Triple Helixes, Classification Schemes and the Knowledge Ecologies of Innovation[1]

Brian Wixted[2] and Susan Cozzens[3]

DRAFT

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[2] Visiting Scholar, Centre for Policy Research on Science and Technology, Simon Fraser University, Vancouver, BC, www.sfu.ca/cprost brian_wixted@sfu.ca
[3] Technology Policy and Assessment Center, School of Public Policy, Georgia Institute of Technology, Atlanta, GA 30332-0345. scozzens@gatech.edu

Abstract

One of the most prominent indicators of research development used in national S&T indicator scoreboard reporting is that of manufacturing industry R&D intensity. Countries that collect data by socio-economic objective can collect data on expenditure in these industry categories by research groups in universities and government, although such data is typically reported as separate statistical silos in indicator reports. Thus, despite the growing policy interest in the role that interaction among universities, business and government laboratories plays in fostering the development of new products and services, current statistics can offer little in the way of information on this process. The concept of innovation systems suggests that government and university research create a knowledge support infrastructure that contributes to the success of industries. For example, the food industry benefits from agricultural research usually performed in universities and government labs. Likewise, the motor vehicle industry is supported by research into fuels, infrastructure and highway management systems. However, we know little about the way such contexts develop and evolve into knowledge ecologies, generating and diffusing knowledge for innovation in specific sectors. This paper suggests that a major challenge for the future is to make progress on frameworks that can incorporate the concept of knowledge ecologies as approach for organising data. Currently we do not have either the conceptual tools or the data to begin to analyse these knowledge ecologies. This paper aims at clarifying the nature of the problem and suggests a number of approaches that could move us towards improving the usefulness of science, technology, and research and development data.

1. Introduction

The research on innovation systems has developed a strong argument that knowledge and innovation are important ingredients in the economic prosperity of nations. However, future policy and theoretical developments in this field will rely upon the availability of new indicators that capture the complex processes of knowledge generation, inter-industry and inter-institutional transmission and business innovation. The primary problem facing national S&T decision makers today is to assess the vitality of their innovation systems, including their capacity to address and solve national problems and to contribute to healthy economies. Some of this assessment must take place at national level, but it cannot be limited to that level. Sectors within any economy vary in their structure and relationships, as well as in their innovative capacities and achievements. A sector-by-sector analysis is therefore an important input to national innovation policies, to identify strengths and weaknesses and to guide public interventions where they are needed.

Current indicator systems seldom provide much help in this systems-oriented analysis. A core problem is the lack of connection between data on in-house industrial research and development and the flows of knowledge between diverse actors and sectors. Current indicator systems on business innovation still rely heavily on R&D intensity in manufacturing as a primary indicator of innovation. This measure has many limitations[4], but of particular concern here are:

1. the lack of information on the contribution of R&D in one sector to innovation in another (the knowledge linkages between sectors);
2. the lack of information on the fields of scientific research performed by business; and

[4] Bender (2006) presents an excellent analysis of the problems of the R&D intensity measure for so called ‘low technology’ industries, identifying that *innovation* in these industries is often not R&D driven. However, the analysis fails to identify the classification problems with knowledge sources and inter-sectoral flows – an issue directly focussed upon in this paper.

3. the lack of information on the contribution of university and government research to sectoral value chain performance and competitiveness.

Each of these points is touched upon in this paper. We refer to the neglected linkages within specific innovation systems as knowledge interdependencies and in the aggregate to the overall patterns of knowledge structure that may support commercial or social[5] innovation systems as "knowledge ecologies[6]" to indicate the idiosyncrasies of knowledge flows, their importance and to the expected cumulative contribution of such flows to the overall performance and operation of sectoral systems (creating specific relations that generate unique resources).

From the early 1990s there has been a general push to de-emphasise the role of R&D in the innovation process and to gather more information on actual innovations through innovation surveys. Although, this is clearly a positive trend, given the significant resources that are currently invested in collecting R&D data, these surveys would return better value for money if they were more attuned to the insights gathered from innovation systems research about interactions as the key to learning in systems (see Edquist and McKelvey 2000).

