Cambridge Journal of Economics 1994, 18, 463–514

CRITICAL SURVEY

This is the first of a series of Critical Survey articles. The aim of the series is to report on recent developments, to provide an assessment of alternative approaches and to suggest lines of future inquiry. It is intended that the articles will be accessible not only to other academic researchers but also to students and others more practically involved in the economy. Future Survey articles will include Allin Cottrell on 'Post-Keynesian Monetary Economics', Herbert Hovenkamp on 'Law and Economics in the United States' and Warren Samuels on 'Institutional Economics'.

The economics of technical change

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1. Introduction

One of the continuing paradoxes in economic theory has been the contrast between the general consensus that technical change is the most important source of dynamism in capitalist economies and its relative neglect in most mainstream literature. Those economists, such as Marx in the nineteenth century and Schumpeter in the twentieth, who attempted to assign a more central role to technical innovation, were regarded as rogue elephants whose work, although certainly of interest, should not be taken too seriously.

This paradox was repeatedly pointed out in survey articles (e.g. Kennedy and Thirlwall, 1973), in books on invention and innovation (e.g. Jewkes, Sawers and Stillerman, 1958) and in histories of economic thought (e.g. Blaug, 1968). Various explanations were advanced, the most frequent being the 'black box' explanation—that technical change was outside the specialised competence of most economists and had to be tackled by engineers and scientists. This approach fitted quite well with the convenient (but erroneous) assumption that science and technology could be treated as exogenous 'manna from heaven' and need not be examined in any depth for most purposes.

Jewkes *et al.* (1985) advanced two other reasons for the relative neglect of technical change by most economists: the lack of quantitative data and the preoccupation of many economists in the 1930s and 1940s with employment and business cycle problems. Both of these explanations are revealing of certain attitudes of mind. If measurement difficulties inhibited work on the most important issues, the response in most disciplines would be to concentrate effort on tackling the measurement problems, not to concentrate attention on other issues.

Manuscript received 1 March 1993; final version received 8 November 1993.

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0309–166X/94/050463+52 $08.00/0

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Furthermore, the 'Keynesian' problems with which many economists were preoccupied in the 1930s (and again today) were in any case not unaffected by technical change and could not therefore be considered as a separate alternative agenda. Yet although Jewkes and his colleagues made a major contribution to the economics of invention (which we shall discuss later), they clearly did regard this as something separate from the rest of theoretical and applied economics—as a specialisation which did not affect other work.

This attitude is still prevalent, both among those who do specialise in the economics of technical change and those who do not, but it has been very much eroded in the 1980s and 1990s. There has been a marked upsurge of interest which is evident both in mainstream economics and an explosion of new specialised journals (for example, *Journal of Evolutionary Economics, Economics of Innovation and New Technology, Industrial and Corporate Change* and *Structural Change and Economic Dynamics* all commenced publication in 1990–1991). In the 1950s, Everett Rogers (1961) could find only one empirical study of the diffusion of innovations by an economist, but by 1986 he found dozens, and it is much the same story in relation to firm behaviour, growth and development economics, international trade and several other areas. There is now a far greater readiness to look inside the 'black box' (Rosenberg, 1982) and study the actual processes of invention, innovation and diffusion within and between firms, industries and countries.

In deference to the work of Schumpeter in the first half of the century, it has been customary to refer to much of this work as 'neo-Schumpeterian' or 'evolutionary' and virtually all those involved share the fundamental postulate of Schumpeter (and Marx) that capitalism is an economic system characterised above all by evolutionary turmoil associated with technical and organisational innovations. Schumpeter never liked the idea of 'disciples' and advised his readers to regard his work as only a first approximation which should not be a dogma but a set of ideas to be revised and amplified in the light of new evidence. This advice was followed with greater alacrity by the neo-Schumpeterians than the somewhat similar advice given by Marx. Although a 'Schumpeter Society' was established in the 1980s and shows every sign of flourishing, it is a broad church and most neo-Schumpeterians have not hesitated to criticise some of Schumpeter's main propositions including, as we shall see, his basic concepts of innovation, diffusion and entrepreneurship (see, for example, the proceedings of the biennial conferences of the Schumpeter Society: *Evolutionary Economics* (Hanusch, 1988), *Studies in Schumpeterian Economics* (Heertje and Perlman, 1990) and *Studies in the Schumpeterian Tradition* (Scherer and Perlman, 1992), all of which illustrate this diversity of approach). The neo-Schumpeterians have criticised Schumpeter's work very much in the spirit of his own advice, i.e. on the basis of new empirical research evidence. They have also tackled topics which he almost completely neglected, such as underdevelopment, international trade and regional development. Consequently, the description 'neo-Schumpeterian' is used here in a very broad sense to indicate the scope of the subject matter, rather than an ideological standpoint. It includes work which could in many respects be described as neoclassical as well as much which could certainly not be so described.

This article will concentrate on those topics where the results of empirical research have been most impressive and where they have presented the greatest challenge to established theory. The primary focus will be on innovations and their diffusion at firm and industry level. This means that many other topics cannot be satisfactorily surveyed.

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Thus, for example, the issue of technical change and employment is entirely neglected and so too are environmental issues, energy, business cycles and the role of military technology. Even though firm-level technical activities are discussed, the more specialised area of project selection and evaluation techniques is not. Some subjects which are of the greatest importance are hardly touched upon, such as international trade and growth theory. These are areas where neo-Schumpeterian research has made a considerable contribution, but fortunately there are major recent reviews of the literature in Dosi, Pavitt and Soete (1990) for international trade and Verspagen (1992) for growth theory. Nor does this review take up themes which have been largely neglected by neo-Schumpeterians, such as consumer behaviour, patterns of consumer demand (with outstanding exceptions such as Pasinetti, 1981) or financial innovations (again, with outstanding exceptions, such as Heertje, 1988; Christensen, 1992; Mowery, 1992A). Finally, the survey does not cover government policies for technology and innovation, which is again an area where neo-Schumpeterian research has made a major contribution (see for example, Nelson *et al.*, 1967; Krauch, 1970, 1990; Pavitt and Walker, 1976; Tisdell, 1981; Rothwell and Zegveld, 1982; Nelson, 1984; Meyer-Krahmer and Soligny, 1985; Salomon, 1985; Dasgupta and Stoneman, 1987; Ergas, 1987; Stoneman, 1987; Teubal, 1987; Sharp and Holmes, 1988; Edqvist, 1989; Hilpert, 1991; Smith, 1991; Soete, 1991; Limpens, Verspagen and Beelen, 1992; Arundel *et al.*, 1993). Fortunately, here too, there are comprehensive recent reviews (OECD, 1991A; Metcalfe, 1993). A major publication (Stoneman, 1994) which is forthcoming, will review many of those topics which are not dealt with here, including government policies, financial innovations, international trade, technical change and employment.

There is another reason for the main part of this paper to concentrate on the results of micro-level studies of innovations and their diffusion at the firm and industry level. In doing so, it takes into account the major critical comments made in earlier literature surveys in the 1970s—those respectively by Kennedy and Thirlwall (1973) and by Nelson and Winter (1977).

After a thorough examination of the relevant literature of the 1950s and 1960s (they cited nearly 300 references), Kennedy and Thirwall concluded:

> We have tried to survey as comprehensively as possible, within the space permitted, the major lines of applied research pursued by economists on the subject of technical progress. The main conclusion can be summed up very briefly. Macro-studies of technical progress which seek to estimate the rate of technical progress as a residual component of the growth of output are fraught with aggregation and identification difficulties but almost invariably find technical progress as the prime determinant of the rate of growth regardless of the production function specified. Technical progress and advances in knowledge are not synonymous without some adjustment for increases in output due to movements towards *known* production possibilities, but even studies which make some adjustment frequently make 'pure' technical progress the single most important determinant of the growth of living standards. For this reason alone the process of technical change is of vital interest. The reader of this survey may well have been struck by the apparent thinness of studies in this field as compared to macro-economic production function studies. While it is possible we may have missed some important 'micro' studies of technical change, we are nevertheless convinced that the general impression given is a fair one. (p. 166)

In their forward-looking paper 'In Search of Useful Theory of Innovation', Nelson and Winter also concluded that micro-level and industry-level studies of technical change were likely to yield more fruitful results than the seductive but blind alley of aggregate production function models.

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We would argue, however, that the breadth and strength of the production function framework is inherently limited. To obtain a more solid understanding of innovation and what can be done to influence innovation, it is necessary to study in some considerable detail the processes involved and the way in which institutions support and mould these processes. Since the 'production function framework' contains at best a rudimentary characterization of process and relevant institutional structure, a considerably more fine grained theoretical structure is needed for these more microscopic studies. (1977, p. 46)

Nelson and Winter argued in particular that variation between industries as diverse as agriculture and aircraft necessitated industry-specific analysis, including differences in the selection environment as well as technological trajectories. Their emphasis on trajectories arose from their challenge to neo-Schumpeterians: how can ordered patterns of innovation emerge despite the industrial diversity and the uncertainty inevitably associated with innovation? How can structure, order and patterns emerge from apparently chaotic variety? Section 7 of this review will deal with some attempts to address this question.

The plea of Nelson and Winter for attention to industrial diversity, for more micro-level studies, and for deeper understanding of trajectories has evoked a significant response, as recognised by Dosi (1988) in his more recent survey in the *Journal of Economic Literature*. It is now possible to make far more reliable generalisations about innovations and their diffusion, both in specific industries and for the entire economy, than was possible fifty or sixty years ago. Schumpeter had very little to go on in the way of case studies and he himself did not attempt to carry out empirical studies of innovation (Heertje, 1977; Shionoya, 1986; Angello, 1990; Svedberg, 1991; Andersen, 1992B, 1994). It is hardly surprising that the results of the research which has been performed since his death considerably modify his pioneering formulations. Nevertheless, his work is an essential point of departure. Before addressing the main findings of neo-Schumpeterian research on technical change in Sections 3 to 7, this survey therefore first summarises the extent of the departure from Schumpeter's own theoretical framework. Section 8 presents some brief conclusions.

2. The departure from Schumpeter

Schumpeter (1939) advised his followers to study business histories, company reports, technical journals and histories of technology in order to understand the behaviour of the economic system. He even went so far as to maintain that economics should only be a postgraduate subject and that undergraduates should study history and mathematics before tackling economics. He particularly admired the achievements of the great American entrepreneurs at the close of the nineteenth century and the early twentieth century and, as recent research has shown, was strongly influenced by the ideas of Nietzsche and other proponents of 'super-man' theories (Svedberg, 1991; Andersen, 1994).

In contrast to the concept of 'represenative agents' enjoying equal access to reliable information and capable of rational calculations about the rate of return on future investments, Schumpeter postulated two types of agent: exceptional individuals (entrepreneurs) who, although certainly not able to foresee the future, were willing to face all the hazards and difficulties of innovation as 'an act of will', and a second much more numerous group of 'imitators', who were merely routine managers and followed in the wake of the heroic pioneers in the first group.

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Whilst preserving Schumpeter's emphasis on the role of uncertainty and on the importance of innovation, neo-Schumpeterian research has moved a long way from this somewhat romantic model. Schumpeter (1928, 1942) himself moved some way from his own original (1912) formulation. In fact, he moved so far that Phillips (1971) distinguished a 'young' Schumpeterian model from an 'old' one (Freeman, Clark and Soete, 1982). In his later years, Schumpeter recognised that in large firms innovation had become bureaucratised and that organised and specialised research and development departments played an increasingly important role in the innovative process. Indeed, he went so far as to maintain that a development engineer in the R&D Department of a large electrical firm could be an 'entrepreneur' in his sense of the word (Schumpeter, 1939).

This led him also to stress the predominant role of large oligopolistic firms in technical innovation and to a more charitable view of monopoly than that prevalent in orthodox theory and policy-making. After his death many attempts were made to discredit this part of his work, which was often (wrongly) assumed to be his main contribution to economic analysis and known as *the* Schumpeterian theorem. The controversy on innovation, size of firm and market structure rumbled on for decades (see Scherer, 1965, 1973, 1992; Sylos-Labini, 1962; Kamien and Schwarz, 1975, 1982; Soete, 1979) and, as we shall see, was one of those long-continuing debates partly resolved by new empirical research in the 1970s and 1980s (Section 5). Another such long-running theoretical controversy was that surrounding 'demand-pull' and 'technology-push' theories of technical change. Schumpeter was a clear proponent of entrepreneurial technology push. Here too we shall attempt to show that the results of micro-level empirical research have largely resolved this ancient debate (Section 6). Interactive systems models have replaced simple linear models whether led by markets or by technology.

The results of the empirical research reviewed in this survey confirm the main assumptions of 'bounded rationality' postulated by Simon (1955, 1959, 1978, 1979), Simon *et al.* (1992) and other behavioural economists studying decision-making under conditions of uncertainty (e.g. Cyert and March, 1963; March and Simon, 1968; Heiner, 1983, 1988; and see also Dosi and Egidi, 1991). The weight of this evidence is such that those who wish to rescue the extreme rationality–optimisation paradigm have been obliged to concede that, above all in relation to innovation, the 'classic defence' of this paradigm is 'not descriptive of the actual process by which decisions are made' (Winter, 1986A). They have had to retreat into 'as if' propositions, and to an evolutionary model: firms do not actually take optimising decisions based on accurate information or rational expectations but those that survive in competition have supposedly behaved as if they did (Alchian, 1950; Friedman, 1953; Lucas, 1986).

However, this defence is no more tenable than its predecessors. As Hodgson (1992, 1993) has shown, biologists themselves do not claim 'optimisation' through natural selection. Darwin (1859) pointed out that the improvements brought about by natural selection were *relative*. 'Natural selection will not produce absolute perfection' (p. 202). In any case, biological evolutionary models provide unsatisfactory analogies for social scientists, since human behaviour has many features which are unique (Penrose, 1952; Clark, 1990; Freeman, 1991B; Hodgson, 1991, 1992; Saviotti and Metcalfe, 1991) and social systems do not evolve on Darwinian principles of natural selection. The 'selection environment' includes many features which are absent in biological evolution, and the purposive design activities of human beings, whether in technology or in institutions, have no parallel elsewhere in the animal world.

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Just as Keynes showed that the economy could be locked in to a less-than-full employment situation, the empirical evidence is again strong that technological systems can be 'locked in' to sub-optimal solutions through a succession of small events. Paul David (1976, 1985, 1986A, 1986B, 1986C, 1992, 1993), David and Greenstein (1990), David and Steinmueller (1990), Brian Arthur (1993, 1986, 1987, 1988, 1989) and his colleagues at the Santa Fe Institute (1990–1993) have been particularly resourceful in demonstrating the causes and consequences of 'lock-in', whether by standardisation, compatibility standards or other reinforcing institutions, for evolution of the economy and for model-building. As some leading neoclassical theorists (e.g. Hahn, 1987) have themselves acknowledged, history always matters. Path-dependence and irreversibility rule, not hyper-rationality. The implications for general equilibrium theory are of course considerable, although many who work in this tradition and even in the neo-Schumpeterian tradition appear reluctant to recognise them. In this, of course, they also follow Schumpeter who never quite cut the Walrasian umbilical cord. Esban Andersen (1992B, 1993) has shed interesting new light on this aspect of Schumpeter's work.

The empirical research surveyed in Sections 3 to 7 also demonstrates the limitations of Schumpeter's theories of innovation and entrepreneurship. Ruttan (1959) put the point a bit too strongly when he said that 'Neither in *Business Cycles* nor in Schumpeter's other work is there anything that can be identified as a theory of innovation'. Nevertheless, it remains true that Schumpeter's emphasis on the role of entrepreneurship as an act of will and his tendency to belittle subsequent adopters of innovations as 'mere' imitators did tend to obscure many important aspects of innovation and diffusion, which have been illuminated by later research (Section 6).

This research points strongly to the cumulative aspects of technology, the great importance of incremental as well as radical innovations, the multiple inputs to innovation from diverse sources within and outside the firm and the changes made to innovations by numerous adopters during diffusion, both within and between countries. It is true that the empirical research does often confirm the importance of individuals variously described as 'product champions' (Schon, 1973), 'business innovators' (Freeman, 1974), or 'network coordinators' but they are sometimes hard to identify within a more anonymous process in which pygmies play an essential part as well as giants (see also Roberts, 1991). We now consider in more depth this complex process of innovation in firms (Sections 3 and 4) and industries (Section 5).

Section 3 summarises the work which has been done on the multiple external linkages of the firm, both with sources of scientific and technical information and knowledge, and with other firms, both users of its products and systems and sub-contract suppliers. The research shows that the view of the firm as a passive recipient of 'information' is untenable. Knowledge accumulation is an interactive process and the flows of information and knowledge are just as important for understanding firm behaviour and that of the economy as the flows of materials, components and intermediates.

Section 4 deals with the learning process and the knowledge accumulation *within* the firm and introduces the considerable discussion of the special characteristics of the Japanese firm. The Japanese techniques for managing innovation appear to have been especially successful in the continuous improvement of products and processes. The neo-Schumpeterian research on incremental innovations and radical innovations is taken up in Section 5, together with the complex problems of definition and measurement. This section also summarises the response of neo-Schumpeterians to the challenge of

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Nelson and Winter on industry-specific studies and the problems of developing a taxonomy of industries.

3. Technical learning from external sources

The strong emphasis in much neo-Schumpeterian research on firm-specific technological knowledge accumulation (e.g. Granstrand, 1982; Dosi, 1984; Pavitt, 1986A, 1986B, 1986C, 1990; Archilladelis *et al.*, 1987, 1990; Foray, 1987; Stiglitz, 1987; Teubal, 1987; Winter, 1987; Amendola and Gaffard, 1988; Teece, 1988; Eliasson, 1990, 1992; Teece *et al.*, 1990; Gaffard, 1991; Granstrand and Sjölander, 1992; Swann, 1992; Miller *et al.*, 1993) should not be taken to mean that exogenously generated scientific discoveries and advances play no part in technical innovation at firm level. On the contrary, much of the recent empirical work, like the earlier studies of Carter and Williams (1957, 1958, 1959A, 1959B) points to the importance of contacts with the world of science and to the increasing interdependence of science and technology (Nelson, 1962; Freeman, 1974; Mansfield, 1980; Price, 1984; Rosenberg, 1982, 1990, 1992, 1993; Grupp, 1992).

A particularly important point made by Pavitt (1993) in his paper on 'What do Firms Learn from Basic Research?' is that the contribution made by basic science to industry is mainly indirect, in the form of young recruits with new and valuable skills and knowledge, rather than direct, in the form of published papers, (though these too can of course be very useful). The Yale University Survey of 650 US industrial research executives (Levin *et al.*, 1987) showed that basic scientific skills and techniques in most disciplines were valued more highly and rated as more relevant than academic research results.

However, although less frequent and directly affecting a much smaller number of firms and innovations, inputs of new scientific knowledge are nevertheless extremely important (Nelson, 1959A, 1959B, 1962). The results of the studies on radical innovations commissioned by the US National Science Foundation (NSF) (Project TRACES, 1969) demonstrated not only that the major twentieth century innovations would have been impossible without the prior accumulation of scientific knowledge, but also that some very *recent* scientific advances played a critical part *during* the development stage (see also Mansfield, 1991).

Later studies of innovation have amply confirmed these results (e.g. Pavitt, 1971). Project SAPPHO (Freeman, 1974; Rothwell *et al.*, 1974) showed that in the chemical and instrument industries, the ability to make use of external sources of scientific expertise and advice was one of the main determinants of success. The Manchester study of Queen's Award winning innovatons (Langrish *et al.*, 1972) also confirmed the NSF conclusions and showed in particular the great importance of *informal* contacts with university scientists in several industries (Gibbons and Johnston, 1974). It is important to note that all of these studies and especially the Yale Survey demonstrated that the nature, depth and frequency of this interaction was highly industry-specific (see Section 5) and varied also with the nature of the innovation. For *incremental* innovations, scientific *skills* may also still be very important, but results of recent academic research will rarely be significant for them except in a few technologies, where the science is almost indistinguishable from the technology.

More recent research on success and failure in innovation (see Van de Ven, 1989; Rothwell, 1992) has generally confirmed these conclusions whilst also demonstrating the role of corporate strategy and government policy in developing networking relationships

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with external sources of information, knowledge and advice (Sharp, 1985, 1991; Coombs, Saviotti and Walsh, 1990; Coombs and Richards, 1991; Dodgson, 1991, 1993; Steele, 1991; Teubal *et al.*, 1991; Carlsson and Jacobsson, 1993). The new generic technologies diffusing rapidly in the 1970s and 1980s (information and communication technology—ICT, biotechnology, and new materials technology) have been shown in numerous studies to intensify the science–technology interface and to enhance the importance of external networks for innovative success (see, for example, Faulkner, 1986; Dodgson, 1989, 1991 and Orsenigo, 1989, 1993 for biotechnology; Cohendet *et al.*, 1987 and Lastres, 1992 for new materials technology; Nelson, 1962; Gazis, 1979; Dosi, 1984; Antonelli, 1986, 1991, 1992, 1993; Molina, 1990; Freeman, 1991A and Lundgren, 1992 for information and communication technology). The intensity of the interaction between science and technology has also been demonstrated in the 'scientometric' literature using citation analysis and similar techniques, notably by Narin and his colleagues (Narin and Noma, 1985; Narin and Olivastro, 1992) and in the work of the Leiden Science Studies Unit (Van Vianen, Moed, and Van Raan, 1990).

Much empirical research (see, for example, Lundvall 1985, 1988, 1992) has also shown that another major determinant of innovative success lies in the nature and intensity of the interaction with contemporary and future *users* of an innovation. In the case of incremental innovations especially, but also for radical innovations, this has often been shown to be a decisive factor (see Section 5). It was one of the main findings of the SAPPHO project and the Manchester project already referred to. Von Hippel (1978, 1980, 1988) and Slaughter (1993) have shown that users may often take the lead in stimulating and organising innovation. So important is the interaction with users that it has become one of the key topics in the research on 'national systems of innovation' (Nelson, 1990, 1992A, 1993; Andersen, 1991, 1992A; Fagerberg, 1992; Lundvall, 1992, 1993; Mjøset, 1992) and on the globalisation of technology (see Section 7).

