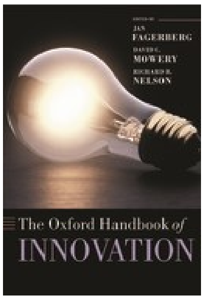


The Oxford Handbook of Innovation
Jan Fagerberg (ed.), David C. Mowery (ed.)

https://doi.org/10.1093/oxfordhb/9780199286805.001.0001
Published: 2006 **Online ISBN:** 9780191577314 **Print ISBN:** 9780199286805

CHAPTER

6 Measuring Innovation

Keith Smith

https://doi.org/10.1093/oxfordhb/9780199286805.003.0006 Pages 148–178
Published: 02 September 2009

Abstract

It is sometimes suggested that it is inherently impossible to quantify and measure innovation. This article argues that while this is true for some aspects of innovation, its overall characteristics do not preclude measurement of key dimensions of processes and outputs. An important development has been the emergence of new indicators of innovation inputs and outputs, including economy-wide measures that have some degree of international comparability. The article's sections firstly discuss some broad issues in the construction and use of science, technology, and innovation indicators. They then turn (briefly) to the strengths and weaknesses of current indicators, particularly R&D and patents. The final sections of this article cover recent initiatives focusing on the conceptualization, collection, and analysis of direct measures of innovation.

Keywords: innovation, science, technology, innovation indicators, R&D

Subject: Innovation, Research Methods, Business and Management

Series: Oxford Handbooks

6.1 Introduction[1]

IT is sometimes suggested that innovation is inherently impossible to quantify and to measure. This chapter argues that while this is true for some aspects of innovation, its overall characteristics do not preclude measurement of key dimensions of processes and outputs. An important development has been the emergence of new indicators of innovation inputs and outputs, including economy-wide measures that have some degree of international comparability. Following sections discuss first some broad issues in the construction and use of science, technology, and innovation (STI) indicators, then turn (briefly) to the strengths and weaknesses of current indicators, particularly R&D and patents. Final sections cover recent initiatives focusing on the conceptualization, collection, and analysis of direct measures of innovation.

New rather than "traditional" indicators are emphasized here because, as Kenneth Arrow remarked many years ago, "too much energy has gone into squeezing the last bit of juice out of old data collected for

different purposes relative to the design of new types of data," a point echoed by Zvi Griliches: "far too little fresh economics data is collected" (Arrow 1984: 51; Griliches 1987: 824). Innovation data producers have responded to this kind of challenge. The most important development has been new survey-based
p. 149 indicators, especially the *Community Innovation Survey* (CIS), ↳ which has been carried out three times in all EU Member States. The basic format of CIS has diffused to many other countries (including Canada, Australia, Hungary, Brazil, Argentina, and China). Has this effort been justified? In answering this much depends on the quality of analysis these surveys make possible, so the final section discusses the rapidly growing research and publication efforts deriving from CIS.

6.2 The Conceptual Background: Measurement Issues

Measurement implies commensurability: that there is at least some level on which entities are qualitatively similar, so that comparisons can be made in quantitative terms.

An immediate problem is that innovation is, by definition, novelty. It is the creation of something qualitatively new, via processes of learning and knowledge building. It involves changing competences and capabilities, and producing qualitatively new performance outcomes. This may lead to new product characteristics that are intrinsically measurable in some way—new lift/drag aspects of an aircraft wing, for example, or improved fuel efficiency of an engine. However, such technical measurement comparisons are only rarely meaningful across products. More generally, innovation involves multidimensional novelty in aspects of learning or knowledge organization that are difficult to measure or intrinsically non-measurable. Key problems in innovation indicators therefore concern the underlying conceptualization of the object being measured, the meaning of the measurement concept, and the general feasibility of different types of measurement. Problems of commensurability are not necessarily insoluble, but a main point arising from recent work is the need for care in distinguishing between what can and what cannot be measured in innovation.

Quite apart from the problem of whether novelty can be measured, a fundamental definitional issue is what we actually mean by "new" (see Ch. 1 by Fagerberg in this volume). Does an innovation have to contain a basic new principle that has never been used in the world before, or does it only need to be new to a firm? Does an innovation have to incorporate a radically novel idea, or only an incremental change? In general, what kinds of novelty count as an innovation? These issues of commensurability and novelty are basic problems for all S&T indicators—R&D in particular—but have been most explicitly addressed in the development of direct innovation indicators.

p. 150

6.3 Theories of Innovation and their Use in Indicator Development

Although statistics are often treated as though their meanings are transparent, they always rest on some kind of (usually implicit) conceptual foundations. The system of national accounts, for example, derives from Keynesian macroeconomic concepts that seek to identify components of aggregate demand. R&D data has a complex background in the scientification of innovation—the notion that acts of research and discovery underpin innovation (Laestadius 2003). These conceptual foundations are rarely considered when indicators are used. Such issues are complicated by the fact that some key S&T indicators are by-products of other processes—legal procedures (as with patents), or academic institutions (as with bibliometrics, which rest on publishing conventions).

What kinds of ideas have formed the conceptual foundations of innovation indicators? An important figure here has been Nathan Rosenberg, whose work quite explicitly affected the OECD's *Innovation Manual* (OECD

1992, 1997). (This manual is usually called the *Oslo Manual* because much of the drafting and expert meetings on it occurred there.) First, Rosenberg challenged the notion of research-based discovery as a preliminary phase of innovation. Second, he challenged the idea of separability between innovation and diffusion processes, pointing out that most diffusion processes involve long and cumulative programs of post-commercialization improvements (see Rosenberg 1976 and 1982). Perhaps his best-known contribution, with Steven Kline, has been the so-called chain-link model of innovation, which stresses three basic aspects of innovation (Kline and Rosenberg 1986):

- innovation is not a sequential (linear) process but one involving many interactions and feedbacks in knowledge creation
- innovation is a learning process involving multiple inputs
- innovation does not depend on invention processes (in the sense of discovery of new principles), and such processes (involving formal R&D) tend to be undertaken as problem-solving within an ongoing innovation process rather than an initiating factor

The work of Rosenberg alone, and of Rosenberg and Kline, has at least two important implications for indicator development. The first is that novelty implies not just the creation of completely new products or processes, but relatively small-scale changes in product performance which may—over a long period—have major technological and economic implications. A meaningful innovation indicator should therefore be able to pick up such change. The second is the importance of non-R&D inputs to innovation—design activities, engineering developments and experimentation, training, exploration of markets for new

products, etc. So there is a ↳ need for input indicators that reflect this input variety and its diverse distributions across activities.

The CIS effort has in general been informed by ideas from recent innovation research. One in particular should be mentioned, especially because it has had a strong impact on research using the new data. This is the idea that innovation relies on collaboration and interactive learning, involving other enterprises, organizations, and the science and technology infrastructure. Data gatherers have been concerned to explore the networking dimension of innovation, and this has been an important conceptual issue in survey design (see Howells 2000, for an overview of research on this topic).

6.3.1 Existing and New Indicators: What Can Be Measured, and What are the Limitations?

What does it mean to measure qualitatively diverse phenomena? Clearly this is a serious problem for R&D data. Research is a knowledge-creating process for which both activities and outcomes are radically incommensurable—there is no meaningful way to assess the dissimilar actions and events that feed into research, let alone to compare the increments to knowledge that follow from research. This problem cannot be overcome—it can only be circumvented by carefully specifying aspects of the research process that are in some serious sense measurable. The solution adopted by the framers of the *Frascati Manual* (the OECD's operating statistical manual for R&D data collection) has been to write definitions of research-comprising activities, and then seek data on either expenditure or personnel resources devoted to such activities. The measurement concept for R&D is therefore economic in character, and the datasets that result are collections of economic indicators compatible with industrial datasets, and indeed with the national accounts.[2]

This approach to measurement has also been taken with innovation surveys. The problem is that innovation is usually conceptualized in terms of ideas, learning, and the creation of knowledge (moreover knowledge creation of a far wider character than research), or in terms of competences and capabilities. As with "research," innovation is a multidimensional process, with nothing clearly measurable about many aspects of the underlying process. Most modern innovation theory rests on some kind of "resource-based" theory of the firm, in which firms create physical and intangible assets that underpin capabilities (see Lazonick in this volume). Innovative learning can be seen as change in the knowledge bases on which capabilities rest. Neither learning, nor the capabilities which result, seem to be measurable in any direct way. However, just as "research" can be captured via expenditures on certain activities, or by the use of time by certain research personnel, so learning processes can to some extent be captured by activities such as design, p. 152 training, market ↳ research, tooling up, etc. Expenditure on such activities can in principle be measured (of course the practice may be difficult, since some of these innovation-related activities are not straightforwardly reflected in the accounting procedures of firms). On the output side, the question is whether capability outcomes can be measured by some tangible change in physical or economic magnitudes. Once again there are also potential measurement areas—experience (with pilot or experimental surveys in the 1980s) showed that firms can identify changes in their product mixes, and can estimate sales from new or changed products (Smith 1992). So it is possible to define product change, in terms of construction, use of materials, technical attributes, or performance characteristics, and then to look at the place of (differently) changed products in the sales of the firm. These considerations lead to expenditure measures of inputs to innovation, and sales measures of outputs of innovation. These economic measures of innovation are clearly analogous to the measurement of research. This similarity in approach incidentally suggests that it makes no sense to use R&D data while rejecting the use of more direct innovation data.

6.4 Current Major Indicators

This section outlines the major established indicators that have been used for innovation analysis, and provides a brief guide to further analysis of them. There are three broad areas of indicator use in STI analysis: first, R&D data; second, data on patent applications, grants and citations; and third, bibliometric data (that is data on scientific publication and citation).