Science, technology and innovation (STI) indicators have been published by governments and international organisations around the world, dating back to at least the first National Science Board 'Indicators' reports in the early 1970s (see 2004). Almost all of these indicator reports follow a standardised format where research and development expenditure by universities, government laboratories and business are presented separately. Often different classification schemes are applied to the former categories against the business surveys. This structure is not helpful in considering the role of universities and government labs in innovation, technological

[5] Although social (including health) innovations are also often commercially viable, this isn't always the case. See the discussion below on the 2005

[6] A previous version of this paper (Wixted and Cozzens 2006) used the term 'knowledge value chains' (KVCs) but that term has already been used (see Cooke *et al.* 2006 and Cooke 2006) to describe related but different concepts. The KVC terminology always was problematic for the argument presented here as it conjures up the image of a linear supply chain, whereas the flows of knowledge between industries and sectors are more complex. For a discussion of how an 'ecological' approach to understanding technological change can be useful see Barnett (1990).

specialisation and technological trajectories. The standard approach likewise neglects contributions of one industrial sector to another. Innovation surveys by focussing on the innovating enterprise do little better for our purposes. The current paper argues that the existing data format and the data collection strategy that lies behind it stands in the way of developing new insights into the nature of technological change. In particular it can be shown that the knowledge features of particular sectors (such as food: agriculture, food manufacturing and food services; or land transport: fuels, automobiles, road infrastructure and highway management systems) are not well mapped with existing data sources.

This argument marks a shift away from relying upon a focus on business, whether through R&D intensity, innovativeness or public sector commercialisation as a measure of a nation’s commitment to new sectoral knowledge. Because of the increasingly critical nature of new knowledge to competitiveness and societal sustainability, it is important to experiment with new methodologies that integrate different STI data sources for the purpose of assessing the contributions to products. The paper aims to draw the threads of existing research into innovation and innovation systems together and apply them to the way we think about research and development.

The paper starts by considering, in Section 2, the policy issues that have emerged over the last ten to fifteen years but which are still being addressed with the existing (inadequate) data. Section 3 reviews some of what we know of inter-industry interdependencies in innovation and technological change and shows why bibliometrics, patent data, or innovation surveys can not by themselves provide a solution to the problem at hand. Section 4 examines different options for collecting information in a way that maximises our understanding of the innovation process, industrial competitiveness and social and environmental sustainability. Section 5 summarizes and draws implications for future research.

2. Science and innovation policy dimensions

One of the pre-occupations of modern science policy is the relationship between university research, government research and economic returns; often called the triple helix[7] or more typically 'commercialisation' of public sector research. As an Industry Canada document states:

> 'Governments are responsible for research in support of the "innovation environment" — the policies that define many of the incentives to innovate and protect the public interest. **Governments also perform research, often with longer time horizons than the private sector, to support their economic development mandates.** Governments provide the financial support that enables academic institutions to perform research and train the next generation of highly qualified people. Government laboratories are increasingly forming partnerships with each other, with academic institutions and firms, and with organizations around the world. **Partnerships are increasingly important to creating and applying the knowledge that underpins sound regulation and economic development.** In performing these functions, governments should themselves be more innovative and contribute to a public environment that is more supportive of creativity and innovation' (emphasis added 2002: 10).

The framing of Australia's research priorities that cover natural sciences, social sciences, and engineering also explicitly makes the connection between universities and industry.

> 'Setting priorities provides a vision of where research can contribute to Australia's future prosperity and well being, and will help to align our nation's research effort in these key areas. National research priorities will enhance the quality and impact of our research effort by building critical mass in these areas and **by promoting collaboration between research organisations and with industry**' (DEST 2002).

Recently, Marburger, Director of the US Office of Science and Technology Policy made a call for a science of science policy, emphasising models (in the economic sense) 'because they are essential for understanding correlations among different quantities or metrics (2006: 2). Links then, the relationships that connect the different parts of innovation systems are of increasingly

[7] To date there have been five conferences on this theme (http://users.fmg.uva.nl/lleydesdorff/th2/index.htm) with another due in May 2007.

value to researchers of techno-economic systems. But it is precisely such links where our understanding of the system is weakest.

3. Knowledge ecologies

3.1 R&D indicators

As we have just shown there are high expectations for the role of science, technology and innovation in the success of nations. However, despite the interest in relations among government, university, and industry sectors, the official sources of data make analysis difficult. R&D, bibliometric, patenting and enterprise innovation data all have limitations. R&D analyses continue to perpetuate an image of three independent silos of knowledge creation and application. Most developed countries report on their national science, technology and innovation systems within an internationally comparative and standardised fashion (although there may be some cosmetic differences). The standard for such reporting was set by the OECD Frascati manual first produced in the early 1960s (see OECD 2002 for the latest version) and incorporated in the ground breaking US National Science Board *Science and Engineering indicators* series. The format of the latter reflects a linear model of innovation, with the contributions of different institutions reported separately, moving from the education system through university research and industry, then on to impacts and public attitudes.

