements' of the system, where classifications and spatial aggregation have been carried out. But the point is that however good the choice of variables, parameters and interaction mechanisms may be, these only concern average behaviour. If we compare reality with the predictions of our model, then we shall necessarily find that variables and parameters 'fluctuate' around average values, and also that there is much greater microscopic diversity than that considered at the level of the macroscopic model.

By making the right taxonomic and spatial aggregations we can model present reality by such a system of boxes and arrows. But the description that results is necessarily probabilistic in character, reflecting the loss of precise information concerning all the details of the system. However, at this first level of reduction it does take into account therefore all possible sequences of events into the future, from the most to the least probable.

A solution of a very simple problem at such a level of description is discussed in the chapter by Brian Arthur, and other more complicated systems have been studies and solved in the physical sciences.[11] But in general most realistic systems would be somewhat too difficult to discuss at such a complex level of description, and this is one reason why such models

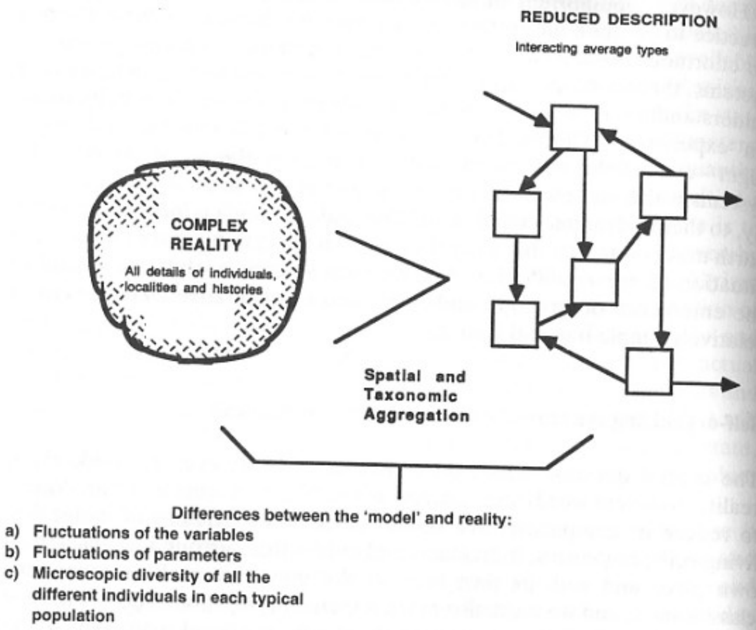


Figure 5.1 Modelling, and even thinking about a complex system, necessitates a simplification into categories, which constitute the system. We make a 'mechanical' replica of present reality. But evolution concerns change in this structure—new boxes and arrows

are not frequently discussed. The other reason is satisfactory for most people. They would immediately go on to ask, 'yes, I see that the evolution is probabilistic and contains all possible evolutions, including very improbable paths, but all I want to know for the moment, in this case, is what will most probably happen, what would happen on average!' By asking this question, we then can proceed to ignore all the non-average behaviour of the system, and find (or create) a satisfying (but misleading) single trajectory for the average behaviour of the system.

So if, in addition to our basic taxonomic and spatial aggregations, we assume that only average elements make up each category, and that only the most probable events actually occur, then our model reduces to a 'machine' which represents the system in terms of a set of differential equations governing its variables.

But such a 'machine' is only capable of 'functioning', not of evolving. It cannot restructure itself or insert new cogs and wheels, while reality can! And this is because of the differences between the left- and right-hand side of Figure 5.1, which must mean that the key to understanding evolution must lie in what has been taken out from complex reality in order to reduce it to the model on the right. Our programme of research must therefore be aimed at exploring how to put back these non-average effects that we have removed, and examining the evolutionary effects that these may have.

Clearly, therefore, evolution is due to two things: first, to the effects of non-average values—fluctuations—of variables and parameters, and, second, to changes introduced by the microscopic diversity which underlies the 'taxonomic' classification of the model. Let us consider these in turn.

Dissipative structures: the origins of complexity

The work of many authors on self-organization and synergetic phenomena has demonstrated the fact that for systems far from equilibrium, basic physical non-linearities can in fact amplify fluctuations of variables and lead to symmetry-breaking instabilities in which structure and organization appear or, if already present, evolve qualitatively.[12–14]

Let us briefly describe a simple example of convection in a fluid which is heated from below. Initially, for only weak temperature gradients heat passes through the fluid from the bottom to the top by thermal conduction alone. However, as the temperature at the lower surface is increased, at a critical value, something quite remarkable happens.

Suddenly, the fluid itself starts to move. Thermal energy is now transported 'bodily' by the fluid itself in a convection process. But the movement is not just some general, random drift which is uniform throughout the system. Instead a remarkable pattern of regular, hexagonal convection cells appear spontaneously in the fluid, which moves upwards in the centre of each cell, and downwards at the edges. This is shown in Figure 5.2.

In fact, as the temperature is further increased a whole series of successive patterns appear in the system until, finally, for very strong thermal gradients complete turbulence occurs and structure can no longer be observed.

The pattern which we observe, and which involves the coherent behaviour of trillions of molecules, is stable but does not necessarily express any particular 'optimality'. Does it give 'maximum' heat transfer between the upper and lower surfaces, for example? Is it the 'most efficient' flow pattern possible, minimizing dissipation as the thermal energy moves through the system? Or, on the contrary, is it the pattern of 'maximum dissipation', taking most 'out of' the heat source? The point is that, even for such a simple system, we cannot answer these questions.