The picture which thus emerges from numerous studies of innovation in firms is one of continuous interactive learning (Stiglitz, 1987; Lundvall, 1992). Firms learn both from their own experience of design, development, production and marketing (Section 4) *and* from a wide variety of external sources at home and abroad—their customers, their suppliers, their contractors (a particularly important aspect of Japanese firm behaviour—see Imai, 1989; Sako, 1992; Dodgson and Sako, 1993) and from many other organisations—universities, government laboratories and agencies, consultants, licensors, licensees and others. They also learn from their competitors through informal contacts and reverse engineering. The precise pattern of external and internal learning networks varies with size of firm, but *all* firms make use of external sources (Foray, 1991, 1993; Kleinknecht and Reijnen, 1992A). The characteristics of the network also vary with the type of technology and innovation (process, product, service, organisation, incremental, radical), with the sector of industry and with the national environment or 'system of innovation' (see Section 7). Equally varied are the methods of learning. For example, learning from other firms may be through informal contacts and 'informal trade' in knowledge (von Hippel, 1982, 1987), through formal collaboration and joint ventures of various kinds (Hagedoorn, 1990; Hagedoorn and Schakenraad, 1990, 1992), through licensing and know-how agreements (OECD, 1988), through recruitment of people, through acquisitions, through reverse engineering and of course, through espionage (see Mansfield, 1985 on 'how quickly does technology leak out?'). The Yale Survey (Levin *et al.*, 1987) showed that the great majority of US industries regard their own R&D and

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reverse engineering as the most effective forms of learning, but this survey may have underestimated the role of informal contacts and of espionage. It is also possible that a survey addressed to industrial R&D executives would contain some bias in the replies towards in-house R&D. But clearly a combination of various forms of external and internal sources of learning is essential.

The work of Häkanson and Johansson (1988) and Häkanson (1982) showed that informal flows of information between users and suppliers were actually more important than formal arrangements. However, Hagedoorn and Schakenraad (1990) and several other studies (e.g. OECD, 1986; Chesnais, 1988A, 1988B; Mowery, 1988, 1989) have surveyed the *formal* arrangements for technology cooperation and exchange and have demonstrated a rapid increase in the 1980s. It should also be remembered that many firms make use of several different arrangements simultaneously. Acs (1990) showed that even small science-based firms in Maryland almost all made use of more than one different form of technology collaboration, while the largest firms may have more than a hundred different agreements affecting different products and technologies. Kleinknecht and Reijnen (1992A) showed in an extensive survey that small firms are involved in technical collaboration to at least the same extent as large firms (see also Rothwell, 1991; Smith *et al.*, 1991).

Although external sources of technology and cooperation with other organisations are important in all sectors of industry and for all sizes of firms (Kleinknecht and Reijnen, 1992), an important result of the work of Hagedoorn and Schakenraad (1990, 1992) was to show that the three major generic technologies had led to an explosion of new cooperative arrangements in the 1980s, with information and communication technology accounting for the lion's share.

Building on the work of Coase (1937, 1988) and Williamson (1975, 1985), a number of neo-Schumpeterian studies (e.g. Goto, 1982; Imai, 1989; Imai and Baba, 1989; Teubal *et al.*, 1991; Foray, 1991, 1993; Fransman, 1990; Sako, 1992) have suggested that the growth of networking arrangements means that both market and hierarchical relationships are being superseded by new forms of organisation. Others have suggested that this may be associated with the diffusion of information and communication technology, providing both the necessity for collaboration and better means for achieving it. Still others (e.g. Bressand and Kalypso, 1989; Bressand, 1990) have pointed to the tendency for today's networks to become tomorrow's monopolies. A good deal of the empirical evidence points to the view that networking can be explained more in terms of strategic behaviour of firms than in terms of costs, whether transaction costs or others (e.g. Hagedoorn and Schakenraad, 1990). Here is a very fertile field for future research, whether by neo-Schumpeterians or others, with major policy implications (De Bresson, 1989, 1991) as well as further illumination of the market structure/innovation debate. Whilst a number of neo-Schumpeterian studies have justifiably emphasised the role of *trust* in networking relationships (e.g. Sako, 1992; Lundvall, 1993; Sabel, 1993) the role of *power* and fear is often neglected.

Much of the discussion on networks relates to Japanese firms (Goto, 1982; Schonberger, 1982; Imai, 1989; Imai and Baba, 1989; Fransman, 1990; Kodama, 1990, 1991; Tanaka, 1991; Friedman and Samuels, 1992; Sako, 1992) and the internal organisation of Japanese firms is often supposed to differ also from typical American and European firms. This question is discussed in the following section and again in the final discussion in Sections 7 and 8 in relation to national differences in systems of innovation.

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4. Technological learning from internal sources

The SAPPHO Project (Freeman, 1974; Rothwell, 1974) had already shown that good internal coupling between design, development, production and marketing functions was one of the decisive conditions for successful innovation. Many failures could be attributed to lack of communication between the R&D, production and marketing functions, as was also shown in the brilliant sociological study of Burns and Stalker (1961).

Whereas they found cases where R&D personnel had never set foot in a factory, in his comparison of Japanese and American electronic firms, Yasunori Baba (1985) defined Japanese development strategies as 'using the factory as a laboratory'. Takeuchi and Nonaka (1986) have described Japanese firms as playing rugby in contrast to their American competitors who are still running relay races with their sequential approach to R&D, production and marketing activities. The results of Japanese integrated management techniques in managing R&D, production and marketing have been shown to be shorter lead times (Graves, 1987, 1992; Mansfield, 1988; Clark and Fujimoto, 1989). These lead times have been achieved very often whilst improving product quality to a higher level than that of competitors (Grupp and Hofmeyer, 1986; Womack *et al.*, 1990). Closer integration of R&D with production means that process innovation can be intimately related to product innovation and the joint design of product and process may be the main achievement of Japanese techniques of innovation management. Freeman (1987B) has suggested that this may be traced to the experience of reverse engineering in Japan in the 1950s and 1960s when Japanese firms were making extensive use of imported technology, but always with a view to improving it, rather than simply copying. It is notable that in the 1980s US firms still rated reverse engineering as the second most important form of technological learning after in-house R&D (Levin *et al.*, 1987).

It should not be forgotten that talented R&D managers such as Morton (1971) of Bell Labs already in the 1960s formulated a strategy designed to link R&D closely with production. Nevertheless, Japanese managerial techniques, both for external networking and for internal coupling, as well as for incentives, industrial relations, training and other aspects of their affairs (Dore, 1973, 1985, 1987), have led some economists (notably Aoki, 1986, 1988, 1990, 1991) to regard the Japanese firm as a specific form of industrial organisation (the 'J-Firm'), differing in many important characteristics from American or European firms. Goto suggested already in 1982 that the Japanese firms could be regarded as a special type of networking corporation transcending both markets and hierarchies and he noted that in a footnote Williamson (1975) himself had described the Japanese corporate structure as 'culturally specific'. Goto (1982), however, maintained that the advantageous features of Japanese organisation could be diffused internationally. Management consultants, as well as some economists, are certainly making considerable efforts to achieve this (Ohmae, 1990).

The importance of learning from production and from marketing, as well as from R&D (Mowery, 1980; Cohen and Levinthal, 1987), help to explain why the 'hollow corporation' has seldom materialised and why sub-contracting of R&D and design has not been more extensive. Mowery (1980, 1983) showed historically how and why US firms relied increasingly on their own in-house R&D, rather than on contract Research Institutes, which were already quite strong in the United States at the close of the nineteenth century (Hughes, 1989). Transaction costs are an insufficient explanation: even in industries where contracting for R&D and licensing of technical know-how are

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common practice, these are hardly ever alternatives to in-house technical activities (including R&D) but are *complementary* to them (see also Reich, 1985). Indeed, one of the most important findings of neo-Schumpeterian research is the demonstration that technical knowledge can seldom be obtained 'off the shelf' and that it almost always requires processing and modification to be used effectively (Bell and Pavitt, 1992; Bell, 1991). Without this assimilation and improvement rather inefficient results are likely to follow, especially in developing countries (Cooper and Sercovich, 1971; Cooper, 1973, 1974; Bell *et al.*, 1976 Bell, 1984).

In any case, it is not simply a question of in-house R&D, whether in Third World countries or OECD countries. The use of R&D measures as a proxy for a wider range of technical and learning activities is unsatisfactory (Winter, 1987; Bell, 1991; Freeman, 1992). It became common practice in neo-Schumpeterian literature and applied research simply because R&D statistics became generally available for firms, industries and countries during the 1950s and 1960s and were standardised internationally through the OECD in the so-called 'Frascati' Manual (OECD 1963, 1970, 1976, 1981, 1993). The authors of this Manual always recognised the limitations of R&D measurements, and in the very first edition (1963) pointed to the need to measure a much wider range of scientific and technical services, including design and engineering, project surveys, scientific and technical information services, technical consultancy, training, etc (see also UNESCO, 1969). In some industries and in industrial countries R&D measures are a reasonably good surrogate for this wider range of activities but in others they are not. A major task for neo-Schumpeterian researchers is to improve their measures of all these technological services (Freeman and Oldham, 1992).

A particularly important aspect of knowledge accumulation is skill formation within firms as the combined result of formal training processes and learning by doing, using and interacting (Kelley and Brooks, 1991; Marsden, 1993). Training statistics have lagged woefully behind but even with the limited data available, valuable international comparative studies have been made of the skills of the labour force in Britain, Germany and other countries (e.g. Prais, 1981, 1987; Prais and Wagner, 1983, 1988) and of skill formation in specific industries (e.g. Senker *et al.*, 1985; Brady, 1986).

In his classic study of technical change, Salter (1960) pointed to the enormous variations in productivity between different firms in the same industry and attributed this primarily to different vintages of capital equipment. The neo-Schumpeterians (Dosi, 1984, 1988) have taken on board the central importance of this finding and of firm-specific knowledge accumulation (Penrose, 1959). In discarding the unreal hypothesis of 'representative agents' and recognising heterogeneity of agents, they have also demonstrated the crucial importance of interactive learning in all functions of the firm and of 'core competences' (Teece, 1982, 1986, 1988) in using new vintages of capital equipment. Marshall (1890) already pointed out that knowledge and organisation were the most important forms of capital and the 'chief engine' of production but neither he nor the neo-Schumpeterians have been able to measure this crucially important indicator.

Winter (1987) is one of the few economists who have addressed this problem. In his paper on 'Knowledge and Competence as Strategic Assets', he pointed to the weakness of surrogate measures of knowledge accumulation, using R&D expenditure statistics and argues that it is necessary 'to confront the difficulties that arise from the complexity and diversity of the phenomena denoted by such terms as knowledge, competence, skill and so forth. When we use such terms we hardly ever know precisely what we are talking

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about . . .' (p. 170). He goes on to discuss the role of tacit knowledge, procedural skills, articulable knowledge and tacit skills and suggests a taxonomy, which could be useful in strategic management. However, neither he nor any other neo-Schumpeterian economist has gone much beyond this. In this area and the related area of measuring scientific and technical services, there is a big challenge to future research in this field, as recognised by several authors (e.g. Coombs, Saviotti and Walsh, 1990; Senker, 1993).

5. Industry-specific incremental and radical innovations

One of the main difficulties in meeting Winter's challenge to neo-Schumpeterian economists lies in the sheer variety and complexity of innovations. They vary enormously by industry (Nelson and Winter, 1977; Nelson, 1984, 1985, 1991; Pavitt, 1984) by degree of novelty and cost (OECD, 1992A), by technology (Dosi, 1982, 1988) and by type (product, process, organisational, system). This section will deal with the first two categories and the other two will be dealt with in Sections 6 and 7.

The difficulties of defining and classifying novelty are immense as every patent system is constantly demonstrating. Nevertheless, the very word itself shows the necessity of making some distinctions. An attempt has been made to rank innovations on a five-point scale from 'systemic' to 'major', 'minor', 'incremental' and 'unrecorded' (Freeman, 1971); Abernathy and Clark (1985) used four categories but the vast majority of authors make a simple two-fold distinction between 'radical' (or 'major') innovations and 'incremental' (or 'minor') (e.g. Stobaugh, 1988). Some make no distinction at all. The difficulties of definition are considerable even for this simple dichotomy, but nevertheless it is an important one because the two types of innovation embody a very different mix of knowledge inputs and have very different consequences for the economy and the firms which make them (see especially Utterback, 1993).

Hollander (1965), in his study of technical change in Du Pont's rayon plants, and Townsend (1976), in his study of technical change in the British Coal industry, found that the great majority of innovations did *not* come from formal R&D (even in organisations like Du Pont and the NCB, which had strong in-house R&D facilities). Most of the hundreds of small improvements to the equipment and the organisation of work came from production engineers, systems engineers, technicians, managers, maintenance personnel and of course from production workers. Just as Adam Smith (1776) had described, other improvements came from the makers of plant and machinery. In this respect both Du Pont and the NCB could be described as 'users' and as we have already seen many other studies have amply confirmed the role of users in making incremental innovations (e.g. Rothwell, 1977; von Hippel, 1978, 1988; Cassiolato, 1982; Lundvall, 1985, 1988, 1992; Slaughter, 1993). However, when it came to a change in the basic process in the rayon industry or to the introduction of electronic 'black boxes' in coal-mining (i.e. a discontinuity in products and processes), then central R&D departments, whether in user or producer firms, became very important, because the new knowledge required went beyond the experience of the people involved in production (see also Utterback, 1979, 1993; Afuah and Utterback, 1991).This points the way to the definitions proposed by Mensch (1975), Utterback (1979) and Freeman and Perez (1988). Mensch defines a radical innovation as one that needs a new factory and/or market for its exploitation and this is similar to Utterback's definition of major or radical innovations. Freeman and Perez added to this the suggestion that, logically, radical innovations would need a new column and a new row in a complete input–output table.

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Incremental innovations, on the other hand, would need only new coefficients in the table of existing products and services since they refer only to improvements in the existing range of output. It must be noted that the *discontinuity* with radical innovations is in *production and marketing* systems and not necessarily in the *firm* (Pavitt, 1986A), although some authors also emphasise the contribution of new firms to radical innovation, as in the US semiconductor industry (e.g. Tilton, 1971; Braun and MacDonald, 1978; Saxenian, 1991).

If one moves away from improvements in production to entirely new products and processes, whether in the chemical industry or in the coal industry, then more formal inputs from the science–technology system are usually needed, which in contemporary industrialised economies usually means from the R&D system (Dosi, 1988). Such radical innovations are much more completely recorded than incremental innovations. They are often the subject of papers in technical journals and of manuals and textbooks as well as blueprints, specifications and patents, and hardware prototypes and pilot plants (Ames, 1961; Machlup, 1962).

Neo-Schumpeterian research has certainly given us a much more complete picture of what is involved in radical innovation in many different industries. However, it has not yet succeeded in developing regular national and international *statistics* of innovations, despite pioneering attempts, which are well described in the *STI Review* (OECD, 1992B) with papers on innovation surveys in six European countries.

Studies in particular *sectors*, such as synthetic materials (Hufbauer, 1966), pesticides (Achilladelis *et al.*, 1987) or particular countries (Pavitt, Robson and Townsend, 1987; OECD, 1992B) have shown the value of more complete records and data banks and of long-term historical perspective. However, the absence of sufficient good historical investigations means that the results of some old controversies are still inconclusive and the answers to some important questions are not yet available. One example is the controversy about the supposed clustering of radical innovations at certain phases of long cycles in economic development (Mensch, 1975; Clark, Freeman and Soete, 1981; Freeman, Clark and Soete, 1982; Kleinknecht, 1987, 1990; Freeman and Perez, 1988). Mensch and Kleinknecht made use of various independent sources on the history of inventions and innovations but none of them could be described as comprehensive. Another very difficult question is the relative contribution of various national systems to world-wide innovation at different historical periods. Dosi, Pavitt and Soete (1990) made use of various incomplete records to provide a partial answer but again they would be the first to agree that these data are far from satisfactory.

Radical innovations played such an obvious and spectacular role during and after the Second World War (especially of course, nuclear weapons and radar) that they tended to overshadow incremental innovations, both in policy-making and in descriptive analysis for a long time. Neo-Schumpeterian research has succeeded in restoring a much more balanced picture of the overall process of technical change both by the indirect evidence of productivity studies (OECD, 1991B, 1992A) and by direct studies, such as those by Hollander and Townsend (see also Surrey, 1992). This has led to an important change of emphasis in policy-making with the recognition that the vast majority of firms do not make radical innovations, but all can and should make incremental innovations and adopt new products and processes first made by others (see Section 6). This shift of emphasis towards diffusion can be observed in most OECD countries in the 1980s and 1990s (Ergas, 1984; OECD, 1991A, 1992A; Arundel *et al.*, 1993).

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Even though many incremental innovations go unrecorded and unarticulated in the general process of tacit knowledge accumulation, learning by doing, using and interacting (see especially Gilfillan, 1935; Utterback, 1979; Lundvall, 1992), it has proved possible to document and measure many aspects of incremental innovation. The *recorded* part of incremental innovation can be traced through technical journals, business histories and above all through patent statistics, which represent a unique long time series of inventive efforts on a worldwide basis. Schmookler (1966), especially, pioneered the systematic use of patent statistics in the study of technical change and even though some of his conclusions are highly controversial (see Section 6), he inspired many others to make use of this goldmine for empirical research. More recently, computerised patent systems have greatly facilitated part of this work.

It is true of course that patents refer to the outcome of *inventive* efforts and are therefore not a direct measure of *innovations*. Nevertheless, there is clearly a very important intermediate output of innovative activities and even though many patents lapse, there is a considerable overlap especially with incremental innovations. It is also true that there are hazards in the use of raw patent statistics (Scherer, 1983; Pavitt, 1982, 1985; Basberg, 1987; Griliches, 1990; Grupp, 1991, 1992), such as varying national legal systems, varying propensities to patent, industry and technology-specific features, classification systems and so forth. Nevertheless, neo-Schumpeterians have on the whole shown admirable caution and much ingenuity in coping with these problems and still producing worthwhile results using patent statistics as a surrogate measure of innovative output (e.g. Freeman *et al.*, 1963, 1987A, 1987B; Schmookler, 1966; Reekie, 1973; Soete, 1981; Scherer, 1982A, 1982B, 1986, 1993; Soete and Wyatt, 1983; Griliches, 1984, 1990; Narin *et al.*, 1985, 1987, 1992; Sirilli, 1987; Archibugi, 1988A, 1988B; Fagerberg, 1988; Patel and Soete, 1988; Cantwell, 1989, 1991B; von Tunzelmann, 1989; Patel and Pavitt, 1991, 1992A, 1992B, 1993; Archibugi and Pinta, 1992; Grupp, 1992).

Far less use has been made of other sources, which though less accessible and less comprehensive than patent records are nevertheless potentially valuable also. Townsend (1976) is one of the few authors who has made systematic use of data on inventor-awards, although some firms have used such schemes for long periods. A difficulty with some of these measures is that they may be oriented more towards industrial relations and PR than to innovation. However, now that Japanese firms have been shown to promote incremental innovation rather successfully by a variety of incentive schemes including inventor awards, quality circles etc. (e.g. Dore, 1973, 1985; Imai and Itami, 1984; Baba, 1985; Aoki, 1988) greater attention is being paid to this topic. Bessant and his colleagues have initiated a research programme specifically to study 'continuous innovation' (Bessant *et al.*, 1993; CI News, 1993) (see also Petroski, 1989 and Paulinyi, 1982, 1989 for continuous innovation in the nineteenth century).

The distinction between radical and incremental innovations is also relevant in terms of the specific features of industrial sectors. Only a few firms make radical innovations and they are clustered in certain industries. There are many service industries and some manufacturing industries which make scarcely any radical innovations, and some which make none at all. As pointed out in Section 1, Nelson and Winter (1977) stressed particularly the importance of these inter-industry variations and there has been a considerable upsurge of industry-specific studies since that time. It is true that most of this research has concentrated on the more 'glamorous' and R&D-intensive industries and mostly though not exclusively on radical innovations,

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especially in electronics (e.g. Nelson, 1962; Freeman *et al.*, 1965; Braun and Macdonald, 1976; Sciberras, 1977; Katz and Phillips, 1982; Dosi, 1984; Baba, 1985; Malerba, 1985; Flamm, 1987, 1988; Molina, 1989, 1990; Antonelli, 1992, 1993; Lundgren, 1992; Sternberg, 1992; Grupp and Soete, 1993; Lovio, 1993), in chemicals (e.g. Enos, 1962; Morris, 1982; Walsh, 1984; Achilladelis *et al.*, 1987, 1990; Hounshell and Smith, 1988; Stobaugh, 1988; Hounshell, 1992A; Qunitella, 1993), and in nuclear power (e.g. Gowing, 1964; Surrey, 1973; Surrey and Thomas, 1980, 1985; Keck, 1982; Walker and Lonnroth, 1983A, 1983B; Samuels, 1987; Thomas, 1988; Cowan, 1990; MacKerron, 1991; Krupp, 1992).

Already in the 1950s and 1960s, pioneering studies by Rosenberg (1963) and other historians had investigated machine tools, and these less research-intensive industries such as automobiles and machinery have recently begun to receive much more attention (e.g. Jacobsson, 1986; Jaikumar, 1988; Womack, Jones and Roos, 1990; Bessant, 1991; Ayres, 1991A, 1991B; Tidd, 1991; Graves, 1992; Dankbaar, 1993). Even industries of very low research intensity, such as textiles (e.g. Antonelli, Petit and Tahar, 1992), construction (Gann, 1992, 1993) and clothing (Hoffmann and Rush, 1988; Whittaker, Rush and Haywood, 1989) are becoming the object of more systematic research.

A serious weakness of this research has been the lack of attention to service industries but this is also a criticism which could be made of industrial economics more generally. Nevertheless, a few pioneering studies have been made, such as Auliana Poon's (1993) highly original research on technical change in tourism, and some work on financial services (e.g. Heertje, 1988; Baba, 1990; Petit, 1991; DeWit, 1990; Cassiolato, 1992; Christensen, 1992). These studies, together with more general analysis of service industries (Barras, 1986, 1990; Posthuma, 1986; Quinn, 1986), show that most of them shared some of the characteristics of manufacturing industries of very low research-intensity (Scherer, 1982B) but are now changing.

It was already evident from the early R&D statistics in the 1950s that industries fall into quite distinct categories (Freeman, 1962; Nelson, 1962; Mansfield, 1968, 1971) of high, medium and low R&D intensity and that the same industries belonged to each category, in whichever country they were located, suggesting that technological trajectories and opportunities and technological competition had a dominant influence on this aspect of firm behaviour (see also Kay, 1979, 1982). These early studies also showed that the fastest growing industries were mainly those with the highest R&D intensity.

A more systematic taxonomy of industrial sectors was developed by Pavitt (1984) which has been widely used in neo-Schumpeterian literature. He classified industries into three categories: (a) supplier-dominated; (b) production-intensive; and (c) science-based. Pavitt argued that each category had a somewhat different pattern of external relationship to sources of knowledge, of in-house scientific and technical activities, of diversification behaviour, of industrial structure and of skill formation. This taxonomy proved a fruitful framework for analysis, further justifying Nelson and Winter's insistence on the importance of inter-sectoral variations both for theory and for policy-making. Scherer (1982A) had already demonstrated the importance of inter-industry technology flows by the use of patent statistics. Utterback (1993) makes an interesting distinction between assembly and non-assembly industries with respect to radical and incremental innovations.