In addition to this there are three other important classes of indicators:

- technometric indicators, which explore the technical performance characteristics of products (see e.g. Saviotti 1996 and 2001 for a theoretical view of this, and Grupp 1994 and 1998 for analysis and empirical specifications);
- synthetic indicators developed for scoreboard purposes mainly by consultants (see World Economic Forum 2003);
- databases on specific topics developed as research tools by individuals or groups (such as the large firm database used by Pavitt and Patel, or the MERIT-CATI database on technological collaboration developed by John Hagedoorn, or the DISKO surveys on technological collaboration emanating from the University of Ålborg (see Patel and Pavitt 1997 and 1999, Hagedoorn and Schakenraad 1990, and—for extensive reporting on the use of collaboration data—OECD 2001).

p. 153

Box 6.1 Bibliometric data

Bibliometric analysis, meaning the analysis of the composition and dynamics of scientific publication and citation, revolves around the Science Citation Index and the Institute for Scientific Information database. The Institute for Scientific Information (ISI) was founded in 1958, and acquired by Thomson Business Information—a subsidiary of the Thomson Corporation—in 1992. The ISI National Science Indicators database currently contains publication and citation statistics from more than 170 countries, and 105 subfields in the sciences, social sciences, and arts and humanities, representing approximately 5,500 journals in the sciences, 1,800 in the social sciences, and 1,200 in the arts and humanities.

The following discussion concentrates on R&D and patents, since bibliometric analysis relates primarily to the dynamics of science rather than innovation (see Moed et al. 1995, and Kaloudis 1997 for reviews of the state of the art).

6.4.1 Research and Development (R&D) Statistics and Indicators

By far the longest-standing area of data collection is R&D.

The key OECD document for the collection of R&D statistics is the *Standard Practice for Surveys of Research and Experimental Development*, better known as the *Frascati Manual*. The first edition was the result of an OECD meeting of national experts on R&D statistics in Frascati, Italy, in 1963. The manual has been continuously monitored and modified through the years: the current version of the manual, the *Frascati Manual* 2002, is the seventh edition (OECD 2002). The Manual defines R&D as comprising both the production of new knowledge and new practical applications of knowledge: R&D is conceived as covering three different kinds of activities: basic research, applied research, and experimental development—these categories are distinguished in terms of their distance from application.

It is often difficult to draw the dividing line between what should be counted as R&D and what should be excluded: "The basic criterion for distinguishing R&D from related activities is the presence in R&D of an appreciable element of novelty and the resolution of scientific and/or technological uncertainty, i.e. when
p. 154 the solution to a problem is not readily apparent to someone familiar with the basic ↳ stock of commonly used knowledge and techniques in the area concerned" (OECD 2002: 33). Education and training in general is not counted as R&D. Market research is excluded. There are also many other activities with a scientific and technological base that are kept distinct from R&D. These include such industrial activities related to innovation as acquisition of products and licenses, product design, trial production, training and tooling up, unless they are a component of research, as well as the acquisition of equipment and machinery related to product or process innovations.

R&D is often classified according to multiple criteria, and data is collected in highly detailed forms. Beyond the distinction between basic research, applied research and development the data is classified into sector of performance: business enterprise, government, higher education, and private non-profit. It also distinguishes between sources of finance, both domestic and international. Then there is classification by socio-economic objectives, and a further classification by fields of research. These detailed classifications are usually ignored both by policy analysts and researchers, who tend to focus on gross expenditure only (at industry or country level), thereby missing most of the really interesting detail in the data. For example, a major issue is that, when looking at R&D by fields of research, ICT (information and communications technologies) turns out to be the largest single category in all countries that classify R&D data in this way.

However most of the ICT research is actually performed outside the ICT sector, in the form of systems and software development by users.[3] On the one hand, this raises interesting questions about the cross-industry significance of the ICT sector; but there are also questions about the extent to which such activity should be classified as R&D at all. Concerns have also been expressed about whether the R&D definitions are comprehensible to firms (especially SMEs), and whether or not there is systematic undercounting of small-firm R&D (Kleinknecht, Montfort, and Brouwer 2002).

R&D data is always constrained as an innovation indicator by the fact that it measures an input only (Kleinknecht et al. 2002). However, R&D also has fundamental advantages. These include the long period over which it has been collected, the detailed sub-classifications that are available in many countries, and the relatively good harmonization across countries. Unfortunately a great deal of the literature consists essentially of an attempt to match aggregate R&D measures across time and across sectors or countries to some measure of productivity (see Griffith, Redding, and Van Reenen (2000) for a very thorough recent example; Dowrick (2003) is a recent survey of this very large literature). However this research effort is limited in two senses—on the one hand it tends to imply (along with the new growth theory, incidentally) that R&D is the primary source of productivity growth, and on the other it fails to exploit the basic complexity of the data that is actually available. The disaggregation processes that are possible with R&D data continue to offer rich and unexploited opportunities for researchers.

6.4.2 Policy Pitfalls: The Use and Misuse of R&D Indicators

It is worth saying something about the pitfalls of R&D as a policy indicator, especially via the most widely-used indicator, that of "R&D Intensity." This is the ratio of R&D expenditure to some measure of output. For a firm, it is usually the R&D/Sales ratio. For an industry or a country it is the ratio of business expenditure on R&D(often known as BERD) to total production or value added. For a country it is usually gross expenditure on R&D (GERD) to GDP.

The R&D/GDP ratio is used in two primary ways. First, it is used to characterize industries—high BERD/GDP ratios for an industry are held to identify hightechnology activities. Second, a high GERD/GDP ratio for a country is often believed to indicate technological progressiveness and commitment to knowledge creation (see Godin 2004 for an account of the historical background to these notions).

For countries, there is a distribution of GERD/GDP intensities, as Table 6.1 indicates. Both analysts and policy makers often treat a particular place in the ranking, or the OECD average, or some particular GERD/GDP ratio as desirable in itself. So Canada, for example, has the objective of raising its ranking to fifth in the OECD table; Norway has the target of reaching the OECD average for GERD/GDP; and the EU as a whole has a target of reaching a GERD/GDP ratio of 3 per cent (it could be argued that this target dominates EU technology policy making at the present time). But what is the indicator really telling us?

A basic problem is that R&D intensity depends on the industrial mix. Currently the OECD uses a four-tier model to classify industries, in which the basic criterion is the BERD/Production ratio:

high-tech industries		> 5%	R&D/Production
medium high-tech industries	> 5%	> 3%	R&D/Production
low-tech industries	> 3%	> 1%	R&D/Production
low-tech industries	> 1%	> 0%	R&D/Production

Since industries vary considerably in their BERD/GDP ratios, the aggregate BERD/GDP ratio may simply be an effect of that fact that industrial structures are different across countries. A country or region with large high-R&D industries will naturally have a higher aggregate BERD/GDP ratio than one with most of its activities in low-R&D industries. These structural issues largely explain the differences in R&D intensities across large and smaller economies (Sandven and Smith 1997). The question then is, does a specific industrial structure really matter? This is question for debate, which cannot be addressed let alone settled here (it is interestingly explored in Pol et al. 2002); however the desirability of specific industrial structures is the real issue underlying use of this aggregate indicator, though it is rarely explicitly discussed. It is worth noting also that within an industry there tends to be a wide distribution of R&D intensities among firms, so it is common to find ↳ high-R&D firms in low-R&D industries and vice versa (Hughes 1988 discusses the intra-industry distributions using UK data).

Table 6.1 GERD/GDP ratios across countries

Country	GERD/GDP 2000	Percentage point deviation from OECD mean
Sweden	3.65 (1999)	1.40
Finland	3.40	1.15
Japan	2.98	0.73
United States	2.72	0.47
Korea	2.65	0.40
Germany	2.49	0.29
France	2.18	−0.07
Netherlands	1.94	−0.26
Canada	1.87	−0.33
United Kingdom	1.85	−0.35
Austria	1.84	−0.36
Norway	1.65	−0.6
Australia	1.53	−0.72
Ireland	1.15	−1.1
Italy	1.07	−1.18
New Zealand	1.03	−1.22
Spain	0.94	−1.31
Greece	0.67	−1.58
Total OECD	2.25	

Source: OECD, *Main Science and Technology Indicators Database*, accessed August 2003.

An important recent modification of this indicator has been the addition of "acquired technology," calculated as the R&D embodied in capital and intermediate goods used by an industry, and computed via the most recent input–output table. The method for calculating acquired R&D is to assume that the R&D embodied in a capital good is equal to the capital good's value multiplied by the R&D intensity of the supplying industry. The most recent year for which relevant input–output data is generally available is 1990. The overall structure of the classification as currently used can be seen in Table 6.2, which shows direct R&D intensities for the main industrial groups for 1997, plus the proportion of acquired to direct R&D for 1990, the last year for which it was calculated.

p. 157 **Table 6.2** Classification of industries based on R&D intensity

	ISIC Rev 3	Direct R&D Intensity 1997	Acquired R&D intensity as % of direct R&D intensity, 1990
High technology Industries			
Aircraft and spacecraft	353	12.7	15
Pharmaceuticals	2423	11.3	8
Office, accounting and computing machinery	30	10.5	25
Radio, television and communications equipment	32	8.2	17
Medical, precision and optical instruments	33	7.9	29
Medium–high-technology industries			
Electrical machinery and apparatus	31	3.8	42
Motor vehicles and trailers	34	3.5	29
Chemicals	24 exc 2423	2.6	18
Railroad and transport eqpt. n.e.c.	352+359	2.8	88
Machinery and eqpt n.e.c.	29	1.9	104
Medium–low-technology industries			
Coke, refined petroleum products and nuclear fuel	23	0.8	30
Rubber and plastic products	25	0.9	127
Other non-metallic mineral products	26	0.9	285
Building and repairing of ships and boats	351	0.7	200
Basic metals	27	0.7	289

Fabricated metals products	28	0.6	133
Low-technology industries			
Manufacturing n.e.c. and recycling	36–37	0.4	n.a.
Wood, pulp, paper, paper products, printing and publishing	20–22	0.3	167
Food products, beverages and tobacco	15–16	0.4	267
Textiles, textile products, leather and footwear	17–19	0.3	250

Sources: OECD, *Science, Technology and Industry Scoreboard 1999: Benchmarking Knowledge-Based Economies* (Paris: OECD 1999), Annex 1, p. 106; OECD, *Science, Technology and Industry Scoreboard 2001: Towards a Knowledge-Based Economy*, Annex 1.1, pp. 13–139.