And this is a fundamental point to which we shall return. In systems

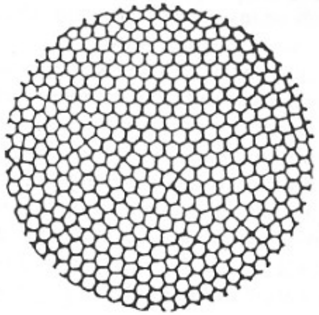


Figure 5.2 Beyond a well-defined critical temperature gradient, the Benard convection cells appear spontaneously

which evolved to thermodynamic equilibrium there was a potential function which governed the evolution of the system. Either the entropy or the free energy imposed a deterministic relaxation process towards a predetermined equilibrium state. And this was where physics got its powers of prediction from. But non-equilibrium systems achieve some kind of autonomy and freedom which means that they become 'creative', generating structure and complexity. The price which we pay for this, however, is a loss of 'predictability'. Many other examples of such behaviour now exist, and a chemical example is shown in Figure 5.3.

In reality, we find that the equations which describe the average evolution of the variables really only specify a tree of potential behaviours. This branching tree of potential structures is typical of non-linear dynamical systems, and is called a bifurcation tree (Figure 5.4). Different branches of solution differ from each other qualitatively. That is, they have distinctive characteristic symmetries, which means essentially that they have different forms. In such a vision, therefore, sudden large jumps and discontinuities can occur, even for systems subjected to slowly changing conditions, and the jump to a new branch may be accompanied by a structural reorganization of the system. In this way new mechanisms can appear spontaneously, and in a human system this may bring into focus new issues and problems, as well as new satisfactions and goals.

Here, at last, is the mathematics of creative processes, where traits and characteristics are not conserved, and where structural instability and evolution can find their legitimate expression.

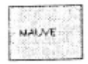
And yet all of them may be generated by the same simple, unchanging scheme of average kinetics, providing that it is non-linear. Which pattern is actually observed in a particular experiment cannot be controlled from the

THE BRUSSELATOR

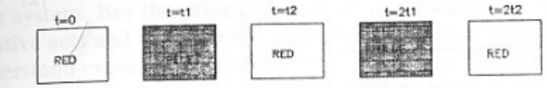
A chemical example of dissipative structure is given by the reaction:

$A \xrightarrow{F1+ \text{ and } F1-} X$
$B + X \xrightarrow{F2+ \text{ and } F2-} Y + D$
$2X + Y \xrightarrow{F3+ \text{ and } F3-} 3X$
$X \xrightarrow{F4+ \text{ and } F4-} E$

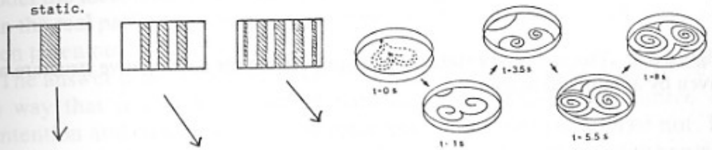
At Equilibrium there is no spatial or temporal structure:



X is red in colour, Y is blue. By pumping in A and B, and extracting D and E the reaction can be driven away from equilibrium, so that the positive flows are greater than the negative ones. Near equilibrium there is no spatial or temporal organization present. But, far from equilibrium we may observe either, a) temporal organization:



or b) a whole cascade of spatial structures, some dynamic and others static.



The input/output matrix for this system would be as follows:

	A	B	X	Y	D	E
A	0	0	F1	0	0	0
B	0	0	0	F2	F2	0
X	0	0	F3	F2	F2	0
Y	0	0	0	0	0	F4
D	0	0	0	0	0	0
E	0	0	0	0	0	0

System Inputs, F1 of a, F2 of B

System Outputs, F2 of D and F4 of E

F1, F2, F3 and F4 are the net flows.

The aggregate flows observed, F1, F2, F3 and F4 will vary depending on the underlying spatio-temporal structure of the system, which is governed by the interplay of non-linearities and fluctuations. So too for economic systems.

Figure 5.3 An example of chemical self-organization

outside. While the external parameters can be fixed at the boundary, and may limit the actual choice, the fact remains that it is the system itself that 'decides' which of the possible patterns it will in fact adopt.

For any particular system, this 'choice' is made by the fluctuations which are present in the system. And this confirms the deduction made above that the key to evolutionary change lays in the differences between reality and its average representation. Because of fluctuations the real system is

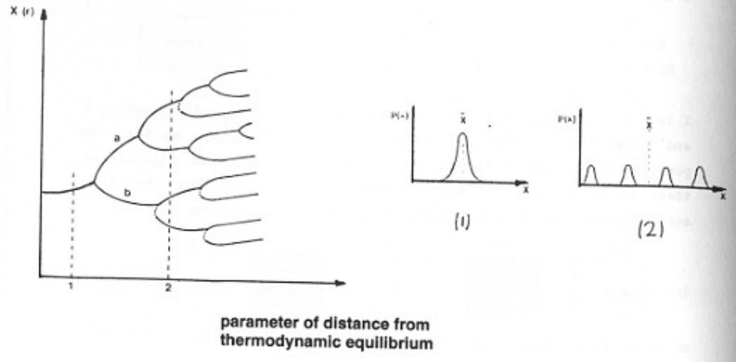


Figure 5.4 The stationary states which are possible for a dissipative structure are given by a 'bifurcation tree'

always in fact probing the *stability* of the particular situation and, depending on which fluctuation occurs at a critical moment, the system will move to one or another of the stable behaviours which are possible. The real world is therefore much more 'lively' than its mechanical representation in terms only of average events occurring for average types. Symmetry-breaking transitions can occur spontaneously and so truly 'new' structures can be created. In this fact lies the real source of innovation in the physical world.