However, the example of the service industries also shows the dangers of classification schemes and taxonomies for neo-Schumpeterians. It was customary and reasonable for

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a long time to regard the service industries as 'supplier-dominated' in the sense that other industries (office machinery, telecommunications, etc.) were responsible for introducing and diffusing most of the technical change which was taking place. With the computer revolution this may be changing. In-house software development (not always classified as R&D—another problem for neo-Schumpeterians!) is now characteristic of many firms in financial services, who also have a heavier investment in ICT equipement than most firms in manufacturing. At the same time, specialist software companies are proliferating and have a very dynamic role in technical change (Brady and Quintas, 1991; Cusumano, 1991; Freeman, 1993; Quintas, 1993). Neo-Schumpeterians have to beware always of 'freezing' a classification or a theory, which may be out-dated by the incessant changes in technology (Barras, 1986, 1990; Bressand and Kalypso, 1989; Poon, 1993) and in industrial structure. Miller and Hobday (1993) have suggested that complex systems such as aircraft flight simulators are made and sold by firms which do not fit into any of Pavitt's categories.

The same danger exists in relation to the old Schumpeterian controversy about the role of oligopoly in innovation. Schumpeter's emphasis on the dominant role of large oligopolistic firms was challenged by many authors (see Hamberg, 1964, 1966; Scherer, 1980; Kamien and Schwartz, 1982). Jewkes *et al.* (1958) in particular attempted to show from the empirical evidence of case studies that major *inventions* were made as frequently by small firms and individual inventors in the twentieth century as in the nineteenth, and that the contribution of large firms was exaggerated (see also MacQueen and Wallmark, 1983). As they themselves emphasised, their findings related to *inventions*, not to innovations. Their own case studies show that about two-thirds of their inventions were actually *innovated* by large firms (Freeman, 1992) and more frequently in the twentieth than in the nineteenth century.

However, more recent empirical work has still confirmed their main finding that small firms do indeed continue to make a significant contribution both to invention *and* innovation and that it may have recently increased (Pavitt, Robson and Townsend, 1987; Acs and Andretsch, 1988). Large firms still account for the great majority of innovations in most industries and the contribution of small firms tends to be concentrated in a few industrial sectors, but their innovations may be used in many others (Pavitt, 1984). The instrument industry and the software industry are obvious examples.

Here too, however, history matters. As Kaplinsky (1983) and others (e.g. Oakey, 1984) have shown in relation to CAD and many other innovations associated with new generic technologies (especially biotechnology) in the early stages, small new firms make an outstanding contribution. However, as the technologies mature, R&D costs often rise, acquisitions take place and Schumpeterian competition may lead to renewed concentration (Utterback and Suarez, 1993). It remains to be seen whether 'new history' will lead to a more stable symbiosis of large and small firms in networks of technological collaboration, as foreshadowed by some authors (Section 3) or to renewed concentrations or to deconcentration. It should be noted that the contribution of small firms is exaggerated in some reports through failure to distinguish 'small' subsidiaries of MNCs and establishments from firms and innovations which are new to the firm from those which are new to the world. Longitudinal and historical studies in a variety of industries (e.g. Lundgren, 1992; Lovio, 1993; Utterback and Suarez, 1993; Utterback, 1993), distinguishing the role of various size and ownership categories and of networks, will be a vitally important task for future neo-Schumpeterian research.

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6. Demand-pull, technology-push and diffusion of innovations

The discussion in Sections 3, 4 and 5 has brought out the importance of flows of information and knowledge *between* firms as well as within firms. Moreover, the results of the empirical research which has been described (especially in Section 3) point to the importance *both* of flows to and from sources of scientific and technical knowledge *and* of flows to and from *users* of products and processes. For a long time controversy has raged both among economists and among historians of science and technology about the relative significance of 'demand-pull' versus 'science and technology push' in generating and sustaining these flows (e.g. Hessen, 1931; Bernal, 1939, 1970; Schmookler, 1966; Scherer, 1982B; Verspagen and Kleinknecht, 1990).

The distinction between radical and incremental innovation is highly relevant here, as is the pattern of diffusion of an innovation. In the early stages of a truly radical innovation, scientific and technological inputs are likely to be prominent, even if they do not provide the original impulse. Katz and Phillips (1982) have shown that in the early days of the electronic computer (arguably the most important twentieth century innovation) science and technology push predominated, and even industrialists as knowledgeable as T.J. Watson (Senior) maintained there was and would be no market demand. Other studies (e.g. Molina, 1989, 1990) have shown that the science 'constituency' was also prominent in originating and shaping later radical innovations in the computer industry. Sociologists (e.g. Mackenzie, 1990A, 1990B; Bijker and Law, 1992) have made a major contribution here (see Coombs *et al.*, 1992).

Nevertheless, in the 1960s and 1970s demand-led theories of innovation made a considerable impact on policy-makers. The empirical survey of over 500 innovations made by Myers and Marquis (1969) appeared to justify the demand-pull approach whilst on a more theoretical level the work of Schmookler (1966) provided a more sophisticated historical justification. He did not entirely deny the independent role of basic scientific research but sought to demonstrate through the painstaking use of very detailed US patent statistics that usually the peaks and troughs of *inventive* activity lagged behind the peaks and troughs of *investment* activity. From this he drew the conclusion that the main stimulus to invention and innovation came from the changing pattern of demand as measured by investment in new capital goods in various industries.

Scherer (1982B) tested Schmookler's hypothesis for a more comprehensive set of US manufacturing industries and found a much weaker relationship. Verspagen and Kleinknecht (1990) also found Schmookler's own data showed a weaker relationship than he had claimed. Scherer made an original analysis of cross-sector flows of patent origin and use which demonstrated that the link for inventions sold *across* industry lines was at least as strong as for those that represented internal processes to their originators.

Pure demand-pull theories were already strongly criticised in the 1970s (e.g. Rosenberg, 1976). However, the *coup de grâce* was given by Mowery and Rosenberg (1979) in their devastating review of 'Market Demand and Innovation'. They showed that empirical studies of innovation which were often cited in support of 'demand-pull' did not in fact justify these conclusions and indeed that the authors themselves repudiated this interpretation (e.g. Langrish *et al.*, 1972; Freeman, 1974). Mowery and Rosenberg further pointed to the confusion in the literature between 'needs' and 'demand' and between 'potential demand' and 'effective demand'. Since human 'needs' are extremely varied and often unsatisfied for long periods, they cannot alone explain the emergence of particular innovations at a particular time. Innovation should not be

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viewed as a linear process, whether led by demand or by technology, but as a complex interaction linking potential users with new developments in science and technology.

The majority of innovations characterised as 'demand led' in the Myers and Marquis survey were actually relatively minor innovations along established trajectories and the same was true of the vast majority of patents analysed by Schmookler. The Mowery and Rosenberg critique of demand-pull has been further reinforced by research using patent statistics and Schmookler's own method (Walsh, 1984). In her study of the chemical industry, Walsh made use of statistics of scientific papers as well as patents and related these to measures of output, investment, innovation and sales after the manner of Schmookler. As in Schmookler's work, the pattern of leads and lags was by no means so clear-cut as to put the issue beyond all doubt. But again as with his work, there was evidence of synchronicity in the pattern of economic and technical developments, i.e. the major upsurge of production and investment in each sector (petrochemicals, dyestuffs, drugs and synthetic materials) was accompanied by a remarkable increase both in the numbers of patents and in the output of related scientific publications. The most interesting result, however, was the evidence suggesting that a 'counter-Schmookler' pattern was characteristic of the early stages of innovation in synthetic materials, drugs and dyestuffs, changing to something more closely resembling a 'Schmookler'-type pattern once the industry 'took off'. Qualitative analysis in all four cases confirmed the importance of early scientific and technological breakthroughs permitting and triggering an upsurge of inventive activity and technical innovations. The work of Fleck (1983, 1988) on robotics shows a similar pattern of early science–technology push, followed by numerous system improvements in specific applications driven by users interacting with suppliers.

These results of empirical research point to the resolution of the persistent controversy between adherents of 'demand-pull' or 'market-led' theories of innovation and advocates of 'technology push' or 'science-driven' theories. One of the achievements of innovation research has been to bury linear models of innovation, whether supply or demand driven and to replace them with more sophisticated models (Rothwell, 1991; OECD, 1992A; Arundel, 1993) which embody the numerous interactions and feedback loops during both innovation and diffusion.

Diffusion of innovations is another Schumpeterian concept which has come in for some heavy criticism. Most empirical studies demonstrate that new products and processes are usually changed considerably *during* the diffusion process. The early models of the 1950s and 1960s which tended to assume an unchanged product diffusing through an unchanged environment have been largely displaced by more complex models (see Stoneman, 1976, 1983, 1978; Mansfield, 1977, 1989; Davies, 1979; Mahajan and Peterson, 1979; Gold, 1981; Metcalfe, 1981, 1988; Zuscovich, 1984; Granstrand, 1986; Nakicenovic and Grübler, 1991; Midgley *et al.*, 1992; Callon, 1993; and see also references to David and Arthur in Section 2)

It is impossible to deny the evidence of further innovations *during* diffusion and in many cases productivity gains are mainly due to this learning process and the competitive pressures engendered by band-wagon effects. Rosenberg (1976, 1982), in particular, has always insisted on this point which could hardly be put more forcefully than by Kline and Rosenberg (1985):

> It is a serious mistake to treat an innovation as if it were a well-defined homogeneous thing that could be identified as entering the economy at a precise date . . . . The fact is that most important innovations go through rather drastic changes over their lifetimes—changes that may, and often do,

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totally transform their economic significance. The subsequent improvements in an invention after its first introduction may be vastly more important, economically than the initial availability of the invention in its original form . . . consider the performance characteristics of the telephone around 1880, the automobile, vintage 1900, or the airplane when the Wright Brothers achieved their first heavier-than-air flight in 1903—in that form, at best a frail and economically worthless novelty.

One could add to these examples that of the electronic computer, where contemporary microprocessors and supercomputers can barely be classed as the same product as Zuse's first electronic computer at Charlottenburg Technische Hochschule in 1940 (Freeman *et al.*, 1965; Stoneman, 1976; Flamm, 1987). To be fair to Schumpeter he did recognise this point. He said himself that:

the motor car would never have acquired its present importance and become so potent a reformer of life if it had remained what it was thirty years ago and if it had failed to shape the environmental conditions—roads among them—for its own further development. (Schumpeter, 1939, p. 167)

These factors led Fleck (1988) to coin the expressions 'Innofusion' and Diffusation' in his analysis of industrial robotics. However, although it is certainly possible to identify products which have been drastically modified and improved during their diffusion (such as the automobile or the computer), there are also some which change little or at all. Examples can be found particularly in the drug industry and the food industry. Even when the product or process is improved during diffusion, this improvement is often very gradual and can be legitimately regarded as *incremental* in nature, rather then *radical*. The pioneering studies of Mansfield (1961) and other researchers of the 1960s contributed a great deal to our understanding of diffusion despite their limitations.

Thus, despite the criticisms of Schumpeter's theory of diffusion, most social scientists still find his conceptual framework useful. Economists and sociologists are actually studying diffusion more than ever, although they are increasingly aware of the need to take into account that they are often examining a changing product in a changing environment. The Venice Conference on diffusion (Arcangeli, David and Dosi, 1986) was the biggest event of its kind for neo-Schumpeterian economists between the NBER Conference in 1961 and the MERIT 5th Anniversary Conference in 1992. Moreover, despite the general recognition that diffusion policy was relatively neglected in most countries and described by Paul David (1986A) as the 'Cinderella' of technology policy, neither can it yet be said that policies for diffusion in OECD countries have measured up to its importance or have satisfactory criteria and guideposts (OECD, 1991A, 1991B).

One of the major problems in diffusion research is to take into account the *supply* side as well as the demand side. As Gibbons and Metcalfe (1986) particularly show, the interaction between supply and demand results in the evolution both of new and improved products and of new design configurations. Although empirical research has amply demonstrated the role of suppliers in improving the product, diversifying new models, enlarging the market, promoting applications research, training potential users, and coping with institutional barriers, much diffusion research (despite the good advice of Metcalfe, 1988 and other researchers) continues to neglect the supply side and treat diffusion as a demand phenomenon. The lessons of the demand-pull/technology-push debate have still not have been fully assimilated. The model of 'network structure' in industrial diffusion processes (Midgley *et al.*, 1992) is an interesting example of the new type of simulation model which *does* endeavour to take into account the interactions of

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suppliers and adopters as well as some third parties. A particularly interesting finding of this research is that third parties may be as important to the diffusion process in some areas as direct links from adopters to potential adopters or suppliers to adopters.

Another even more difficult problem is the systems aspect of diffusion. Most innovations are not discrete events or isolated products but form part of a technology system (Gille, 1978; Hughes, 1982, 1992; Carlsson and Stankiewicz, 1991). Obvious examples are contemporary electronic products which require appropriate software, user-friendly peripherals and so forth. Diffusion research on computer-controlled machine tools and robotics (Fleck, 1983, 1988, 1993; Camagni, 1984, 1991; Jacobsson, 1986; Edqvist, 1989; Arcangeli *et al.*, 1991; Ayres, 1991B; Bessant, 1991; Bessant and Haywood, 1991; Carlsson and Jacobsson, 1993) has demonstrated the enormous importance of these systemic features and of local skills and institutions, but it cannot yet be said that international comparisons of diffusion of flexible manufacturing systems (FMS) and, still less, computer integrated manufacturing (CIM) yet give us a full picture of what is going on on a comparative international basis. The problems of compatibility standards also play a complex role in the diffusion of systems (David and Greenstein, 1990; David and Steinmueller, 1990; Greenstein, 1990).

Diffusion research in this and other fields has, nevertheless, shown conclusively that rates of diffusion vary a great deal, both by product, by system and by country (Nabseth and Ray, 1974; Romeo, 1975; Rosenberg, 1976; Stoneman, 1976, 1983; Ray, 1984; Mansfield, 1989; Ayres, 1991A; Dosi, 1991; Nakicemovic and Grübler, 1991). It has also shown that the productivity gains associated with diffusion vary enormously, partly because of the strong systemic features of most innovation (see Hughes, 1982, David 1991, for electric power; Miles, 1989; Thomas and Miles, 1989; Jagger and Miles, 1991; Mansell and Morgan, 1991; Antonelli, 1993, 1986, for telecommunications and telematic services; Fleck, 1983, 1988, 1993; Jacobsson, 1986; Kodama, 1986, 1991, 1992; Bessant and Haywood, 1991, for mechatronics). Moreover, comparative international research (e.g. Ray and Nabseth, 1974; Ray, 1984) has also shown that the country of first innovation is not necessarily the same as the country of most rapid diffusion or highest productivity gains.

7. Institutional change, trajectories and paradigms

In attempting to explain inter-firm, inter-industry and inter-country differences in rates of diffusion and associated productivity gains, neo-Schumpeterians have shown that such differences cannot be attributed simply to capital-embodied technical change but are heavily dependent in the first place on skill intensity, learning and training (as discussed in Section 4) and on managerial and organisational innovations in such areas as labour relations, incentives, hierarchical managerial structures, communication systems within and between firms, stock control systems and so forth (e.g. Dertouzous *et al.*, 1989; Matthews, 1989; Perez, 1989; Whiston, 1989; Cressey and Williams, 1990; Womack, Jones and Roos, 1990; Sorge *et al.*, 1990; Bessant and Haywood, 1991; OECD, 1991A, 1991B, 1992A; Gjerding *et al.*, 1992; Dankbaar, 1993; Piore, 1993; Sorge, 1993; Watanabe, 1993). This is especially true when it is a question of new technological systems (Bailey and Chakrabarty, 1985; David, 1991). Historians, such as Lazonick (1990, 1992A, 1992B), Chandler, (1990, 1977) and Landes (1970), had of course demonstrated the enormous importance of managerial innovations and their connections with more narrowly technical innovations in earlier waves of technical change. There are

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welcome indications of increasing cooperation and convergence between economists, business historians, organisation theorists and sociologists in studying these phenomena (see, for example, Stephen, 1984; Coombs, Saviotti and Walsh, 1987, 1992, ch. 1; Nakicenovic and Grübler, 1991; Dosi *et al.*, (eds), 1992, and the new journal *Industrial and Corporate Change*).

By definition, any radical innovation involves some change in the organisation of production and markets. Organisational and institutional innovations are thus inextricably associated with technical innovations. They are also often related to changes in infrastructure, as Kondratieff and Schumpeter suggested (see the pioneering study by Grübler, 1990). Moreover, as Schumpeter also pointed out, sometimes organisational managerial innovations can lead the way. Obvious major examples are the assembly line, containerisation, self-service, supermarkets and hypermarkets. Organisational innovations may often induce technical innovations too (Klein, 1977) but do not necessarily do so. On the other hand, technical developments in ICT have greatly facilitated new telematic services, such as telematic shopping, telematic banking and data networks (Mansell, 1988, 1989; Miles *et al.*, 1988; Miles, 1989, 1990; Thomas and Miles, 1989; Jagger and Miles, 1991) which may transform many aspects of social life (see also Gershuny, 1983; Gershuny and Miles, 1983, for social innovations in the division of labour). The introduction, implementation and diffusion of such generic technologies as information and communication technology or biotechnology are so obviously and intimately associated with a complex process of institutional and infrastructure change that neo-Schumpeterians (like the management of the firms which they study) have been obliged to pay more and more attention to these issues (Perez, 1985, 1989).

Another reason for the increasing preoccupation of neo-Schumpeterian economists with institutional change lies in the need to explain how relatively ordered processes of technical change can emerge from the diversity and uncertainty associated with invention and innovation. As evolutionary economists such as Boyer (1988, 1993), Eliasson (1988), Dosi and Orsenigo (1988), Johnson (1992), Foray (1993) and Nelson and Winter (1982) have strongly insisted, while macroeconomic growth requires microeconomic diversity and instability, it also requires processes of harmonisation, regulation, standardisation and routinisation to avoid chaotic instability and to reap the benefits of scale economies. In studying these processes neo-Schumpeterians have been responding to another of the challenges posed by Nelson and Winter (1977) in their search for 'useful theories of innovation'. They themselves (1982) assigned an important role to behavioural routines and also suggested that technologies had 'natural trajectories' of their own which enabled designers, engineers, managers and entrepreneurs to visualise likely future paths of development and growth. Very pervasive technologies, such as electric power, with multiple potential applications might be described as 'generalised natural trajectories'.

The notion of 'natural' trajectories has, on the other hand, been criticised by some sociologists (e.g. MacKenzie, 1990B; Sorge, 1993) on the grounds that these trajectories are not 'natural' phenomena but are socially and institutionally determined by the expectations, theories, activities and self interest of engineers, scientists, managers, entrepreneurs and their 'constituencies' (Bijker and Law, 1992). The 'natural' rate of interest and 'natural' rate of unemployment could be criticised on much the same grounds (Freeman, 1992). Nevertheless, the critics do not deny that trajectories, whatever their basis, do play an important role in the evolution of technology and do impart a definite pattern of development in much the same way as Kuhn's (1962)

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'normal' science. A useful and influential analogy has been made between scientific and technological paradigms (Dosi, 1982).

However, even within a paradigm, by definition innovation involves initially an increase in diversity—an extension of the range of products, processes and services. In the early stages of *diffusion*, also, as the research reviewed above has shown, this diversity will usually increase. Burton Klein (1977) has described the wide range of steam cars, electric cars and petrol-driven cars available in the United States in the early days of the internal combustion engine. Fleck (1983, 1988) has described the diversification of design of industrial robots to meet the wide variety of application environments. Utterback (1993) has analysed several industries and shown similar patterns in the early stages. At this stage, design is fluid, there are no standards (or very few) and there is great uncertainty about the future of the new products. This diversity may be further increased by the divergence of *national* markets, production and technology systems (e.g. Foray and Grübler, 1990). Since radical innovations also involve organisational and other institutional innovations there is scope for very considerable variety. Thus, although the assembly line, introduced by Ford to manufacture automobiles, was imitated in many other countries and other industries, Boyer (1990) describes several variations in Europe as well as in Japan, which made 'Fordism' a somewhat different system in each country. Boyer (1993), Foray (1993), Saviotti (1991) and Johnson (1992) are among many authors who maintain that institutional diversity in the diffusion of new technologies is an essential and beneficial feature of evolutionary development, as well as the technical diversity associated with technological competition (see Part IV of Foray and Freeman, 1993).

It is the institutional diversity which has led to the growing interest among neo-Schumpeterians in what have become known as 'national systems of innovation' (Lundvall, 1985, 1992; Nelson, 1985, 1992A, 1993; Freeman, 1987; Niosi, 1991; Mjøset, 1992). It is not only firms which diverge in their mode of implementing new technologies and in their management systems but many other institutions (Hollingsworth, 1993). Since firms depend on a variety of external linkages in acquiring the necessary technical, scientific and organisational knowledge, information and skills (Section 3), it is obvious that the national education and training system may have a considerable influence on firms' innovative performance, as well as a wide variety of research institutes, sources of technical information, consultancy services and government laboratories. However, most neo-Schumpeterians, following Lundvall (1992) and his colleagues, stress that a 'national system of innovation' is much more than a network of institutions supporting R&D; it involves inter-firm network relationships and especially user-producer linkages of all kinds (Andersen, 1992A), as well as incentive and appropriability systems, labour relations and a wide range of government institutions and policies (see also Perrin, 1988). Just as heterogeneity of firms and oligopoly have led neo-Schumpeterians to discard the assumptions of representative agents and perfect competition (Sylos-Labini, 1962; Dosi, 1984, 1988), so heterogenity of national systems of innovation and the hegemony of great powers have led them to discard notions of international convergence and to stress the phenomena of divergence in growth rates, 'forging ahead', catching up and falling behind (Abramowitz, 1986; Dosi and Freeman, 1992; Lundvall, 1992; Verspagen, 1992).

Dahmen (1950, 1988) already anticipated some features of 'national systems' with his theory of 'Development Blocks'. Three recent major contributions to the literature on national systems are Lundvall (1992), Mjøset (1992) and Nelson (1993). The Nelson

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book is a comparative study of a dozen or more countries, while the Lundvall book is a more theoretical analysis. The Mjøset book is about the Irish economy but reviews this in the context of comparisons with other small European countries. Together they go far to explain why countries like the United States (late nineteenth century) (Mowery, 1992B) and Japan (late twentieth century) could catch up with the erstwhile leaders and forge ahead in technology without necessarily leading in basic scientific research at the time (but see also Hicks *et al.*, 1992A, 1992B; and Cantwell, 1993). However, the Nelson study, together with such in-depth studies of Korea and Taiwan as Wade (1990), Amsden (1989), Jang-Sup Shin (1992) and Hobday (1992), show that catching up countries *do* need the sort of capability in basic science and education insisted upon by Pavitt (1993) as part of their national systems (see also Villaschi, 1992, on the case of Brazil). The work of the neo-Schumpeterians has clearly had a considerable influence on development economics as well as on the so-called 'new growth theory', with the acceptance of the key role of intangible investment in economic development (see especially World Bank, 1991). The research also, of course, throws much light on why countries fall behind (Cantwell, 1991B; Mjøset, 1992; Walker, 1993).