Note: The ISIC classification was revised in 1996, though changes were relatively minor. 1990 data has been reassigned to the most relevant Rev 3 category.

p. 158 Table 6.2 shows that "acquired technology" as a proportion of direct R&D rises dramatically as we move from high-to low-technology industries. This suggests that technology intensity is likely to be very sensitive to how the measurement of acquired technology is carried out. For example: suppose we assume that when a firm buys a machine it acquires not a proportion of the R&D that went into the machine (corresponding to the R&D/output ratio) but all of it? In other words, purchasing a computer gives the customer access to all of the R&D that was used to produce it—this assumption seems to be compatible with the knowledge externality ideas of the new growth theory (for an overview see Verspagen 1992, see also Verspagen in this volume). Making this assumption would significantly alter the rankings of technology intensity in Table 6.2 by improving the position of industries with subpopulation in selected countries, stantial use of R&D embodied in capital goods. Another point to make here is that so-called low-technology industries do not create or access knowledge via direct R&D, and the classification is in effect biased against all industries that employ non-R&D methods of knowledge creation (Hirsch-Kreinson et al. 2003). So the indicator has drawbacks at the levels of countries, industries and firms; there are therefore pitfalls in the uncritical use of this apparently simple indicator.

6.4.3 Patent Data

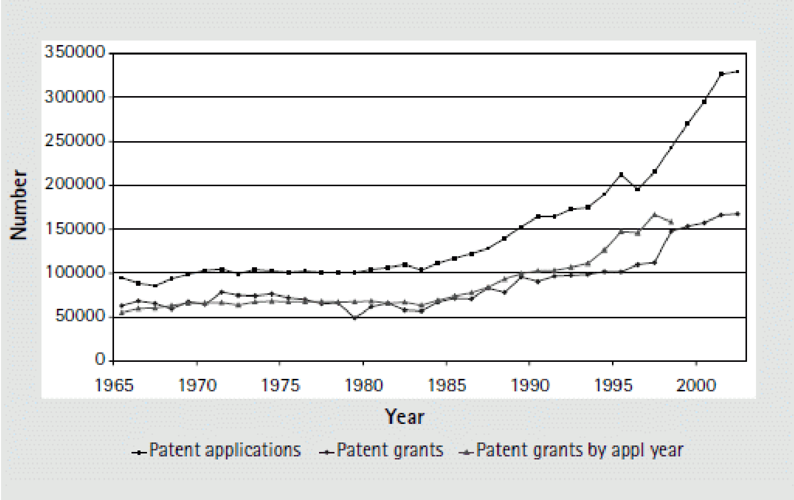
A patent is a public contract between an inventor and a government that grants time limited monopoly rights to the applicant for the use of a technical invention (see Iversen 1998 for a good review). The patentee must first demonstrate a non-obvious advance in the state of the art after which the inventor enters into a binding relationship with the state: in general, the inventor contracts to reveal detailed information about the invention in return for limited protection against others using that invention for the time and geographical area for which the contract is in force. In terms of the concessions made by the parties, there is a trade-off between the disclosure of detailed information by the inventor against the permission of limited monopoly by the state. In this sense, the patent-system is designed as an incentive-mechanism for the creation of new economically valuable knowledge and as a knowledge-dissemination mechanism to spread this information. There has been a prolonged debate about whether the patent system would be worth creating if we did not have it (the usual answer is no), and whether—since we do have it—it should be abolished (again the usual answer is no), or whether a reward system would be superior (again, no).[4]

In general the patent system gathers detailed information about new technologies into a protracted public record of inventive activity, which is more or less continuous. This gives it striking advantages as an p. 159 innovation-indicator. These include: ↳

- Patents are granted for inventive technologies with commercial promise (i.e. innovation).
- The patent system systematically records important information about these inventions.
- The patent system collates these technologies according to a detailed and slow-tochange classification system.
- The patent system systematically relates the invention to relevant technologies, and also provides links (via citations) to relevant technical and scientific literature.
- The patent system is an old institution, providing a long history (see Granstrand in this volume)—it is the only innovation indicator extending back over centuries, and this means that it is possible to use patents to explore quantitative issues over very long periods (see Bruland and Mowery in this volume).
- The data is freely available.

The major sources of patent data are the records of the US Patent Office and the European Patent Office. Recent years have seen major increases in patenting activity, as Figure 6.1 shows. The causes of this rise are an important issue: there does seem to be growth of patenting extending back at least fifteen years, possibly signifying acceleration of innovation efforts, or changes in strategic behavior by firms; however, the rise may also be shaped by significant reductions in patent costs. (An analysis of the issues here can be found in Hall and Ziedonis 2001; see also Kortum and Lerner 1999.)

Fig. 6.1



USPTO utility patents 1965–2002

Source: Hall 2003.

p. 160 Patents also of course have weaknesses, the most notable of which is that they are an indicator of invention rather than innovation: they mark the emergence of a new technical principle, not a commercial innovation. Many patents refer to inventions that are intrinsically of little technological or economic significance. More generally, Kleinknecht et al. have argued that

> It is obvious that the patent indicator misses many non-patented inventions and innovations. Some types of technology are not patentable, and, in some cases, it is still being debated whether certain items (e.g. new business formulae on the internet) can be patented. On the other hand, what is the share of patents that is never translated into commercially viable products and processes? And can this share be assumed to be constant across branches and firm size classes? Moreover in some cases patent figures can be obscured by strategic behavior: a firm will not commercialize the patent but use it to prevent a competitor patenting and using it. (Kleinknecht et al. 2002: 112)

But taking such qualifications into account, the analysis of patent data has proven very fruitful. Important achievements include the mapping of inventive activity over long time periods (Macleod 1988; Sullivan 1990); assessing the impacts of economic factors on the rate of invention (Schmookler 1971); the elucidation of the complexity of technological knowledge bases in large firms (Patel and Pavitt 1999); the use and roles of science in industrial patenting (Narin and Noma 1985; Meyer 2000); the mapping of inter-industry technology flows (Scherer 1982); the analysis of spillovers of knowledge using patent citations (Jaffe, Henderson, and Trajtenberg 1993) and the analysis of patent values (Hall, Jaffe, and Trajtenberg 2001).

6.5 New Innovation Indicators

Recent years have seen attempts to create new and better-designed indicators focused directly on innovation: for example, the European Commission has supported large-scale efforts to overcome the absence of direct data on industrial innovation—and there have been other attempts to improve our knowledge of outputs, sources, instruments and methods of innovation (recent discussions are Hansen 2001; Guellec and Pattinson 2001; Smith 2002).

6.5.1 Types of Innovation Survey

Innovation surveys divide into two basic types: those that focus on firm-level innovation activity, asking p. 161 about general innovation inputs (both R&D and non-R&D) ↳ and outputs (usually of product innovations), and those that focus on significant technological innovations (usually identified through expert appraisal, or through new product announcements in trade journals or other literature). Sometimes the first of these approaches is called a "subject" approach, since it focuses on the innovating agent; the latter is referred to as the "object" approach, since it focuses on the objective output of the innovation process, on the technology itself (Archibugi and Pianta 1996). Both approaches can and do incorporate attempts to explore aspects of the innovation process itself: sources of innovative ideas, external inputs, users of innovation, and so on. Both approaches define an innovation in the Schumpeterian sense, as the commercialization of a new product or process. However the object approach tends to focus on significantly new products, while the subject approach includes small-scale, incremental change.

6.5.2 The "Object" Approach to Innovation Indicators

Perhaps the most important example of the "object" approach is the SPRU database, developed by the Science Policy Research Unit at the University of Sussex, which collected information on major technical innovations in British industry, covering sources and types of innovation, industry innovation patterns, cross-industry linkages, regional aspects, and so on.[5] The SPRU approach used a panel of about 400 technical experts, drawn from a range of institutions, to identify major innovations across all sectors of the economy, from1945 through to 1983. The database covered a total of about 4,300 innovations. An important related database is the US Small Business Administration database, covering innovations introduced to the market by small firms in the US in one year, 1982. This was constructed through an examination of about one hundred trade, engineering, and technology journals—a major study by Acs and Audretsch (1990) has been based upon it. In addition there is a range of smaller literature-based surveys—based on searches of trade literature—that have been undertaken in recent years: the Netherlands, Austria, Ireland, and the UK for example—Kleinknecht and Bain (1993) and Kleinknecht (1996) report the results from this work.

This type of approach has a number of strong advantages. Technology-oriented approaches have the merit of focusing on the technology itself, and allow a form of external assessment of the importance of an innovation—the fact that an innovation is recognized by an expert or a trade journal makes the counting of an innovation somewhat independent of personal judgements about what is or is not an innovation. Both expert-based and literature-based approaches can be backward looking, thus giving a historical perspective on technological development.