Overview

Chapter 1. Elementary and Secondary Education
Chapter 2. Higher Education in Science and Engineering
Chapter 3. Science and Engineering Workforce
Chapter 4. U.S. and International Research and Development: Funds and Alliances
Chapter 5. Academic Research and Development
Chapter 6. Industry, Technology, and the Global Marketplace
Chapter 7. Science and Technology: Public Attitudes and Public Understanding
Chapter 8. Significance of Information Technology

The European commission irregularly releases a Europe wide science and technology indicators report. The 3rd edition of this report was published in 2003. Its summarised contents are:

Chapter 1: Facing the Challenges of the 21st Century.
Chapter 2: Investment in Science, Technology and New Knowledge.
Section I Trends In R&D Investment.
Section II The Role Of Government And Public Sector In R&D.
Section III Government R&D Performance.
Section IV The Higher Education Sector.
Conclusions
Chapter 3: Private Sector Investment in Scientific and Technological Knowledge
Chapter 4: Human Resources in Science & Technology
Chapter 5: Scientific Output and Impact: Europe's Leading Role in World Science
Chapter 6: Europe's Technological Competitiveness
Section I The Competition for Invention in World Markets.
Section II Trade in High-Tech Products: Europe's Performance
Section III European Performance in Future Technologies – The Emergence of Biotechnology and Nanotechnology
Conclusions

This third report, interestingly, contained a thematic section on biotechnology and nanotechnology, on the basis that they are important *technologies* for the future. In this section of the report, public spending is analysed alongside that of industrial expenditure on the development of the new knowledge. It also maps various academic networks involved in researching these technologies. However, in general few indicators reports develop such an analysis, and where data is available it is typically for high technology activities.

3.2 Limitations of existing STI indicators

This organisation of data reporting has probably developed for numerous reasons. Typically governments around the world split decision-making responsibility not just between Ministries (Departments of State) but also between levels of governments (Federal, State and Provincial). The schools system is separated from the university system that is separated from the commerce and industry ministries. Government laboratories may be spread across many ministries. Whatever the reasons that generated this approach, once this trajectory was adopted it became the standardised approach. As countries continue to create their own indicators reports, both for the reasons outlined above and to be internationally comparable, similar formats are perpetuated.

Indicators thus reflect the institutional silos. Even with the different classification schemes between business and government and universities, the latter two at least could be reported by fields of research / science.

Beyond this silo approach the R&D intensity measure has become a *de facto* indicator of an industry's commitment to innovation and new knowledge creation. Its influence can be understood from the observation that the chapters in both the NSF and European Commission indicators reports focus on those industries that are defined as high technology (i.e. those industries that have a high percentage of business R&D expenditure to value added). However, this mapping of industry R&D treats each 'manufacturing industry' as separate entities and ignores the important linkages between them (discussed further in section 4 below). Furthermore, this leads to the important limitation of this measure, in that any *public sector investment* in parts of the value chain is not included. Thus, public sector R&D investment in agriculture is not included in the measure of food R&D intensity and neither is the public investment in health research included in the measure of pharmaceuticals R&D intensity. This has the effect of biasing policy analyses away from investigating the contribution of the entire investment portfolio to particular industries that may or may not be the most R&D intensive.

It is not surprising then, that given our nascent knowledge of the interdependencies between industries and between universities and industries, patent and to a lesser extent bibliometrics data have been used to try to fill the gap. Cooke for example uses co-publications (between authors in Business and academia) to emphasis the areas of science that are particularly attractive to business (Table 1).

Table 1: High & Low Ranking UK University-Industry Co-publishing Sectors, 1995-2000

High Ranking Sectors	Annual Average Co-publications U-I	Low Ranking Sectors	Annual Average Co-publications U-I
1. Pharmaceuticals	659	15. Metals	29
2. Chemicals	128	16. Materials	25

3. Utilities	107	17. Machinery	18
4. Biotechnology	92	17. Software	18
5. Electronics	88	19. Automotive	15
6. Food	82	20. Electrical	11

Source: Cooke (2006: 8) adapted from Calvert and Patel.

For this purpose the analysis is useful. Naturally the areas of Pharmaceuticals and biotechnology which rely heavily on a scientific base rank highly and thus form part of a relatively direct knowledge value chain (as Cooke describes them). However, as a measure of the overall contribution of universities to knowledge ecologies, the figures may be misleading. First when the analysis is based in the industry (manufacturing) sector classification, it treats only one sector at a time. It thus misses the contributions of the same body of research to different sectors (see Figures 1-3 above). Second, as Sandven and Smith have argued, 'bibliometric data tells us much about the changing shape of fundamental research, but little about the innovation process. Innovation data faces basic challenges in capturing all aspects of the novelty, learning and change which are involved in innovation' (1998: 6). Third, the industrial sector is frequently only interested in knowledge of greater direct relevance to its innovation and industrial production systems. It may not be interested in research related to the social, infrastructural and environmental systems that surround and embed the production activities with its wider context.