A major problem confronting this neo-Schumpeterian research tradition is to reconcile their emphasis on national diversity (and regional diversity: see Thwaites, 1978; Oakey, 1984; Russo, 1985; Thwaites and Oakey, 1985; Amin and Goddard, 1986; Goddard, Thwaites and Gibbs, 1986; Harris, 1988; Morgan and Sayer, 1988; Alderman and Davies, 1990; Bianchi and Bellini, 1991; Camagni, 1991; Saxenian, 1991; Scott, 1991; Storper and Harrison, 1991; Alderman *et al.*, 1993) in systems of innovation with the role of multinational corporations in the diffusion and global standardisation of both management methods and technical developments (Chesnais, 1988A, 1992; Dunning, 1988; Cantwell, 1989, 1991A, 1993; Casson, 1991). Following the tendency of multinationals to locate some production outside their home base there has also been a tendency to locate some R&D activities abroad. The extent and consequences of this tendency have been strongly debated among neo-Schumpeterians (Howells, 1990; Ohmae, 1990; Pearce, 1990; Porter, 1990; Wortmann, 1990; Niosi, 1991; Patel and Pavitt, 1991; Pausenberger, 1991; Reich, 1991; Freeman and Hagedoorn, 1992; Hu, 1992; Pearce and Singh, 1992; Cantwell, 1993). Some have stressed the role of cultural, educational, political and geographical factors (especially in diffusing tacit knowledge) in reinforcing national and regional networks of collaboration (Porter, 1990; Lundvall, 1992). Others have pointed to the role of world-wide liberalisation of trade and investment and of telecommunications and airlines in reducing the significance of such national influences and strengthening globalisation (Ohmae, 1990). Whilst 'globalisation' need not necessarily mean worldwide standardisation and loss of diversity, there are clearly powerful incentives within MNCs to reap scale economies in R&D and design as well as production and marketing.

Some degree of national and international 'lock-in' by standardisation is unavoidable for a whole variety of reasons such as the need for 'connectivity' in systemic innovations, consumer acceptance and learning, as well as scale economies. All of these have been especially evident in the world of computers and their multiple applications in industry and services, as well as in telecommunication systems and the new network services (Rosario and Schmidt, 1991; Hawkins, 1992). The dilemma of 'freezing' on standards too early and thereby locking out potentially superior innovations at least for a while, or of failing to set standards early enough, is one that is permanently associated with innovation and is resolved not by optimal rationality but by oligopolistic competition,

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political bargaining and conflict at both national and international levels (David, 1986; David *et al.*, 1990A, 1990B; Greenstein, 1990; Mansell, 1990B; Mansell and Morgan, 1991; Rosario and Schmidt, 1991). Nor is this dilemma confined to diffusion and standardisation, as Gjerding (1992) and Holbek (1988) have shown; it is inherent in innovation itself. There is always the possibility of improving a design and/or a technology so that the firm is constantly involved in the dilemma of when to 'freeze' the design. As Rothwell and Gardiner (1988) have shown, the best designs are 'robust designs' which have the potential for 'stretch' and adaptation over a considerable period, but these are robust not optimal (see also Utterback and Suarez, 1993, for the concept of 'dominant design').

Finally, there has always been a dilemma between the choice of incentives for *innovation* and incentives for *diffusion*. The patent system has had as one of its primary objectives to provide a stimulus to invention by granting a temporary monopoly for exploitation but this monopoly may of course retard diffusion. The dilemma of designing an 'optimal' appropriability regime has never been satisfactorily resolved, as is evident both from the literature (e.g. Taylor and Silberston, 1973; Mansfield *et al.*, 1981; Levin *et al.*, 1985, 1987; Levin, 1986, 1988; Teece, 1987; Winter, 1989, 1993; Antonelli and Foray, 1992; Foray, 1992; Cohendet *et al.*, 1993) and from the history of patent legislation in many countries. Neo-Schumpeterian research has made a significant contribution in this field, by confirming the relatively limited role that patents play in protecting firms' new technology in most industries (Levin *et al.*, 1987) and by demonstrating the important contribution of other methods. The Yale Survey has also been valuable in demonstrating the industry-specific nature of these methods; the extension of this Survey to Europe in 1993 was therefore very welcome.

The constant re-emergence of novelty and diversity means that unique features of historical development must always be important for neo-Schumpeterians (see, for example, Pierre Dockès on 'histoire raisonée et économie historique', 1991). History always matters and much research has been devoted to 'mapping' the nature and direction of technical change. Sahal (1977, 1981, 1985), Dosi (1982), Utterback and Abernathy (1975), Hill and Utterback (1979) and Utterback (1993) all represent attempts to identify characteristic patterns of the evolution of technology. Sahal starts from the rejection of either exclusively demand-pull theories of technological development or of pure supply-push theories, maintaining that technology both shapes its socioeconomic environment and is shaped by it. He stresses in particular the influence of scale and size on the evolution of technology: ultimately, the process of scaling up (or of miniaturisation) reaches limits and at this time radical innovations are needed to open up new 'avenues of innovation'. Some of those avenues may be so broad that they afford new opportunities in many sectors—recalling Nelson and Winter's 'generalised natural trajectories'.

Sahal's approach, like that of Metcalfe (1981), points to the importance of cyclical phenomena in the growth of industries and technologies and to the importance of *timing* in relation to public policy. Utterback and Abernathy (1975) and Abernathy and Clark (1975) also stress the cyclical path of evolution of technology and their work is of particular interest in relation to the issue of *process* innovations associated with scaling up. It also indicates an important link between theories of evolution of technology and the problems of firm strategies discussed by Teece *et al.* (1990), Teece (1986), Coombs and Richards (1991), Dodgson (1991) and many others. Neo-Schumpeterians have not on the whole succeeded in developing a behavioural theory relating firm *strategy* to routines

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and rules of thumb (but see Mulder and Vergragt, 1990; Quintella, 1993). Business studies theorists and economists have remained too far apart in this area.

There have been relatively few attempts to place the whole discussion of technological trajectories, patterns of innovation and the selection environment in the wider context of the evolution of the economic system as a whole. Many authors have followed Dosi (1982) in drawing a parallel between Kuhn's idea of 'paradigms' in the development of science and the evolution of technology. But the notion of a 'techno-economic paradigm', as put forward by Carlota Perez (1983, 1985, 1989) in her papers on microelectronics and world structural and institutional change, has several original distinguishing features. In the first place, her concept of a change in 'techno-economic paradigm' is one of a change in the basic approach and 'common-sense' of designers, engineers and managers which is so pervasive that it affects almost all industries and sectors of the economy. Secondly, she argues that the *economic* motivation for such a change of paradigm lies not only in the availability of a cluster of radical innovations offering numerous new potential applications, but also in the *universal* and *low cost* availability of a key factor or combination of factor inputs. This recalls Schumpeter's 'successive industrial revolutions' based on new factor combinations. Finally, she argues that, before a new techno-economic paradigm can generate a new wave of world-wide economic growth, there is a period of adaptation of the socio-institutional framework, corresponding to the recession and depression phases of Schumpeter's 'long waves' of economic development. The old institutions suffer from inertia (see also Olson, 1982) and were in any case adapted to a now increasingly obsolete technological style and hence tend to 'lock out' alternative systems. There is therefore a period of 'mismatch' or structural adjustment between the new technology and the old framework affecting especially education and training, but also management structures, capital and labour markets, standards and regulation systems (see also Andersen, 1991). Perez therefore offers a link between the cyclical theories of technological evolution advanced by Sahal, Utterback, Abernathy and others and the theories of path-dependency, structural change and 'lock out' of alternatives put forward by Arthur, David, Dosi and others. The French 'Régulation' School (Boyer, 1988) has many points of resemblance but originally did not attribute such a big role to technical change. (See also the concept of 'socio-technical paradigms', Dockès, 1993; Roobeek, 1987.)

For Perez as for the 'Régulation' School, the problem of stable growth is fundamentally a cyclical one. Periods of 'structural adjustment' are characterised by a high degree of instability and institutional turmoil but they are succeeded by quite long periods of prosperous growth based on the achievement of a good match between new technology, new routines and procedures in the sphere of the economy and other new institutions. Thus, both at the micro- and the macro-level, many neo-Schumpeterians look to institutional change to achieve and maintain harmonious growth and development.

A far more controversial twist to long-run theories of evolutionary development has come from Gomulka (1990). After many penetrating comments on the former East European national systems of innovation he comes by an ingenious route to the paradoxical conclusion that Schumpeter was right after all and the future will be a slow-down of innovation and a socialist system for reasons of social justice. (See also the subtle analysis of Schumpeter's 'Capitalism, Socialism and Democracy' by Heertje, 1992.)

From this it is evident that the neo-Schumpeterians, as well as other institutional economists, have breathed some new life into the debates which were central to classical

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political economy and have always been the preoccupation of historians, but had been somewhat neglected by mainstream theory (Hodgson, 1993).

8. Conclusions

Clearly, it has not been possible within the limits of a relatively short survey article to cover an exploding field in all its depth and richness. As indicated in Section 1, entire topics have been left aside, including some where neo-Schumpeterian research has made an outstanding contribution, such as international trade (e.g. Posner, 1961; Hufbauer, 1966; Vernon, 1966; Walker, 1977; Soete, 1981, 1987; Krugman, 1986; De la Mothe, 1990; Dosi, Pavitt and Soete, 1990; Dalum, 1992; Fagerberg, 1992) and others where it has done very little, such as consumer behaviour. For the same reasons, this section concentrates only a few of the most important topics.

Measurement

Neo-Schumpeterians have made original and ingenious use of a wide variety of statistics for the measurement of various aspects of technical change (scientometrics, technometrics, patents, R&D expenditures and personnel, innovations, diffusion rates and so forth). They have certainly not been uncritical in these endeavours and have initiated improvements in many areas (Freeman, 1962, 1987A; OECD, 1992B; Martin and Irvine, 1981, 1983, 1985; Soete *et al.*, 1983, 1989; Archibugi *et al.*, 1987; Basberg, 1987; Irvine and Martin, 1987; Pavitt, 1987, 1985; Griliches, 1990; Grupp, 1991; Archibugi and Pinta, 1992). They have been fortunate in the encouragement and support they have received from the OECD Directorate for Science, Technology and Industry, the US National Science Foundation and UNESCO on Science and Technology Indicators. The OECD took the lead in standardisation of R&D statistics and has worked hard at improving them (OECD, 1963, 1970, 1976, 1981, 1993). It has also stimulated the development of new statistics intended to measure the 'output' of R&D (e.g. OECD, 1992B).

Nevertheless, as the neo-Schumpeterians certainly recognise, there are still some serious gaps and problems with the available statistics which have been pointed out in Sections 4, 5 and 6. In particular, it is often unsatisfactory to use R&D expenditure statistics as a surrogate for all those activities at the level of the firm which are directed towards knowledge accumulation, technical change and innovation. We have measures of 'capital-intensity' and of 'energy-intensity' but not of 'knowledge-intensity'. There will always be problems in defining and measuring 'knowledge-intensity' but a more serious attempt will be needed in the 1990s and the twenty-first century. Now that the role of 'intangible investment' has been generally recognised as equal in importance or even more important than fixed investment (World Bank, 1991; OECD, 1992A) it should be possible to make significant progress. These comments should not of course be taken as a denial of the great importance of R&D in the twentieth century. R&D remains at the heart of the network of institutions promoting technical change and is itself evolving (see for example, Meyer-Krahmer, 1990, 1992).

Another major gap, where there has however already been some progress, is in the measurement of innovation outputs (OECD, 1992B). The OECD *STI Review* (December) reports the results of innovation measurement and survey work in six different European countries (Smith and Vidrei, Norway; Deiaco, Sweden; Kleinknecht and Reijnen, Netherlands; Cesaratto and Sirilli, Italy; Scholz, Germany;

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Auzeby and Francois, France). As the OECD (1992B) Introduction points out, these surveys are 'quite heterogeneous in terms of objectives, methods, definitions and so on' but nevertheless add considerably to our knowledge about innovation. Moreover, these efforts and earlier work have made it possible for the OECD to produce guidelines for Standard Statistical Practice in this field (The 'Oslo Manual') and to work with the EC on a European Innovation Survey in 1993 based partly on the Manual.

This is a good example of fruitful interaction between academic research, national statistical offices in various countries, industrial agencies and firms and international organisations to generate valuable new data and analysis. It is to be hoped that it will be followed by much further work on scientific and technical services, intangible investment, diffusion of innovations and skills. However, there are still big problems of definitions (Winter, 1986, 1987, 1988), classification and measurement to be resolved in all these areas.

Industry-specific studies

Neo-Schumpeterians have made a significant response to the plea of Nelson and Winter (1977) for greater attention to industry-specific features of technical change. Nevertheless, as noted in Section 5, there are still many industries which have received very little attention. In particular, in common with industrial economics in general, far too little attention has been paid to the tertiary sector. Agriculture (e.g. Griliches, 1958; Ruttan, 1982; Feller *et al.*, 1987), mining (e.g. Townsend, 1976; Surrey, 1992) and especially manufacturing (see Section 5) have all been fairly intensively studied, but service industries hardly at all.

This is very unsatisfactory for many reasons, though principally, of course, for the fact that service industries now account for nearly three-quarters of total employment in some industrial countries. A second reason is that they are now deeply affected by new technologies (in particular, information technology). For example, financial services are becoming very capital intensive and in particular, computer intensive; however, from the little work that has been done, it seems that they may not yet be very knowledge intensive. This is a rapidly changing situation and illustrates exactly the kind of transformation which merits the attention of neo-Schumpeterian research. Certainly there have been some studies (e.g. Heertje, 1988; Baba and Takai, 1990; Barras, 1990; DeWit, 1990; Cassiolato, 1992; Christensen, 1992) but they do not yet measure up to the scale of the problems. Organisational innovations in particular have been relatively neglected.

Perhaps even more important, and an even bigger gap, are the new and rapidly expanding services associated with computerisation: above all, software, multimedia, data banks and telematic services. Again, of course, there have been some pioneering studies (e.g. Mansell, 1988, 1989, 1990A; Thomas and Miles, 1989; Miles *et al.*, 1990, 1991; Brady, 1991; Quintas, 1993) but the rate of change is so rapid and the emerging structures, services and products so difficult to define and measure that they merit far more continuous study and research over a considerable period.

Networks, concentration and firm behaviour

As indicated in Sections 3 and 7, there are major theoretical issues which are still unresolved in the exciting area of firm behaviour, inter-firm networking and so-called 'globalisation'. The neo-Schumpeterians have surely been right to emphasise the

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evolutionary and changing aspects of firm organisation and behaviour (Chandler, 1977, 1990; Winter, 1964, 1971, 1986b, 1988; Witt, 1993). Their vision of the firm as a learning, innovating organisation, their insistence on the heterogeneity of firms (Dosi, 1984; Nelson, 1991B, 1992B) and their observations of the multiple external knowledge and information linkages of firms have brought realism and plausibility to economic theory in an area which was in danger of losing touch altogether with the realities of everyday life. Schumpeter was right to exonerate Walras and Marshall from the simplistic charge of believing that the entrepreneur could have omniscient knowledge (Andersen, 1992B) but both Schumpeter and neo-Schumpeterians are surely right in their critique of the poverty-stricken assumptions that price signals contained sufficient information to explain the most important features of firm behaviour, or that firms behave 'as if' they had perfect knowledge and foresight.

In particular, neo-Schumpeterians have given an extremely interesting account of Japanese firms. However, it is by no means clear whether the 'J-firm' is culturally specific to Japan, whether the activities of Japanese MNCs will diffuse its essential features through the world, or indeed, whether Japanese firms will adopt some features of their American and European competitors. In some senses, the 'networking' firm has always been with us (Allen, 1983; Freeman, 1991). The neo-Schumpeterians have not yet really clarified just what is new about the networking firms of the late twentieth century. Is it their use of ICT? Or their adoption of management techniques characteristic of J-firms? Or is it a temporary upsurge of networking to cope with the need for technological complementarities associated with the new generic technologies? How do networking firms affect the theory of monopoly and oligopoly? It is very much to the credit of neo-Schumpeterians that they are alive to new trends in firm behaviour and some of the effects of diffusion of new technologies, and it would also be unfair to expect them to provide complete answers to some questions which puzzle everyone. Nevertheless, these questions indicate that the neo-Schumpeterians still have a long way to go in their theoretical analysis as well as in their empirical research on such questions as the behaviour of Japanese firms outside Japan and the behaviour of American and European subsidiaries inside Japan, and the evolution of networks over time. Indeed, for people who believe above all in evolutionary development, the approach of some neo-Schumpeterians to networks has been surprisingly 'static'. (But see Lundgren (1991) for an extremely interesting longitudinal analysis of image processing networks in Sweden.)

Models

In view of their emphasis on diversity of firms, industries and economic systems, as well as on discontinuities in technical change, and their reluctance to accept easy simplifying generalisations too remote from reality, it is perhaps surprising that neo-Schumpeterians have in fact already generated quite a large family of interesting models. In his review of this new generation of models, however, Silverberg (1988) points out that there were early predecessors, such as Goodwin's (1951) demonstration that self-sustaining business cycles were only possible in the context of non-linear models. Boyer (1993) also points to the importance of Keynesian and Kaldorian models in the development of evolutionary approaches (see also Boyer and Petit, 1989)

As Boyer (1988, 1993) shows, the findings of neo-Schumpeterian research (Sections 3 to 7 above) have had two rather different outcomes. On the one hand, they have led some economists to try and improve general equilibrium modelling by extending it to include more realistic assumptions about the externalities associated with innovation,

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networks, and education and increasing returns. This is the direction of the so-called 'new growth theory' (Helpman and Grossman, 1991; Romer, 1986, 1993; Aghion and Howit, 1993). On the other hand, most neo-Schumpeterians have preferred to follow the pioneering approach of Nelson and Winter (1974, 1982) and to discard altogether the general equilibrium approach in favour of evolutionary modelling (e.g. Gibbons and Metcalf, 1983; Iwai, 1984A, 1984B; Silverberg, 1984, 1987, 1988, 1990; Dosi, Silverberg and Orsenigo, 1988; Silverberg *et al.*, 1988; Smith, 1991; Amable, 1992, 1993; Dosi *et al.*, 1992; Silverberg and Lehnert, 1992; Weidlich and Braun, 1992; Chiaromonte and Dosi, 1993; and see also Arthur *et al.*, 1987, and the references to Arthur and David in Section 2).

These and other simulation models have certainly demonstrated the feasibility of modelling aspects of economic behaviour which were previously ignored (innovations and their diffusion, various appropriability regimes, heterogeneity of agents, learning by interacting, quality improvements, dynamic efficiency and so forth). However, the diversity of agents, industries and national circumstances, the complexity of their interactions, and the lack of sufficient understanding of some of the key relationships, mean that these evolutionary models, although more realistic and richer in many respects than their predecessors, need to be constantly complemented and tested against the type of historical and empirical research which has been the hallmark of the neo-Schumpeterian tradition. Such research is in any case always essential, since the reality which they attempt to represent is in a constant state of flux and is a unique historical process. Probably the best example of such an evolutionary micro–macro model is that developed by Eliasson at IUI in Sweden (1986, 1990, 1991A, 1991B, 1991C). This work is particularly good in illustrating the importance of new entry and diversity for stable and rapid economic growth.

It is very much to be hoped that the neo-Schumpeterians above all do not fall into the trap of recent generations of economists in sacrificing descriptive realism and richness of historical evidence to the requirements of formal mathematisation. With this reservation, they have given a valuable new impulse to the prolonged efforts of the profession to provide satisfactory formal representation of the complex, untidy and changing behaviour of the economic system.

A new form of assessment?

This section has raised some criticisms of neo-Schumpeterian research as well as a rather positive general view of its achievements. The empirical research discussed in Sections 3 to 7 has been a relatively strong feature of the neo-Schumpeterian tradition. But also on any showing, such books and papers as Nelson and Winter (1974, 1982); Nelson (ed.) (1993); Rosenberg (1976, 1982, 1993), Stoneman (1983), Dosi *et al.* (1988), Antonelli, Petit and Tahar (1992), Aoki (1988), Arthur (1986, 1988, 1989), David (1976, 1985, 1991, 1993), Hodgson (1993), Lundvall *et al.* (1992), Winter (1971, 1988), Dosi, Pavitt and Soete (1990) and Soete (1981, 1991) represent a significant contribution to economic theory, which challenges a number of cherished conventional ideas and assumptions. Clearly this is a biassed survey coming from someone who has been rather heavily involved in this type of research for nearly 35 years. It would be desirable, therefore, to invite a more critical survey from someone who has been closer to the mainstream of economic theory. But even better might be to innovate with a new form of assessment. Most refereeing work in any discipline and most literature survey work is done by specialists *within* that discipline or sub-discipline, for obvious reasons. However,

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there would be a good argument in this case for inviting an assessment or critical survey from well-qualified people *outside* the discipline of economics, i.e. an international panel of engineers, biologists, physicists, historians, geographers, sociologists, political scientists, psychologists and scholars from business studies.

An assessment from neighbouring disciplines is desirable in any case for several reasons, especially:

(i) the overlap with several of these disciplines is considerable and in some cases interdisciplinary research is already important. Collaboration with engineers and scientists is in any case essential in this field;

(ii) there is a possibility of a more objective and certainly more independent view of some fundamental issues than from within the economics discipline.

A century ago the *Methodenstreit* divided the German economics profession and raised many similar questions. Whilst the neo-Schumpeterians would probably not wish to be identified with Schmoller or the neoclassicals necessarily with Carl Menger, the basic questions of how much does history matter, the role of country-specific institutions, and the limits of universal generalisations about economic behaviour are still with us. Schumpeter attempted (and according to most accounts failed) to bridge the warring camps in the *Methodenstreit*. It could be a fruitful experiment, although difficult to set up, to see if an interdisciplinary assessment could make any contribution to the dilemmas of the economics profession today.