But the approach also has weaknesses. The very fact that innovations must pass a test of significance—that p. 162 is, must be sufficiently innovative to be publicized in trade ↳ journals or the general press—also imparts a sample selection bias to the exercise. In effect what these surveys cover is an important subset of the population of innovations: those that are new to an industry. What gets lost is the population of innovation outputs which are "routine," incremental, part of the normal competitive activity of firms, yet not strikingly new enough to be reported.

6.5.3 Results from "Object" Studies

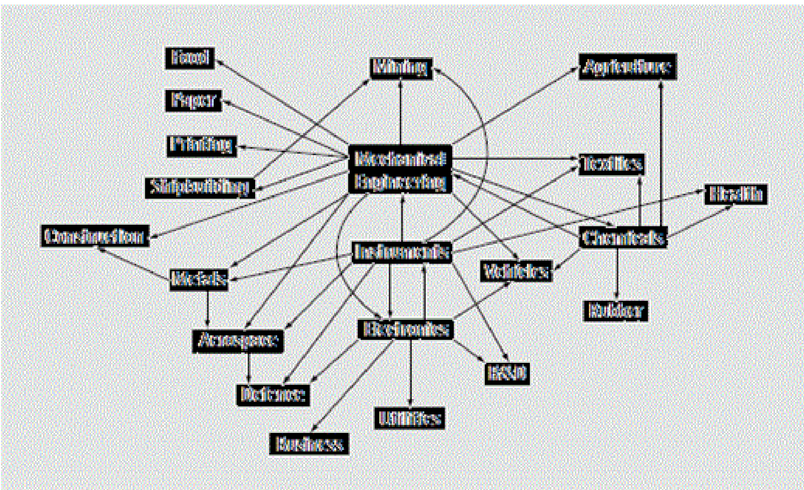
One of the most important results of work using the SPRU database was to show the existence of quite different types of innovative activity across different types of industry. In a pioneering study, Pavitt (1984) distinguished between four basic firm types, which he called "science based," "scale intensive," "specialized suppliers," and "supplier dominated." He showed that these categories of firms were characterized by differences in sources of technology, types of users, means of appropriation, and typical firm size. This work was among the first to really demonstrate empirically the importance of technological diversity within the economy, with important implications for the design of R&D policy in circumstances where firms have very different technology creation patterns. Other work with the SPRU database has emphasized the inter-sectoral flow of innovations (using the important data on first users of innovations within the dataset), and gave an early empirical insight into the complexity of what is now called the system of innovation (Pavitt, 1983; Robson et al. 1988). Geroski (1994: 19) has summarized these intersectoral flows as shown in Figure 6.2 where the key result is the importance of the three major engineering sectors (mechanical engineering, instruments and electronic engineering) in terms of the flow of innovations into other sectors. But it is important to note also the importance of flows within this broad engineering complex.

6.5.4 The "Subject" Approach and the Community Innovation Survey

In the early 1990s, the OECD attempted to synthesize the results of earlier trial innovation surveys, and to develop a manual that might form the basis of a common practice in this field. A group of experts was convened, and over a period of approximately fifteen months developed a consensus on an innovation manual which became known as the *Oslo Manual* (OECD 1992).

The European Commission, in a joint action between Eurostat and DG Enterprise, followed up the OECD initiative in 1992–3, implementing the *Community Innovation Survey*. CIS was an innovative action in a
p. 163
number of respects. First, it ↳ was a large-scale attempt to collect internationally comparable direct measures of innovation outputs. Second, it collected data at a highly disaggregated level and made this data available in disaggregated form to analysts. The survey has now been carried out three times, most recently in 2002; in that year the survey covered approximately 140,000 European firms.

Fig. 6.2



The SPRU innovation database: The intersectoral flow of innovations

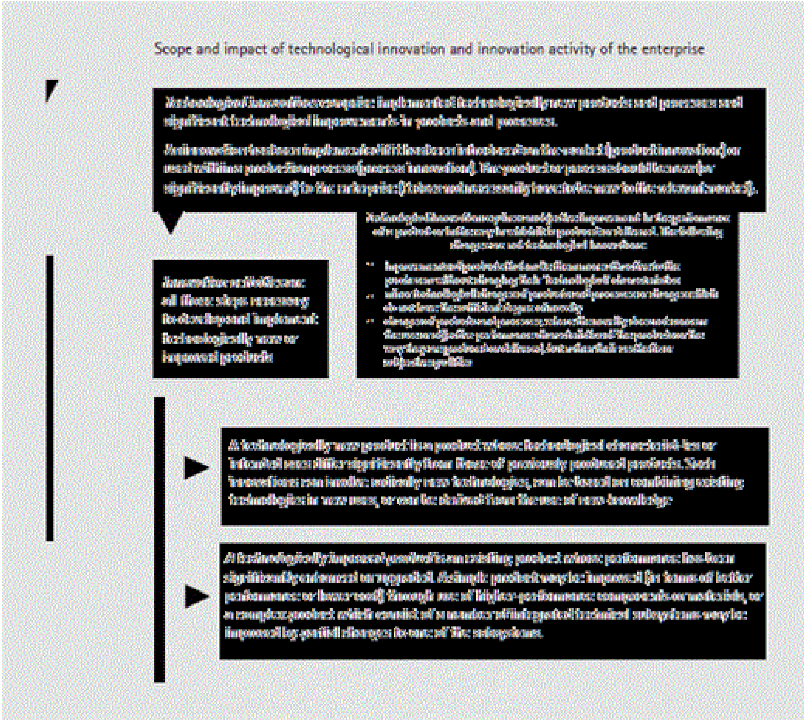
Source: Geroski (1994).

CIS, in its various versions, developed and incorporated data on the following topics:

- expenditure on activities related to the innovation of new products (R&D, training, design, market exploration, equipment acquisition and tooling-up etc). There is therefore a unique focus on non-R&D inputs to the innovation process;
- outputs of incrementally and radically changed products, and sales flowing from these products;
- sources of information relevant to innovation;
- technological collaboration;
- perceptions of obstacles to innovation, and factors promoting innovation.

In terms of definitions, the CIS followed the *Oslo Manual* in a number of crucial respects. Firstly, it focused on technological innovation, particularly in products. But it then defined different categories of change, asking firms to assign the product range of the firm to these different categories. The CIS also asked firms to estimate the proportions of sales which were coming from: new or radically changed products, from products which had been changed in minor ways, or from unchanged products. The definitions of p. 164 technological innovation used in CIS-2, which have ↳ been consistent throughout the various versions of CIS, are shown in Figure 6.3. It should be noted that although both product and process definitions are offered, the survey in fact concentrates on technologically changed products, mainly because of the availability of an economic measure. Most processes are of course products of capital goods-producing firms, although expenditure on changing processes extends well beyond just buying new equipment. Clearly, this limits the scope of the innovations on which data is being sought—apart from processes, other aspects of innovative change, such as organizational change, underlying learning processes, and so on are excluded. However, this was done for considered reasons: focusing on technologically changed products allows a fairly rigorous definition of change to be developed. Sales of such products permit at least a degree of economic commensurability across firms and even industries. It also permits reasonable definitions of novelty: in deciding what was "new" about an innovation, the Oslo Manual and CIS identified different p. 165 degrees of product innovation by asking firms to distinguish ↳ between sales of products new to the firm only, products new to the industry, or products that were wholly new. So although the *Oslo Manual*/CIS approach constrains innovation to the field of the technological, it does so in a way that allows a consistency between the concepts of change, novelty, and commensurability. Without such consistency, survey methods are not appropriate.

Fig. 6.3



Defining technological innovation–Community Innovation Survey (CIS)

Source: CIS-2 Questionnaire.

6.5.5 Innovation Activities and their Measurement

A second feature of the *Oslo Manual* and of CIS was the attempt to estimate expenditures on categories of innovation activity other than R&D. Six main categories of innovation activities were identified, and the basic structure of the questions and definitions was as shown in Figure 6.4. The basic idea here was that firms invest in a wide range of non-R&D activities, resulting in both tangible and intangible assets, and that these are likely to vary across firms and industries. The categories here are drawn closely from Kline and Rosenberg (1986), which provides the general conceptual foundation. But it can easily be seen that there are likely to be problems: these are complex categories, in an area where firms do not necessarily keep separate or detailed records. In practice, in the first round of the CIS, there were many firms who did not respond to the questions which were asked on this topic, and many who were clearly able to answer only in terms of broad estimates. But there are strong interfirm variations—some firms operate project management systems that permit accurate answers in this area, and the data quality seems to have improved over time.

