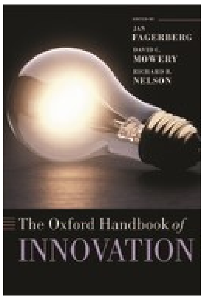

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CHAPTER

15 Innovation In "Low-Tech" Industries

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Abstract

This article considers not just traditional "low-tech" industries but also those classified by the Organization for Economic and Co-operation Development (OECD) as "medium-tech." It combines them hereafter as "low- and medium-tech" (LMT) industries. These are frequently "mature" industries, where technologies and market conditions may change slowly. Furthermore, this article untangles the relationship between the technologies and markets which comprise an "industry"—effectively OECD type classifications are rejected in favor of alternative sectoral taxonomies. This article also elucidates the roles of firm strategies and structures in the LMT industries. The implications of this discussion for the evolution of industry structure, especially entry, are also considered in this text. Finally, this article concludes with a call for revising the academic agenda.

Keywords: low-tech industries, OECD, medium-tech industries, sectoral taxonomies, academic agenda
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15.1 Introduction

THE title of this chapter is inherently paradoxical—low-tech industries are not supposed to be characterized by any significant amount of innovation *ex definitione*. We intend to resolve this conundrum by arguing that there are few—if any—industries in present-day advanced countries which conform to the general understanding of what constitutes a "low-tech" industry. In our view, this is more than just a matter of semantics, and it is crucial for understanding where the comparative advantages of countries at varying levels of development may lie. We believe that a policy obsession with purported "gaps" in "high-tech" industries has distracted the attention of both policy makers and academics away from making more positive efforts to develop and sustain development in other sectoral directions which some countries might find more viable. In the OECD, high-tech industries as the OECD itself defines them account for only about 3 per cent of value-added (Hirsch-Kreinsen et al. 2003), rising to 8.5 per cent if medium-high-tech industries
p. 408 like ↳ motor vehicles are included (OECD 2003), so even if they could be expanded the impact on GDP would

be quite small. Governments need to give more thought to the activities which generate most of the output and employment of their countries and the best targets for "dynamic comparative advantage" for growth.

In this chapter we will consider not just traditional "low-tech" industries but also those classified by the OECD as "medium-tech." We combine them hereafter as "low- and medium-tech" (LMT) industries. Our reason for banding the two together is that both are being driven by similar factors which somewhat distinguish them from the high-tech industries. These are frequently "mature" industries, where technologies and market conditions may change more slowly. They can include non-manufacturing activities, such as exploration for new resources in the oil and gas industry. We naturally avoid much discussion of services as being the subject of the following chapter, but this ignores the growing interrelationships of service and production/manufacturing activities in many relevant areas, so we include some consideration of the services sector.

Section 15.2 untangles the relationship between the technologies and markets which comprise an "industry"—effectively we reject OECD-type classifications in favor of alternative sectoral taxonomies. This permits a more constructive analysis of the key drivers of change at the industry/sector level as between demand and supply factors in Section 15.3. Section 15.4 elucidates the roles of firm strategies and structures in the LMT industries. The implications of this discussion for the evolution of industry structure, especially entry, are considered in Section 15.5, and illustrations from some "low-tech" industries are given in Section 15.6. Section 15.7 provides implications for government policy, which we believe requires radical rethinking, and Section 15.8 concludes with a call for revising the academic agenda.

15.2 The "Technology Profile" of Industrial Sectors

Sectors are generally taken to be identifiably similar aggregations of productive activities. Conventionally, sectors of all types were supposed to be recognizably different from one another not only in the goods and services they produced but also in the technologies and processes they used to produce them. However, the boundaries have blurred over historical time in both dimensions. Technologies originally developed for one set of products spill over into use in the production or "architecture" of other sets of products. Moreover, new technologies more often tend to supplement and complement old technologies rather than replace p. 409 them. ↳ One simple consequence is that even "old" products can be produced by, or partly consist of, elements drawn from what had previously been a totally different set of activities. Equally, markets have become more blurred through the bundling of goods and services (e.g. sales of music products via the Internet).

As a result, conventional classifications of sectors as high- or low-tech (etc.), as long practised by the OECD, are becoming less and less useful for academic analysis, though their sway still prevails in government policy making (see Section 15.7 below). To be fair, the OECD (2003) is coming—rightly—to place greater emphasis on the "knowledge-intensity" of industries, based on criteria such as their use of capital inputs from R&D-intensive industries. This necessitates rethinking the kinds of taxonomies that help us to comprehend structural change (see Ch. 6 by Smith, this volume).

15.2.1 Technologies vs. Products

The conventional definition of the technological profile of industrial sectors put forward by the OECD claims to measure the direct plus indirect technology content of particular industries. The majority of manufacturing industries are defined mostly according to their product range but a good number have in common their technologies rather than their products, e.g. biotechnology. Whether, say, plant biotechnology is regarded as part of the biotechnology industry (technology-defined) or of agriculture (product-defined) makes a big difference to the inferences drawn.

Allowing for these difficulties, others then arise in connection with the measures of technology content. The key issues are outlined by Smith (Ch. 6 in this volume), and need not be reiterated here. However we would emphasize that a good part of the innovation activities in LMT industries may fall outside the Frascati definition of R&D (OECD 1994), for example oil and gas exploration (see Box 15.1). Knowledge search, identification and proof, rather than basic research, are likely to be of particular importance to innovation in the non-manufacturing activities of LMT industries. Most importantly, we have to ask what part of each "industry" we are characterizing as high- or low-tech when considering their growth potential.

Meliciani (2001) found that in the 1980s the ICT industries figured prominently among the fastest-growing industries in advanced industrial countries, but in the 1970s they did not, whereas many LMT industries were present among the fastest growing group at this time. For the years after 1994, the OECD high-tech sectors show first rapid growth then rapid contraction. Governments have been attracted towards the high-tech industries for their potential for growth and structural change. The benchmarks here are however confused by the definitional problems already highlighted—for instance Denmark appears to have a
p. 410 comparative ↳ advantage in low-growth sectors (such as processed foods), but its production lies towards the high-tech end of these low-growth sectors (like applying biotechnology to food processing).

Box 15.1 Planetary science in the North Sea

There are many who believe that all of the science and technology needed to dig oil and gas out of the ground has been already discovered and deployed. Relatively low R&D intensity figures attest to the same; over the period 1995 to 1997, the top ten oil majors worldwide averaged an R&D intensity of 0.52 per cent. However the accounting category of R&D does not capture the full scope of investment into the search for novelty and the applications thereof in the upstream petroleum industry. Many exploration activities that involve, in the words of the Frascati Manual, an "appreciable element of novelty and the resolution of scientific and/or technological uncertainty" and "contribute to the stock of knowledge" are captured under different budgetary headings, notably exploration costs (Acha 2002). Mansfield (1969: 53) was also concerned that geological and geophysical exploration were excluded from the R&D definitions for precisely these reasons.