Bibliography

Abernathy, W. J. and Clark, K. B. 1985. Innovation: mapping the winds of creative destruction, *Research Policy*, vol. 14, 3–22

Abramowitz, M. 1986. Catching up, forging ahead and falling behind, *Journal of Economic History*, vol. 46, 385–406

Achilladelis, B. G., Schwarzkopf, A. and Lines, M. 1987. A study of innovation in the pesticide industry, *Research Policy*, vol. 16, no. 2, 175–212

Achilladelis, B. G., Schwarzkopf, A. and Lines, M. 1990. The dynamics of technological innovation: the case of the chemical industry, *Research Policy*, vol. 19 no. 1, 1–35

Acs, Z. J. L. 1990. 'High Technology Networks in Maryland', paper presented at Montreal Conference on Network Innovators, May

Acs, Z. J. and Audretsch, D. B. 1988. Innovation in large and small firms: an empirical analysis, *American Economic Review*, vol. 78, no. 4, September

Afuah, A. N. and Utterback, J. M. 1991. The emergence of a new supercomputer architecture, *Technological Forecasting and Social Change*, vol. 40, 315–28

Aghion, P. and Howitt, P. 1993. A model of growth through creative destruction, in Foray, D. and Freeman, C. (eds) (1993)

Alchian, A. 1951. Uncertainty, evolution and economic theory, *Journal of Political Economy*, vol. 58, 211–22

Alderman, N. and Davies, S. 1990. Modelling regional patterns of innovation diffusion in the UK metal-working industries, *Regional Studies*, vol. 24, 513–528

Alderman, N. and Wynarczyk, W. 1993. The performance of innovative small firms: a regional issue, in Swann, P. (ed.) (1992)

Allen, R. C. 1983. Collective invention, *Journal of Economic Behaviour and Organisation*, vol. 4, 1–24

Amable, B. 1992. 'Radical and Incremental Innovation in a Model of Endogenous and Unsteady Growth', paper at MERIT Conference, Maastricht, December

Amable, B. 1993. National effects of learning, international specialisation and growth paths, in Foray, D. and Freeman, C. (eds) (1993)

Amendola, M. and Gaffard, J. L. 1988. *The Innovation Choice: An Economic Analysis of the Dynamics of Technology*, Oxford, Blackwell

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Ames, E. 1961. Research, invention, development and innovation, *American Economic Review*, vol. 51, no. 3, 370–81
Amin, M. and Goddard, J. B. (eds) 1986. *Technological Change, Industrial Restructuring and Regional Development*, London, Allen and Unwin
Amsden, A. 1989. *Asia's Next Giant: South Korea and Late Industrialisation*, Oxford and New York, Oxford University Press
Andersen, E. S. 1991. Techno-economic paradigms as typical interfaces between producers and users, *Journal of Evolutionary Economics*, vol. 1, no. 2, 119–144
Andersen, E. S. 1992A. Approaching national systems of innovation from the production and linkage structure, in Lundvall, B.-Å. (ed.) (1992)
Andersen, E. S. 1992B. 'The Difficult Jump from Walrasian to Schumpeterian Analysis', paper at International Schupeter Society Conference, Kyoto, August
Andersen, E. S. 1994. *Schumpeter and the Elements of Evolutionary Economics*, London, Pinter
Angello, M. M. 1990. *Joseph Alois Schumpeter: A Reference Guide*, Berlin, Springer-Verlag
Antonelli, C. 1986. The international diffusion of new information technologies, *Research Policy*, vol. 15, 139–47
Antonelli, C. 1992. 'The Economics of Localised Technological Change: The Evidence from Information and Communication Technologies', University of Turin, Department of Economics
Antonelli, C. (ed.) 1992. *The Economics of Information Networks*, Amsterdam, Elsevier
Antonelli, C. 1993. The dynamics of technological inter-relatedness: the case of information and communication technologies, in Foray, D. and Freeman, C. (eds) (1993)
Antonelli, C. and Foray, D. 1991. 'The Economics of Intellectual Property Rights and Systems of Innovation', University of Turin, mimeo
Antonelli, C, Petit, P. and Tahar, G. 1992. *The Economics of Industrial Modernisation*, London, Academic Press
Aoki, M. 1986. Horizontal versus vertical information: structure of the firm, *American Economic Review*, vol. 76, no. 5, 971–83
Aoki, M. 1988. *Information, Incentives and Bargaining in the Japanese Economy*, New York, Cambridge University Press
Aoki, M. 1990. Towards an economic model of the Japanese firm, *Journal of Economic Literature*, vol. 28, 1–27
Aoki, M. 1991. 'The Japanese Firm as a System: Survey and Research Agenda', paper at Stockholm Conference on Japan, Stockholm School of Economics, September
Arcangeli, F., David, P. and Dosi, G. (eds) 1994. *Frontiers on Innovation Diffusion*, Report of the Venice Conference on Innovation Diffusion (1986) (3 vols), DAEST, Venice, Oxford University Press, in press
Arcangeli, F., Dosi, G. and Moggi, M. 1991. Patterns of diffusion of electronics technologies: an international comparison, *Research Policy*, vol. 20, no. 6, 515–31
Archibugi, D. 1988A. In search of a useful measure of technological innovation, *Technological Forecasting and Social Change*, vol. 34, 253–77
Archibugi, D 1988B. The inter-industry distribution of technological capabilities. A case study in the application of the Italian patenting in the USA, *Technovation*, vol. 7, no. 3, 259–74
Archibugi, D., Cesaratto, S. and Sirilli, G. 1987. Innovative activity, R&D and patenting: the evidence of the survey on innovation diffusion in Italy, *Science Technology Industry Review*, vol. 2, 135–50
Archibugi, D. and Pinta, M. 1992. *The Technological Specialisation of Advanced Countries*, Report to the EC on International Science and Technology Activities, Dordrecht, Kluwer
Arrow, K. 1962. The economic implications of learning by doing, *Review of Economic Studies*, vol. 29, 155–73
Arthur, W. B. 1983. 'Competing Techniques and Lock-in by Historical events. The Dynamics of Allocation Under Increasing Returns', IIASA, Luxemburg. Revised edition (1985) CEPR, Stanford University
Arthur, W. B. 1986. 'Industry, Location and the Importance of History', Center for Economic Policy Research Paper 84, Stanford University
Arthur, W. B. 1988. Competing technologies: an overview, in Dosi, G. *et al.* (eds) (1988)
Arthur, W. B. 1989. Competing technologies, increasing returns and lock-in by historical events, *Economic Journal*, vol. 99, vol. 1, 116–31

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Arthur, W. B., Ermoliev, Y. M. and Kaniovski, Y. M. 1987. Path-dependent processes and the emergence of macro-structure, *European Journal of Operational Research*, vol. 30, 294–303
Arundel, A. and Soete, L. (eds) 1993. 'An Integrated Approach to European Innovation and Technology Diffusion Policy: A Maastricht Memorandum', University of Limburg, MERIT
Auzeby, F. and Francois, J.-P. 1992. Technological innovation in the French industry, *STI Review*, vol. 11, 118–24
Ayres, R. V. 1991A. 'Information, computers, CIM and productivity', in OECD (1991B)
Ayres, R. V. 1991B. *Computer Integrated Manufacturing 1*, (4 vols) London, Chapman and Hall/IIASA
Baba, Y. 1985. 'Japanese Colour TV Firms. Decision-making from the 1950s to the 1980s', DPhil dissertation, University of Sussex.
Baba, Y. and Takai, S. 1990. Information technology introduction in the big banks: the case of Japan, in Freeman, C. and Soete, L. (eds) (1990)
Bailey, M. W. and Chakrabarti, A. K. 1985. Innovation and productivity in US industry, *Brookings Papers*, vol. 2, December, 609–32
Barras, R. 1986. Towards a theory of innovation in services, *Research Policy*, vol. 15, no. 4, 161–173
Barras, R. 1990. Interactive innovation in financial and business services: the vanguard of the service revolution, *Research Policy*, vol. 19, no. 3, 215–237
Basberg, B. 1987. Patents and the measurement of technological change: a survey of the literature, *Research Policy*, vol. 12, 131–143
Bell, M. 1984. Learning and accumulation of industrial and technological capability in developing countries, in King, K. and Fransman, M. (eds) *Technological Capacity in the Third World*, London, Macmillan
Bell, M. 1991. 'Science and Technology Policy Research in the 1990s: Key Issues for Developing Countries', Brighton, University of Sussex, SPRU
Bell, R. M. N., Cooper, C. M., Kaplinsky, R, M. and Wit Sakyarakwit 1976. *Industrial Technology and Employment Opportunity: A Study of Technical Alternatives for Can Manufacture in Developing Countries*, Geneva, International Labour Organisation
Bell, M., Pavitt, K. 1992. 'National Capacities for Technological Accumulation', World Bank Conference on Development Economics, 1 May
Bernal, J. D. 1939. *The Social Function of Science*, London, Routledge and Kegan Paul
Bernal, J. D. 1970. *Science and Industry in the Nineteenth Century*, 3rd edn, Bloomington, Indiana University Press
Bessant, J. 1991. *Managing Advanced Manufacturing Technology*, Oxford, Blackwell, NEC
Bessant, J. and Haywood, W. 1991. Mechatronics and the machinery industry, in Freeman, C., Sharp, M. and Walker, W. (eds), *Technology and the Future of Europe*, London, Frances Pinter
Bessant, J., Burnell, J., Hardy, R. and Webb, S. 1994. Continuous innovation in British manufacturing, in *Technovation*, in press
Bianchi, P. and Bellini, N. 1991. Public policies for local networks of innovators, *Research Policy*, vol. 20, no. 5, 487–97
Bijker, W. E. and Law, J. (eds) 1992. *Shaping Technology, Building Society*, Cambridge MA, MIT Press
Blaug, M. 1964. *Economic Theory in Retrospect*, London, Heinemann
Boyer, R. 1988. Technical change and the theory of regulation, in Dosi, G. *et al.* (eds) (1988)
Boyer, R. 1993. The models revolution, Introduction to Part II, in Foray, D. and Freeman, C. (eds) (1993)
Boyer, R. and Petit, P. 1989. Kaldor's growth theories: past, present and prospects, in Semmler, W. and Neil, E. (eds) *Nicholas Kaldor and Mainstream Economics*, London, Routledge
Brady, T. M. 1986. *New Technology and Skills in British Industry*, Skills Series 5, Manpower Services Commission
Brady, T. and Quintas, P. 1991. Computer software: the IT constraint, in Freeman, C., Sharp, M. and Walker, W. (eds) *Technology and the Future of Europe*, London, Frances Pinter
Braun, E. and MacDonald, S. 1978. *Revolution in Miniature: The History and Impact of Semi-Conductor Electronics*, Cambridge, Cambridge University Press
Bressand, A. 1990. Electronic cartels in the making? *Transatlantic Perspectives*, no. 21, 3–6
Bressand, A and Kalypso, N. (eds) 1989. *Strategic Trends in Services: an Inquiry into the Global Service Economy*, New York, Harper and Row

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Burns, T. and Stalker, G. M. 1961. *The Management of Innovation*, London, Tavistock
Callon, M. 1993. Variety and irreversibility in networks of technique conception and adoption, in Foray, D. and Freeman, C. (eds) (1993)
Camagni, R., Dellisanti, G., Pattarozzi, M. and Taranto, R. 1984. *Il Robot Italiano Produzione e Mercato della Robotica Industriale*, Milano, 24 Ore
Camagni, R. (ed.) 1991. *Innovation networks: Spatial Perspectives*, London, Belhaven Press
Cantwell, J. 1989. *Technological Innovation and Multinational Corporations*, Oxford, Blackwell
Cantwell, J. 1991A. The International agglomeration of R&D, in Casson, M. (ed.) (1991)
Cantwell, J. 1991B. Historical trends in international patterns of technological innovation, in Foreman-Peck, J. (ed.) *New Perspectives on the Late Victorian Economy: Essays in Quantitative Economic History 1860–1914*, Cambridge, Cambridge University Press
Cantwell, J. 1994. *Transnational Corporations and Innovatory Activities*, London, Routledge
Carlsson, B. (ed.) 1989. *Industrial Dynamics*, Boston, Kluwer Academic Publishers
Carlsson, B. and Jacobsson, S. 1993. Technological systems and economic performance: the diffusion of factory automation in Sweden, in Foray, D. and Freeman C. (eds) (1993)
Carlsson, B. and Stankiewicz, R. 1991. On the nature, formation and composition of technological systems, *Journal of Evolutionary Economics*, vol. 1, no. 2, 93–119
Carter, C. F. and Williams, B. R. 1957. *Industry and Technical Progress*, Oxford, Oxford University Press
Carter, C. F. and Williams, B. R. 1958. *Investment in Innovation*, Oxford, Oxford University Press
Carter, C. F. and Williams, B. R. 1959A. *Science and Industry*, London, Oxford University Press
Carter, C. F. and Williams, B. R. 1959B. The characteristics of technically progressive firms, *Journal of Industrial Economics*, vol. 7, no. 2, 87–104
Cassiolato, J. 1992. The user-producer connection in hi-tech: a case study of banking automation in Brazil, in Schmitz, H and Cassiolato, J. (eds) *High-Tech for Industrial Development*, London, Routledge
Casson, M. (ed.) 1991. *Global Research Strategy and International Competitiveness*, Oxford, Blackwell
Cesaratto, S. and Sirilli, G. 1992. Some results of the Italian survey on technological innovation, *STI Review*, vol. 11, 80–95
Chandler, A. D. 1977. *The Invisible Hand: The Managerial Revolution in American Business*, Cambridge, MA, Belknap Press, Harvard University
Chandler, A. D. 1990. *Scale and Scope: The Dynamics of Industrial Capitalism*, Cambridge, MA, Belknap Press, Harvard University
Chandler, A. D. 1992. What is a firm?: a historical perspective, *European Economic Review*, vol. 36, 483–94
Chesnais, F. 1988A. *Multinational Enterprises and the International Diffusion of Technology*, in Dosi, G. *et al.* (eds) (1988)
Chesnais, F. 1988B. Technical cooperation agreements between firms, *STI Review*, vol. 4, Paris, OECD
Chesnais, F. 1992. National systems of innovation, FDI and the operations of MNEs, in Lundvall, B.-Å. (ed.) (1992)
Chiaromonte, F. and Dosi, G. 1993. The micro foundations of competitiveness and their macroeconomic implications, in Foray, D. and Freeman, C. (eds) (1993)
Christensen, J. L. 1992. The role of finance in national systems of innovation, in Lundvall, B.-Å. (ed.) (1992)
CI News 1993. Bulletin of the CIRCA, Continuous Improvement Network 2
Clark, J. A., Freeman, C. and Soete, L. L. G. 1981. Long waves, inventions and innovations, *Futures*, vol. 13, no. 4, 308–322
Clark, K. B. and Fujimoto, T. 1989. Lead time in automobile product development: explaining the Japanese advantage, *Journal of Engineering and Technology Management*, vol. 6, 25–58
Clark, N. 1990. Evolution, complex systems and technological change, *Review of Political Economy*, vol. 2, no. 1, 26–42
Coase, R. H. 1937. The nature of the firm, *Economica NS*, vol. 4, 386–405
Coase, R. H. 1988. The nature of the firm: origin, *Journal of Law, Economics and Organisation*, vol. 4, no. 1, 3–47

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Cohen, W. M. and Levinthal, D. A. 1987. Innovation and learning: the two faces of R&D, *Economic Journal*, vol. 99, no. 3

Cohendet, P. M., Ledoux, M. J. and Zuscovitch, E. 1987. *Les Matériaux Nouveaux*, Paris, Économica

Cohendet, P., Héraund, J.-A. and Zuscovitch, E. 1993. Technological learning, economic networks and innovation appropriability, in Foray, D. and Freeman, C. (eds) (1993)

Coombs, R., Saviotti, P. and Walsh, V. 1987. *Economics and Technological Change*, London, Macmillan

Coombs, R. and Richards, A. 1991A. Technologies, products and firms' strategies: Part 1—a framework for analysis, *Technology Analysis and Strategic Management*, vol. 13, no. 1, 77–86

Coombs, R, and Richards, A. 1991B. Technologies, products and firms' strategies: Part 2—analysis of three cases, *Technology Analysis and Strategic Management*, vol. 13, no. 2, 157–75

Coombs, R., Saviotti, P. and Walsh, V. 1992. *Technological Change and Company Strategies*, London, Academic Press

Cooper, C. 1974. Science policy and technological change in undeveloped economies, *World Development*, vol. 2, no. 3

Cooper, C. (ed.) 1973. *Science, Technology and Development*, London, Frank Cass

Cooper, C. M. and Sercovitch, F. 1971. *The Channels and Mechanisms for the Transfer of Technology from Developed to Developing Countries*, Geneva, UNCTAD

Cowan, R. 1990. Nuclear power reactors: a study in technological lock-in, *Journal of Economic History*, vol. 50, 541–67

Cressey, P. and Williams, R. 1990. *Participation in Change: New Technology and the Role of Employee Involvement*, Dublin, European Foundation for the Improvement of Living and Working Conditions

Cusumano, M. A. 1991. *Japan's Software Factories: A Challenge to US Management*, Oxford, Oxford University Press

Cyert, R. M. and March, J. G. 1963. *A Behavioural Theory of the Firm*, Englewood Cliffs, NJ, Prentice-Hall

Dahmen, E. 1950. *Entrepreneurial Activity in Swedish Industry 1909–1939*, Stockholm IUI

Dahmen, E. 1988. Development blocks in industrial economies, *Scandinavian Economic History Review*, vol. 1, 3–14

Dalum, B. 1992. Export specialisations, structural competitiveness and national systems of innovation, in Lundvall, B.-Å. (ed.) (1992)

Dankbaar, B. 1993. *Economic Crisis and Institutional Change: The Crisis of Fordism from the Perspective of the Automobile Industry*, Maastricht, University Press

Darwin, C. 1859. *The Origin of Species*, London, Murray

Dasgupta, P. and Stoneman, P. (eds) 1987. *Economic Policy and Technological Progress*, Cambridge, Cambridge University Press

David, P. A. 1975. *Technical Choice, Innovation and Economic Growth*, Cambridge, Cambridge University Press

David, P. A. 1985. Clio and the economics of QWERTY, *American Economic Review*, vol. 75, no. 2, 332–37, extended version published in Parker, W. N. (ed.) (1986) *Economic History and the Modern Economist*, Oxford, Blackwell

David, P. A. 1986A. 'Narrow Windows, Blind Giants and Angry Orphans: The Dynamics of Systems Rivalries and Dilemmas of Technology Policy', CEPR Working Paper 10, Stanford University, and in Arcangeli, F., David, P. and Dosi, G. (eds), in press

David, P. A. 1986B. Technology diffusion, public policy and industrial competitiveness, in Landau, R. and Rosenberg N. (eds) *The Positive Sum Strategy*, Washington DC, National Academy of Sciences

David, P. A. 1991. Computer and dynamo: the modern productivity paradox in a not-too-distant mirror, in OECD (1991B)

David, P. A. 1992. 'Knowledge, Property and the System Dynamics of Technological Change', paper presented to the World Bank Conference on Development Economics, Washington DC, 30 April–1 May

David, P. A. 1993. Path-dependence and predictability in dynamic systems with local network externalities: a paradigm for historical economics, in Foray, D. and Freeman, C. (eds) (1993)

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

David. P. and Greenstein, S. 1990. The economics of compatibility standards: an introduction to recent research, *Economics of Innovation and New Technology*, vol. 1, no. 1, 3–43
David, P. and Steinmuller, E. 1990. The ISDN bandwagon is coming, but who will be there to climb aboard? Quandaries in the economics of data communications networks, *Economics of Innovation and New Technology*, vol. 1, no. 1, pp. 43–63
Davies, S. 1979. *The Diffusion of Process Innovations*, Cambridge University Press
DeBresson, C 1989. Breeding innovation clusters: a source of dynamic development, *World Development*, vol. 17, no. 1, 1–6
DeBresson, C. 1993. *Comprendre Le Changement Technique*, Ottawa, Les Presses de l'Université d'Ottawa
DeBresson, C. and Amesse, F. 1991. Networks of innovators: a review and introduction to the issue, *Research Policy*, vol. 20 no. 5, 363–79
Deiaco, E. 1992. New views on innovative activity and technological performance: the Swedish innovation survey, *STI Review*, no. 11, 36–62
De la Mothe, J. 1990. *Science, Technology and Free Trade*, London, Pinter
Dertouzos, M., Lester, R. and Solow, R. (eds) 1989. *Made in America*, Report of the MIT Commission on Industrial Productivity, Cambridge MA, MIT Press
Dockès, P. 1991. Histoire 'raisonnée' et économie historique, *Revue Économique*, vol. 2, 181–208
Dockès, P. 1994. Les recettes fordists et les marmites de l'histoire (formation et transferts des paradigmes socio-techniques), *Revue Économique*, in press
Dockès, P. and Rosier, B. 1991. Économie et histoire, nouvelles approaches, *Revue Économique*, numéro special 2, March
Dodgson, M. 1991. *The Management of Technological Learning: Lessons from a Biotechnology company*, Berlin, De Gruyter
Dodgson, M. 1993. *Technological Collaboration in Industry*, London, Routledge
Dodgson, M. (ed.) 1989. *Technology Strategy and the Firm: Management and Public Policy*, London, Longman
Dodgson, M. and Sako, M. 1993. 'Learning and Trust in Inter-firm Linkages', paper at Conference on 'Technological Collaboration: Networks, Institutions and States', University of Manchester, April
Dore, R. 1973. *British Factory–Japanese Factory: the Origins of National Diversity in Industrial Relations*, Berkeley, University of California Press
Dore, R. 1985. The sources of the will to innovate, papers in *Science and Technology Policy*, vol. 4, London, Imperial College
Dore, R. 1987. *Taking Japan Seriously: A Confucian Perspective on Leading Economic Issues*, London, Athlone Press
Dosi, G. 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, *Research Policy*, vol. 11, no. 3, 147–62
Dosi, G. 1984. *Technical Change and Industrial Transformation*, London, Macmillan
Dosi, G. 1988. Sources, procedures and microeconomic effects of innovation, *Journal of Economic Literature*, vol. 36, 1126–71
Dosi, G. 1991. The research in innovation diffusion: an assessment, in Nakicenovic, N. and Grübler, A. (eds) (1991)
Dosi, G. and Egidi, M. 1991. Substantive and procedural uncertainty: an exploration of economic behaviour in changing environments, *Journal of Evolutionary Economics*, vol. 1, no. 2, 145–68
Dosi, G. and Freeman, C. 1992. 'The Diversity of Development Patterns: On the Processes of Catching Up, Forging Ahead and Falling Behind', paper prepared for the International Economics Association meeting, Varenna, 1–3 October
Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (eds) (1988). *Technical Change and Economic Theory*, London, Frances Pinter, and New York, Columbia University Press
Dosi, G., Gianetti, G. and Toninelli, P. A. (eds) 1992. *Technology and Enterprise in a Historical Perspective*, Oxford, Oxford University Press
Dosi, G. and Orsenigo, L. 1988. Coordination and transformation: an overview of structure, behaviour and change in evolutionary environment, in Dosi, G. *et al.* (eds) (1988)
Dosi, G., Pavitt, K. and Soete, L. 1990. *The Economics of Technical Change and International Trade*, Brighton, Wheatsheaf