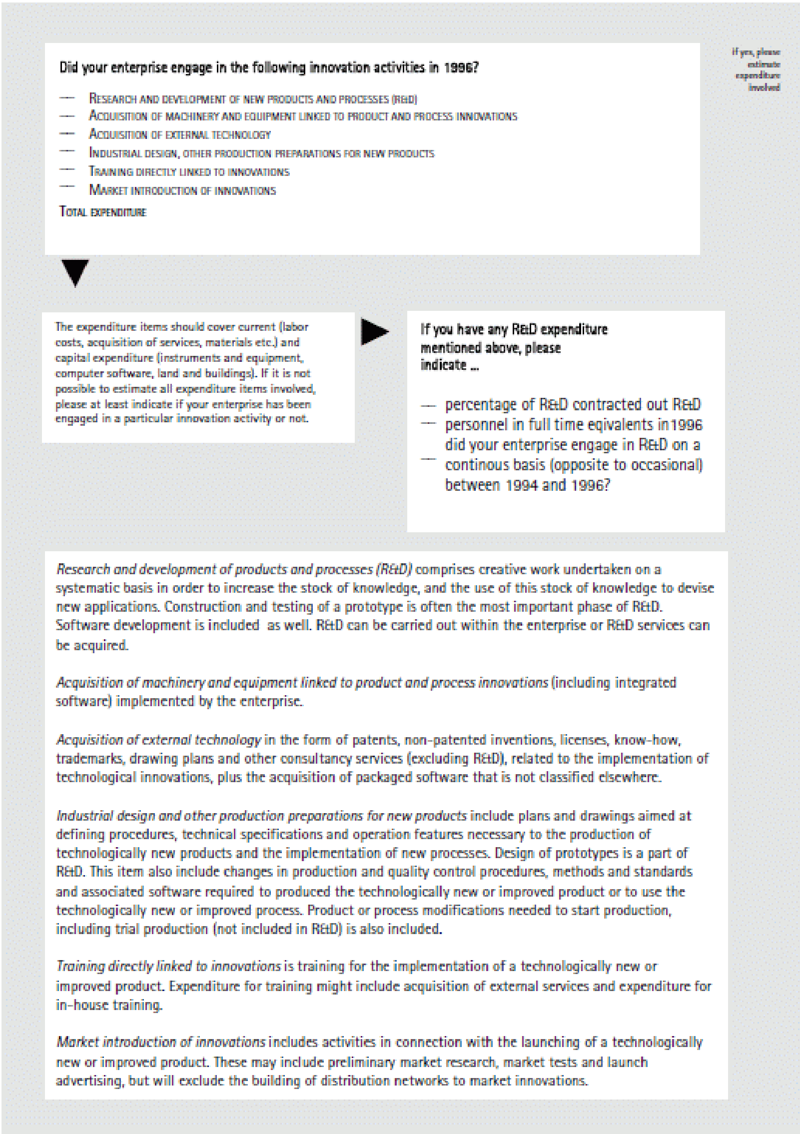
One of the important results to have emerged from this part of CIS is that capital expenditure related to innovation is the largest single component of innovation expenditure across all sectors (Evangelista et al. 1998). This emphasizes the importance of the embodied R&D in capital and intermediate goods, discussed above.

6.5.6 CIS: Some Main Results

What have we learned so far from attempts to measure and map innovation? In this section we look at some of the results that have emerged from a range of studies using CIS. The literature using innovation survey data is growing rapidly at the present time, and it falls into three broad categories.

Descriptive overviews of data results at national level. These studies are usually written for policy makers, and typically consist of tables and charts, accompanied by commentary, showing results such as the distribution of innovation expenditures and their differences across industries, proportions of firms introducing product
p. 166 or ↳ process innovations, the distribution of different types of new product sales across industries, major patterns of technological collaboration, perceptions of obstacles to innovation, and data on objectives of
p. 167 innovation. These studies tend to be important ↳ not just in reaching policy makers, but in emphasizing some robust results which emerge from this data—in particular the conclusion that innovation is pervasively distributed across modern economies, and that non-R&D inputs to innovation are particularly important in non-high-tech sectors. In some cases these reports are sophisticated productions—the German reports, for example, rest on a substantial panel dataset, and the Canadian analytical effort (similar to but not identical with CIS) is very wide ranging indeed (Janz et al. 2002, and Statistics Canada: www.statcan.ca).[6] Most EU countries produce these reports and Eurostat in addition produces a Europe-wide overview (Eurostat 2004).

Fig. 6.4



Did your enterprise engage in the following innovation activities in 1996?

If yes, please estimate expenditure involved

- Research and development of new products and processes (R&D)
- Acquisition of machinery and equipment linked to product and process innovations
- Acquisition of external technology
- Industrial design, other production preparations for new products
- Training directly linked to innovations
- Market introduction of innovations

Total expenditure

The expenditure items should cover current (labor costs, acquisition of services, materials etc.) and capital expenditure (instruments and equipment, computer software, land and buildings). If it is not possible to estimate all expenditure items involved, please at least indicate if your enterprise has been engaged in a particular innovation activity or not.

If you have any R&D expenditure mentioned above, please indicate ...

- percentage of R&D contracted out R&D
- personnel in full time eqivalents in 1996
- did your enterprise engage in R&D on a continous basis (opposite to occasional) between 1994 and 1996?

Research and development of products and processes (R&D) comprises creative work undertaken on a systematic basis in order to increase the stock of knowledge, and the use of this stock of knowledge to devise new applications. Construction and testing of a prototype is often the most important phase of R&D. Software development is included as well. R&D can be carried out within the enterprise or R&D services can be acquired.

Acquisition of machinery and equipment linked to product and process innovations (including integrated software) implemented by the enterprise.

Acquisition of external technology in the form of patents, non-patented inventions, licenses, know-how, trademarks, drawing plans and other consultancy services (excluding R&D), related to the implementation of technological innovations, plus the acquisition of packaged software that is not classified elsewhere.

Industrial design and other production preparations for new products include plans and drawings aimed at defining procedures, technical specifications and operation features necessary to the production of technologically new products and the implementation of new processes. Design of prototypes is a part of R&D. This item also include changes in production and quality control procedures, methods and standards and associated software required to produced the technologically new or improved product or to use the technologically new or improved process. Product or process modifications needed to start production, including trial production (not included in R&D) is also included.

Training directly linked to innovations is training for the implementation of a technologically new or improved product. Expenditure for training might include acquisition of external services and expenditure for in-house training.

Market introduction of innovations includes activities in connection with the launching of a technologically new or improved product. These may include preliminary market research, market tests and launch advertising, but will exclude the building of distribution networks to market innovations.

Resources devoted to innovation activities in 1996

Analytical studies sponsored by the European Commission. The European Innovation Monitoring System (within DG-Enterprise) has sponsored twenty-five specific studies addressing a wide range of questions arising from the innovation data. These cover, for example, Europe-wide surveys of innovation expenditure patterns, innovation outputs across Europe, studies of links between innovation and employment patterns, and sectoral studies (pharmaceuticals, telecoms, pulp and paper, machinery, machine tools, service sector innovation, spin-offs, and regional impacts). Most of these studies are substantial pieces of work, often book length. An overview of the full range of material is provided in Appendix 6.2 to this chapter (reports are accessible via the European Innovation Monitoring System on the EU's CORDIS website: www.cordis.lu)

Econometric or statistical studies of innovation. The innovation survey data has a more or less unique feature, which is that it is available in a highly disaggregated form (as so-called "micro-aggregated" data). This makes possible a wide range of microlevel studies of innovation processes and their effects, and the research opportunities this provides are being exploited rather vigorously at the present time. Publication in this field has been building rapidly, in the form of books (e.g. Thuriaux, Arnold, and Couchot 2001; Kleinknecht and Mohnen 2002, and Gault 2004), articles, journal special issues (such as *STI Review* 27 (2001), and a forthcoming special issue of *Economics of Innovation and New Technology*), and so on. The book edited by Thurieaux et al. collects no less than thirty-one chapters on various empirical aspects of innovation using primarily CIS data. These covered methodological issues, the extension of the CIS approach to services, micro analysis of innovation and firm performance, innovation and employment, innovation in traditional industries, regional innovation, and the use of indicators in policy decision making.

By far the most rapidly growing area of publication is in scholarly journals. A non-exhaustive review of journals in 2002–4 reveals eighteen CIS-based publications. These articles are briefly summarized in Appendix 6.1 to this chapter. Studies focus on such topics as determinants of innovation, innovation and firm performance analysis, diversity (both in innovation patterns and firm performance outcomes), p. 168 ↳ the role of science in innovation, sectoral performance (such as employment impacts), inter-firm collaboration and innovation performance, as well as regional and country studies, and methodological issues. There is every sign that this pace of publication will continue in years ahead. This is a rapid growth in publication, and it is worth noting that it is occurring not only in the front-line journals of innovation studies, but also in the heart of the economic mainstream (notably Mairesse and Mohnen in *American Economic Review*).

Space limitations prevent a detailed overview of the results from the work described above, but some robust conclusions that seem to have emerged from the literature as a whole are as follows:

- Innovation is prevalent across all sectors of the economy—it is not confined to high-tech activities, and so-called low-tech activities contain high proportions of innovating firms, and often generate high levels of sales from new and changed products (SPRU, 1996; European Commission 2001).[7]
- R&D is by no means the most important innovation input. In all sectors, across all countries, investment in capital equipment related to new product introduction is the major component of innovation expenditure, suggesting the need to focus on the knowledge elements embodied in such items (STEP, 1997; Evangelista et al. 1998; Evangelista 1999).
- Across all sectors and countries innovation inputs and outputs are distributed highly asymmetrically—small proportions of firms account for large proportions of innovation outputs as measured by the CIS.
- Collaboration is widespread among innovating firms, to such an extent that it appears almost a *sine qua non* for innovation activity. This result from CIS has led to a range of specific subsidiary surveys, which have generated deeper detail and have confirmed the importance of collaboration suggested by the CIS surveys (see OECD 2001 for papers on this).

- Extension of the CIS format to service sector activities is illustrative but problematical, and deserves more attention (Djellal and Gallouj 2001; Tether and Miles 2001; Ch. 16 by Miles in this volume).
- There continue to be significant differences in collection methodologies and response rates across countries, implying that the data appears to be much better suited to within-sector micro studies than to cross-country macro comparisons.