R&D[8], bibliometric and patent data all have important limitations. Importantly, however, the R&D collections can be developed to have more utility because of their threefold classification scheme (fields of research, socio-economic objective and industry). The difficulty of mining the co-publication and patent information too deeply is that they rely at one end of the matrix upon industry classifications. This classification is in turn constructed upon the concept of principal activity (see OECD 2002) and without a way of understanding all the knowledge requirements of the sector, measures based in industrial classifications will obscure the diversity

[8] 'R&D numbers measure only an input, which has no necessary relation to innovation outcomes' … R&D data [may] underestimates the amount of innovative activity in small firms, while patent data underestimates innovation in large firms.

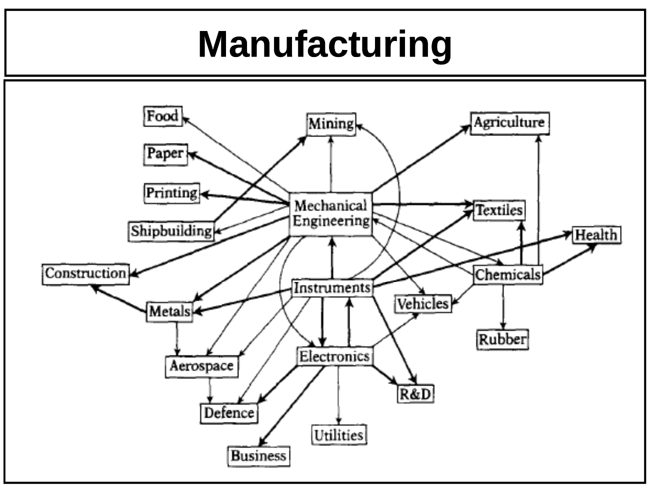
of interactions across the silos, between industrial sectors themselves and of the requirements for other non-industrial systems (environmental management, town planning, health infrastructure, education systems etc) to co-evolve.

Thus, while it is true that R&D is only an input to the innovation process, its broader frameworks are a starting place to think about the role of knowledge generation in environmental and societal sustainability and economic competitiveness.

3.3 Stylised facts on the relationships between system sectors

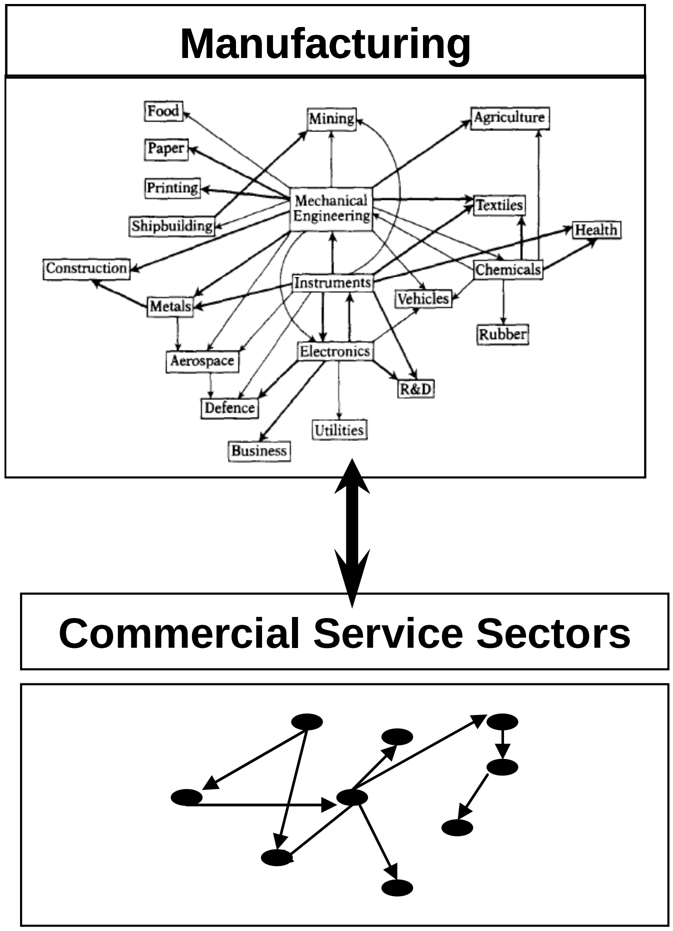
A useful means of summarising our existing knowledge and the gaps in our knowledge base of the interactions between the different elements of our innovation systems is through a series of diagrams.