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Dosi, G., Silverberg, G. and Orsenigo, L. 1988. Innovation diversity and diffusion: a self-organisation model, *Economic Journal*, vol. 98, no. 393, 1032–54
Dunning, J. H. 1988. *Multinationals, Technology and Competitiveness*, London, Unwin Hyman
Edqvist, C. 1989. 'The Realm of Freedom in Modern Times: New Technology in Theory and Practice', Tema T, Report 18, University of Linkøping, Department of Technology and Social Change
Eliasson, G. 1986. Micro-heterogeneity of firms and stability of industrial growth, in Day, R. and Eliasson, G. (eds) *The Dynamics of Market Economies*, Amsterdam, North Holland
Eliasson, G. 1988. Schumpeterian innovation, market structure, and the stability of industrial development, in Hanusch, H. (ed.) (1988)
Eliasson, G. 1990. The firm as a competent team, *Journal of Economic Behaviour and Organization*, vol. 13, no. 3
Eliasson, G. 1991A. Deregulation, innovative entry and structural diversity as a source of stable and rapid economic growth, *Journal of Evolutionary Economics*, vol. 1, no. 1, 49–63
Eliasson, G. 1991B. Modelling economic change and restructuring' in de Wolf, P. (ed) *Competition in Europe*, Kluwer, Dordrecht
Eliasson, G. 1991C. Modelling the experimentally organised economy: complex dynamics in an empirical micro-macro model of endogenous economic growth, *Journal of Economic Behaviour and Organisation*, vol. 16, 153–182
Eliasson, G. 1992. Business competence, organizational learning and economic growth: establishing the Smith–Schumpeter–Wicksell (SSW) connection, in Scherer, F, and Perlman, M. (eds) (1992)
Enos, J. L. 1962. *Petroleum Progress and Profits: A History of Process Innovation*, Cambridge, MA, MIT Press
Ergas, H. 1984. 'Why Do Some Countries Innovate More Than Others?' Center for European Policy Studies Paper 5, Bruxelles
Ergas, H. 1987. The importance of technology policy, in Dasgupta, P. and Stoneman, P. (eds) (1987)
Fagerberg, J. 1987. A technology gap approach to why growth rates differ, *Research Policy*, vol. 16, nos: 2–4, 87–101
Fagerberg, J. 1992. The home market hypothesis re-examined: the impact of domestic-user-producer interaction in exports, in Lundvall, B.-Å. (ed.) (1992)
Faulkner, W. 1986. 'Linkage between Academic and Industrial Research: The Case of Biotechnological Research in the Pharmaceutical Industry', DPhil thesis, University of Sussex
Feller, I., Madden, P., Kaltreider, L., Moore, D. and Sims, L. 1987. The new agricultural research and technology transfer policy agenda, *Research Policy*, vol. 16, no. 6, 315–327
Flamm, K. 1987. *Targeting Technology, National Policy and International Competition in Computers*, Washington DC, Brookings Institute
Flamm, K. 1988. *Creating the Computer: Government, Industry and High Technology*, Washington DC, Brookings Institution
Fleck, J. 1983. Robots in manufacturing organisations, in Winch, G. (ed.) *Information Technology in Manufacturing Processes*, London, Rossendale
Fleck, J. 1988. 'Innofusion or Diffusation? The Nature of Technological Development in Robotics', ESRC Programme on Information and Communication Technologies (PICT), Working Paper series, University of Edinburgh
Fleck, J. 1993. Configurations crystallising contingency, *The International Journal of Human Factors in Manufacturing*, vol. 3, no. 1, 15–36
Foray, D. 1987. *Innovation Technologique et Dynamique Industrielle*, Lyon, Presses Universitaires de Lyon
Foray, D. 1991. The secrets of industry are in the air: industrial cooperation and the organisational dynamics of the innovative firm, *Research Policy*, vol. 20, no. 5, 393–405
Foray, D. 1992. 'The Economics of Intellectual Property Rights and Systems of Innovation: The Inevitable Diversity', paper at MERIT Conference, Maastricht, December
Foray, D. 1993. General Introduction, in Foray, D. and Freeman, C. (eds) (1993)
Foray, D. and Freeman, C. (eds) 1993. *Technology and the Wealth of Nations*, London, Pinter
Foray, D. and Grübler, A. 1990. Morphological analysis: diffusion and lock-out of technologies: ferrous casting in France and the FRG, *Research Policy*, vol. 19, no. 6, 535–550

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Fransman, M. 1990. *The Market and Beyond: Cooperation and Competition in IT in the Japanese System*, Cambridge, Cambridge University Press
Freeman, C. 1962. Research and development: a comparison between British and American industry, *National Institute Economic Review*, vol. 20, 21–39
Freeman, C. 1971. *The Role of Small Firms in Innovation in the UK since 1945*, Bolton Committee Research Report 6, London, HMSO
Freeman, C. 1974. *The Economics of Industrial Innovation*, 1st edn, Harmondsworth, Penguin, second edition (1982) London, Frances Pinter
Freeman, C. (ed.) 1987A. *Output Measurement in Science and Technology*, Amsterdam, North-Holland
Freeman, C. 1987B. *Technology Policy and Economic Performance: Lessons from Japan*, London, Frances Pinter
Freeman, C. 1991A. Networks of innovators: a synthesis of research issues, *Research Policy*, vol. 20, no. 5, 499–514
Freeman, C. 1991B. Innovation, changes of techno-economic paradigm and biological analogies in economics, *Revue Économique*, vol. 42, no. 2, 211–32
Freeman, C. (ed.) 1992. *The Economics of Hope*, London, Pinter
Freeman, C. 1993. 'The Political Economy of the Long Wave', European Association of Political Economy, Barcelona Conference, October
Freeman, C., Clark, J. and Soete, L. 1982. *Unemployment and Technical Innovation*, London, Frances Pinter
Freeman, C, Fuller, J. K. and Young, A. J. 1963. The plastics industry: a comparative study of research and innovation, *National Institute Economic Review*, vol. 26, 22–62
Freeman, C. and Hagedoorn, J. 1992. 'Convergence and Divergence in the Internationalisation of Technology', paper for MERIT Conference, University of Limburg, December
Freeman, C., Harlow, C. J. E. and Fuller, J. K. 1965. Research and development in electronic capital goods, *National Institute Economic Review*, vol. 34, 40–97
Freeman, C. and Oldham, G. 1992. Requirements for science and technology policy in the 1990s, in Freeman, C. (ed.) (1992)
Freeman, C. and Perez, C. 1988. Structural crises of adjustment: business cycles and investment behaviour, in Dosi, G. *et al.* (eds) (1988)
Freeman, C. and Soete, L. (eds) 1990. *New Explorations in the Economics of Technical Change*, London, Pinter
Friedman, D. B. and Samuels, R. J. 1992. 'How To Succeed without Really Flying: the Japanese Aircraft Industry and Japan's Technology Policy', Cambridge, MA, MIT-JP 92-10, MIT Japan Program
Friedman, M. 1953. The methodology of positive economics, in *Essays in Positive Economics*, Chicago, Chicago University Press
Gaffard, J.-L. 1990. *Economie industrielle de l'innovation*, Paris, Dalloz
Gaffard, J.-L. 1993. Towards a theory of the creation of technology as an out-of-equilibrium process, in Foray, D. and Freeman, C. (eds) (1993)
Gann, D. 1992. 'Intelligent Building Technologies: Japan and Singapore', DTI Overseas Science and Technology Mission, Visit Report, London, DTI
Gann, D. 1994. 'Innovation and the Built Environment', Brighton, University of Sussex, SPRU.
Gazis, D. L. 1979. The influence of technology on science: a comment on some experiences of IBM research, *Research Policy*, vol. 8, no. 4, 244–259
Gershuny, J. 1983. *Social Innovation and the Division of Labour*, Oxford, Oxford University Press
Gershuny, J. and Miles, I. D. 1983. *The New Service Economy*, London, Frances Pinter
Gibbons, M. and Johnston, R. 1974. The role of science in technological innovation, *Research Policy*, vol. 3, 220–42
Gibbons, M. and Metcalfe, J. S. 1986. Technological variety and the process of competition, in Arcangeli, F. *et al.* (eds) (1994)
Gilfillan, S. C. 1935. *The Sociology of Invention*, Chicago, Follet Publishing Company
Gille, B, 1978. *Histoire des Techniques*, Paris, Gallimard
Gjerding, A. N. 1992. Work organisation and the innovation design dilemma, in Lundvall, B.-Å. (ed.) (1992)

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Gjerding, A. N., Johnson, B., Kallehauge, L., Lundvall, B.-Å. and Madsen, P. T. 1992. *The Productivity Mystery: Industrial Development in Denmark in the Eighties*, Copenhagen, DJØF Publishing

Goddard, J., Thwaites, A. and Gibbs, D. 1986. The regional dimension to technological change in Great Britain, in Amin, A. and Goddard, J. B. (eds) (1986)

Gold, B. 1981. Technological diffusion in industry: research needs and shortcomings, *Journal of Industrial Economics*, vol. 29, no. 3, 247–69

Gomulka, S. 1990. *The Theory of Technological Change and Economic Growth*, London, Routledge

Goodwin, R. M. 1951. The nonlinear accelerator and the persistence of business cycles, *Econometrica*, vol. 19, 1–17

Goto, A. 1982. Business groups in a market economy, *European Economic Review*, vol. 19, 53–70

Gowing, M. 1964. *Britain and Atomic Energy: Vol. I, Independence and Deterrence, Vol. 2, Policy Execution*, London, Macmillan

Granstrand, O. 1982. *Technology, Management and Markets*, London, Frances Pinter

Granstrand, O. 1986. The modelling of buyer/seller diffusion processes. A novel approach to modelling diffusion and simple evolution of market structure, in Arcangeli, F. *et al.* (eds) (1994)

Granstrand, O. and Sjölander, S. 1992. Managing innovation in multi-technology corporations, *Research Policy*, vol. 19, no. 1, 35–61

Graves, A. 1987. 'Comparative Trends in Automobile R&D', DRC Discussion Paper 54, Brighton, SPRU, University of Sussex

Graves, A. 1992. 'International Competitiveness and Technological Development in the World Automobile Industry', DPhil thesis, University of Sussex

Greenstein, S. 1990. Creating economic advantage by setting compatibility standards: can physical tie-in extend monopoly power? *Economics of Innovation and New Technology*, vol. 1, no. 1, 63–85

Griliches, Z. 1958. Research costs and social-returns: hybrid corn and related innovations, *Journal of Political Economy*, vol. 66, no. 5, 419–31

Griliches, Z. 1984. *R&D, Patents and Productivity*, Chicago, Chicago University Press

Griliches, Z. 1990. Patent statistics as economic indicators: a survey, *Journal of Economic Literature*, vol. 28, 1661–1707

Grübler, A. 1990. *The Rise and Fall of Infrastructures*, Heidelberg, Physica-Verlag

Grupp, H. 1991. Innovation dynamics in OECD countries: towards a correlated network of R&D—trade, patent and technometric indicators, in OECD (1991B)

Grupp, H. 1992. *Dynamics of Science-Based Innovation*, Berlin, Springer-Verlag

Grupp, H. and Hofmeyer, O. 1986. A technometric model for the assessment of technological standards and their application to selected technology comparisons, *Technological Forecasting and Social Change*, vol. 30, 123–137

Grupp, H. and Soete, L. 1993. 'Analysis of the Dynamic Relationship between Technical and Economic Performances in ICT Sectors 1', Synthesis Report to EC, DGXIII, Karlsruhe, ISI and Maastricht, MERIT

Hagedoorn, J. 1990. Organisational modes of interfirm cooperation and technology transfer, *Technovation*, vol. 10, no. 1, 17–30

Hagedoorn J. and Schakenraad, J. 1990. Strategic partnering and technological cooperation, in Freeman, C. and Soete, L. (eds) (1990)

Hagedoorn, J. and Schakenraad, J. 1992. Leading companies and networks of strategic alliances in information technologies, *Research Policy*, vol. 21, no. 2, 163–91

Hahn, F. 1987. Information dynamics and equilibrium, *Scottish Journal of Political Economy*, vol. 35, no. 4, 321–34

Håkansson, H. 1989. *Corporate Technological Behaviour: Cooperation and networks*, London, Routledge

Håkansson, H. and Johanson, J. 1988. Formal and informal cooperation strategies in international industrial networks, in Contractor, F. J. and Lorange, P. (eds) *Cooperative Strategies in International Business*, Lexington, MA, Lexington Books

Hamberg, D. 1964. Size of firm, oligopoly and research: the evidence, *Canadian Journal of Economic and Political Science*, vol. 30, no. 1, 62–75

Hamberg, D. 1966. *Essays on the Economics of Research and Development*, New York, Random House

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Hanusch, H. (ed.) 1988. *Evolutionary Economics: Applications of Schumpeter's Ideas*, Cambridge, Cambridge University Press
Harris, R. I. D. 1988. Technological change and regional development in the UK: evidence from the SPRU database, *Regional Studies*, vol. 22, 361–74
Hawkins, R. 1992. 'Standards for Technologies of Communication: Policy Implications of the Dialogue between Technical and Non-technical Factors', DPhil thesis, University of Sussex, SPRU
Heertje, A. 1977. *Economic and Technical Change*, London, Weidenfeld and Nicholson
Heertje, A. (ed.) 1988. *Innovation, Technology and Finance*, Oxford, Blackwell
Heertje, A 1992. 'Capitalism, Socialism and Democracy after Fifty Years', International Economics Association, Tenth World Congress, Moscow
Heertje, A. and Perlman, M. (eds) 1990. *Evolving Technology and Market Structure; Studies in Schumpeterian Economics*, Ann Arbor, University of Michigan Press
Heiner, R. 1983. The origin of predictable behaviour, *American Economic Review*, vol. 73, no. 4, 560–95
Heiner, R. 1988. Imperfect decisions, routinized behaviour and inertial technical change, in Dosi, G. *et al.* (eds) (1988)
Helpman, E. and Grossman, I. 1991. *Endogenous Growth Theory*, Cambridge, MA, MIT Press
Hessen, B. 1971 (1931). The social and economic roots of Newton's *Principia*, in Bukharin, N. (ed.) *Science at the Crossroads*, London, Frank Cass
Hicks, D., Ishizuka, T. and Sweet, S. 1992A. 'Japanese Corporations, Scientific Research and Globalisation', DRC Discussion Paper 91, ESRC Research Centre, Brighton, University of Sussex, SPRU
Hicks, D., Isard, P. and Hirooka, M. 1992B. Science in Japanese companies, *Japan Journal for Science, Technology and Society*, vol. 1, 108–149
Hill, C. and Utterback, J. 1979. *Technological Innovation for a Dynamic Economy*, Oxford, Pergamon
Hilpert, U. 1991. *State Policies and Techno-industrial Innovation*, London, Routledge
Hobday, M. 1992. 'Foreign Investment, Exports and Technology Development in the Four Dragons', UN TNC Division, Campinas Conference, Brazil, November
Hodgson, G. 1991. Evolution and intention in economic theory, in Saviotti, P. and Metcalfe, J. S. (eds) (1991)
Hodgson, G. M. 1992. 'Optimisation and Evolution: Winter's Critique of Friedman Revisited', Newcastle Polytechnic, Department of Economics
Hodgson, G. M. 1993. *Economics and Evolution: Bringing Life Back into Economics*, Cambridge, Polity Press
Hoffmann, K. and Rush, H. 1988. *Microelectronics and the Clothing Industry*, New York, Praeger
Holbek, J. 1985. The innovation-design dilemma, in Grønlaug, K,. and Kaufmann, E. (eds) *Innovation: A Cross-Disciplinary Perspective*, Oslo, Norwegian University Press
Hollander, S. 1965. *The Sources of Increased Efficiency: A Study of DuPont Rayon Plants*, Cambridge, MA, MIT Press
Hollingsworth, R. 1993. Variation among nations in the logic of manufacturing sectors and international competitiveness', in Foray, D. and Freeman, C. (eds) (1993)
Hounshell, D. A. 1992A. DuPont and large-scale R&D, in Galison, P and Herly, B. (eds) *Big Science: The Growth of Large-Scale Research*, Stanford, Stanford University Press
Hounshell, D. A. 1992B. Continuity and change in the management of industrial research: the DuPont Company 1902–1980, in Dosi, G., Gianetti, R. and Toninelli, P. A. (eds) (1992)
Hounshell, D. A. and Smith, J. K. 1988. *Science and Corporate Strategy: DuPont R&D 1902–1980*, Cambridge, Cambridge University Press
Howells, J. 1990. The globalisation of research and development, a new era of change, *Science and Public Policy*, vol. 17, no. 4, 273–85
Hu, Y. S. 1992. Global or transnational corporations are national firms with international operations, *Californian Management Review*, vol. 34
Hufbauer, G. C. 1966. *Synthetic Materials and the Theory of International Trade*, London, Duckworth
Hughes, T. P. 1982. *Networks of Power: Electrification in Western Society 1800–1930*, Baltimore, MD, Johns Hopkins University Press
Hughes, T. P. 1989. *American Genesis*, New York, Viking

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Hughes, T. P. 1992. The dynamics of technological change: salients, critical problems and industrial revolutions, in Dosi, G., Giannetti, R. and Toninelli, P. A. (eds) (1992)
Imai, K. 1989. Evolution of Japan's corporate and industrial networks, in Carlsson, B. (ed.) (1989)
Imai, K. and Itami, H. 1984. Interpenetration in organisation and market: Japan's firm and market in comparison with US, *International Journal of Industrial Organisation*, vol. 2, 285–310
Imai, K, and Baba, Y. 1989. 'Systemic Innovation and Cross-border Networks: Transcending Markets and Hierarchies to Create a New Techno-economic System', OECD Conference on Science Technology and Economic Growth, Paris, June
Irvine, J., Martin, B. R., Abraham, J. and Peacock, T. 1987. Assessing basic research: reappraisal and update of an evaluation of four radio astronomy laboratories, *Research Policy*, vol. 16, nos. 2–4, 213–27
Iwai, K. 1984A. Schumpeterian dynamics: an evolutionary model of innovation and imitation, *Journal of Economic Behavior and Organization*, vol. 5, 159–90
Iwai, K. 1984B. Schumpeterian dynamics, Part II: technological progress, firm growth and economic selection, *Journal of Economic Behavior and Organization*, vol. 5, 321–51
Jacobsson, S. 1986. *Electronics and Industrial Policy: The Case of Computer-Controlled Machine Tools*, London, Allen and Unwin
Jagger, N. S. B. and Miles, I. D. 1991. New telematic services in Europe, in Freeman, C., Sharp, M. and Walker, W. (eds) *Technology and the Future of Europe*, London, Pinter
Jaikumar, R. 1988. 'From Filing and Fitting to Flexible Manufacturing', WP 88-045, Harvard Business School
Jang Sup Shin 1992. 'Catching Up and Technological Progress in Late Industrialising Countries', MPhil Dissertation, University of Cambridge
Jewkes, J., Sawers, D. and Stillerman, R. 1958. *The Sources of Invention*, London and New York, Macmillan (revised edition 1969)
Johnson, B. 1992. Institutional learning, in Lundvall, B.-Å. (ed.) (1992)
Kamien, M. and Schwartz, N. 1975. Market structure and innovation: a summary, *Journal of Economic Literature*, vol. 13, no. 1, 1–37
Kamien, M. and Schwartz, N. 1982. *Market Structure and Innovation*, Cambridge, Cambridge University Press
Kaplinsky, R. 1983. Firm size and technical change in a dynamic context, *Journal of Industrial Economics*, vol. 32, 39–59
Katz, B. G. and Phillips, A. 1982. Government, technological opportunities and the emergence of the computer industry, in Giersch (ed.), *Emerging Technologies*, Tübingen, J. C. B. Mohr pp. 419–66
Kay, N. 1979. *The Innovating Firm*, London, Macmillan
Kay, N. 1982. *The Evolving Firm*, London, Macmillan
Keck, O. 1982. *Policy-Making in a Nuclear Reactor Programme: The Case of the West German Fast-Breeder Reactor*, Lexington, Lexington Books, Heath
Kelley, M. B. and Brooks, H. 1991. External learning opportunities and the diffusion of process innovations to small firms: the case of programmable automation, in Nakicenovic, N. and Grübler, A. (eds) (1991)
Kennedy, C and Thirlwall, A. P. 1973. Technical progress, in *Surveys of Applied Economics*, vol. 1, London, Macmillan for the Royal Economic Society and SSRC
Keirstead, B. S. 1948. *The Theory of Economic Change*, Toronto, Macmillan
Klein, B. H. 1977. *Dynamic Economics*, Cambridge, MA, Harvard University Press
Kleinknecht, A. 1987. *Innovation Patterns in Crisis and Prosperity: Schumpeter's Long Cycle Reconsidered*, London, Macmillan
Kleinknecht, A. 1990. Are there Schumpeterian waves of innovation? *Cambridge Journal of Economics*, vol. 14 no. 1, 81–92
Kleinknescht, A. and Reijnen, J. O. N. 1992A. Why do firms cooperate on R&D? An empirical study, *Research Policy*, vol. 21, no. 4, 347–60
Kleinknecht A. and Reijnen, J. O. N. 1992B The experience with new innovation data in the Netherlands, *STI Review*, vol. 11, 64–76
Kline, S. and Rosenberg, N. 1985. An overview of the process of innovation, in Landau, R. and Rosenberg, N. (eds) *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, Washington DC, National Academy Press

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Kodama, F. 1986. Japanese innovation in mechatronics technology, *Science and Public Policy*, vol. 13, no. 1, 44–51

Kodama, F. 1990. 'Rivals' Participation in Collective Research: Economic and Technological Rationale', Tokyo, NISTEP Conference, 2–4 February

Kodama, F. 1991. *Analysing Japanese High Technologies*, London, Pinter

Kodama, F. 1992. Japan's unique capacity to innovate: technology fusion and its international implications, in Arrison, T. S., Bergsten, C. F., Graham, E. M. and Harris, M. C. (eds) *Japan's Growing Technological Capability: Implications for the US Economy*, Washington DC, National Academy Press

Krauch, H. 1970. *Die Organisierte Forschung*, Berlin, Luchterhand

Krauch, H. 1990. *Prioritäten für die Forschungspolitik*, Munich, Hanser-Verlag

Krugman, P. 1990. *Rethinking International Trade*, Cambridge, MA, MIT Press

Krupp, H. 1992. *Energy Politics and Schumpeter Dynamics*, Tokyo, Springer-Verlag

Kuhn, T. S. 1962. *The Structure of Scientific Revolutions*, Chicago, Chicago University Press

Landes, M. 1970. *The Unbound Prometheus: Technological and Industrial Development in Western Europe from 1750 to the Present*, Cambridge, Cambridge University Press