6.6 Conclusion

While the CIS is clearly a step forward in terms of the type and volume of innovation data that is available, it
p. 169 is of course open to criticism. Most criticisms focus on the ↳ definitional restrictions in CIS with respect to innovation inputs and outputs, and on whether an approach that was originally adopted for manufacturing is extendable to services. On the output side, the decisions made concerning the technological definitions of change obviously limit the forms of innovation that can be studied: it seems to be the case that CIS works well for manufactures, but not for the extremely heterogeneous services sector and its often intangible outputs. The analyses of Djellal and Gallouj (2001) and Tether and Miles (2001) suggest the need for quite different approaches to data gathering on services. In defence of the CIS approach it can be argued that it is, and was intended to be, manufacturing-specific and that extension to services would always be problematic. Similar problems arise with other non-technological aspects of innovation, such as organizational change (see Lam, this volume, for an overview of organizational innovation). It is very unclear whether CIS, or indeed any other survey-based method, can grasp the dimensions of this. The challenge for those who would go beyond this is whether they can generate definitional concepts, survey instruments, and collection methodologies that make sense for other sectors or other aspects of innovation.

On the side of R&D and non-R&D innovation inputs, it is generally unclear just how much of a firm's creative activity is captured by the types of innovation outputs that CIS measures. Arundel has pointed out that “When we talk about a firm expending a great deal of effort on innovation, we are not only speaking of financial investments, but of the use of human capital to think, learn and solve complex problems and to produce qualitatively different types of innovations” (Arundel 1997: 6). This point cannot be argued with, but again the question arises as to what can be done with survey questionnaires and what cannot. If we want to explore complex problem solving, for example, then it is doubtful whether a survey instrument is the right research tool at all. Perhaps an underlying issue here is the longstanding tension between statistical methods, with their advantages of generality but lack of depth, versus case study methods, which offer richness at the expense of generalizability.

Nevertheless it is reasonable to conclude that this data source is proving itself with researchers. Both formal evaluations of CIS as well as data tests by researchers have been broadly positive to the quality of the data flowing from the survey (Aalborg University 1995). One of the positive features of CIS is that survey definition and construction, collection methodologies, and general workability have been subjected to a degree of evaluation, critique, and debate that goes far beyond anything that has been carried out with other indicators (see Arundel et al. 1997, for one contribution to the critical development of CIS). This process is continuing, with both positive and negative potential outcomes. On the positive side, the data source may continue to be improved; on the negative, too much may be asked of this approach. But the real achievement is that CIS has produced results that have not been possible with other data sources, and there is no doubt
p. 170 more to come as researchers master the intricacies of the data. In fact empirical studies using CIS ↳ data may well be the most rapidly growing sub-field of publication within innovation studies at the present time. An interesting feature of the publications using CIS is the breadth of work being done—the data is being used for public presentations, for policy analyses, and for a wide range of scholarly research. It was argued above that researchers have yet to make full use of the richness of R&D data, and this applies even more to

the existing survey-based innovation data. This source will continue to offer considerable scope to researchers in years ahead: issues such as innovation and firm performance, the use of science by innovating firms, the roles of non-R&D inputs, and the employment impacts of innovation are among likely areas of development.

This chapter has concentrated on the Community Innovation Survey, but future developments are unlikely to rely on this source alone. One possible trend is for greater integration of existing data sources, and this can already be seen in multiindicator approaches to such issues as national competitiveness. Another likely trend is for the continued development of new survey instruments aligned to specific needs, along the lines of the DISKO surveys on interfirm collaboration (OECD, 2001). Such developments are much to be welcomed as Innovation Studies seeks to generalize its propositions beyond the limits of the case study method.

Appendix 6.1 Recent (2002 onwards) journal publications using CIS data

Author(s)	Data source	Topic
Cox, Frenz, and Prevezer (2002)	CIS-2	Distinguishing high- and low-tech industries
Evangelista and Savona (2002)	CIS 1 and 2	Employment impacts of innovation in service sector
Hesselman (2002)	CIS-2	Methodological issues and response patterns
Hinloopen (2003)	CIS-1 and CIS-2	Determinants of innovation performance at firm level across Europe
Inzelt (2002)	CIS-2	Service sector innovation in Hungary
Kleinknecht et al (2002)	CIS-2	Indicator choice and biases
Lööf and Heshmati (2004)	CIS-2	Innovation and firm performance
Lööf and Heshmati (2002)	CIS-2	Performance diversity and innovation
Mairesse and Mohnen	CIS-1	Determinants of innovation at firm level
Mohnen and Horeau (2003)	CIS-2	University–industry collaboration
Mohnen, Mairesse, and Dagenais (2003)	CIS-1	Expected vs. actual innovation output levels
Nascia and Perani (2002)	CIS-1	Diversity of innovation patterns in Europe
Quadros et al. (2001)	Brazilian innovation survey	Innovation in San Paulo region
Sellenthin and Hommen (2002)	CIS-2	Innovation patterns in Swedish industry
Tether (2002)	CIS-2	Innovation and inter-firm collaboration
Tether and Swann (2003)	CIS-3	Role of science in innovation
Van Leeuwen and Klomp (2004)	CIS-2	Innovation and multi-factor productivity

p. 171

Appendix 6.2 Publications using CIS data sponsored by the European Commission

p. 172 Publications are listed in chronological order, by topic and instituion.

Evaluation of the Community Innovation Survey (CIS)—Phase 1, Aalborg University (Denmark), 1995
Europe's Pharmaceutical Industry: An Innovation Profile (CIS), SPRU (UK), 1996
Innovation Outputs in European Industry (CIS), SPRU (UK), 1996
Innovation in the European Food Products and Beverages Industry (CIS), IKE (Denmark) and SPRU (UK), 1996
Technology Transfer, Information Flows and Collaboration (CIS), Manchester School of Management & University of Warwick (UK), 1996
The Impact of Innovation on Employment: Alternative interpretations and results of the Italian CIS, University of Rome "La Sapienza" (Italy), 1996
Innovation in the European Chemical Industry (CIS), WZB (Germany) 1996
Innovation in the European Telecom Equipment Industry (CIS), MERIT (Netherlands), 1996
Innovation Activities in Pulp, Paper and Paper Products in Europe (CIS), STEP Group (Norway), 1996
The Impact of Innovation in Employment in Europe—An Analysis Using CIS Data, Centre for European Economic Research/ZEW (Germany), 1996
Computer and Office Machinery—Firms' external growth & technological diversification: analysis during CIS, CESPRI (Italy) 1997
Innovation Expenditures in European Industry: analysis from CIS, STEP Group (Norway), 1997

Manufacture of Machinery and Electrical Machinery (CIS),

Centre for European Economic Research/ZEW (Germany), 1997

Innovation Measurements and Policies: Proceedings of International Conference,

20–21 May 1996, Luxembourg

Analysis of CIS 2 Data on the Impact of Innovation on the Pharmaceuticals and Biotechnology Sector,

SOFRES (Belgium), 2001

Analysis of CIS 2 Data on the Impact of Innovation on Growth in the Sector of Office Machinery and Computer Manufacturing,

SOCINTEC (Spain), 2001

Analysis of CIS 2 Data on the Impact of Innovation on Growth in Manufacturing of Machinery and Equipment and of Electrical Equipment,

STEP Group (Norway), 2001

Analysis of CIS Data on the Role of NTBFs, Spin-offs and Innovative Fast Growing SMEs in the Innovation Process,

Institute for Advanced Studies and Johanneum Research (Austria), 2001

Innovation and the Acquisition and Protection of Competencies,

MERIT (Netherlands), 2001

Analysis of Empirical Surveys on Organisational Innovation and Lessons for Future Community Innovation Surveys,

Fraunhofer Institute (Germany), 2000

Regional Patterns of Innovation: the Analysis of CIS 2 Results and Lessons from other Innovation Surveys,

STEP S.A.S (Italy), 2000

Use of Multivariate Techniques to Investigate the Multidimensional Aspects of Innovation,

University of Newcastle Upon Tyne (ISRU) (UK), 2000

Statistics on Innovation in Europe,

European Commission, 2001

Analysis of CIS 2 Data on Innovation in the Service Sector,

Manchester University (UK), 2000

“Innovation and enterprise creation: Statistics and indicators,” Proceedings of the International Conference, 23

Notes

1. I would like to thank Ian Miles, Bart Verspagen, and Richard Nelson for comments on an earlier draft, and in particular Bronwyn Hall for comments and advice. None are implicated in the outcome, of course.

2. The question of what can be measured is an issue with all economic statistics. For example, the national accounts do not cover all economic activity (in the sense of all human activity contributing to production or material welfare). They incorporate only activity that leads to a measurable market outcome or financial recompense. This tends to leave out economic activity such as domestic work, mutual aid, child rearing, and the informal economy in general. Those services that are measured not by the value of output but by the compensation of inputs also provide problems for measurement of output and productivity.

3. In both Australia and Norway, each of which collects data by field of research for all industrial sectors, roughly 25 per cent of all R&D is in ICT.

4. An excellent overview of the literature on these and other patent issues can be found on the website of Bronwyn Hall: http://emlab.berkely.edu/users/bhhall See also Granstrand in this volume.

5. For analyses using the SPRU database, see e.g. Pavitt 1983, 1984; Robson et al. 1988; the most recent sustained analytical work using the SPRU database is Geroski 1994.

6. Canada is a leading site of policy-related indicator work at the present time—see e.g. the outstanding work of the Canadian Science and Innovation Indicators Consortium which can be found at the website given above.