Figure 1: Manufacturing technological interdependencies



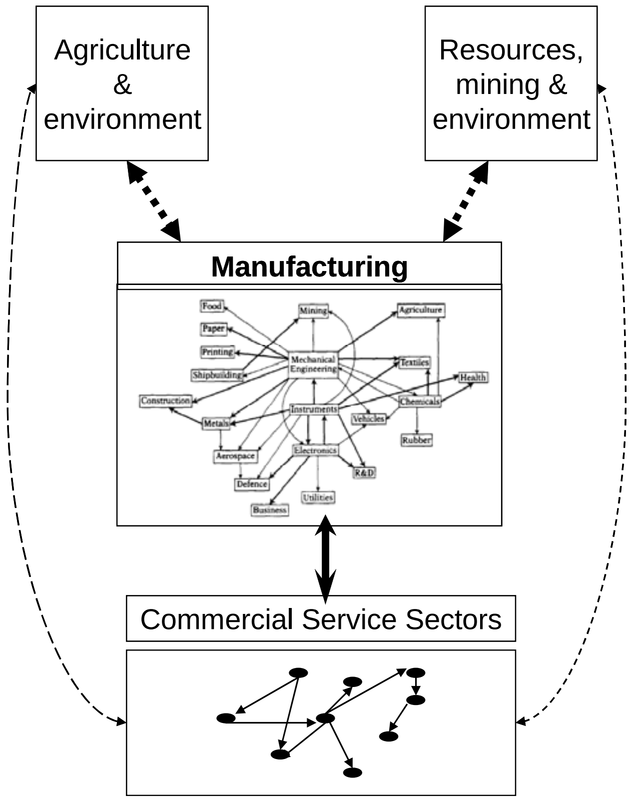
A number of authors have commented on the flow of innovations between manufacturing industries (see e.g. Geroski 1994). Thus, we have a strong foundation of empirical research with which to analyse manufacturing innovation (see section 4 below) [Figure1].

Figure 2: **The connections between manufacturing and services**



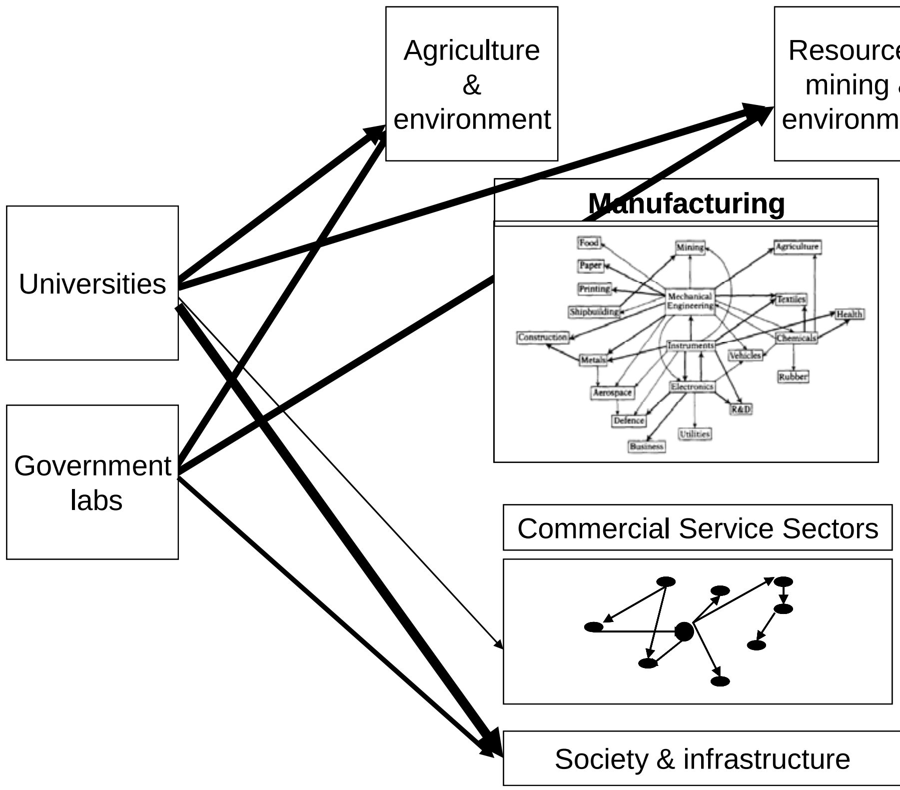
We have some knowledge on the flows of knowledge, embodied technology and innovation between manufacturing and services (again see Section 4 below), but less on the flows of innovation within the commercial services sector (Figure 2).