However, in physics and chemistry the elements of the system are atoms or molecules, which are essentially identical and incapable of internal reorganization beyond that fixed by the chemical transformations. But in the living world, we must examine the possibility that the internal structure of the individuals or elemental objects themselves could evolve in time. Indeed, these elements could themselves be dissipative structures in competition for the energy and matter that they need to maintain and transcend themselves.

In this connection, then, it is the existence of microscopic diversity and modes of individual liberty that must be discussed.

Evolutionary drive: the role of noise and error-making in evolution

Studies concerning dissipative structures and the self-organization of systems have largely concentrated on the aspects discussed in the preceding section, while the possible effects of microscopic diversity have been relatively neglected. In some very recent work,[15] however, it has been shown that this too is of major importance.

The point in question here is that of attempting to understand the possible effects of 'putting back' the existence of real microscopic diversity into a model which has assumed populations made up only of average individuals. This assumption was made in order to obtain nice, deterministic differential equations governing the changing populations inhabiting the system. But the price paid was that evolutionary processes due to innovative acts and non-average performance were eliminated. If we wish to understand evolution, therefore, or to frame our strategies so as to take into account evolutionary processes, then we must try to put back into our model the mechanisms of mutation and innovation which create and maintain the real pattern of microscopic diversity. But can we put back what has been taken out?

The answer is no. Once we have 'averaged over' the detail, then there is no way that it can be recreated with certainty. This is the source of contention and confusion as to whether 'mutations' are random or not. In the absence of any information concerning the precise nature of the variability that may be present, then it may well be that an assumption of 'complete randomness' is the most reasonable one that could be made. Darwin himself adopts this point of view. But in fact there is a whole variety of possible hypotheses that could be made, which range from the completely random to a view in which the 'environment' completely determines which mutations occur. In problems of human and technological evolution one may favour an intermediate solution in which one views innovations as being 'channelled' somewhat by existing practices. However, the real issue is simply that having thrown away the really important detail which is involved, in order to build a mechanistic model of a system, then we can only try to guess the precise way in which non-average events may occur in the system. The first important step, however, is to study models which at least do include non-average behaviour, even if its exact nature in a particular case is uncertain.

In simple ecological models of competition we have examined the effects of 'error-making' in reproduction, which we have supposed to be due to the occurrence of some 'random mutations', or variablility. On average, however, we have assumed that random changes such as these would lead more often to less efficient individuals than to more efficient ones. In this way, the net effect is to introduce on average a negative drift into the performance parameters of a population, which is counteracted by a positive drift caused by the differential elimination of the less effective individuals. What our model shows explicitly, as we summarize in Figures

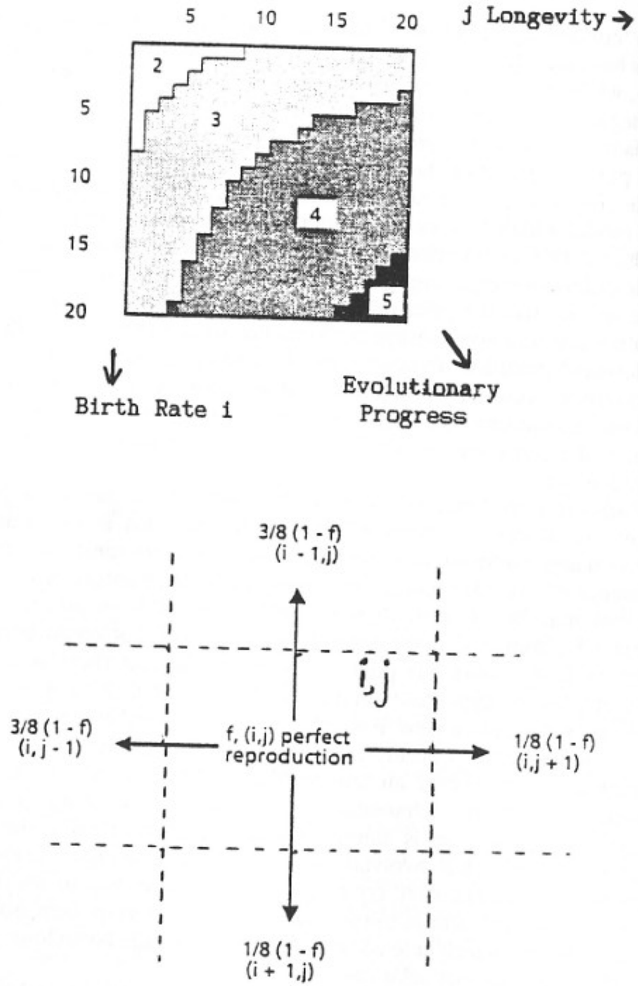


Figure 5.5 In this simple evolutionary landscape random variability in reproduction leads mostly to less efficient individuals, but also to some which are more efficient