7. On innovation in low-tech industries, see Ch. 15 by von Tunzelmann and Acha in this volume.

References

Aalborg University (1995), *Evaluation of the Community Innovation Survey (CIS)—Phase* 1, 2 vols., Report to the European Innovation Monitoring System.
Google Scholar Google Preview WorldCat COPAC

ACS, Z., and AUDRETSCH, D. (1990), *Innovation and Small Firms*, Cambridge, Mass: MIT Press.
Google Scholar Google Preview WorldCat COPAC

* Archibugi and PIANTA (1996), "Innovation surveys and patents as technology indicators: the state of the art," in OECD, *Innovation, Patents and Technological Strategies*, Paris: OECD.
Google Scholar Google Preview WorldCat COPAC

ARROW, K. J. (1984), "Statistical Requirements for Greek Economic Planning," *Collected Papers of Kenneth J. Arrow*, vol. 4: *The Economics of Information*, Oxford: Blackwell.
Google Scholar Google Preview WorldCat COPAC

ARUNDEL, A. (1997), "Why Innovation Measurement Matters," in A. Arundel and R. Garrelfs (eds.), *Innnovation Measurement and Policies*, EU Luxembourg: EIMS 94/197.
Google Scholar Google Preview WorldCat COPAC

ARUNDEL, A., PATEL, P., SIRILLI, G., and SMITH, K. (1997), *The Future of Innovation Measurement in Europe: Concepts, Problems and Practical Directions*, IDEA Paper No 3, STEP Group Oslo.
Google Scholar Google Preview WorldCat COPAC

p. 174 BIFFL, G., and KNELL, M. (2001), "Innovation and Employment in Europe in the 1990s," *WIFO Working Paper* 169/2001.
WorldCat

BROUWER, E., and KLEINKNECHT, A. (1997), "Measuring the Unmeasurable: A Country's Expenditure on Product and Service Innovation," *Research Policy* 25: 1235–42. 10.1016/S0048-7333(96)00902-X
WorldCat Crossref

—— —— (1999), "Innovative Output and a Firm's Propensity to Patent: An Exploration of CIS Micro-Data," *Research Policy* 28: 615–24. 10.1016/S0048-7333(99)00003-7
WorldCat Crossref

COX, H., FRENZ, M., and PREVEZER, M. (2002), "Patterns of Innovation in UK Industry: Exploring the CIS Data to Contrast High and Low Technology Industries," *Journal of Interdiciplinary Economics* 13(1–3): 267–304.
WorldCat

* DJELLAL, F., and GALLOUJ, F. (2001), "*Innovation surveys for Service Industries: A Review,*" in Thurieaux, Arnold, and Couchot 2001: 70–6.
Google Scholar Google Preview WorldCat COPAC

DOWRICK, S. (2003), "*A Review of the Evidence on Science, R&D and Productivity,*" Working Paper, Department of Economics, Australian National University.
Google Scholar Google Preview WorldCat COPAC

European Commission (1994), *The European Report on Science and Technology Indicators* 1994 (EUR 15897), Luxembourg.
Google Scholar Google Preview WorldCat COPAC

—— (1997), Second European Report on Science and Technology Indicators 1997 (EUR 17639), Luxembourg.

European Commission (2001), *Statistics on Innovation in Europe (EUR KS-32-00-895- EN-1),* Luxembourg.
Google Scholar Google Preview WorldCat COPAC

—— (2003), Third European Report on Science and Technology Indicators, Luxembourg.

EUROSRAT (2004), *Innovation in Europe. Results for the EU, Iceland and Norway: Data 1998–2001*, (Luxembourg: Office for one official publications of the European Communities)
Google Scholar Google Preview WorldCat COPAC

—— SANDVEN, T., SIRILLI, G., and SMITH, K. (1998), "Measuring Innovation in European Industry," *International Journal of the Economics of Business* 5(3): 311–33. 10.1080/13571519884413
WorldCat Crossref

—— and SAVONA, M. (2002), "The Impact of Innovation on Employment in Services: Evidence from Italy," *International Review of Applied Economics* 16(3): 309–18. 10.1080/02692170210136136
WorldCat Crossref

EVANGELISTA, R. (1999), *Knowledge and Investment*, Cheltenham: Edward Elgar.
Google Scholar Google Preview WorldCat COPAC

GAULT, F. (ed.) (2004), *Understanding Innovation in Canadian Industry*, Montreal and Kingston: McGill-Queen's University Press.
Google Scholar Google Preview WorldCat COPAC

GEROSKI, P. (1994), *Market Structure, Corporate Performance and Innovative Activity*, Oxford: Clarendon Press.
Google Scholar Google Preview WorldCat COPAC

GODIN, B. (2004), "The Obsession with Competitiveness and its Impact on Statistics: The Construction of High Technology Indicators," *Research Policy* (forthcoming).
WorldCat

GRIFFITH, R., REDDING, S., and VAN REENEN, J. (2000), "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries," *LSE Centre for Economic Performance Discussion Paper*, 2457: 1–74.
WorldCat

GRILICHES, Z. (1987), "*Comment,*" Washington, DC: Brookings Papers on Economic Activity, 3.
Google Scholar Google Preview WorldCat COPAC

GRUPP, H. (1994), "The Measurement of Technical Performance of Innovations by Technometrics and its Impact on Established Technology Indicators," *Research Policy* 23: 175–93. 10.1016/0048-7333(94)90052-3
WorldCat Crossref

*—— (1998), *Foundations of the Economics of Innovation, Theory, Measurement and Practice*, Cheltenham: Elgar.
Google Scholar Google Preview WorldCat COPAC

GUELLEC, D., and PATTINSON, B. (2001), "Innovation Surveys: Lessons from OECD Countries' Experience," *STI Review* 27: 77–102.
WorldCat

HAGEDOORN, K., and SCHAKENRAAD, J. (1990), "Inter-firm Partnerships and Co-operative Strategies in Core Technologies," in C. Freeman and L. Soete (eds.), *New Explorations in the Economics of Technological Change*, London: Pinter.
Google Scholar Google Preview WorldCat COPAC

HALL, B. H. and Ziedonis, R. H. (2002), "The determinants of patenting in the U.S. semiconductor industry, 1980–1994", *Rand Journal of Economics*, 32: 101–28.
WorldCat

——, Jaffe, A., and Trajtenberg, M., 2001, “*The NBER Patent Citations Daa file: Lessons, Insights and Methodological Tools*”, NBER Working Paper No. 8498.
Google Scholar Google Preview WorldCat COPAC

* HANSEN, J. A. (2001), “Technological Innovation Indicators: A Survey of Historical Development and Current Practice,” in M. P. Feldmann and A. Link (eds.), *Innovation Policy in the Knowledge-Based Economy*, Dordrecht: Kluwer, 73–103.
Google Scholar Google Preview WorldCat COPAC

HESSLEMAN, L. (2002), “A Description of Responses to the UK Community Innovation Survey 2,” *The Journal of Interdiciplinary Economics* 13(1–3): 243–66.
WorldCat

HINLOOPEN, J. (2003), “Innovation Performance across Europe,” *Economics of Innovation and New Technology* 12(2): 145–61. 10.1080/10438590303125
WorldCat Crossref

HIRSCH-KREINSEN, H., JACOBSEN, D., LAESTADIUS, S., and SMITH, K. (2003), “Low Tech Industries and the Knowledge Economy: State of the Art and Research Challenges,” *Working Paper 2003:10*, Dept of Industrial Economics and Management, Royal Institute of Technology (KTH), Stockholm.
Google Scholar Google Preview WorldCat COPAC

HOLBROOK, J. (1991), “The Influence of Scale Effects on International Comparisons of R&D Expenditure,” *Science and Public Policy* 18(4): 259–62.
WorldCat

HOWELLS, J. (2000), “Innovation Collaboration and Networking: A European Perspective,” in Science Policy Support Group, *European Research, Technology and Development. Issues for a Competitive Future*, London.
Google Scholar Google Preview WorldCat COPAC

HUGHES, K. (1988), “The Interpretation and Measurement of R&D Intensity: A Note,” *Research Policy* 17: 301–7. 10.1016/0048-7333(88)90010-8
WorldCat Crossref

INZELT, A. (2002), “Attempts to Survey Innovation in the Hungarian Service Sector,” *Science and Public Policy* 29(5): 367–83. 10.3152/147154302781780813
WorldCat Crossref

IVERSEN, E. (1998), “Patents,” in K. Smith (ed.), *Science, Technology and Innovation Indicators—a Guide for Policymakers*, IDEA Report 5, STEP Group Oslo.
Google Scholar Google Preview WorldCat COPAC

JAFFE, A., and Henderson, R., and Trajtenberg, M., 1997, “University Versus Corporate Patents: A Window on the Basicness of Invention”, *Economics of Innovation and New Technology*, 19–50.
Google Scholar Google Preview WorldCat COPAC

JANZ, N., et al. (2002), *Innovation Activities in the German Economy. Report on Indicators from the Innovation Survey 2000*, Mannheim: ZEW.
Google Scholar Google Preview WorldCat COPAC

KALOUDIS, A. (1998), “Bibliometrics,” in K. Smith (ed.), *Science, Technology and Innovation Indicators—a Guide for Policymakers*, IDEA Report 5, STEP Group Oslo.
Google Scholar Google Preview WorldCat COPAC

* KLEINKNECHT, A. (ed.) (1996), *Determinants of Innovation: The Message From New Indicators*, London: Macmillan.