Figure 3: Resource based and Community oriented sectors



However, unfortunately, our understanding of the technology, innovation and knowledge flows between primary and manufacturing sectors (Figure 3) is quite limited.

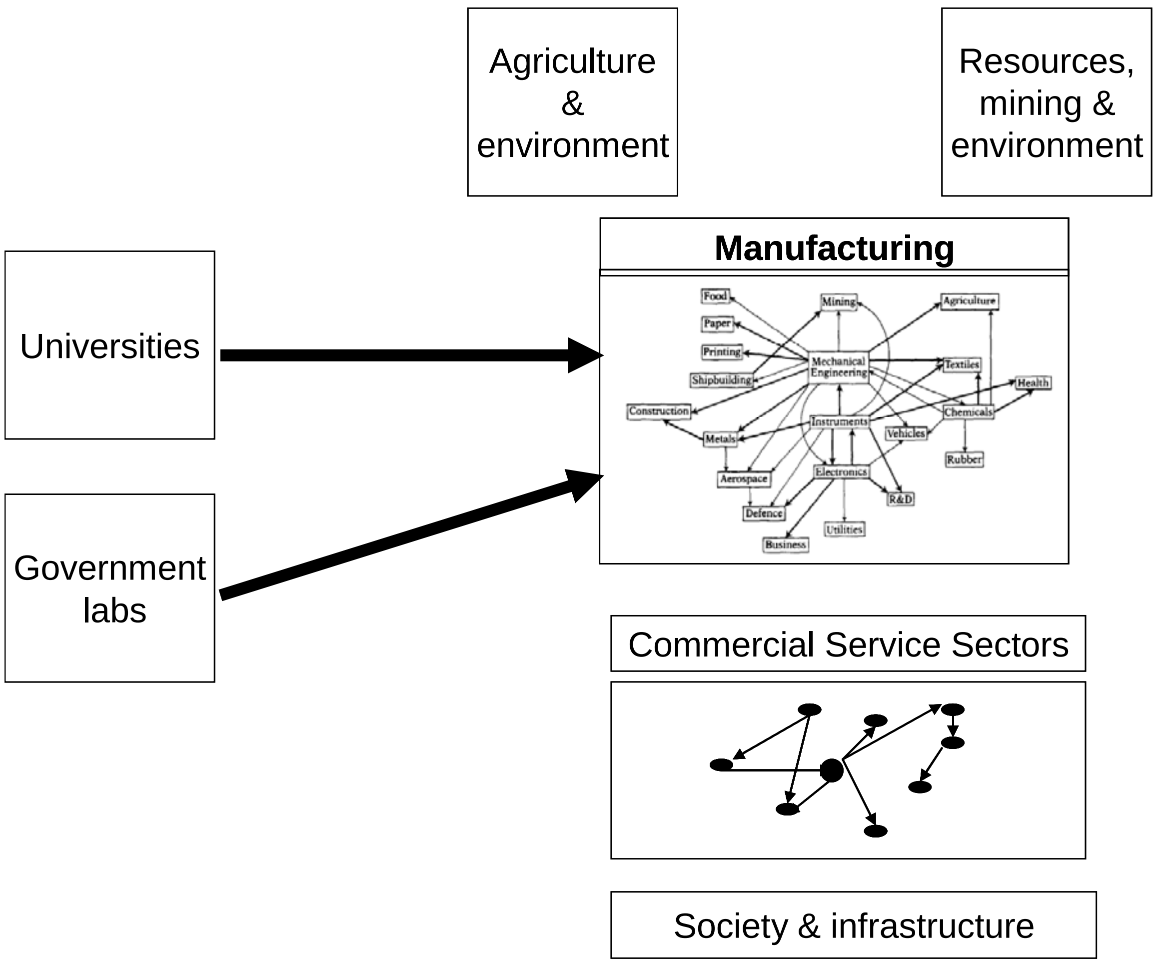
Figure 4: Particular linkages between public sector research and nation are poorly measured



In contrast to what we know of the flows of technology between commercial sectors, we know that universities and government significantly contribute to the knowledge base of new crop creation, natural resources and services, particularly those that have significant non-commercial characteristics (Figure 4). All of these have been traditionally seen to have public interest involvement, whether that is through resource management or population health. Further, the interests of commercial innovation and societal innovation do not always align. For example the winners of the 2005 Nobel Prize for Physiology or Medicine ‘made the remarkable and unexpected discovery that inflammation in the stomach (gastritis) as well as ulceration of the stomach or duodenum (peptic ulcer disease) is the result of an infection of the stomach caused by the bacterium *Helicobacter pylori*. Thus ‘peptic ulcer disease is no longer a chronic, frequently disabling condition, but a disease that can be cured by a short regimen of antibiotics and acid secretion inhibitors'[9]. In making this finding these researchers simultaneously wiped out a profitable line of pharmaceuticals and improved the life of many.