In fact, the annually growing numbers (in their hundreds per company) of technical and academic papers produced by the leading oil operating and service companies reflect a substantially developed research program for the evolution of the science and technologies underpinning this industry. This fact is better reflected in the number of Ph.D. qualified staff from these firms actively working on a better understanding of the composition and dynamics of this planet. This scientific endeavor in planetary science does not go unnoticed even outside the industry. NASA has enlisted the help of upstream oil industry companies in developing new technologies for drilling on Mars (Babaev 2000). Likewise space scientists are collaborating with the geologists and geophysicists who have been delineating marine space impact craters on Earth, including one off the UK whose only natural analog exists on Jupiter's ice moon, Europa.

15.2.2 Factor intensity

The LMT industries are usually regarded as providing many points of entry for developing countries, in view of their relative labor-intensity. Not all are of this nature, however. Some branches of such "low-tech" industries as food processing are highly capital-intensive (e.g. tobacco and many beverages), as are some branches of building materials (e.g. cement). Many more take on varying shades of labor- or capital-intensity depending on the economic environment in which they find themselves—the same industry may be capital-intensive in the USA and laborintensive in China. Areas like software production have been
p. 411 favored points of entry into "high-tech" production in countries like India in the 1990s and beyond ↳ precisely because they are "labor-intensive" (though intensive in cheap skilled labor rather than cheap unskilled labor).

Peneder (2001) provides a tripartite classification of manufacturing industries, at the 3-digit level of disaggregation. One of his taxonomies rests on factor intensity (mainstream i.e. average; labor-intensive; capital-intensive; marketing-driven; technology-intensive), another on labour skills (low-skill; medium-skill blue-collar; medium-skill white-collar; high-skill), and the third on external service inputs (from knowledge-based services; from retail and advertising services; from transport services; and from other industries). Only one of the ninety-nine manufacturing industries he lists (aircraft and spacecraft) has the classic high-tech profile of being technology-intensive and predominantly using high-skill and knowledge-based services; conversely there are labor-intensive industries which utilize high skills (e.g. machine tools) and others utilizing knowledge-based service inputs (some branches of metallurgy). His classification underlines the great variety of observable combinations.

15.2.3 Pavitt's taxonomy

In contrast to classifying industrial sectors according to product range, Pavitt (1984) arranged them according to technology characteristics (see Tidd et al. 2001). The suggested categories are: "supplier-dominated," "scale-intensive," "informationintensive," "science-based," and "specialized-supplier" (for further discussion of this taxonomy see the Introduction and Chapter 6 by Smith, in this volume). A modified taxonomy of this kind that is more explicitly geared to the kinds of technological paradigms (chemical, mechanical, etc.) in different sectors is given by Marsili (2001). Both Pavitt and Marsili deliberately aimed at means of classification that brought together characteristics which certain groups of technologies appeared to share, even though they might pertain to different "sectors." Generally this taxonomy does a better job of explaining technological performance than factor content, but since this is its intention that may not be too surprising. However, again the LMT industries resist easy classification, precisely because many of them are not very distinctive or singular in technological terms.

An attempt to use a modified Pavitt taxonomy to analyze changes in world export shares is given in Table 15.1. The industries given special attention in this chapter are sprinkled across the first four categories, as already implied (e.g. food products, oil and gas, paper in agricultural products and raw materials; textiles and clothing, glass in traditional manufactures; vehicles, steel in scale-intensive; machinery for many of these in specialized suppliers). The inroads made into European and US export shares during the 1970–95 period by Japan and the Asian NICs in science-based and specialized suppliers are evident, though the share
p. 412 of the Asian NICs also increases in ↳ traditional manufactures. The US actually loses least, in percentage points, in traditional manufactures from 1970 to 1995, though its share in such trade was very low throughout the period compared with Europe. Nevertheless the table should warn us against making oversimplified statements about technological patterns of development.

Table 15.1 Market shares, 1970–1995 (percentage ratio of national exports to world exports)

		Agricultural products and raw materials	Traditional industries	Scale-intensive	Specialized suppliers	Science-based	Total
Europe	1970	24.1	57.0	55.7	61.2	48.6	44.6
	1995	31.6	40.1	47.3	47.6	33.8	39.6
	Change	+7.5	−16.9	−8.4	−13.6	−14.8	−5.0
USA	1970	13.1	7.4	14.5	22.3	29.5	14.8
	1995	11.0	6.7	10.3	13.7	17.9	11.8
	Change	−2.1	−0.7	−4.2	−8.6	−11.6	−3.0
Japan	1970	1.2	9.3	13.8	6.4	7.7	6.7
	1995	1.4	3.2	12.8	15.7	14.3	9.0
	Change	+0.2	−6.1	−1.0	+9.3	+6.6	+2.3
Asian	1970	2.0	6.1	1.0	0.8	1.0	2.1

NICs	1995	3.4	16.2	8.7	8.8	17.8	10.8
	Change	+1.4	+10.1	+7.7	+8.0	+16.8	+8.7

Source: Fagerberg et al. 1999: 12.

15.2.4 Sutton's taxonomy

Yet another way of classifying industries can be derived from the work of Sutton (1991, 1998), who demonstrated that what firms are prepared to spend on marketing their products on the one hand, and on developing their technologies on the other, depend on factors that were partly under a firm's control and partly beyond it. The latter means that if the firms belong to a certain industry they are committed to a certain level of "sunk costs," e.g. for their production processes, regardless of what strategies they then adopt. The nature of technologies as they relate to products sets "bounds" to market concentration in a particular line of activity. The tire industry, for example, is very capital intensive, bound by production p. 413 technologies that have ↳ not essentially changed since the first large-scale use of rubber; this promotes a global oligopolistic structure (Box 15.2 discusses the tire industry more fully). But what firms, in tires or elsewhere, choose to do as a result of strategic decision making—the endogenous element—would rest on the profitability of their strategic expenditures in the face of similarly strategic investment behavior by their competitors.

Box 15.2 What's so clever about a rubber tube?

The modern tire industry has its origins in the nineteenth century and, by and large, its development has mirrored that of the automotive industry. The world tire industry has evolved to address several markets which each have different characteristics, direct customers, and potential for growth. Over a century of development, it has segmented across a wide number of markets, including automotive, aerospace, bicycle, and locomotive tires. The industry is relatively highly concentrated; in 2000, the top ten global tire manufacturers accounted for 83 per cent of the sales of the top seventy-five tire manufacturers globally (www.tirebusiness.com/statistics).

Technology is applied by the tire manufacturers to reduce costs, to differentiate the product line and to focus on greater value-adding activities (Acha and Brusoni 2003). Facing a global market where it is more and more difficult to make a profit, the leading manufacturers are continuously focusing on reducing costs through reducing throughput and labor costs (including the long-awaited introduction of robotics), innovations in processing technologies and source product (a new polyurethane tire polymer), and in the method itself.

Beyond influencing the cost and ease of production, tire manufacturers have invested in research and technology to also help them to move away from the "commodity trap," where products can only compete on price. Product differentiation has occurred as companies offer a variety of tire profiles and even colours to match cars (the latter was led by Kumho, a Korean tire manufacturer that has successfully broken into the top ten manufacturers). Such differentiation is certainly much more than cosmetic; manufacturers have successfully incorporated new sensors into tire assemblies and developed run-flat tires. Leading tire manufacturers are now looking to move up the value chain by manufacturing entire tire assembly systems rather than simply supplying the tire itself.