Google Scholar Google Preview WorldCat COPAC

—— and BAIN, D. (eds.) (1993), *New Concepts in Innovation Output Measurement*, London: Macmillan.
Google Scholar Google Preview WorldCat COPAC

—— and MOHNEN, P. (eds.) (2002), *Innovation and Firm Performance. Econometric Explorations of Survey Data*, Hampshire and New York: Palgrave.
Google Scholar Google Preview WorldCat COPAC

—— VAN MONTFORT, K., and BROUWER, E. (2002), "The Non-Trivial Choice Between Innovation Indicators," *Economics of Innovation and New Technology* 11(2): 109–21. 10.1080/10438590210899
WorldCat Crossref

KLINE, S., and ROSENBERG, N. (1986), "An Overview of Innovation," in R. Landau (ed.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, Washington: National Academy Press, 275–306.
Google Scholar Google Preview WorldCat COPAC

KORTUM, S., and LERNER, J. (1999), "What is Behind the Recent Surge in Patenting?" *Research Policy* 28: 1–22. 10.1016/S0048-7333(98)00082-1
WorldCat Crossref

p. 176 LAESTADIUS, S. (2003), "Measuring Innovation in the Knowledge Economy," Paper presented to Pavitt Conference on Innovation, SPRU, Sussex, 13 Nov 2003.

LÖÖF, H., and HESHMATI, A. (2002), "Knowledge Capital and Performance Heterogeneity: A Firm-Level Innovation Study," *International Journal of Production Economics* 76(1): 61–85. 10.1016/S0925-5273(01)00147-5
WorldCat Crossref

—— —— (2004), "On the Relationship between Innovation and Performance: A Sensitivity Analysis," *Economics of Innovation and New Technology* 13(1–2): forthcoming.
WorldCat

MCLEOD, C. (1988), *Inventing the Industrial Revolution: The English Patent System, 1660–1800*, Cambridge: Cambridge University Press.
Google Scholar Google Preview WorldCat COPAC

MAIRESSE, J., and MOHNEN, P. (2001), "To be or not to be Innovative: An Exercise in Measurement," *STI Review* 27: 103–28.
WorldCat

*—— —— (2002), "Accounting for Innovation and Measuring Innovativeness: An Illustrative Framework and an Application," *American Economic Review* 92(2): 226–30. 10.1257/000282802320189302
WorldCat Crossref

* MEYER, M. (2000), "Does Science Push Technology? Patents Citing Scientific Literature," *Research Policy* 29: 409–34. 10.1016/S0048-7333(99)00040-2
WorldCat Crossref

MOED, H. F., DE BRUIN, R. E., and VAN LEEUWEN, Th. N. (1995), "New Bibliometric Tools for the Assessment of National Research Performance: Database Description, Overview of Indicators and First Application," *Scientometrics* 33: 381–422. 10.1007/BF02017338
WorldCat Crossref

MOHNEN, P., and HOAREAU, C. (2003), "What Types of Enterprise Forge Close Links with Universities and Government Labs? Evidence from CIS-2," *Managerial and Decision Economics* 24: 133–45. 10.1002/mde.1086

WorldCat Crossref

—— MAIRESSE, J., and DAGENAIS, M. (2004), “Innovativeness: A Comparison across Seven European Countries,” *Economics of Innovation and New Technology* 13(1–2): forthcoming.
WorldCat

NARIN, F., and NOMA, E. (1985), “Is Technology Becoming Science?” *Scientometrics* 3–6: 369–81. 10.1007/BF02017155
WorldCat Crossref

NASCIA, L., and PERANI, G. (2002), “Diversity of Innovation in Europe,” *International Review of Applied Economics* 16(3): 277–94. 10.1080/02692170210136118
WorldCat Crossref

OECD (1992, rev. 1997), *Innovation Manual: Proposed Guidelines for Collecting and Interpreting Innovation Data* (*Oslo Manual*), Paris: OECD, Directorate for Science, Technology and Industry.
Google Scholar Google Preview WorldCat COPAC

—— (1996), *Technology, Productivity and Job Creation*, Paris: OECD.
Google Scholar Google Preview WorldCat COPAC

—— (2001), *Innovating Networks: Collaboration in National Innovation Systems*, Paris: OECD.
Google Scholar Google Preview WorldCat COPAC

—— (2002), *The Measurement of Scientific and Technological Actvities. Proposed Standard Practice for Surveys on Research and Experimental Development: Frascati Manual*, Paris: OECD.
Google Scholar Google Preview WorldCat COPAC

PATEL, P., and PAVITT, K. (1997), “The Technological Competencies of the World's Largest Firms, Complex and Path-Dependent, but not Much Variety,” *Research Policy* 26: 141–56. 10.1016/S0048-7333(97)00005-X
WorldCat Crossref

*—— —— (1999), “The Wide (and Increasing) Spread of Technological Competencies in the World's Largest Firms: a Challenge to Conventional Wisdom,” in A. Chandler et al. (eds.), *The Dynamic Firm: The Role of Technology, Strategy, Organization and Regions*, Oxford: Oxford University Press.
Google Scholar Google Preview WorldCat COPAC

PAVITT, K. (1983), “Some Characteristics of Innovation Activities in British Industry,” *Omega* 11.
WorldCat

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

POL, E., CARROLL, P., and ROBERTSON, P. (2002), “A New Typology for Economic Sectors with a View to Policy Implications,” *Economics of Innovation and New Technology* 11(1): 61–76. 10.1080/10438590210892
WorldCat Crossref

p. 177 QUADROS, R., FURTADO, A., BERNADES, R., and ELIANE, F. (2001), “Technological Innovation in Brazilian Industry: An Assessment Based on the San Paulo Innovation Survey,” *Technological Forecasting and Social Change* 67: 203–19. 10.1016/S0040-1625(00)00123-2
WorldCat Crossref

ROBSON, M., TOWNSEND, J., and PAVITT, K. (1988), “Sectoral Patterns of Production and Use of Innovations in the UK: 1945–1983,” *Research Policy* 17(1): 1–15. 10.1016/0048-7333(88)90017-0

WorldCat Crossref

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

—— (1982), *Inside the Black Box: Technology and Economics*, Cambridge: Cambridge University Press.
Google Scholar Google Preview WorldCat COPAC

SANDVEN, T., and SMITH, K(1997), "*Understanding R&D Indicators: Effects of Differences in Industrial Structure and Country Size,*" IDEA Paper 14, STEP Group Oslo.
Google Scholar Google Preview WorldCat COPAC

SAVIOTTI, P. P. (1996), *Technological Evolution, Variety and the Economy*, Cheltenham: Elgar.
Google Scholar Google Preview WorldCat COPAC

—— (2001), "Considerations about a Production System with Qualitative Change," in J. Foster and J. Stanley Metcalfe (eds.), *Frontiers of Evolutionary Economics. Competition, Self-Organization and Innovation Policy*, Aldershot: Edward Elgar, 197–227.
Google Scholar Google Preview WorldCat COPAC

SCHERER, F. (1982), "Inter-industry Technology Flows in the United States," *Research Policy* 11(4): 227–45. 10.1016/0048-7333(82)90011-7
WorldCat Crossref

SCHMOOKLER, J. (1971), "Economic Sources of Inventive Activity," in N. Rosenberg (ed.), *The Economics of Technological Change*, London: Pelican, 117–36.
Google Scholar Google Preview WorldCat COPAC

SELLENTHIN, M., and HOMMEN, L. (2002), "How Innovative is Swedish Industry? A Factor and Cluster Analysis of CIS II," *International Review of Applied Economics* 16(3): 319–32. 10.1080/02692170210136145
WorldCat Crossref

Smith K. (1992), "Technological Innovation Indicators: Experience and Prospects," *Science and Public Policy* 19(6): 24–34.
WorldCat

—— (2001), "*Innovation Indicators and the Knowledge Economy: Concepts, Results and Challenges,*" in Thurieaux, Arnold, and Couchot (eds), Luxembourg: European Commission, 14–25.
Google Scholar Google Preview WorldCat COPAC

SPRU (1996), *Innovation Outputs in European Industry (CIS)*, Report to the European Innovation Monitoring System.
Google Scholar Google Preview WorldCat COPAC

STEP GROUP (1997), *Innovation Expenditures in European Industry: Analysis from CIS*, Report to the European Innovation Monitoring System.
Google Scholar Google Preview WorldCat COPAC

SULLIVAN, R. (1990), "The Revolution of Ideas: Widespread Patenting and Invention During the Industrial Revolution", *Journal of Economic History* 50(2): 340–62.
WorldCat

TETHER, B. (2002), "Who Cooperates for Innovation and Why: An Empirical Analysis," *Research Policy* 31(6): 947–67. 10.1016/S0048-7333(01)00172-X
WorldCat Crossref

—— and MILES, I. (2001), "*Surveying Innovation in Services—Measurement and Policy Interpretation Issues,*" in Thurieaux, Arnold,

and Couchot (2001).
Google Scholar Google Preview WorldCat COPAC

—— and SWANN, G. M. P. (2003), "*Services, Innovation and the Science Base: An Investigation Into the UK's 'System, of Innovation' Using Evidence from the Third Community Innovation Survey,*" paper to CNR/Univerity of Urbino Workshop on Innovation In Europe.
Google Scholar Google Preview WorldCat COPAC

* THURIEAUX, B., ARNOLD, E., and COUCHOT, C. (eds.) (2001), *Innovation and Enterprise Creation: Statistics and Indicators*, Luxembourg: European Commission (EUR 17038).
Google Scholar Google Preview WorldCat COPAC

Van Leeuwen, G., and KLOMP, L. (2004), "On the Contribution of Innovation to Multifactor Productivity," *Economics of Innovation and New Technology* 13(1–2): forthcoming.
WorldCat

VERSPAGEN, B. (1992), "Endogenous Innovation in Neo-classical Growth Models: A Survey," *Journal of Macroeconomics* 631–62. 10.1016/0164-0704(92)90004-R
WorldCat Crossref

World Economic Forum (2003), *Global Competitiveness Report 2002–2003*, ed. P. Cornelius, K. Schwab, and M. E. Porter, New York:
p. 178 Oxford University Press. ↳
Google Scholar Google Preview WorldCat COPAC