But our focus of studies tends to be on the contribution of universities and government to manufacturing innovation. This is done through analysis of university spin-offs, patenting, and co publication bibliometrics which tends to focus particularly, as seen in Table 2, on pharmaceuticals, chemicals and health related biotechnology.

Figure 5: Commercialisation indicators



This focus on the measurable ignores a number of aspects of the contribution of universities and government. Business school interactions with all types of organisations are not mentioned in such analyses, neither is the role of urban studies or public policy schools in

[9] See http://nobelprize.org/nobel_prizes/medicine/laureates/2005/press.html accessed 27 October 2006.

government decision making. These indicators measure only one particular kind of interaction and used without a sense of their deficiencies. In time, the continued promotion of the most popular indicators may begin to bias science policies in a way that is damaging to the system as a whole. In the next section we further analyse these linkages to highlight with greater detail some of the features of sectoral systems that have been sketched out in the literature.

4. Technological interdependencies and knowledge ecologies in innovation systems

Smith (1997, 2000, and 2002) has written on the concept of "distributed knowledge bases," a concept that is closely related to the way we use the term *knowledge ecologies*. Smith argues (2002) that many products, even in so called 'low tech' industries rest upon a range of advanced scientific input and the use of advanced equipment developed in other sectors. He suggests that there are three levels of knowledge generation within industrial systems; the firm level, the sectoral or product research field level, and then the generally applicable knowledge bases level. From this starting point he describes three categories for an analysis of these distributed knowledge bases. The phases of economic activity of product production (1) are necessary to facilitate the development of a list of the actual sciences that contribute to the value chain (the knowledge bases) (2). Finally, from this point it should be possible to develop a list of the national institutions (3) that contribute to generation of relevant knowledge. Smith maps the examples of: Norway's oil & gas sector (2000) and Norway's food products system (2000 and 2002), see table 1. However, he didn't extend the analysis to the point of attempting to calculate STI indicators for the complete knowledge bases.

Table 2: ***Activities, technology / knowledge areas and knowledge network in the Norwegian food processing industry***

Activity	Technology /Knowledge-area	Knowledge suppliers
Selection and preparation of raw materials	Filtering-, centrifugal-, washing technology; steaming (thermic treatment); sensorics; molecular biology and micro biology; chemistry and biochemistry	Matforsk, Norconserv, NLH, NVH
Processing	Process lines (engineering); IT and informatics; logistics; heating and refrigerating technology; sensorics; molecular biology, micro-biology, bacteriology; chemistry, biochemistry, analytical chemistry; gastronomical skills	Norconserv, Matforsk., NLH, NVH, NTNU (kkt); SINTEF, Norske Meierier, Potetindustriens Laboratorium
Preservation and storing	Cooling/freezing technology; vacuum; hermetics and modified atmosphere packing; sterilisation; pasteurisation and homogeinisation; biological preservation (f.ex. fermentation); bio-technology; bio-chemistry; bacteriology and micro-biology; analytical chemistry	NLH, NVH (ins. fmn), Matforsk (avd. pros.), Norconserv, SINTEF (knt), NTNU (kkt), Norsk Kjøtt, NTH (ins. kt)
Packing/wrapping and coating	Disposal technology and environmental issues; materials technology; process lines (engineering, informatics); design; consumer preferences and marketing; micro-biology and bacteriology; bio-chemistry and analytical chemistry; cooling/freezing technology; vacuum; hermetics and modified atmosphere packing	NVH (ins. fmn; ins.bfe), Norske Meierier, Matforsk (avd.kval.), Norconserv, NLH
Hygiene and safety	Micro-biology; bacteriology; bio-chemistry; analytical chemistry	Norsk Kjøtt, Norske Meierier, Potetindustriens Laboratorium, NVH (ins. fmn), Matforsk (avd.kval.), NLH, SSF
Quality and nutrition	Chemistry; micro-biology; additives; texture; sensoric analysis and evaluation	Matforsk, Norconserv, NLH, UiO NVH (ins. fmn; ins.bfe), Norsk Kjøtt, Norske Meierier, Fisk.dir. Ernær.inst.
Quality control and quality documentation	Testing/measurement technology; spectroscopology; sensorics; micro-biology and bacteriology; bio-chemistry and analytical chemistry	Norske Meierier, Kontroll inst. f. meieriprodukter; Norconserv; NVH (ins. fmn; ins.bfe),NLH, Matforsk (avd. kval.)
Transport and distribution	Logistics; IT and informatics; general transport technology; cooling/freezing technology; micro-biology and bacteriology; bio-chemistry and analytical chemistry	SINTEF (knt), NTNU (kkt), NLH, Matforsk, NVH (ins. fmn), UiO (informatics and logistics)
Trading/marketing/ sales	Sociology (consumer preferences and trends); economy (price elasticities etc.)	BI, NLH, SIFO