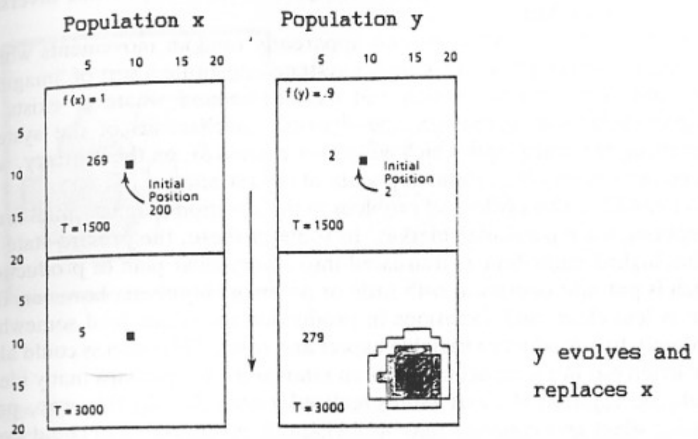


Figure 5.6 Evolution selects for the population with variability, even though at each instant it would be more efficient not to make 'errors'

5.5 and 5.6, is that in competition between a population with perfect reproduction and one with mutations and variability, evolution retains the latter rather than the former.

In an evolutionary landscape of hills and valleys representing levels of functional efficiency of different possible organisms, it is the error-maker who can move up a hill, eventually out-competing a perfectly reproducing rival. And this despite the fact that at each and every instant it would be better not to make errors, since the majority of these are loss-making.

This work shows that evolution does not lead to optimal behaviour, because evolution concerns not only 'efficient performance' but also the constant need for new discoveries. What is found is that variability at the microscopic level, individual diversity, is part of the evolutionary strategy of survivors, and this is precisely what mechanical 'systems' representations do not include. In other words, in the shifting landscape of a world in continuous evolution, the ability to climb is perhaps what counts, and what we see as a result of evolution are not species or firms with 'optimal behaviour' at each instant, but rather actors that can learn!

Because of this, at any moment, behaviour in the system itself will not be optimal, because of the existence of apparently random or highly eccentric behaviour, which at that time is meaningless and on average loss-making. However, in order to maintain adaptivity to the environment some stochastic, risk-taking behaviour is retained by evolution. In short, then, evolution is both driven by, and leads to, microscopic diversity and individual variability. Selection viewed at the 'macroscopic level' of averages cannot destroy the microscopic diversity. Indeed, it is just this diversity which drives evolution!

The fluctuations, mutations and apparently random movements which are naturally present in real complex systems constitute a sort of 'imaginative' and creative force which will explore around whatever exists at present. Selection or, rather, the dynamic mechanisms of the system operate on these attempts which will either regress or, on the contrary, will sweep the system off to some new state of organization.

We can liken this ecological problem to the situation of many small firms competing for a particular market. In some of these, the present state of technological know-how is translated into a very clear plan of production which is put into operation with little or no error. In others, however, the plan is less clear, and variations in production technique lead somewhat randomly to a product of variable aspect and costs. This process could also be carried out in the imagination of an innovator, and perhaps many ideas would be rejected without being realized materially. In this way, pre-existing ideas and concepts may well channel 'invention', and could even block a real breakthrough. Of course, most such initiatives will give rise to less satisfactory products, but a few of them will be improvements. The 'information' created by this random probing can be used by the discoverers to change their product. This would correspond to 'learning by doing' and obviously if production plans are too rigid, then no such discoveries will be made. What is really required is the right compromise between local 'experimentation' (resulting either from error, ignorance or research) and efficient production techniques.

Of course, it may be true that the exact 'pattern' of the innovative variability is not truly 'random', because there may be technological channelling of ideas and initiatives. This was information that was available perhaps in the more complete probabilistic description which took into account all possible sequences of events—with their appropriate probabilities. However, once the discussion is reduced to the average behaviour of a particular set of variables, corresponding to a given level of disaggregation, then we have eliminated precisely the information which, as regards evolutionary change, is the most vital.

Here we can see the paradox which surrounds the very notion of stability—it can only be defined in terms of an ability to return to a pre-existing state or trajectory when subject to a particular fluctuation. But if the fluctuations are simply the result of the 'non-average' behaviour of the system, then what we see is that the choice of variables and the level of disaggregation partly determine what is 'state' and what is 'fluctuation'. It therefore becomes very important to study the differences between observed and predicted values of the variables of the system. This may even be the real use of such models, since they may 'take out' what is the result of 'normal' or 'average' behaviour for a system and allow us to focus

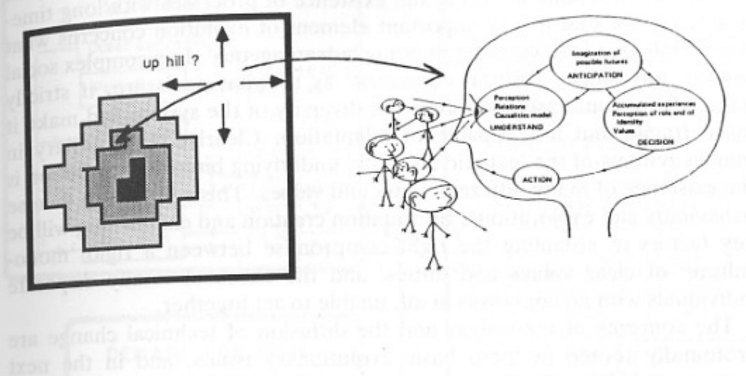


Figure 5.7 In human systems, behaviour is no longer shaped predominantly by natural selection. Instead it is affected by the perception of 'success' and imitative processes

on what is not! The behaviour of the system with respect to these fluctuations is then what may be decisive for the future evolution.