Of course all of this could be achieved through the support of suppliers from the high-tech sectors of electronics and chemicals, yet the tire manufacturers themselves patent in these areas and lead developments as applied to their business. Patenting in technologies related to tires has increased, and most dramatically so for the tire manufacturers (Acha and Brusoni 2003). The top ten tire manufacturers worldwide had an average R&D intensity of 4 per cent in 2000. Moreover, their patents are applicable to a large number of International Patent Classification (IPC) subclasses (an average of forty-four subclasses over the period 1990 to 2000), indicating some complexity in the nature of these firms' knowledge bases. These firms have broadened their focus to address the crucial interface between their chemical knowledge base (i.e. rubber and other chemical compounds) on the one side, and mechanical engineering and electronics (e.g. sensors) on the other.

p. 414 Drawing on this reasoning, Davies and Lyons (1996) classified country strengths on the basis of dividing industries into four categories: those with high R&D (i.e. technology) expenditures; those with high advertising (i.e. sales) expenditures; those with both; and those with neither. They showed that Western Europe was relatively strong in the second and third of these categories, i.e. those where both R&D and advertising were high (like pharmaceuticals) or advertising alone was high. The latter includes particularly some industries normally regarded as "lowtech," especially food processing (the industry selected by Sutton in his 1991 book to validate his theory). The Sutton approach and associated taxonomycan be especially useful for analyzing LMT industries, because supply (technology) is combined with demand (product) aspects in a rigorous way.

15.2.5 Summary

Attempts to appraise innovation through adopting conventional sectoral classifications can be quite misleading. Innovation is rapid in particular segments of both high-tech and LMT "sectors," even if more segments of the high-tech sectors display such rapid innovation (for evidence see Ch. 6 by Smith in this volume). It is admittedly possible to detach the high-tech segments from LMT "industries" and label them as new high-tech sectors, as was done for artificial fibers in textiles when they arose to compete with natural fibers in the early twentieth century (see Section 15.6), but the final products remain very similar so this looks specious. Approaches that blend the technology dimension and the product dimension, such as those by Sutton or by Peneder, appear to be not only more analytically satisfying but better able to account for observed empirical differences between countries and regions. As suggested below, they are also better able to account for dynamic paths of industrial evolution over historical time. Furthermore, they are in our view a more advisable platform for policy than simple OECD-style definitions of high- or low-tech. They need however to be supplemented by technology-oriented distinctions among sectors such as the Pavitt taxonomy to provide a better grasp of the nature of structural change and competitiveness.

15.3 The Key Drivers

The drivers of change as they affect low, medium, and high-tech sectors can be similarly envisaged from the
p. 415 side of the products or from the side of the technologies, ↳ which again give rise to significant differences in interpretation and understanding. Firms hold different interpretative "frames" (see below), and in LMT industries firm-level differences in the interpretation of demand drivers are particularly important because their well-established markets necessitate a broader variety of strategic choices for differentiation. Demands change sometimes slowly but sometimes rapidly and unpredictably, negating attempts to routinize operations and generating turbulence.

15.3.1 Demand Differentiation

15.3.1.1 Quality Innovation

An important way in which even older industries can bounce back is by producing for new markets. Producing the same type of goods for untouched regions canwork for well-known brands, like Coca-Cola, but producing different types of the same categories of good ("product differentiation") is generally necessary for such resurgence. Within given markets, product growth is heavily determined by income elasticities of demand, i.e. the responsiveness of consumers to the particular product as their incomes rise. It is usually the case that low-tech industries face somewhat inelastic demands because many produce comparative "necessities," and as consumers attain higher income levels they have satisfied most of their needs for necessities. To stave off this "satiation of wants," producers in LMT industries have to find new products to attract the custom of higher earners. The availability of advanced technologies may be an important factor for innovation strategies in LMT firms through dictating the scope for such new products, and even then may not result in products that customers find attractive, as has been the case for genetically modified (GM) foodstuffs in some countries (see below).

15.3.1.2 New Tastes

In addition to quality upgrading, consumers may switch their demand patterns to goods which have new characteristics. While high-tech sectors may have greater innate capacity to spawn product innovations, LMT industries may be faced with a greater necessity to do so. Sectors such as food, energy generation and automobiles have to confront intense pressure from communities and from governments to produce safer and more environmentally friendly items. The same pressures extend to the processes by which they produce these outputs. Less essential but often more lucrative for LMT industries have been shifts in their product mixes to reflect the changing composition of consumers, for example the implications of
p. 416 demographic change (gender relations, ageing, etc.). These create new niches in which firms in ↳ low-tech industries can experience some resurgence. For example, a leading Japanese toy manufacturer, Bandai, recently launched a new doll product range ("Primopuel") targeted not at children but at "empty nesters" (women without children at home) by embedding sophisticated electronic sensors and programming within this "real baby" doll in an effort to develop a higher value market.

Both the potential for developing higher-quality products ("quality ladders") and new products therefore offset the seemingly inevitable maturation of older industries, and give rise to new production and trade patterns (Grossman and Helpman 1991). Indeed, over time, through adding value in processing and in new products, the declines in demand for the products of these industries have been less marked than might be expected. In the case of tires, companies have developed new model profiles (e.g. "fat" tires) to shift demand options from simple requirements (four tires per vehicle) to a series of options (different tires for different occasions), and to differentiated product lines of increasing quality (e.g. "run-flat" tire systems).

The challenge for innovation strategies becomes how and how well firms in LMT industries can alter their products and services and leverage the outcomes through introducing better products or new products, as explored in Sections 15.4 to 15.6 below.

15.3.2 New Technological Paradigms

15.3.2.1 General Purpose Technologies and Learning in LMT Firms

Certain new technologies can spill out of their industry of origin and be recruited by older industries. Key technologies often have the property of being able to become "pervasive," through their take-up in one industry after another (Freeman and Perez 1988; Freeman and Louçã 2001). Industrial revolutions are generally constituted of several of these "general purpose technologies" (Helpman 1998); for example machinery, steam power, and iron in the First Industrial Revolution of the late eighteenth century; chemicals, internal combustion, electricity and steel in the Second Industrial Revolution of the late nineteenth century; and information and communication technologies, biotechnology and smart materials in the Third Industrial Revolution of the late twentieth century. In our view, the general-purpose technologies associated with the Third Industrial Revolution create new opportunities for LMT industries to enhance their innovative and economic performance through the effective adoption and application of ICT, biotechnology, and smart materials.

The properties of these technologies are not of concern here, being the high-tech sectors of their day, but
p. 417 their spread to adopting sectors is of great significance. They ↳ arise most commonly (though not invariably) in "upstream" activities—in the cases mentioned, in equipment and capital goods, in motive power and in basic materials—from which they trickle down to user industries.