Langrish, J., Gibbons, M., Evans, P. and Jevons, F. 1972. *Wealth from Knowledge*, London, Macmillan

Lastres, H. 1992. 'Advanced Materials and the Japanese National System of Innovation', DPhil thesis, University of Sussex, SPRU

Lazonick, W. 1990. *Competitive Advantage on the Shop Floor*, Cambridge, MA, Harvard

Lazonick, W. 1992A. Business organisation and competitive advantage: capitalist transformations in the twentieth century, in Dosi, G., Giannetti, R. and Toninelli, P. A. (eds) (1992)

Lazonick, W. 1992B. Controlling the market for corporate control: the historical significance of managerial capitalism, in Scherer F. M. and Perlman, M. (eds) (1992)

Levin, R. C. 1986. A new look at the patent system, *American Economic Review*, vol. 76, 199–201

Levin, R. C. 1988. Appropriability, R&D spending and technological performance, *American Economic Review (PP)*, vol. 78, 424–8

Levin, R., Cohen, W. M. and Mowery, D. C. 1985. R&D appropriability, opportunity and market structure: new evidence on some Schumpeterian hypotheses, *American Economic Review*, vol. 75, no. 2, 20–24

Levin, R. C., Klevorick, A. K., Nelson, R. R. and Winter, S. G. 1987. Appropriating the returns from industrial research and development, *Brookings Papers on Economic Activity*, vol. 3, 783–820

Limpens, I., Verspagen, B. and Beelen, E. 1992. 'Technology Policy in Eight European Countries: A Comparison', University of Limburg, MERIT

Lovio, R. 1993. 'Evolution of Firm Communities in New Industries: The Case of the Finnish Electronic Industry', PhD Dissertation, Helsinki, School of Economics and Business Administration

Lucas, R. E. B. 1986. Adaptive behaviour and economic theory, *Journal of Business*, vol. 59, 401–476

Lundgren, A. 1991. 'Technological Innovation and Industrial Evolution: The Emergence of Industrial Networks', DPhil dissertation, Stockholm School of Economics

Lundvall, B.-Å. 1985. Product innovation and user-producer interaction, in *Industrial Development Research Series*, vol. 31, Aalborg, Aalborg University Press

Lundvall, B.-Å. 1988. Innovation as an interactive process: from user-producer interaction to the national system of innovation, in Dosi, G. *et al.* (eds) (1988)

Lundvall, B.-Å. (ed.) 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London, Pinter

Lundvall, B.-Å. 1993. User-producer relationships, national systems of innovation and internationalisation, in Foray, D. and Freeman, C. (eds) (1993)

Machlup, F. 1962. *The Production and Distribution of Knowledge in the United States*, Princeton, Princeton University Press

Mackenzie, D. 1990. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*, Cambridge MA, MIT Press

Mackenzie, D. 1990. 'Economic and Sociological Exploration of Technical Change', paper presented at Manchester Conference on Firm Strategy and Technical Change

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Mackerron, G. S. 1991. De-commissioning costs and British nuclear policy, *Energy Policy*, vol. 12, 13–28
MacQueen, D. H. and Wallmark, J. T. 1983. *100 Viktige Innovationer i Sverige 1945–1980*, Stockholm, STU
Mahajan, V. and Peterson, R. A. 1979. Integrating firm and space in technological diffusion models, *Technological Forecasting and Social Change*, vol. 14, 127–146
Malerba, F. 1985. *The Semiconductor Business: The Economics of Rapid Growth and Decline*, Madison, University of Wisconsin Press
Malerba, F., Torrisi, S. and von Tunzelmann, N. 1991. Electronic computers, in Freeman, C., Sharp, M., and Walker, W. (eds) *Technology and the Future of Europe*, London, Pinter
Mansell, R. 1988. Telecommunication network-based services: regulation and market structure in transition, *Telecommunication Policy*, vol. 12, no. 3, 243–55
Mansell, R. 1989. *Technology Network-Based Services: Policy Implications*, Paris, OECD
Mansell, R. 1990A. Rethinking the telecommunication infrastructure: the new 'black box', *Research Policy*, vol. 19, no. 6, 507–515
Mansell, R. 1990B. Multinational relationships: shaping telecommunication markets, in Wilkinson, C. (ed.) *International Aspects of Industrial Policies*, Luxembourg, Institut Universitaire International
Mansell, R. and Morgan, K. 1991. Evolving telecommunication infrastructures: organising the new European community market-place, in Freeman, C. Sharp, M. and Walker, W. (eds) *Technology and the Future of Europe*, London, Pinter
Mansfield, E. 1961. Technical change and the rate of imitation, *Econmetrica*, vol. 29, no. 4, 741–66
Mansfield, E. 1963. Size of firm, market structure and innovation, *Journal of Political Economy*, vol. 7, no. 61, 556–76
Mansfield, E. 1968. *The Economics of Technological Change*, New York, Norton
Mansfield, E., Rapoport, J., Schnee, J., Wagner, S. and Hamburger, M. 1971. *Research and Innovation in the Modern Corporation*, New York, Norton, and London, Macmillan
Mansfield, E., Rapoport, J., Romeo, A., Wagner, S. and Beardsley, G. 1977. *The Production and Application of New Industrial Technology*, New York, Norton
Mansfield, E. 1980. Basic research and productivity increase in manufacturing, *American Economic Review*, vol. 70, 863–73
Mansfield, E. 1985. How rapidly does new industrial technology leak out?, *Journal of Industrial Economics*, vol. 34, no. 2, 217–23
Mansfield, E. 1988. Industrial Innovation in Japan and the United States, *Science*, 241, 1760–1764
Mansfield, E. 1989. The diffusion of industrial robots in Japan and the United States, *Research Policy*, vol. 18, 183–92
Mansfield, E. 1991. Academic research and industrial innovation, *Research Policy*, vol. 20, no. 1, 1–13
Mansfield, E., Schwartz, M. and Wagner, S. 1981. Imitation costs and patents: an empirical study, *Economic Journal*, vol. 91, no. 4, 907–18
March, J. G. and Simon, H. A. 1958. *Organizations*, New York, Wiley
Marsden, D. 1993. Skill flexibility, labour market structure, training systems and competitiveness, in Foray, D. and Freeman, C. (eds) (1993)
Marshall, A. 1890. *Principles of Economics*, London, Macmillan
Martin, B. R. and Irvine, J. 1981. Internal criteria for scientific choice: an evaluation of the research performance of electric high-energy physics accelerators, *Minerva*, vol. XIX, 408–32
Martin, B. R. and Irvine, J. 1983. Assessing basic research: some partial indicators of scientific progress in radio astronomy, *Research Policy*, vol. 12, 61–90
Martin, B. R. and Irvine, J. 1985. Evaluating the evaluators: a reply to our critics, *Social Studies of Science*, vol. 15, 558–75
Matthews, J. 1989. *Tools of Change: New Technology and the Democratisation of Work*, Sydney, Pluto Press
Mensch, G. 1975. *Das Technologische Patt*, Frankfurt, Umschau
Metcalfe, J. S. 1981. Impulse and diffusion in the study of technical change, *Futures*, vol. 13, no. 5, 345–359
Metcalfe, J. S. 1988. The diffusion of innovations: an interpretative survey, in Dosi, G *et al.* (eds) (1988)

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Metcalfe, J. S. 1993. 'The Economic Foundations of Technology Policy: Equilibrium and Evolutionary Perspectives', University of Manchester, mimeo, reprinted in Stoneman, P. (ed.) (1994)

Metcalfe, J. S. and Gibbons, M. 1983. 'On the Economics of Structural Change and the Evolution of Technology', Manchester University paper presented at the 7th World Congress of the International Economics Association, Madrid, September, reprinted in Pasinetti (ed.) (1987) *Growth and Structural Change*, London, Macmillan

Metcalfe, J. S. and Gibbons, M. 1989. Technology, variety and organisation: a systematic perspective in the competitive process, *Research on Technological Innovation, Management and Policy*, vol. 4, 153–93

Meyer-Krahmer, F. 1990. *Science and Technology in the Federal Republic of Germany*, London, Longman

Meyer-Krahmer, F. 1992. The German R&D system in transition: empirical results and prospects of future development, *Research Policy*, vol. 21, no. 5, 423–37

Meyer-Krahmer, F. and Soligny, P. 1989. Evaluation of government innovation programmes in selected European countries, *Research Policy*, vol. 18, 315–32

Midgley, D. F., Morrison, P. D. and Roberts, J. H. 1992. The effect of network structure in industrial diffusion processes, *Research Policy*, vol. 21, no. 6, 533–552

Miles, I. 1989. *Home Informatics: Information Technology and the Transformation of Everyday Life*, London, Pinter

Miles, I. 1990. Teleshopping: just around the corner?, *Journal of the RSA*, vol. 138, 180–189

Miles, I., Rush, H., Turner, K. and Bessant, J. 1988. *Information Horizons: The Long-Term Social Implications of New IT*, London, Edward Elgar

Miles, I, and Thomas, G. 1990. The development of new telematics services, *STI Review*, vol. 7, 35–63

Miles, I., Schneider, V. and Thomas, G. 1991. The dynamics of videotex development in Britain, France and Germany: a cross-national comparison, *European Journal of Communication*, vol. 6, 187–212

Miller, R., Hobday, M., Leroux-Demers, T. and Olleros, X. 1994. Innovation in complex systems industries: the case of flight stimulation, *Industrial and Corporate Change*, in press

Mjøset, L. 1992. *The Irish Economy in a Comparative Institutional Perspective*, Dublin, National Economic and Social Council

Molina, A. H. 1989. 'Transputers and Parallel Computers: Building Technological Competition Through Socio-technical Constituencies', PICT Paper 7, Edinburgh, Research Centre for Social Sciences

Molina, A. H. 1990. Transputers and transputer-based parallel computers, *Research Policy*, vol. 19, no. 4, 309–35

Morgan, K. and Sayer, A. 1988. *Microcircuits of Capital*, Oxford, Polity Press

Morris, P. J. T. 1982. 'The Development of Acetyline Chemistry and Synthetic Rubber by IG Farben AG 1926–1945', DPhil thesis, University of Oxford

Morton, J. A. 1971. *Organizing for Innovation*, New York, McGraw-Hill

Mowery, D. C. 1980. 'The Emergence and Growth of Industrial Research in American Manufacturing 1899–1946', PhD dissertation, Stanford University

Mowery, D. C. 1983. The relationship between intrafirm and contractual forms of industrial research in American manufacturing 1900–1940, *Explorations in Economic History*, vol. 20, no. 4, 351–74

Mowery, D. C. (ed.) 1988. *International Collaborative Ventures*, Cambridge, Ballinger

Mowery, D. C. 1989. Collaborative ventures between US and foreign manufacturing firms, *Research Policy*, vol. 18, no. 1, 19–33

Mowery, D. C. 1992A. Finance and corporate evolution in firm industrial economics 1900–1950, *Industrial and Corporate Change*, vol. 1, no. 1, 1–37

Mowery, D. C. 1992B The US national innovation system: origins and prospects for change, *Research Policy*, vol. 21, no. 2 125–45

Mowery, D. C. and Rosenberg, N. 1979. the influence of market demand upon innovation: a critical review of some recent empirical studies, *Research Policy*, vol. 8, 102–53

Mulder, K. F. and Vergragt, P. J. 1990. Synthetic fibre technology and company strategy, *R&D Management*, vol. 20, no. 3, 247–56

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Myers, S. and Marquis, D. G. 1969. *Successful Industrial Innovation*, Washington, DC, National Science Foundation
Nabseth, L. and Ray, G. F. 1974. *The Diffusion of New Industrial Processes*, Cambridge, Cambridge University Press
Nakicenovic, N. and Grübler, A. (eds) 1991. *Diffusion of Technologies and Social Behaviour*, IIASA, Berlin, Springer-Verlag
Narin, F, and Noma, E. 1985. Is technology becoming science? *Scientometrics*, vol. 7, no. 3, 369–81
Narin, F., Noma, E. and Perry, R. 1987. Patents as indicators of corporate technological strength, *Research Policy*, vol. 16, nos. 2–4, 143–157
Narin, F. and Olivastro, D. 1992. Status report: linkage between technology and science, *Research Policy*, vol. 21, 237–51
National Science Foundation 1969. Report on Project TRACES by Illinois Institute of Technology Research Institute, Washington DC
Nelson, R. R. 1959A. The simple economics of basic scientific research, *Journal of Political Economy*, vol. 67, no. 3, 297–306
Nelson, R. R. 1959B. The economics of invention: a survey of the literature, *Journal of Business*, vol. 32, no. 2, 101–27
Nelson, R. R. 1962. The link between science and invention: the case of the transistor, in NBER, *The Rate and Direction of Inventive Activity*, Princeton , NJ, Princeton University Press
Nelson, R. R. 1984. *High Technology Policies: A Five-Nation Comparison*, Washington DC, American Enterprise Institute
Nelson, R. R. 1985. Institutions supporting technical advance in industry, *American Economic Review*, vol. 75, 186–9
Nelson, R. R. 1990. Capitalism as an engine of progress, *Research Policy*, vol. 19, 193–214
Nelson, R. R. 1991. Why do firms differ, and how does it matter?, *Strategic Management Journal*, vol. 12, no. 1
Nelson, R. R. 1992A. National innovation systems: a retrospective on a study, *Industrial and Corporate Change*, vol. 1, no. 2 347–74
Nelson, R. R. 1992B. The roles of firms in technical advance: a perspective from evolutionary theory, in Dosi, G., Giannetti, R. and Toninelli, P. A. (eds) (1992)
Nelson, R. R. (ed.) 1962. *The Rate and Direction of Inventive Activity*, National Bureau of Economic Research, Princeton, Princeton University Press
Nelson, R. R. (ed.) 1993. *National Systems of Innovation: A Comparative Study*, Oxford, Oxford University Press
Nelson, R. R., Peck, M. J. and Kalachek, E. D. 1967. *Technology, Economic Growth and Public Policy*, London, Allen and Unwin
Nelson, R. R. and Winter, S. G. 1974. Neoclassical versus evolutionary theories of economic growth, *Economic Journal*, vol. 84, 886–905
Nelson, R. R. and Winter, S. G. 1977. In search of useful theory of innovation, *Research Policy*, vol. 6, no. 1, 36–76
Nelson, R. R. and Winter, S. G. 1982. *An Evolutionary Theory of Economic Change*, Cambridge, MA, Harvard University Press
Niosi, J. (ed.) 1991. *Technology and National Competitiveness*, Montreal, McGill-Queens University Press
Oakey, R. 1984. *High Technology Small Firms*, London, Pinter
OECD 1963, 1970, 1976, 1981, 1993. *The Measurement of Scientific and Technical Activities*, Paris, Directorate for Scientific Affairs
OECD 1986. *Technological Agreements between Firms*, Paris, OECD
OECD 1988. A survey of technology licensing, *STI Review*, vol. 4, 7–51
OECD 1991A. *TEP: Technology in a Changing World*, Paris, OECD
OECD 1991B. *Technology and Productivity: The Challenges for Economic Policy*, Paris, OECD
OECD 1992A. *Technology and the Economy: The Key Relationships*, Paris, OECD
OECD 1992B. *STI Review*, vol. 11
Ohmae, K. 1990. *The Borderless World*, New York, Harper
Olson, M. 1982. *The Rise and Decline of Nations*, Newhaven, Yale University Press

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Orsenigo, L. 1989. *The Emergence of Biotechnology: Institutions and Markets in Industrial Innovation*, London, Pinter

Orsenigo, L. 1993. The dynamics of competition in a science-based technology: the case of biotechnology, in Foray, D. and Freeman, C. (eds) (1993)

Pasinetti, L. L. 1981. *Structural Change and Economic Growth*, Cambridge, Cambridge University Press

Patel, P. and Pavitt, K. 1991. Large firms in the production of the world's technology: an important case of 'non-globalisation', *Journal of International Business Studies*, vol. 22, no. 1, 1–21

Patel, P. and Pavitt, K. 1992A. The innovative performance of the world's largest firms: some new evidence', *Economics of Innovation and New Technology*, vol. 2, 91–102

Patel, P. and Pavitt, K. 1992B 'The Continuing Widespread (and Neglected) Importance of Improvements in Mechanical Technologies', paper presented at Stanford Conference on 'The Role of Technology in Economics' in honour of Nathan Rosenberg, Brighton, University of Sussex, SPRU, mimeo, November

Patel, P. and Pavitt, K. 1993. Patterns of technological activity, in Stoneman, P. (ed.) (1994)

Patel, P. and Soete, L. 1988. Measuring the economic effects of technology, *STI Review*, vol. 4, 121–66

Paulinyi, A. 1982. Der technologietransfer für die Metallbearbeitung und die preussische Gewerbeförderung 1820–1850, in Blaich, F. (Hg), *Die Rolle des Staates für die Wirtschaftlinche Entwicklung*, pp. 99–142, Berlin, Blaich

Paulinyi, A. 1989. *Industrielle Revolution: vom Ursprung der modernen Technik*, Hamburg Deutsches Museum, Rowohlt

Pausenberger, R. 1991. Technologie Politik Internationaler Unternehmen, *Zeitschrift für Betriebswirtschaftlicherforschung*, 1025–1054

Pavitt, K. 1971. *The Conditions for Success in Technological Innovation, Paris*, OECD

Pavitt, K. 1982. R&D, patenting and innovation activities: a statistical exploration, *Research Policy*, vol. 11, no. 1, 35–51

Pavitt, K. 1984. Patterns of technical change: towards a taxonomy and a theory, *Research Policy*, vol. 13, no. 6, 343–73

Pavitt, K. 1985. Patent statistics as indicators of innovative activities: possibilities and problems, *Scientometrics*, vol. 7, no. 1–2, 77–99

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

Pavitt, K. 1986B. Technology, innovation and strategic management, in McGee, J. and Thomas, H. (eds) *Strategic Management Research: A European Perspective*, New York, Wiley

Pavitt, K. 1986C. International patterns of technological accumulation, in Hood, N. (ed.) *Strategies in Global Competition*, New York, Wiley

Pavitt, K. 1990. What we know about the strategic management of technology, *California Management Review*, vol. 32, 3–26

Pavitt, K. 1993. What do firms learn from basic research?, in Foray, D. and Freeman, C. (eds) (1993)

Pavitt, K., Robson, M. and Townsend, J. 1987. The size distribution of innovative firms in the UK: 1945–1983, *Journal of Industrial Economics*, vol. 35, no. 3, 297–319

Pavitt, K. and Walker, W. 1976. Government policies towards industrial innovation, *Research Policy*, vol. 5, no. 1, 1–96

Pearce, R. 1990. *The Internationalisation of R&D by Multinational Enterprises*, London, Macmillan

Pearce, R. D. and Singh, S. 1992. *Globalising Research and Development*, London, Macmillan

Penrose, E. 1952. Biological analogies in the theory of the firm, *American Economic Review*, vol. 41, 804–19

Penrose, E. T. 1959. *The Theory of the Growth of the Firm*, Oxford, Basil Blackwell

Perrin, J. 1988. *Comment Naissent les Techniques*? Paris, Publisud

Perez, C. 1983. Structural change and the assimilation of new technologies in the economic and social system, *Futures*, vol. 15, no. 5, 357–375

Perez, C. 1985. Microelectronics, long waves and world structural change: new perspectives for developing countries, *World Development*, vol. 13, no. 3, 441–63

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Perez, C. 1989. 'Technical Change, Competitive Restructuring and Institutional Reform in Developing Countries', World Bank Strategic Planning and Review, Discussion Paper 4, Washington, DC, World Bank, December
Petit, P. 1991. New technology and measurement of services: the case of financial activities, in OECD (1991B)
Petroski, H. 1989. H. D. Thoreau, Engineer, in *American Heritage of Invention and Technology*, New Haven, Yale University Press
Phillips, A. 1971. *Technology and Market Structure*, Lexington, MA, Heath
Piore, M. J. 1993. The revival of prosperity in industrial economies: technological trajectories, organisational structure, competitivity, in Foray, D. and Freeman, C. (eds) (1993)
Poon, A. 1993. *Tourism, Technology and Competitive Strategies*, Wallingford, CAB International
Porter, M. 1990. *The Competitive Advantage of Nations*, New York, Free Press, Macmillan
Posner, M. 1961. International trade and technical change, *Oxford Economic Papers*, vol. 13, no. 3, 323–343
Posthuma, A. 1987. 'The Internationalisation of Clerical Work: a Study of Offshore Office Services in the Caribbean', SPRU Occasional Paper 24, Brighton, University of Sussex
Prais, S. J. 1981. Vocational qualifications of the labour force in Britain and Germany, *National Institute Economic Review*, vol. 98, 47–59
Prais, S. J. 1987. Education for productivity: comparisons of Japanese and English schooling for vocational preparation, *National Institute Economic Review*, vol. 119, 40–56
Prais, S. J. and Wagner, K. 1983. Some practical aspects of human capital investment: training standards in five occupations in Britain and Germany, *National Institute Economic Review*, vol. 105, 46–65
Prais, S. J. and Wagner, K. 1988. Productivity and management: the training of foremen in Britain and Germany, *National Institute Economic Review*, vol. 123, 34–47
Price, D. de S. 1984. The science/technology relationship, the craft of experimental science and policy for the improvement of high technology innovation, *Research Policy*, vol. 13, no. 1, 3–20
Quinn, J. B. 1987. The impacts of technology in the services sector, in Guile, B. and Brooks, H. (eds) *Technology and Global Industry*, Washington, DC, National Academy Press
Quintas, P. (ed.) 1993. *Social Dimensions of Systems Engineering*, Chichester, Ellis Harwood
Quintella, R. 1993. 'The Relationship between Business and Technology Strategies in the Chemical Industry', DPhil thesis, University of Brighton
Ray, G. F. 1984. *The Diffusion of Mature Technologies*, Cambridge, Cambridge University Press
Reekie, W. D. 1973. Patent data as a guide to industrial activity, *Research Policy*, vol. 2, no. 3, 246–66
Reich, L. S. 1985. *The Making of American Industrial Research: Science and Business at GE and Bell 1876–1926*, Cambridge, Cambridge University Press
Reich, R. B. 1991. *The Work of Nations*, New York, Vintage Books
Roberts, E. B. 1991. *Entrepreneurs in High Technology: Lessons from MIT and Beyond*, New York, Oxford University Press
Rogers, E. M. 1962. *Diffusion of Innovations*, New York, Free Press of Glencoe
Rogers, E. M. 1986. 'Three Decades of Research on the Diffusion of Innovations: Progress, Problems, Prospects', paper presented at DAEST Conference, Venice, reprinted in Arcangeli *et al.* (eds) (1994)
Romeo, A. A. 1975. Interindustry and interfirm differences in the rate of diffusion of an innovation, *Review of Economic Statistics*, vol. 57, no. 3, 311–19
Romer, P. 1986. Increasing returns and long-run growth, *Journal of Political Economy*, vol. 94, no. 5, 1002–37
Romer, P. 1993. 'The Determinants of Economic Growth: Stimulus, Conditioning and Techniques', Toronto, Honda Foundation, October
Roobeek, A. J. M. 1987. The crisis in Fordism and the rise of a new technological paradigm, *Futures*, vol. 19, 129–154
Rosario, M. and Schmidt, S. K. 1991. Standardisation in the EC: the example of ICT, in Freeman, C., Sharpe, M. and Walker, W. (eds) *Technology and the Future of Europe*, London, Pinter
Rosenberg, N. 1963. Technological change in the machine tool industry, *Journal of Economic History*, vol. 23, 414–43
Rosenberg, N. 1976. *Perspectives on Technology*, Cambridge, Cambridge University Press