Returning to our example, we see that because in general each firm is in competition with others, technological and organizational changes will lead to responses and counter-measures, to an 'arms race', with no obvious end. Evolution, therefore, is a continuing process, and that is why selection favours individuals and firms which maintain the ability to adapt and learn new things.

In the biology of simple beings, genetic reproduction ensures that the 'information' about a successful strategy resulting from advantageous genetic variability can only be passed on to the descendants. But, of course, an entirely new phase of evolution is reached once information can be 'perceived' and imitative modes of behaviour are possible. The fulcrum of evolution passes from 'genetics' to 'perception–judgement–behaviour' (Figure 5.7). For higher animals, the diverse personalities and circumstances of individuals lead to experimentations which, when successful, can be imitated by others. For this, however a gradient of some measure of 'success' must be defined in the 'mind' of each individual concerned, and here selection will act upon diverse systems of value, leading to cultural evolution. Once again, if conformity is too strong, then the creativity of the system will decline.

Such a mechanism represents a much faster mode of evolution than that which required the physical elimination of the 'unfit'. But in this new, more rapid evolutionary mechanism the discovery of better strategies and the concealment or diffusion of this information become the key elements and evolution moves to a new focus. Given the complex complementarities (divisions of labour, family roles, complex loyalties) and competitivities of the human situation, as well as the existence of processes with long time-scales, we see that a very important element of evolution concerns what individuals decide to consider as being 'advantageous'. In a complex social system, any single 'cultural consensus' as to what goals are, if strictly adhered to, would greatly reduce the diversity of the system and make it more fragile and less capable of adaptation. Clearly, the corollary in human systems of the 'genetic diversity' underlying biological evolution is the existence of many different views and values. This will lead to diverse behaviours and explorations. Information creation and channelling will be key factors in obtaining the right compromise between a rigid 'mono-culture' of clear values and duties, and the chaos of totally disparate individuals with no consensus at all, unable to act together.

The concepts of innovation and the diffusion of technical change are profoundly rooted in these basic evolutionary issues, and in the next section we shall briefly discuss some practical applications of these ideas, in order to point the way that these new paths can be explored.

Generic studies

Science is about finding generic statements and widely applicable principles which can be used to understand particular systems, and this should be distinguished from simply making descriptive models in case studies. The models described below are based on mechanisms and processes which underlie appearances. They discuss global behaviour which results from microscopic processes, and recognize the 'cognitive' dimension that must be taken into account when considering human behaviour.

The first example which we shall briefly describe concerns the development of mathematical models of fisheries. This may seem to be a subject rather far removed from that of 'hi-tech' and 'Silicon Valley', but we shall see that it is an example which makes the basic issues and problems very clear. It is an 'archetypal' complex system, with many aspects: the physical behaviour of the ocean or coastal waters; the complexity of the marine ecosystem with its many levels and species in constant evolution; the behaviour (and technology) of fishermen deciding what and where to fish; the needs and directives of the processing industry which buys much of what is landed; the need for employment both in the fishing and processing industries; the demand from both local and foreign consumers and the competition with other foodstuffs in the international and domestic marketplace.

In several recent papers[16], [17] these applications have been described. Here we shall just briefly outline some of the main features.

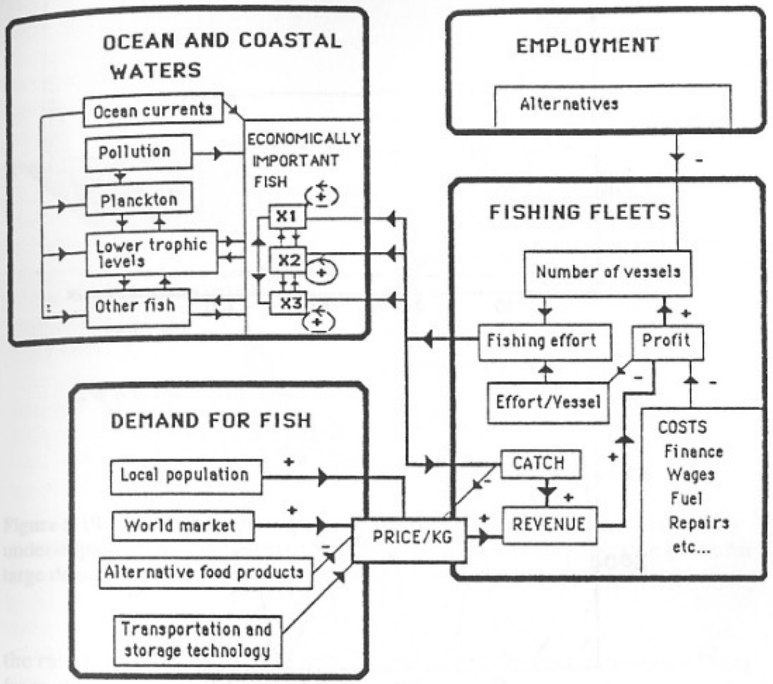


Figure 5.8 The dynamical system of our fishing model

The first and simplest consists of a dynamic model of a fishery corresponding to the scheme shown in Figure 5.8. Contrary to the customary management models, we have included the complexity of the fisherman's behaviour over time, and that of the market. Also, our model is dynamic and is based on the effects of mechanisms of growth and decline in fish populations, fishing fleets, fish prices and fish markets, whereas the models which are used at present assume that these are in equilibrium.