In LMT industries there is usually relatively little formal learning by science and technology, at least at the firm level. Instead, innovation- and adoption-related learning activities operate in practical and pragmatic ways by doing and using. The bulk of the new technologies on which they draw, including these general-purpose technologies, are developed by separate companies (rarely subsidiaries), specialized in the relevant technological fields. However the downstream LMT industries need to have "absorptive capacities" to make productive use of these upstreamdevelopments. As shown by Cohen and Levinthal (1989, 1990), absorptive capacities are best inculcated by doing some of the innovative activities oneself, even if this means replicating what has already been done elsewhere. Thus food-processing companies involved in advanced ("third-generation") biotechnology do not carry outmuch of the associated research themselves but are often prominent in patenting in less advanced ("second-generation") biotechnology—this seems to provide them with the necessary absorptive capabilities. In addition, the national systems of innovation literature has drawn attention to how formal science may congregate in national or regional laboratories in such industries, instead of being internalized within firms (Nelson 1993). The applicable science produced by these organizations (e.g. public laboratories) may be generic, but the applications themselves will require firm-specific absorptive capacities, generated not just from formal R&D but from broader-based innovative activities that include engineering, continuous improvement processes, and organizational innovations such as integrated service and supply.

15.3.2.2 Carrier Industries

Describing one particular industry supplying technologies, namely machine tools, Rosenberg (1963) showed how the number of different types of tools was quite limited and as a result their principles could readily be stretched to being applied in industries other than where they were first deployed. The counterpart of this process was the equally significant role of "carrier industries," which incorporated these proliferating machine tools into making the machines they produced or used. Based on the notion of general purpose technologies, any industry can act as a carrier if its demand for the new capital good is large enough or growing fast enough. Thus even low-tech sectors can act as receptors for new process-oriented technologies, and many examples are given below.

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15.4 Firms and Corporate Change in LMT Industries

This section raises issues concerning strategies and structures at the firm level, issues of scale and scope in both Carge firms and SMEs, and discusses different kinds of integration.

15.4.1 Strategy and Structure

15.4.1.1 Strategy in LMT Industries

According to Porter (1985), there are three main types of corporate strategy, namely cost leadership, differentiation, and focus. If viewed from the aspect of the orthodox product lifecycle, cost leadership is the likely choice of firms in a "mature" LMT industry that rely on process innovation to pare down costs even though the innovative spark has largely ceased. From the alternative points of view outlined above, however, the other two strategies also are plausible candidates for companies wishing at least to survive if not to thrive in competitive lower-tech environments. Branding is often crucial to the choice of a differentiation strategy, as consumers choosing between a Saab and a Škoda can be influenced by product reputations (Škoda is nowadays using advertising of its new technologies to change deep-seated customer prejudices).

15.4.1.2 Functions and Structures of the Firm

LMT firms and industries do not differ from any others in the tasks that need to be carried out, but clearly they may place less emphasis on technology functions and more on product/marketing functions than, say, a science-based industry. Building implicitly on this presumption, Chandler (1990) argued that the multidivisional ("M-form") company was an appropriate organizational structure for diversified firms in industries characterized by "branded, packaged goods" (as well as many that were science-based), such as many branches of the food industry. By organizing divisions entrusted with specific product lines in multiproduct firms, and giving middle management the job of running these divisions, there could be greater focus on the targeting of markets, as all the functions necessary for the product line were incorporated within the division (and the responsibility of lower management tiers). However this raised several problems, for example if there were inherent spillovers between the same functions located in different divisions—this could make it awkward for M-form companies to introduce information systems p. 419 and ↳ other radical technological changes, which were bound to affect all their carefully separated divisions (Mowery 1995).

15.4.1.3 "Frames" for Each Function

In previous work, we suggested that large firms interpret competitive challenges and problems through mental "frames," organizational cognitive maps through which they view their horizons and functions, including technology (Acha 2002). In contrast to the Porter concept of corporate strategy, the frame is the filter through which strategies are conceived and chosen. This filter, held by individuals and mediated at the organizational level by senior management, comprises the main variables, functions, and contingencies of a particular phenomenon. In practice, managers consider particular activities rather than the whole at once. A technology frame, therefore, is the interpretative system of managers to understand the firm's technological position and opportunities as well as the expectations of the dynamics of their relevant innovation system(s) (Orlikowski and Gash 1994; Orlikowski 2000).[1]

For the oil and gas industry we found that frames significantly influenced performance differences among companies with similar technological competencies. That is, there is little direct correlation between technological performance (say patenting and scientific publications) and business performance (say expansion or profitability), unless this intervening variable of the frame is accounted for.

The frame concept is relevant to the study of innovation in LMT sectors. Firms in LMT industries are basically using rather than selling technology, and therefore tend to adopt technology frames that are quite different from those in high-tech industries (where technology itself is a key selling point), and often quite different from other LMT firms even in the same industry. In general, the market characteristics of LMT industries (where, over time, markets become segmented and competitive advantage depends upon product differentiation, cost efficiency and control of complementary assets) lead firms to different interpretations about the role for technology for commercial success.

In "high-tech" firms, by contrast, the role for technology is more explicitly central to commercial success, and there may be greater tendencies for consensus (general or by groups) on aspects of technology frames across these competing firms because: (1) the market is relatively "thin," with relatively fewer product and technology options as yet; (2) appropriation of technology through IPR is more aggressively pursued and this structures the role of technology for the industry; and (3) regulatory environments more frequently play a structuring role (e.g. biotech). To generalize, variation in technology frames across "high-tech" firms derives more from a focus on how the technology (broadly stated) should develop, whereas variation in technology frames amongst LMT firms pertains more to what the role for technology (broadly stated) should be.

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15.4.2 Scale and Scope: Large Firms and SMEs

Although they are now mature, such "LMT" industries as meatpacking, automobile production, and consumer durables were important sources of production innovation in their early years, essentially developing the technologies of mass production. The driving force of mass production was to reap economies of scale in the production processes, and the M-form company was a very suitable organizational form for doing so (Chandler 1977). Beyond being labour-saving and capital-intensive, the main direction of technical change was to be "time-saving." This was achieved through raising throughput, reducing downtime, and improving the machinery so as to ensure the speedy throughflow in all stages of its operation. These benefits can be thought of as arising from "dynamic economies of scale," as contrasted with the usual static scale economies arising, for instance, out of having large plant and equipment. In some medium-tech industries like steel, the adoption of new production technologies (the electric furnace) has led to a decline in average establishment size (e.g. huge "integrated plants" have been replaced by "minimills"), in which the losses in terms of static scale economies have been more than offset by increases in dynamic scale economies through specialization and throughput.

Because of the high capital costs of large-scale assembly lines in automobiles, it was necessary to produce very long runs of the product in order to cover them. Competition in this industry increasingly took the form of maintaining the same major components (body, engine, etc.) for as long as possible, while giving the semblance of regular updating of the model by adding on inexpensive "frills," e.g. associated with annual product launches. In essence the assembly line, to pay off, required producing products that were as standardized as possible.

This approach was challenged by the Toyota system of "lean production" (Womack et al. 1990), which was a response to the needs of customers for variety and specialization while sacrificing as little as possible of the benefits of high throughput—in effect obtaining "dynamic economies of scope." Best known of the constituents of lean production was just-in-time production, accelerating the speed of response to changes in customer needs, but other changes worked in the same direction. The lean production system was intended to supplement the American system of interchangeable parts in the product with interchangeable parts in the process. The economies of scope obtained in the efficient production of a variety of products (the Toyota Crown car family allegedly came in over 100,000 variants) more than compensated for abandoning standardization.