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Rosenberg, N. 1982. *Inside the Black Box*, Cambridge, Cambridge University Press
Rosenberg, N. 1990. Why do firms do basic research with their own money?, *Research Policy*, vol. 19, no. 2, 165–75
Rosenberg, N. 1992. Scientific instrumentation and university research, *Research Policy*, vol. 21, no. 4, 381–90
Rosenberg, N. 1994. *Exploring the Black Box: Technology, Economics and History*, Cambridge, Cambridge University Press, in press
Rothwell, R. 1977. Innovations in textile machinery, *R&D Management*, vol. 6, no. 3, 131–8
Rothwell, R. 1991. External networking and innovation in small and medium-sized manufacturing firms in Europe, *Technovation*, vol. 11, no. 2, 93–112
Rothwell, R. 1992. 'Successful Industrial Innovation: Critical Factors for the 1990s', SPRU 25th Anniversary, Brighton, University of Sussex, Reprinted in *R&D Management* vol. 22, no. 3, 221–39
Rothwell, R. and Gardiner, P. 1988. Re-innovation and robust design: producer and user benefits, *Journal of Marketing Management*, vol. 3, no. 3, 372–87
Rothwell, R., Freeman, C., Horsley, A., Jervis, V. T. P., Robertson, A. B. and Townsend, J. 1974. SAPPHO updated, *Research Policy*, vol. 3, no. 5
Rothwell, R. and Zegveld W. 1982. *Industrial Innovation and Public Policy*, London, Frances Pinter
Russo, M. 1985. Technical change and the industrial district: the role of inter-firm relations in the growth and transformation of ceramic tile production in Italy, *Research Policy*, vol. 14, no. 6, 329–44
Ruttan, V. 1959. Usher and Schumpeter on innovation, invention and technological change, *Quarterly Journal of Economics*, vol. 73, no. 4, 596–606
Ruttan, V. W. 1982. *Agricultural Research Policy*, Minneapolis, University of Minnesota Press
Sabel, C. F. 1993. Studied trust: building new forms of cooperation in a volatile economy, in Foray, D. and Freeman, C. (eds) (1993)
Sahal, D. 1977. The multi-dimensional diffusion of technology, *Technological Forecasting and Social Change*, vol. 10, 277–98
Sahal, D. 1981. *Patterns of Technological Innovation*, New York, Addison-Wesley
Sahal, D. 1985 Technology guide-posts and innovation avenues, *Research Policy*, vol. 14, no. 2, 61–82
Sako, M. 1992. *Contracts, Prices and Trust: How the Japanese and British Manage Their Subcontracting Relationships*, Oxford, Oxford University Press
Salomon, J. J. 1985. *Le Gauloise, le Cowboy et le Samurai*, Centre de Perspective et d'Évolution, Paris, CNAM
Salter, W. 1960. *Productivity, Growth and Technical Change*, Cambridge, Cambridge University Press
Samuels, R. J. 1987. *Energy Markets in Comparative and Historical Perspective*, Ithaca, NY, Cornell University Press
Santa Fé Institute 1990, 1991, 1992, 1993. Working Papers, Economics Research Programme, New Mexico
Saviotti, P. P. 1991. The role of variety in economic and technological development, in Saviotti, P. P. and Metcalfe, J. S. (eds) (1991)
Saviotti, P. P. and Metcalfe, J. S. (eds) 1991. *Evolutionary Theories of Economic and Technological Change*, Reading, Harwood Academic Publishers
Saxenian, A. 1991. The origins and dynamics of production networks in Silicon Valley, *Research Policy*, vol. 20, no. 5, 423–437
Scherer, F. M. 1965. Firm size, market structure, opportunity and the output of patented inventions, *American Economic Review*, vol. 55, no. 5, 1097–1123
Scherer, F. M. 1973. *Industrial Market Structure and Economic Performance*, Chicago, Rand McNally
Scherer, F. M. 1980. *Industrial Market Structure and Economic Performance*, 2nd edition, Chicago, Rand McNally
Scherer, F. M. 1982A. Inter-industry technology flows in the US, *Research Policy*, vol. 11, no. 4, 227–45
Scherer, F. M. 1982B. Demand pull and technological innovation revisited, *Journal of Industrial Economics*, vol. 30, 215–18

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Scherer, F. M. 1983. The propensity to patent, *International Journal of Industrial organisation*, vol. 1, 107–28
Scherer, F. M. 1986. *Innovation and Growth. Schumpeterian Perspectives*, Cambridge, MA, MIT Press
Scherer, F. M. 1992. *International High Technology Competition*, Cambridge, MA, Harvard University Press
Scherer, F. M. and Perlman, M. (eds) 1992. *Entrepreneurship, Technological Innovation and Economic Growth: Studies in the Schumpeterian Tradition*, Ann Arbor, University of Michigan Press
Schmookler, J. 1966. *Invention and Economic Growth*, Cambridge, Harvard University Press
Scholz, L. 1992. Innovation surveys and the changing structure of investment in different industries in Germany, *STI Review*, vol. 11, 97–117
Schon, D. A. 1973. Product champions for radical new innovations, *Harvard Business Review*, vol. 51, March–April
Schonberger, R. 1982. *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*, New York, Free Press
Schumpeter, J. A. 1928. The instability of capitalism, *Economic Journal* vol. 38, 361–86
Schumpeter, J. A. 1934. *The Theory of Economic Development*, Cambridge, MA, Harvard University Press (English translation from 1912 German edition, Leipzig)
Schumpeter, J. A. 1939. *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process*, 2 vols, New York, McGraw-Hill
Schumpeter, J. A. 1942. *Capitalism, Socialism and Democracy*, New York, McGraw-Hill
Sciberras, E. 1977. *Multinational Electronic Companies and National Economic Policies*, Greenwich, CT, JAI Press
Scott, A. J. 1991. The aerospace-electronics industrial complex of Southern California: the formative years 1940–1960, *Research Policy*, vol. 20, no. 5, 439–56
Senker, J. 1993. 'The Role of Tacit Knowledge in Innovation', Brighton, University of Sussex, SPRU, mimeo
Senker, P. J., Swords-Isherwood, N., Brady, T. M. and Huggett, C. M. 1985. 'Maintenance Skills in the Engineering Industry: The Influence of Technological Change', EITB Occasional Paper 8, revised second edition
Sharp, M. 1985. 'The New Biotechnology: Governments in Search of a Strategy', Brighton, University of Sussex, Sussex European Paper 15
Sharp, M. 1991. Pharmaceuticals and biotechnology: perspectives for the European industry, in Freeman, C., Sharp, M. and Walker, W. (eds) *Technology and the Future of Europe*, London, Pinter
Sharp, M. and Holmes, P. (eds) 1988. *Strategies for New Technologies*, London, Philip Allan
Shionoya, Y. 1986. The science and ideology of Schumpeter, *Revista Internazionale di Science Economiche e Commerciale*, vol. 33, no. 8, 729–62
Silverberg, G. 1984. Embodied technical progress in a dynamic economic model: the self-organisation paradigm, in Goodwin, R. M., Krüger, M. and Vercelli, A. (eds) *Nonlinear Models of Fluctuating Growth*, Berlin Springer-Verlag
Silverberg, G. 1987. 'Technical Progress, Capital Accumulation and Effective Demand: A Self-organisation Model', paper presented at the Fifth International Conference on Mathematical Modelling, Berkeley, June 1985, reprinted in Batten, D., Casti, J. and Johansson, B. (eds) *Economic Evolution and Structural Adjustment*, Berlin, Springer-Verlag
Silverberg, G. 1988. Modelling economic dynamics and technical change, in Dosi, G. *et al.* (eds) (1988)
Silverberg, G. 1990. Adoption and diffusion of technology as a collective evolutionary process, in Freeman, C. and Soete, L. (eds) (1990)
Silverberg, G., Dosi, G. and Orsenigo, L. 1988. Innovation, diversity and diffusion: a self organising model, *Economic Journal*, vol. 98, no. 393, 1032–55
Silverberg, G. and Lehnert, D. 1992. 'Long Waves and Evolutionary Change in a Simple Schumpeterian Model of Technical Change', paper at MERIT Conference, Maastricht, December
Simon, H. A. 1955. A behavioural model of rational choice, *Econometrics*, vol. 19, 99–118
Simon, H. A. 1959. Theories of decision-making in economics and behavioural science, *American Economic Review*, vol. 49, June, 253–83

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Simon, H. A. 1978. Rationality as process and as product of thought, *American Economic Review*. vol. 68, May, 1–16
Simon, H. A. 1979. Rational decision-making in business organisations, *American Economic Review*, vol. 69, no. 4 493–513
Simon, H. A., Egidi, M., Marris, R. and Viale, R. 1992. *Economics, Bounded Rationality and the Cognitive Revolution*, Aldershot, Edward Elgar
Sirilli G. 1987. Patents and inventors: an empirical study, *Research Policy*, vol. 16, nos. 2–4, 157–74
Slaughter, S. 1993. Innovation and learning during implementation: a comparison of user and manufacturer innovation, *Research Policy*, vol. 22, no. 1, 81–97
Smith, A. 1910. (1776) *Wealth of Nations*, London, Dent
Smith, H. L., Dickson, K. and Smith, S. L. 1991. 'There are two sides to every story': innovation and collaboration within networks of large and small firms, *Research Policy*, vol. 20, no. 5, 457–68
Smith, K. 1991. Innovation policy in an evolutionary context, in Saviotti, P. P. and Metcalfe, J. S. (eds) (1991)
Smith, K. and Vidrei, T. 1992. Innovation activity and innovation outputs in Norwegian industry, *STI Review*, vol. 11, 11–35
Smith, S. 1991. A computer simulation of economic growth and technical progress in a multi-sectoral economy, in Saviotti, P. P. and Metcalfe, J. S. (eds) (1991)
Soete, L. 1979. Firm size and innovative activity: the evidence reconsidered, *European Economic Review*, vol. 12, no.4, 319–40
Soete, L. 1981. A general test of the technological gap trade theory, *Weltwirtschaftliches Archiv*, vol. 117, no. 4, 638–60
Soete, L. 1987. The impact of technological innovation on international trade patterns: the evidence reconsidered, *Research Policy*, vol. 16, nos. 2–4, 101–30
Soete, L. 1991. (rapporteur), Synthesis Report, TEP, *Technology in a Changing World*, Paris, OECD
Soete, L. and Wyatt, S. 1983. The use of foreign patenting as an internationally comparable science and technology output indicator, *Scientometrics*, vol. 5, no. 1, 31–54
Soete, L. and Verspagen, B. 1993. Technology and growth: the complex dynamics of catching up in Szimac, A. *et al.* (eds) *Explaining Economic Growth*, Amsterdam, Elsevier
Soete, L., Verspagen, B., Pavitt, K. and Patel, P. 1989. 'Recent Comparative Trends in Technology Indicators in the OECD Area', Conference on Science, Technology and Growth, Paris, 5–8 June
Sorge, A. 1993. Introduction to Part IV, in Foray, D. and Freeman, C. (eds) (1993)
Sorge, A., Campbell, A. and Warner, M. 1990. Technological change, product strategies and human resources: defining Anglo-German differences, *Journal of General Management*, vol. 15, no. 3, 39–54
Steele, I. 1991. *Managing Technology: A Strategic View*, New York, McGraw-Hill
Sternberg, E. 1992. *Photonic Technology and Industrial Policy*. New York, State University of New York Press
Stiglitz, J. 1987. Learning to learn: localised learning and technological progress, in Dasgupta, P. and Stoneman, P. (eds) (1987)
Stobaugh, R. 1988. *Innovation and Competition: The Global Management of Petrochemical Products*, Boston MA, Harvard Business School Press
Stoneman, P. 1976. *Technological Diffusion and the Computer Revolution*, Oxford, Clarendon Press
Stoneman, P. 1983. *The Economic Analysis of Technological Change*, Oxford, Oxford University Press
Stoneman, P. 1987. *The Economic Analysis of Technology Policy*, Oxford, Oxford University Press
Stoneman, P. (ed.) 1994. *Handbook on the Economics of Innovation and Technical Change*, Oxford, Blackwell, in press
Storper, M. and Harrison, B. 1991. Flexibility, hierarchy and regional development: the changing structure of industrial production systems and their forms of governance in the 1990s, *Research Policy*, vol. 20, no. 5, 407–422
Surrey, A. J. 1973. The future growth of nuclear power. Part 1: demand and supply, *Energy Policy*, vol. 1, no. 1. 107–29

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Surrey, A. J. 1973. The future growth of nuclear power. Part II: choices and obstacles, *Energy Policy*, vol. 1, no. 2, 298–24
Surrey, J. 1992. Technical change and productivity growth in the British coal industry 1974–1990, *Technovation*, vol. 12, no. 1, 15–37
Surrey, J. and Thomas, S. 1980. World-wide nuclear plant programmes: lessons for technology policy, *Futures*, vol. 12, no. 1, 3–18
Svedberg, R. 1991. *Joseph A Schumpeter: His Life and Work*, Oxford, Polity Press
Swann, P. L. (ed.) 1992. *New Technology and the Firm*, London, Routledge
Sylos Labini, P. 1962. *Oligopoly and Technical Progress*, Cambridge, MA, Harvard University Press
Takeuchi, H. and Nonaka, I. 1986. The new product development game, *Harvard Business Review*, January/February, 285–305
Tanaka, M. 1991. Government policy and biotechnology in Japan, in Wilks, S. and Wright, M. (eds) *The Promotion and Regulation of Industry in Japan*, London, Macmillan
Taylor, C. T. and Silberston, Z. A. 1973. *The Economic Input of the Patent System*, Cambridge, Cambridge University Press
Teece, D. J. 1982A. Toward an economic theory of the multiproduct firms, *Journal of Economic Behaviour and Organisation*, vol. 3, no. 1, 39–63
Teece, D. J. 1986. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy, *Research Policy*, vol. 15, no. 6, 285–305
Teece, D. J. 1987. Profiting from technological innovation: implications for integration, collaboration, licensing and public policy, in Teece, D. J. (ed.) *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, Cambridge, MA, Ballinger
Teece, D. J. 1988. The nature and the structure of firms, in Dosi, G. *et al.* (eds) (1988)
Teece, D. J. Pisano, G. and Shuen, A. 1990. 'Firm Capabilities, Resources and the Concept of Strategy,' CCC Working Paper 90–8, Berkeley, Center for Research in Management
Teubal, M. 1987. *Innovation, Performance, Learning and Government Policy: Selected Essays*, Madison, University of Wisconsin Press
Teubal, M., Yinnon, T and Zuscovitch, E. 1991. Networks and market creation, *Research Policy*, vol. 20, no. 5, 381–92
Thomas, G. and Miles, I. 1989. *Telematics in Transition: The Development of New Interactive Services in the UK*, Harlow, Longman
Thomas, S. D. 1988. *The Realities of Nuclear Power: International Economic and Regulatory Experience*, Cambridge, Cambridge University Press
Thwaites, A. T. 1978. Technological change, mobile plants and regional development, *Regional Studies*, vol. 12, 455–61
Thwaites, A. T. and Oakey, R. P. (eds) 1985. *The Regional Impact of Technological Change*, London, Frances Pinter
Tidd, J. 1991. *Flexible Manufacturing Technology and International Competitiveness*, London, Pinter
Tilton, J. 1971. *International Diffusion of Technology: The Case of Semi-conductors*, Washington, DC, Brookings Institution
Tisdell, C. 1981. *Science and Technology Policy: Priorities of Governments*, London, Chapman and Hall
Townsend, J. 1976. 'Innovation in Coal-mining Machinery', SPRU Occasional Paper no. 3, Brighton, University of Sussex
UNESCO 1969. 'The Measurement of Scientific and Technological Activities, Paris
Utterback, J. M. 1979. The dynamics of product and process innovation in industry, in Hill C. and Utterback, J. M. (eds) (1979)
Utterback, J. M. 1993. *Mastering the Dynamics of Innovation*, Boston, MA, Harvard Business School Press
Utterback, J. M. and Abernathy, W. J. 1975. A dynamic model of product and process innovation, *Omega*, vol. 3, no. 6, 639–56
Utterback, J. M. and Suarez, F. F. 1993. Innovation, competition and industry structure, *Research Policy*, vol. 22, no. 1, 1–23
Van de Ven, A. H., Angle, H. L. and Poole, M. S. 1989. *Research on the Management of Innovation*, New York, Harper and Row
Van Vianen, B. G., Moed, H. F. and Van Raan, A. J. F. 1990. An exploration of the science base of recent technology, *Research Policy*, vol. 19, no. 1, 61–81

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Vernon, R. 1966. International investment and international trade in the product cycle, *Quarterly Journal of Economics*, vol. 80, 190–207
Verspagen, B. 1992. Endogenous innovation in neo-classical growth models: a survey, *Journal of Macro-Economics*, vol. 14, no. 4, 631–k62
Verspagen, B. 1992. 'Uneven Growth between Interdependent Economies: An Evolutionary View on Technology Gaps, Trade and Growth', University of Limburg, Dissertation 92–10
Verspagen, B. and Kleinknecht, A. 1990. Demand and innovation: Schmookler reexamined, *Research Policy*, vol. 19. 387–394
Villaschi, A. F. 1993. 'The Brazilian National System of Innovation: Opportunities and constraints for Transforming Technological Dependency', DPhil thesis, University of London
von Hippel, E. 1978. A customer-active paradigm for industrial product idea generation, *Research Policy*, vol. 7, 240–266
von Hippel, E. 1980. The user's role in industrial innovation, in Burton, D. and Goldhar, J. (eds) *Management of Research and Innovation*, Amsterdam, North-Holland
von Hippel, E. 1982. Appropriability of innovation benefit as a predictor of the source of innovation, *Research Policy*, vol. 11, no. 2, 95–115
von Hippel, E. 1987. Cooperation between rivals: informal know-how trading, *Research Policy*, vol. 16, no. 5, 291–302
von Hippel, E. 1988. *The Sources of Innovation*, Oxford, Oxford University Press
von Tunzelmann, G. N. 1989. Market forces and the evolution of supply in the British telecommunications and electricity supply industries, in Silberston, A. (ed.) *Technology and Economic Progress*, London, Macmillan
Walker, W. B. 1979, *Industrial Innovation and International Trading Performance*, Connecticut, JAI Press
Walker, W. B. 1993. From leader to follower: Britain's dwindling technological aspirations, in Nelson, R. R. (ed.) (1993)
Walker, W. B. and Lönnroth, M. 1983A. *Nuclear Power Struggles: Industrial Competition and Proliferation Control*, London, Allen and Unwin
Walker, W. B. and Lönnroth, M. 1983B. The viability of the civil nuclear industry, in Somat, J. (ed.) *World Nuclear Energy*, Baltimore, Johns Hopkins
Walsh, V. 1984. Invention and innovation in the chemical industry: demand pull or discovery push, *Research Policy*, vol. 13, 211–34
Watanabe, S. 1993. Work organisation, technical progress and culture, in Foray, D. and Freeman, C. (eds) (1993)
Weidlich, W. and Braun, M. 1992. The master equation approach to non-linear economics, *Journal of Evolutionary Economics*, vol. 2, no. 3, 233–67
Whiston, T. 1989, 1990. Managerial and organisational integration needs arising out of technical change and UK commercial structures, *Technovation*, vol. 9, no. 6, vol. 10, nos. 1, 2, 3, 47–58, 95–118, 143–61, respectively
Whittaker, M., Rush, H. and Haywood, W. 1989. 'Technical Change in the British Clothing Industry', Occasional Paper, Brighton: Centre for Business Research
Williamson, O. E. 1975. *Markets and Hierarchies: Analysis and Antitrust Implications. A Study in the Economics of Internal Organization*, New York, Free Press
Williamson, O. E. 1985. *The Economic Institutions of Capitalism*, New York, Free Press
Winter S. G. 1964. Economic natural selection and the theory of the firm, *Yale Economic Essays*, vol. 4, 225–72
Winter, S. G. 1971. Satisficing, selection and the innovating remnant, *Quarterly Journal of Economics*, vol. 85, no. 2, 237–61
Winter, S. G. 1986A. Comments on Arrow and Lucas, *Journal of Economics*, vol. 54, 427–34
Winter, S. G. 1986B. Schumpeterian competition in alternative technological regimes, in Day, R. and Eliasson, G. (eds) *The Dynamics of Market Economies*, Amsterdam, North-Holland
Winter, S. G. 1987. Knowledge and competence as strategic assets, in Teece, D. J. (ed.) *The Competitive Challenge: Strategies for Industrial Innovation and Renewal*, Cambridge, MA, Ballinger
Winter, S. G. 1988. On Coase, competence and the corporation, *Journal of Law, Economics and Organization*, vol. 4, no. 1, 163–80
Winter, S. G. 1989. Patents in complex contexts: incentives and effectiveness, in Weill, K. and Snapper, R. (1989) *Owning Scientific and Technical Information*

Downloaded from http://cje.oxfordjournals.org/ at ETH ZÃ¼rich on October 10, 2016

Winter, S. G. 1993. Patents and welfare in an evolutionary model, *Industrial and Corporate Change*, vol. 2, no. 2, 211–232

de Wit, G. R. 1990. The character of technological change and employment in banking, in Freeman, C. and Soete, L. (eds) (1990)

Witt, U. (ed.) 1993. *Evolutionary Economics*, International Library of Critical Writings in Economics, Aldershot, Edward Elgar

Womack, J., Jones, D. and Roos, D. 1990. *The Machine that Changed the World*, New York, Rawson Associates (Macmillan)

World Bank 1991. *World Development Report, 1991*, New York, Oxford University Press

Wortmann, M. 1990. Multinational and the internationalisation of R&D: new development in German companies, *Research Policy*, vol. 19, 175–183

Zuscovitch, E. 1984. 'Une approche meso-économique du progrès technique: Diffusion de l'innovation et apprentissage industriel', PhD thesis, Strasbourg, Université Louis Pasteur

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