The first important result concerns the qualitative nature of the behaviour observed. If we run our 'mechanical model' of Figure 5.8 purely deterministically from some initial condition, it will tend to a steady equilibrium state. It may take some thirty years to get there, but there is an equilibrium. Previous management strategies are based on the relation between this equilibrium state and the fishing effort applied by the fleets. However, if we insert the reality of environmental fluctuations, which affect the yearly production of young fish, then the result is dramatic. The system amplifies these short-term, random events into large, long-term (seventeen years) cycles of 'boom' and 'bust'. This, in fact, agrees with

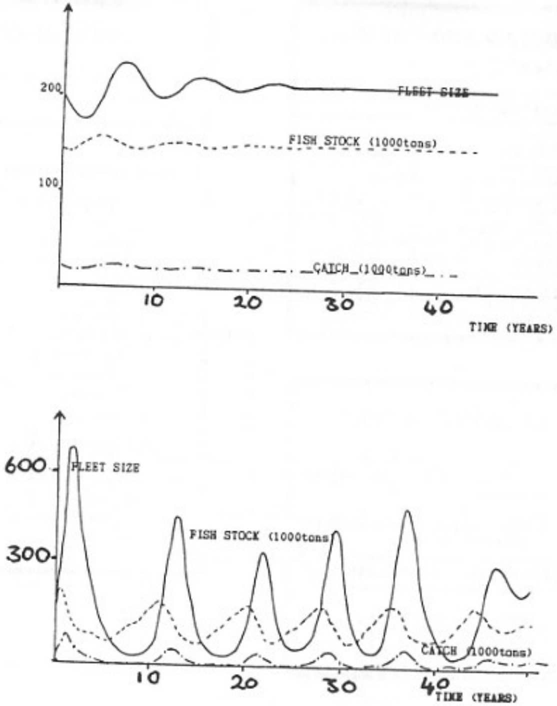


Figure 5.9 (a) A deterministic run leading to equilibrium after about thirty years; (b) the effects of yearly fluctuations is to introduce 'boom' and 'bust' cycles with a period of roughly seventeen years

reality for the Canadian fisheries which were the subject of our model. This bears out the points made by Figure 5.9, where an understanding of the qualitative state of the system cannot be obtained from the mechanical model. The effects of fluctuations must be considered.

Furthermore, if we add in the effects of microscopic diversity of behaviour on the part of fishermen, and the economic success that accrues to those with faster responses, and better technology, we see that in fact we can understand the long-term evolution of most fisheries, as they move from the stable exploitation of a large stock to the unstable, over-exploitation of a much reduced one (Figure 5.10).

Also, our model shows that there can exist two possible regimes of functioning of the fishery. The first is the relatively normal one of 'boom' and 'bust' cycles referred to above. The second occurs at some time during a system 'crash'. If the elasticity of demand is sufficiently low, the price of

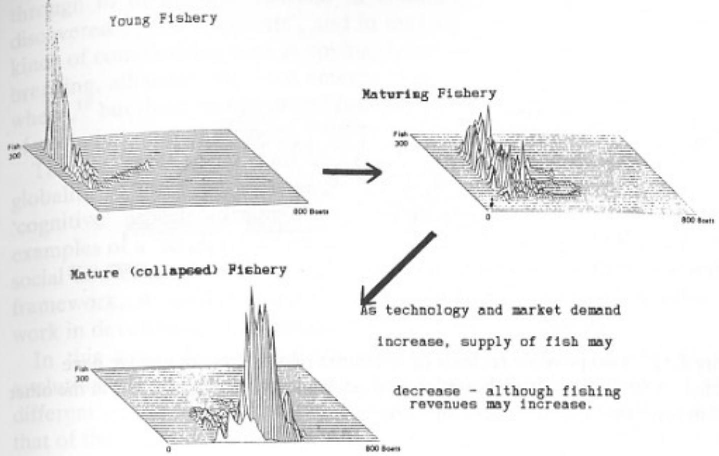


Figure 5.10 The long-term evolution of our model fishery shows how an initially under-exploited stock (a) becomes progressively less stable, until at some point, for large demand and greater fishing effort, it ceases to be a source of food

the rare fish caught rises dramatically, permitting fishermen to earn a living from the tiny stock. This means that they continue their efforts, and the stock remains small and prices high. The fish have become a 'luxury' product and the industry may well survive, but as a source of food the resources has largely disappeared. All of these results give a far greater understanding of the effects of different policies, and also of the different regimes possible (Figure 5.11).

In another, more detailed fishing model, however, we generate the spatial behaviour of the fishing fleets and the fish stocks and show how extraordinarily complex behaviour emerges. This model focuses on fishermen's behaviour, including the manner in which they make decisions about where, and what, to fish.

Our model has two sets of equations, one for the fish in each spatial zone, and the other for the boats. We shall focus briefly here on the latter. Interested readers should consult the original publications for more details. This set of equations describes how the numbers of boats of a given fleet, situated at a point, changes over time due to two terms: an economic 'selection', where revenue must exceed costs; and a term governing the movement of the boats to zones of high expected profit.