At the other end of the spectrum, small and medium-sized enterprises (SMEs) have reappeared on government technology policy agendas. One of the reasons for renewed emphasis on them as sources of innovation is the perceived advantage of SMEs in responding quickly to technological change, because of the absence of complex management structures within smaller enterprises. Against that, SMEs may lack the financial clout to undertake the kinds of investments in new technologies ↳ p. 421 necessitated by radical change (Dodgson and Rothwell 1995). Questions of access to new technologies and on what terms then become paramount. This becomes significant in those LMT industries which are dominated by SMEs, which include many of the more traditional areas. Whilst SMEs are frequently seen as a cause of hope in high-tech sectors, they are often (perhaps unfairly) seen as a matter for despair in LMT sectors.

15.4.3 Vertical and horizontal integration

The LMT industries have been characterized by a variety of patterns of vertical integration and disintegration through their development. The low-tech industries (plus some medium-tech ones) for the most part long pre-date the onset of industrial revolutions and some date back to prehistoric times. When industries first emerge, there is usually a high degree of vertical stratification, i.e. with different firms responsible for each stage of production (the "chain"). Some go on to acquire additional technological capabilities which may eventually spin off into newly created companies (as Rosenberg (1963) showed for machine tools). However the segments interact in systemic fashion with one another through the vertical "chains." In textiles, there were "imbalances" between each stage of production—the early mechanization of weaving speeded up the production of cloth, so pressure was placed on spinners to speed up their own production of yarns to go into the cloth, thereby giving rise to the mechanization of spinning; this in turn became so successful that renewed pressure was put on the weaving segment to develop power-based weaving, and so on. The other stages of textile production—fiber production (e.g. cotton growing), preparation and finishing—were similarly affected along the "value chain." Similar "imbalances" arose in the stages of production of iron.

In the second phase of industrialization there were pressures to link the segmented processes more directly through moves towards vertical integration. The pressures of throughput that gave rise to "mass production" in the USA in the late nineteenth century also promoted vertical integration, because this could ensure smooth production flows throughout the value chain.

More recently, the rise of the steel minimill, partly from technical change, at the expense of the large integrated mill has been one of the more dramatic demonstrations of a retreat from vertical integration. Tasks that corporations previously undertook themselves have been "outsourced" where possible, thereby returning to the traditional low-tech model of vertical disintegration even in some high-tech industries. To retain and intensify the economies of scope required in this unfolding set of circumstances, companies also chose to limit the range of their horizontal diversification. Firms, including some of the largest
p. 422 corporations, practised ↳ "downsizing" and in many cases stripped out large numbers of middle management in the belief that this furthered "lean production."

While financial considerations had often encouraged diversification into unrelated activities, studies demonstrated that "conglomerate" firms based on unrelated diversification were not very profitable (Rumelt 1974). Taking on board the technological and production aspects, and thereby taking into account the issues of synergies and economies of scope, many firms reoriented their structure to limit themselves to "related" diversification. Yet many of the larger companies in low-tech industries like food manufacturing continue to pursue apparently unrelated diversification. The most likely reason for this is that low technological opportunity in traditional segments of low-tech industries may also go with relatively high appropriability, especially through branding. This generates a pool of resources (Penrose 1959), which can be used to invest in other areas in which branding provides a secure financial base. The scale and scope of economies thus arise via marketing rather than through technologies.

15.5 Change at the Industry Level

15.5.1 Vertical Alignment and Networks

These changes at the firm level in terms of size, integration and diversification carry strong implications for the structure of the industries in which they are embedded. Firms have been driven to develop closer relationships with upstream suppliers and downstream customers. Among the best known of these developments are those in the motor vehicle industry. One implication of the Toyota system of flexible and just-in-time manufacture was the need for high reliance on suppliers to deliver equipment and components on time and of high quality. Rather than controlling this process hierarchically, Toyota undertook joint development with the suppliers, spending long periods of time negotiating the exact specifications and costings required. Some of the most critical suppliers became "first-tier" suppliers and worked in close association with Toyota wherever the production was located. Others were seen as less critical or supplied the suppliers: these became "second-tier" and "third-tier" suppliers and were involved less and less directly in negotiations with Toyota itself.

Many of these firms saw themselves as developing into "system integrators," acting as the hub for operations immediately connected to their central activity. Depending on how far they outsourced these
p. 423 related activities, they might end up as ↳ directly producing only a minority of the value added by their "system." Moreover system integrators could emerge at varying points on the value chain, so that vertical links might increasingly be occurring between various system integrators. That is, each integrator would be surrounded by a network of suppliers and related activities.

Within these complex structures of interrelationships, new power balances could emerge. In the lower-tech industries especially, like textiles and some branches of food, the manufacturing stages of the "chain" were squeezed as power tended to shift downstream to the final stages and even to the retailers. The growing competition in diversified products in conjunction with the rising incomes and influence of consumers, often dissatisfied with what they are getting, is driving this trend. It remains to be seen whether this pattern will proceed further in the direction of buyer-driven rather than producer-driven chains (Gereffi 1999).

15.5.2 Industry Differences

These observations raise the issue of how industries differ in their behavior; in particular, can one observe different patterns in LMT industries than high-tech industries at the industry and sector levels? Many studies have sought to classify industry behavior by resorting to the two broad ideal types usually identified with the name of Schumpeter (see Ch. 14 by Malerba in this volume).

One group of such studies identifies the key conditions as opportunity, appropriability, cumulativeness, and knowledge base (Malerba and Orsenigo 1996, 1997). Using these criteria, the great majority of industries in Europe are classified as Mark I or Mark II using objective indicators. Thus among the LMT industries, clothing falls obviously into the category of Mark I, characterized by low technological opportunity, weak appropriability of any innovations, small firms and rapid entry and exit, and a practical rather than scientific knowledge base. Motor vehicles as a mediumtech industry have greater technological opportunities, greater appropriability and the persistence of large firms. High-tech industries naturally have high technological opportunities and a scientific knowledge base, though they may be variously typified by large or small firms.

From the viewpoint of LMT industries, where demand plays such a large role (see Section 15.3.1 and case studies below), market opportunity can be as important as technological opportunity, and may be very different in extent as well as in nature. Fast-growing areas of consumption are not always the same as fast-growing areas of technology, as noted above. Moreover, for our immediate purposes, some of the lowtech industries are Mark I but others are nearer to Mark II, while food-processing resists any easy classification since its sub-branches operate in a whole variety of ways.

We have indicated that technological opportunities may be enlarging again for "low-tech" industries (see
p. 424 Section 15.3.2 above), although firms in such industries ↳ will for the most part outsource the development of these new technologies. Outsourcing may limit opportunities for "user" firms to appropriate the returns from innovation that relies on this approach (recall that appropriability was a key factor in the Sutton analysis discussed above). In the supplier-dominated low-tech industries (as defined by Pavitt) the appropriability of technologies rests upon the division of power between the technology developers—the upstream suppliers—and the users, like food or clothing companies. These activities are rarely vertically integrated, because the suppliers usuallywish to supply a variety of users both within the same activity and outside. The appropriability of the products depends on both the marketing endeavours of the companies concerned, and the power balance vis-à-vis downstream distributors and retailers. Links with technology suppliers tend to be much more distant than in high-tech sectors.