Now, for us, the important point is that these 'expected returns' can only be formulated in the light of information about the catches that are being made in the different zones. Therefore it requires both the presence of

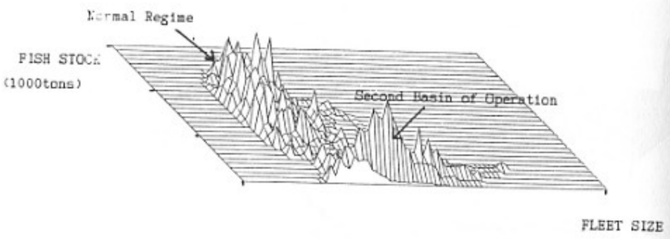


Figure 5.11 Two possible regimes of operation of a fishery. In one we have 'normal' cycles of 'bust' and 'boom', based on fish stock variability, and in the other the fish are a rare luxury of very high unit value

boats making catches in that zone, and the flow of information between those boats, and the boat that is considering where to fish. This gives rise to a positive feedback mechanism which will shape the spatial pattern of fishing effort. This pattern over time will in fact be 'explained' not according to an 'optimal' rationality, but instead according to history, accident and communication.

However, apart from this fairly obvious 'rational' term, there is the dependence of attractivity, and decision, on the personality and beliefs of the skippers. How carefully do they weigh the evidence? We can identify two extremes. At one limit, we have 'Stochasts'. They pay absolutely no attention to economic rationality and simply diffuse at random. At the other extreme, we have 'Cartesians'. These weigh absolutely precisely the information available, and move with probability 1 to the point with the greatest attractivity, even if this is only marginally better than elsewhere.

Obviously, fishermen fall somewhere between these two extremes, but nevertheless, the idea of 'stochasts' and 'cartesians' seems to capture a basic truth about people. In the Canadian fleets, as elsewhere, we find 'risk-takers', who make the discoveries of new fish aggregates, and the others, who are content to rely on the information generated by risk-takers.

What our model allows us to do is to explore the evolution of such a system, and we find that a population of 'cartesians' alone survives poorly on a small part of the system's potential, never exploring beyond this. However, although 'stochasts' can beat 'cartesians', they remain too dispersed to exploit their discoveries efficiently. A most efficient strategy for the fishing fleets as a whole is to have 'cartesians' who 'spy' on 'stochasts'.

We can show that providing, say, 1/10 of the information about catch gets through to them, they succeed in creaming off the good fishing areas discovered by the 'stochasts', and in making a good living. Of course, all kinds of complexities such as spying, lying, communicating in code, code-breaking, alliances, etc., can emerge, and this has been reported on elsewhere,[18] but these results are of fundamental importance in our discussion of evolution, and of economic innovation and enterprise.

The key point about these models is that they attempt to consider the globality of the processes taking place in a given region, and also the 'cognitive' aspects of the decision-making behaviour. They are really examples of a 'Regional Science', where the ecosystem and the economic, social and cultural realities and values are brought together in a unified framework. A similar initiative with a different emphasis underlies our work in developing evolutionary models of 'urban' systems.

In this work dynamic spatial models describing urban and regional evolution of socio-economic structure have been developed.[19–20] Vastly different spatial scales were modelled, from that of a city like Brussels,[21] to that of the entire continental United States,[22] and simple versions of these models have also been applied to some French cities.[23]

The models consist of sets of interacting equations, each of which represents the change occurring at a particular point in the different activities and populations located there.

Running the model over a long period generates the evolution of each employment sector and population in each spatial zone. In doing this it also generates the changing flows of commuters, raw materials, intermediate components, finished products, and services between the different sectors of the economy and different places. This evolution can then be compared with the actually observed, and the parameters which characterize the different activities adjusted until they produce an evolution which agrees with reality.

In each aggregate category—manufacturing, services, etc.—there will in fact be parts which are growing and others declining. Evolution results not from the 'average' behaviour shown in the input–output table, but from the relative growth and decline of small sub-sectors which make up the real 'microscopic' diversity of the system. The important point, then, is to identify the parts (sub-sectors, particular zones) which are growing, and to specify more accurately their particular 'input–output' matrices. In this way, we can focus on the 'growth system' in the economy, and facilitate the processes of technical change and innovation.

We can also examine the extent to which evolutionary processes are captured by a model such as ours. There are four basic kinds of evolution which can influence an urban or regional system: (a) the spatial diffusion of population and activities according to perceived opportunities; (b) changes resulting from technological progress, changing input and output requirements and costs; (c) entirely new activities resulting from some technological breakthrough; (d) changes in people's expectations and desired lifestyle.

Now, our model can in fact deal quite well with the first two of these. The system evolves through the perception of opportunities by the different actors. These may be due to earlier changes, to technological advance, demography, or to changing terms of trade. Our model makes the input–output table dynamic, but underlines the fact that what really matters for evolution is what is happening at the 'leading edge' of all this. It is in the growth of some sub-sectors, and the inductive loops of these that the future lies. The model therefore serves as a framework within which to identify and study these important, diffusing disequilibria.

The third and fourth types of evolution are not really in this model and it is difficult to see how they could be included in any precise way. Entirely new products cannot be anticipated easily, or they would not be new. Neither is it easy to say when and in what way people may modify their values and adopt new goals. What could be done, however, would be to explore the consequence of some possible change. If this were done, some estimate could be made of the 'advantages' for individuals making such a 'move', and from that it would be possible perhaps to estimate whether such a change was really very likely or not.

Conclusions

The fundamental point raised in this chapter is that discovery and innovation can only be achieved by going 'beyond' the present system. We require 'stochasts' who, for whatever reason, do not respond simply to the information which exists about the present returns on effort. The 'cartesians', on the other hand, are the backbone of the system. They represent 'normality', and also will be the ones who push any particular activity to its ultimate in excellence. The success of the overall system will be determined by the balanced existence of the two types, and the manner in which new information is channelled into the system. While the adaptive capacity of a system lies in its 'stochasts', the stability, and efficient performance resides with the 'cartesians'. A harmonious system must alllow 'discoveries' to recuperate their search costs, or risk losing them, and this will depend critically on the time of 'monopoly' allowed to them.

A period of expansion will follow a discovery, as the spread of information leads to increased demand, economies of scale and 'learning by doing'. However, after some time either the market begins to saturate, or the resource required starts to become rare. Either way, competition intensifies, and a period of 'rationalization' follows when investment is directed to making production more efficient, usually decreasing employment in the sector. Competition increases, and only the discovery of new activities and products, made perhaps by the displaced 'stochasts', can save the situation.

Usually, 'cartesians' will not listen to news of discoveries while things in the established areas are not in crisis. Hence, venture capital may well be lacking during a period of prosperity. When a crisis approaches, however, the first reaction is for 'cartesians' to try to do what they already do, better! The more they do this, the greater the crisis will be when it comes. When catastrophe finally does occur, then information concerning discoveries will be acted upon, by all those still in a position to act. New structure will emerge, new job definitions and new specialities will come into being, and start to fossilize, as they 'hill climb' up to apparently greater rationality and efficiency. And so our model suggests the existence of a 'long wave' or Kondratiev cycle, and offers a real possibility of its analysis.

This underlines the aim of this approach. It is not to predict the future. Instead, it is to offer an integrating framework into which existing knowledge can be put. With this, the future can be explored and better imagined. However, the real world is really much richer than any model, and therefore will always manage to evolve in ways that have not been included in the model. This is not a reason to abandon modelling, but rather the opposite! Without the model, we would not be able to 'order' the system to an extent sufficient to realize that something 'inexplicable' was occurring. With it, we can be aware of the emergence of some new mechanism or factor, and we can then search for the best manner in which to include it. That is to say that the model we have of a particular situation will probably always require modification because the real world is itself evolving.

The real message of the new concepts in science are that change and disequilibria are probably more 'natural' than equilibrium and stasis. Those who can adapt and learn will survive. And this will depend on their 'creativity'. For example, when we suppose that change is a response to perceived opportunities, then it is saying that the potential for growth and diversity of any region or city depends to an extent on the imagination of the people who live there. What openings for what activities do they perceive? This will depend on the finer details of their history, culture and social interactions. Generally speaking, microscopic diversity resulting from the mixing of cultures, conflicting doctrines and individual freedom will be an important ingredient in this response. In other words, technical change and economic evolution are related to factors such as originality, risk-taking and creativity in a population.

In human systems, the 'pay-off' of any particular behaviour will depend on what other individuals do. For example, an 'intelligent' move may only be deemed to be so if others keep behaving 'unintelligently'. And it may well be true that the real 'intelligence' of the system is precisely in having several different behaviours present. Once again, what we have stressed above is that evolution will select for variability, and this may well be interpreted by an observer (particularly a Newtonian) as corresponding necessarily to individuals with different systems of values, or degrees of intelligence! In reality, though, there may be an evolutionary explanation of the spectrum of behaviour, but not of each specific spectral line.

Furthermore, if we consider the whole system, with its many levels of interacting populations and interdependent mechanisms, then the progress made in one sector will set the standard for others, and once again the evolution of a population and its artefacts cannot be considered in isolation. Each living cell is part of an organism and cannot be understood alone. Similarly, each individual and artefact is part of a culture, and its behaviour can only be viewed correctly within the larger unit. Ultimately, each population is part of the ecosystem, and evolution acts on the global entity. Traditionally, science has accepted as 'explanation' of behaviour a description of the internal functioning of an object considered in isolation. Here, however, we see innovation and change as part of an evolving whole, and the explanation of history reflects the inherent unity of the living world.

Hopefully, the ideas discussed here can help to lay the foundations of a new synthesis in the human sciences. Creativity and change find a place together with structure and function in this new scientific paradigm. Although the reassuring feeling lent by 'determinism' has had to be sacrificed, in return we now have a unified view of the world which bridges the gap between the physical and the human sciences. And it is not true that this represents a final 'reduction' of human and social phenomena to the 'mechanical' dictates of physics! Instead, the latter has been 'elevated', and has had to abandon its immature search for absolute certainties. What we now see is a world of multiple facets and reflections, perceived in different ways, evolving through successive states of organization as a result of non-average events and individuals. Instead of being limited to approaching human systems from a descriptive or ideological standpoint, science now offers us a mathematical basis on which to understand how such complex systems came into being, and how they may evolve in the future. The next decade will see a rapid growth in research aimed at exploring this new and exciting path.

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