15.5.3 Industrial Dynamics

15.5.3.1 Entry, Exit, and Technological Accumulation

Models of industrial dynamics in the Schumpeterian tradition often contrast Mark I and Mark II industries in respect of the technological advantage of incumbent firms over possible entrants (Marsili 2001). The deciding factor can be the extent to which individual firms in an industry—incumbents or entrants—can earn economies of scope in combining or differentiating technological trajectories (Sutton 1998).

Many LMT industries are however characterized by high levels of "turbulence," with a churning of entry and exit. These pose the issue of learning in turbulent environments—if the individuals cannot be retained in the industry when exit occurs, new entrants may simply replicate their predecessors' mistakes. However, in North American environments at least, the individuals concerned do tend to go on to form another firm (Baldwin 1995). Alternatively the continuity can be maintained by technological dependence on a large supplier or an industrial district, as is often found in clothing. In complex products systems, where alliances are reconstituted for each new project, learning is achieved by the flux of interactions of the constituent firms, although a high level of "forgetting" also seems to be common (Hobday 1998). The dichotomous Mark I and II categorizations may be too restrictive to portray the main patterns of evolution of different industries, and more complex schema such as that of Pavitt (1984) or Marsili (2001) may be preferable for understanding the impact of differing technologies.

15.5.3.2 Dynamic Competition in Time

Across the full range of industries, the modern era is supposed to be characterized by competition that has
p. 425 intensified because of globalization and because of more rapid ↳ change in market demand. In LMT industries the pace of change and competition may be less intense, as market leaders seek to retain their predominance by brand loyalty. In the tobacco industry, the trajectory of a new product launch is normally to begin with a new brand marketed at low prices and with high tobacco content. Once loyalty is obtained the producer relaxes the prices and/or the material content until eventually consumers lose faith, whereupon a new brand is launched on the same terms to eclipse it. Equally, brand loyalty can be extended through globalized marketing.

Thus marketing-based appropriability offsets some of the pressures to develop new products. However firms in LMT industries are arguably almost as susceptible as those in higher-tech industries to innovations that accelerate the development times ("cycle time") and rate of application and diffusion for new technologies. In the clothing industry, Benetton combined its production network of small suppliers with a sophisticated ICT system for feedback from customers, achieving rapid global growth in a relatively mature industry (Belussi 1987). For the more basic production technologies, the LMT industries are distinguished less by the pressure to innovate than by the difficulties encountered in applying those basic technologies to purposes that may be very different from their original intentions. Having to confront such difficulties amplifies rather than diminishes the importance of speed to market for competitiveness even in LMT industries. The key issue here is surely the real-time achievability of economies of scope—do integrated firms or outsourced networks effect this better?

15.6 Innovation in Some Low-Tech Industries

15.6.1 Textiles and Clothing

As the original "leading sector" of the First Industrial Revolution in Britain, textiles have often been regarded as the quintessential low-tech industry in the modern era. First, however, most low-tech industries today are not structured like textiles and clothing. Second, textiles themselves have shown a repeated ability to update by bringing in contemporary developments in technology. In the early twentieth century the chemicals technologies at the forefront of the Second Industrial Revolution were recruited to launch "artificial fibers" (rayon etc.); in the middle of the century "synthetic fibers" (nylon etc.) drew upon synchronous advances in plastics. Both artificial and synthetic fibers remained branches of the chemicals industry in p. 426 ↳ terms of corporate structures as well as technologies and are thus often thought of not as textiles proper, but this hardly seems reasonable. In more recent times computerized technology is making inroads into the still more fragmented clothing sector, while genetics is assisting advances in textiles. "Microfibers" of exceptional fineness have evolved for particular market niches and have begun penetrating standard clothing segments.

It is indeed the case that the recent developments have been slow to diffuse, but this probably has less to do with technological limits than with organizational aspects. The textile–clothing industry is still largely based on a pre-industrial vertical structure that is highly segmented and allows countries with low wage rates to enter through the use of relatively simple technologies, such as sewing machines. To leverage new textile technologies in the way we have described, change in production technologies may have to be linked to product changes, as for instance with microfibers.

The demand side normally offers greater prospects for leverage than the supply (technologies) side in the textiles and clothing sector. As incomes rise, consumers are willing to pay extra for fashionable brand-names. Many of the observed changes in what is fashionable rest on styling rather than technological innovation, though naturally that does not imply any lesser need for creativity. Even here, however, new technology may help bridge the gap between designers, producers, and theirmarkets. An important innovation by Benetton was the firm's use of ICT to learn quickly about changes in market tastes in order to instruct their suppliers (Belussi 1987).

15.6.2 Food-processing

A second industry frequently, and often inappropriately, classified as low-tech is food manufacturing. The "industry" is characterized by a huge variety of organizational forms, related principally to the extent to which marketing can be leveraged (Sutton 1991). It has been customary to see the industry as "supplier-dominated" according to Pavitt's taxonomy, resting on a dependence on suppliers of the machinery for production, but this is changing nowadays in some critical ways. As such, the industry is becoming more market-driven, but one cannot reasonably leave technology out of the picture.

Like all industries, the technical efficiency of this industry comes from the knowledge bases it draws upon, but here there exists an unusual amount of variety to go with the variety of organizational structures. The range of expertise from science (e.g. food microbiology) through to engineering has to span not just production conditions but sanitation, quality assurance, environmental acceptability, and so on. The range of new technologies currently being drawn upon in this industry covers almost the whole spectrum. The traditional reliance on suppliers of machinery is being overtaken by needs for technologies from advanced p. 427 ↳ instrumentation (e.g. lasers), electronics and computing (problematic because of the irregular shape of some of the leading products), biotechnology (for both materials and production processes), pharmaceuticals, and smart materials (especially in packaging), supplied by high-tech firms or public laboratories. The seemingly simple packaging of readymade and microwavable foods for sale in supermarkets in fact required very sophisticated analyses of smart materials to combine heat responsiveness, gas release (controlled oxygenation), ease of production, ease in filling during processing, as well as ease of consumer use.

Many of these new techniques remain controversial, particularly in the field of biotechnology (genetic modification, GM). At the heart of these controversies lies an issue already noted—is a GM food the same product or a different one? Around such points trade wars rage. As already implied, the nature of the product as a staple of human existence means that safety and quality procedures play a substantial role. The difficulty with prevailing methods for testing food safety (wet chemistry) is that they involve cutting off a piece of the product—which may or may not be representative—taking it to the laboratory and waiting about three weeks for the results. By this time the rest of the product could long since have been sold and consumed. Biotechnological methods and other procedures are therefore being sought to effect testing in "real time," i.e. synchronously with the processing. Again the main motivation for technological innovation is time-saving—reducing downtime and waste and increasing throughput in the interests of systemic efficiency.

Changes on the demand side (from socioeconomic factors like rising wealth, growing female employment, ageing of the population) and the above technological changes on the supply side are channeled in part through a changing vertical structure of the industry, in which growing power is accruing to giant retailers vis-à-vis large processors. At the time of writing, the US food retailer Wal-Mart has become the world's largest company according to the *Fortune* list, superseding the high-tech and medium-tech companies of the recent past. Similarly in Europe, supermarket chains have been proactively utilizing information technologies for robust expansion of their power base. These developments make the predominance of demand-side influences on innovation here abundantly clear.

15.7 Role of Government Policy

Government technology policies at national and supranational levels have on the whole tended to give the highest priority to high-tech sectors and activities. One of the most commonly used benchmarks for the
p. 428 success of a government's technology ↳ strategy is the proportion of total output emanating from high-tech sectors, in which dimension East Asian countries tend to score very highly (see Ch. 19 by Fagerberg and Godinho in this volume). Such a benchmark falls into the trap, emphasized throughout this chapter, of confusing the sector with the technology level. Success in low-end activities in high-tech industries, such as "screwdriver" assembly activities, may or may not lead on to success in high-end activities in those sectors—often it may simply generate competition from new rivals in the low-end activities, based on providing still cheaper labour.

As noted in Chapter 22 by Lundvall and Borrás in this volume, government policy towards innovation was for long dominated by the so-called "linear model" of technology-push. Although this approach does not preclude applications of high technology to more traditional fields, the bias in practice usually veers towards new fields as well as new technologies. For many decades the bias towards such technologies was also coupled to one towards consolidation of firms and industries, seen as "national champions" for technological and commercial success. This view has been weakened in recent times as small and medium-sized enterprises (SMEs) have been increasingly thought of as progenitors of high technology, in fields such as biotechnology and genomics, software, advanced instrumentation, and so on. Yet in lowtech industries, SMEs are most widely seen as dragging down overall performance.

The antithesis of the "supply–push" contribution of the linear model is the "demand–pull" approach to innovation, in which the causal sequence is roughly reversed. Governments, though, tend to be loath to "leave it all to market forces," in an arena in which "market failures" are so evidently present as they are in innovative activities. An intermediate position is for governments to foster diffusion rather than upstream invention and innovation (Stoneman and David 1986). While this may not overcome all the market failure shortcomings, there is much to be said for rebalancing policy in such a way as to place greater stress on the diffusion aspects. Of particular relevance to this chapter would be the diffusion of high-tech activities into supposedly low-tech sectors. As we have observed, there is a much wider scope for such migration of technologies across sectoral boundaries than is often supposed.

Many countries have in fact based their development on starting in supposedly low-tech activities like the food-processing or textile industries surveyed above—Denmark, Switzerland, and Australia are evident examples (von Tunzelmann 1995). At the same time, a perhaps even larger number of countries have become locked into the low-tech activities and never adequately escaped, as is often alleged for Latin America. The difficulty remains that countries' comparative advantages often remain indissolubly linked to the low-tech sectors. Our view that there are no true low-tech sectors in the modern world however overrides this. It is perfectly possible to diffuse high technologies into the "low-tech sectors," as our illustrations of chosen low-tech sectors aimed to underline. In that way intermediate and developing
p. 429 countries do not need to face a dilemma when choosing between static comparative ↳ advantage in traditional fields and dynamic comparative advantage from technological opportunity—they can have their cake and eat it.

This would involve moving away from usual defeatist views of traditional sectors as "sunset industries." As Ernest Hemingway observed, "the sun also rises." The sun can rise both from downstream diffusion of high-tech activities into "low-tech sectors," and from the lateral diffusion of old technological fields into new ones. Countries like Switzerland developed, consciously or unconsciously, a pattern of evolution that went—in this case—from textiles to dyeing and chemicals and then into strength in pharmaceuticals on the one hand, and into machinery and thence to advanced engineering on the other.

A clear implication of these policy considerations is that strength in low-tech sectors does not have to act as a “block to development,” although national and supranational governments frequently embody this error in their technology policies. The EU, for instance, counterposes the Framework Programs and the Structural Funds as means for overcoming development-oriented market failures, but it is conceivable to think of reconciling the two, and using the Structural Funds as means for implementing innovation in catching-up regions (Fagerberg et al. 1999). The “block to development” view can be replaced by a “development block” view, in which LMT sectors act as “carrier industries” for diffusing the gains from new technologies across the industrial spectrum, as they have so often managed to do in the past (Rosenberg 1976).

We do not pretend that this has yet happened on any major scale, though it is significant in some services and a number of older branches of manufacturing. On the contrary, on analogy with past “long waves” of technological innovation and industrial growth, it is the key challenge for the next few decades.

15.8 Conclusions

The underlying argument of this chapter is that low-tech sectors do not lack for technological opportunities, nor indeed for appropriability and other factors associated with benefiting from technological innovation. Indeed, our principal analytical conclusion is that in the modern world there are no true “low-tech sectors.” Instead what we observe is a varying degree of permeation of high technologies into low-tech and medium-tech as well as into high-tech sectors.

The primary issue for further research is thus the need to explore much more critically how industries and sectors ought to be classified. The OECD itself appears p. 430 ↳ to be moving towards replacing its conventional accounting of direct and indirect R&D with a more subtle assessment of the knowledge intensity of industries (OECD 2003; see Ch. 6 by Smith, for further discussion). This will have substantial implications for government policy making but also for analytical understanding of structural change and the sources of long-term development. We would suggest going further and aiming to think not just of improving our conception of how technologies can be clustered (as for instance in the Pavitt taxonomy) but also of how technologies map into products. Some pioneering work has been published by individual scholars in this regard (e.g. Piscitello 2003) but this work needs support from national and supranational agencies to instil the notion that demand as well as supply factors drive technological change and long-term prosperity. The LMT industries bulk far too large in total output to be relegated to the scrap-heap of stagnation.

Notes

1. Frames should not be confused with organizational “culture”; the latter comprises the values established at the group level and interpreted by individuals, whereas frames comprise the interpreted relationships between phenomena (and their associated values) and are composed of individuals, mediated at a group level.

References

ACHA, V. L. (2002), "Framing the Past and Future: The Development and Deployment of Technological Capabilities in the Upstream Petroleum Industry," Unpublished D.Phil. Thesis, SPRU, University of Sussex.

—— and BRUSONI, S. (2003), "Complexity and Industry Evolution: New Insights from an Old Industry," in Best Papers Proceedings of 2002, European Association for Evolutionary Political Economy Conference, 2003.

BABAEV, H. (2000), "Scientists, Engineers Teaming up to Develop Mars Drilling Technology," reprinted in *Oil and Gas Journal* 98 (17).
WorldCat

BALDWIN, J. R. (1995), *The Dynamics of Industrial Competition: A North American Perspective*, Cambridge: Cambridge University Press.
Google Scholar Google Preview WorldCat COPAC

—— and SABOURIN, D. (2002), "Advanced Technology Use and Firm Performance in Canadian Manufacturing in the 1990s," *Industrial and Corporate Change* 11: 761–90. 10.1093/icc/11.4.761
WorldCat Crossref

BELUSSI, F. (1987), "*Benetton, Information Technology in Production and Distribution: A Case Study of the Innovative Potential of Traditional Sectors,*" SPRU Occasional Papers 25, SPRU, University of Sussex.
Google Scholar Google Preview WorldCat COPAC

p. 431 CHANDLER, A. D. Jr. (1977), *The Visible Hand: The Managerial Revolution in American Business*, Cambridge Mass,: Belknap Press.
Google Scholar Google Preview WorldCat COPAC

—— (1990), *Scale and Scope: The Dynamics of Industrial Capitalism*, Cambridge, Mass.: Belknap Press.
Google Scholar Google Preview WorldCat COPAC

COHEN, W. M., and LEVINTHAL, D. A. (1989), "Innovation and Learning: The Two Faces of R&D," *Economic Journal* 99: 569–96. 10.2307/2233763
WorldCat Crossref

—— —— (1990), "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly* 35: 128–52. 10.2307/2393553
WorldCat Crossref

* DAVIES, S., and LYONS, B. (1996), *Industrial Organization in the European Union: Structure, Strategy and the Competitive Mechanism*, Oxford: Oxford University Press.
Google Scholar Google Preview WorldCat COPAC

DODGSON, M., and ROTHWELL, R. (eds.) (1995), *The Handbook of Industrial Innovation*, Cheltenham: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

* FAGERBERG, J., GUERRIERI, P., and VERSPAGEN, B. (eds.) (1999), *The Economic Challenge of Europe: Adapting to Innovation-Based Growth*, Cheltenham: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

* FREEMAN, C., and LOUÇÃ, F. (2001), *As Time Goes By: From the Industrial Revolutions to the Information Revolution*, Oxford: Oxford University Press.
Google Scholar Google Preview WorldCat COPAC

—— and PEREZ, C. (1988), “Structural Crises of Adjustment: Business Cycles and Investment Behaviour,” in G. Dosi, C. Freeman, R. Nelson, G. Silverberg, and L. Soete (eds.), *Technical Change and Economic Theory*, London: Pinter, 38–66.
Google Scholar Google Preview WorldCat COPAC

GEREFFI, G. (1999), “International Trade and Industrial Upgrading in the Apparel Commodity Chain,” *Journal of International Economics* 48: 37–70. 10.1016/S0022-1996(98)00075-0
WorldCat Crossref

GROSSMAN, G. M., and HELPMAN, E. (1991), *Innovation and Growth in the Global Economy*, Cambridge, Mass.: MIT Press.
Google Scholar Google Preview WorldCat COPAC

HELPMAN, E. (ed.) (1998), *General Purpose Technologies and Economic Growth*, Cambridge, Mass.: MIT Press.
Google Scholar Google Preview WorldCat COPAC

* HIRSCH-KREINSEN, H., JACOBSON, D., LAESTADIUS, S., and SMITH, K. (2003), “*Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges,*” mimeo, EU 5th Framework project, “Pilot: Policy and Innovation in Low-tech.”
Google Scholar Google Preview WorldCat COPAC

HOBDAY, M. (1998), “Product Complexity, Innovation and Industrial Organisation,” *Research Policy* 26: 689–710. 10.1016/S0048-7333(97)00044-9
WorldCat Crossref

MALERBA, F., and ORSENIGO, L. (1996), “Schumpeterian Patterns of Innovation,” *Cambridge Journal of Economics* 19: 47–65.
WorldCat

*—— —— (1997), “Technological Regimes and Sectoral Patterns of Innovative Activities,” *Industrial and Corporate Change* 6: 83–117.
WorldCat

MANSFIELD, E. (1969), *Industrial Research and Technological Innovation: An Econometric Analysis*, New Haven: Yale University Press.
Google Scholar Google Preview WorldCat COPAC

* MARSILI, O. (2001), *The Anatomy and Evolution of Industries: Technological Change and Industrial Dynamics*, Cheltenham: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

MELICIANI, V. (2001), *Technology, Trade and Growth in OECD Countries: Does Specialisation Matter?* London: Routledge.
Google Scholar Google Preview WorldCat COPAC

MOWERY, D. C. (1995), “The Boundaries of the US Firm in R&D,” in N. R. Lamoreaux and D. M. G. Raff (eds.), *Coordination and Information: Historical Perspectives on the Organization of Enterprise*, Chicago: University of Chicago Press, pp. 147–82.
Google Scholar Google Preview WorldCat COPAC

p. 432

NELSON, R. R. (ed.) (1993), *National Innovation Systems: A Comparative Analysis*, New York: Oxford University Press.
Google Scholar Google Preview WorldCat COPAC

OECD (1994). *The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Experimental Development* (Frascati Manual: 1993), Paris: OECD.
Google Scholar Google Preview WorldCat COPAC

—— (2003), *Science, Technology and Industry Scoreboard 2003–Towards a Knowledge-Based Economy*, Paris: OECD. 10.1787/sti_scoreboard-2003-en
Google Scholar Google Preview WorldCat COPAC Crossref

ORLIKOWSKI, W. J. (2000), "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations," *Organization Science* 11: 404–28. 10.1287/orsc.11.4.404.14600
WorldCat Crossref

—— and GASH, D. C. (1994), "Technological Frames: Making Sense of Information Technology in Organizations," *ACM Transactions on Information Systems* 2: 174–207. 10.1145/196734.196745
WorldCat Crossref

* PAVITT, K. (1984), "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory," *Research Policy* 13: 343–73. 10.1016/0048-7333(84)90018-0
WorldCat Crossref

* PENEDER, M. (2001), *Entrepreneurial Competition and Industrial Location*, Cheltenham: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

PENROSE, E. T. (1959), *The Theory of the Growth of the Firm*, 3rd edn., Oxford: Oxford University Press, 1995.
Google Scholar Google Preview WorldCat COPAC

PISCITELLO, L. (2003), "Generation and Applicability of Technological Competencies: Another way of Measuring Coherence in Corporate Diversification," paper for Conference in Honour of Keith Pavitt, Politecnico di Milano.

PORTER, M. E. (1985), *Competitive Advantage: Creating and Sustaining Superior Performance*, New York: Free Press.
Google Scholar Google Preview WorldCat COPAC

ROSENBERG, N. (1963), "Technological Change in the Machine Tool Industry, 1840–1910," *Journal of Economic History* 23: 414–46.
WorldCat

—— (1976), *Perspectives on Technology*, Cambridge: Cambridge University Press.
Google Scholar Google Preview WorldCat COPAC

RUMELT, R. (1974), *Strategy, Structure and Economic Performance*, Boston: Harvard Business School Press, rev. edn., 1986.
Google Scholar Google Preview WorldCat COPAC

STONEMAN, P. L., and DAVID, P. A. (1986), "Adoption Subsidies vs. Information Provision as Instruments of Technology Policy", *Economic Journal*, Conference papers, 96: 142–50. 10.2307/2232977
WorldCat Crossref

SUTTON, J. (1991), *Sunk Costs and Market Structure*, Cambridge, Mass.: MIT Press.
Google Scholar Google Preview WorldCat COPAC

*—— (1998), *Technology and Market Structure*, Cambridge, Mass.: MIT Press.
Google Scholar Google Preview WorldCat COPAC

TIDD, J., BESSANT, J., and PAVITT, K. (2001), *Managing Innovation: Integrating Technological, Market and Organizational Change*, Chichester: Wiley.
Google Scholar Google Preview WorldCat COPAC

* von Tunzelmann, G. N. (1995), *Technology and Industrial Progress: The Foundations of Economic Growth*, Cheltenham: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

WOMACK, J. P., JONES, D. T. and ROOS, D. (1990), *The Machine that Changed the World*, New York: Rawson.
Google Scholar Google Preview WorldCat COPAC