Source: Smith 2000: 22

In the Australian context, farmers, in a range of primary industry activities tax themselves an R&D levy and contribute more than AUD$200m annually to sectorally focussed R&D

corporations[10]. The Commonwealth Government contributes an additional AUD$200m in matching levies. These funds then buy research from a range of providers such as the universities. This source of funds is in addition to money allocated to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) through the budget process and to the universities through research councils. The Agrifood Innovation Working Group reported that in the mid 1990s the research intensity of Australian agriculture was approximately 1.3 per cent (1999: 24). Compared with other R&D intensity measures (OECD 2001: 138) this would rank alongside other low R&D manufacturing activities.

It is possible, then to begin to see the agro-food value system, not as it is commonly classified as *low technology* by the OECD but as one that is dependent upon a platform of R&D investments in crop science, environmental management through manufacturing and then into food distribution. Often this expenditure is outside of ‘food manufacturing’ as an industrial classification and often performed by university and government laboratories and often financially supported by these different silos.

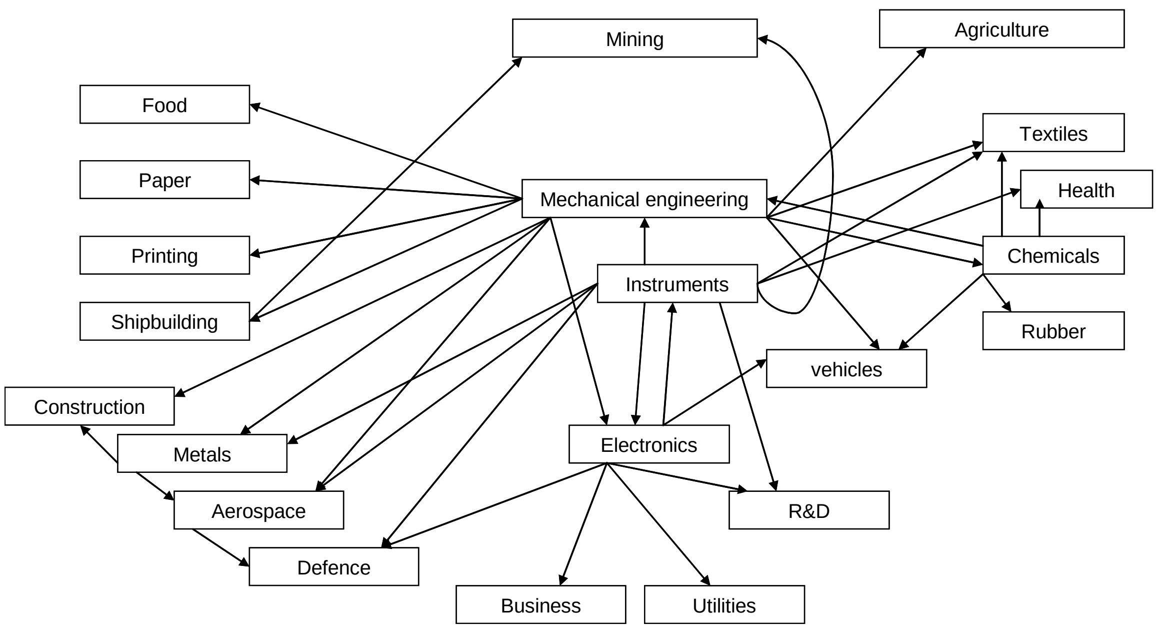
Although, high technology snobbery is still strong (see Hulst and Olds 1995), ‘Medium-tech manufacturing provides the backbone of the techno-economic structure of The Netherlands, according to Leydesdorff *et al.* (2006). Kaloudis *et al.* (2005) have shown that low technology industries contribute significantly to OECD member country GDP and will likely to continue to do so for some time to come.

In contrast to our lack of knowledge of the flows of research and development based knowledge, in recent decades we have become increasingly aware of the connections between innovations made in different sectors. For example, the SPRU database on innovations has provided a number of important insights (see e.g. Pavitt 1984 and Robson et al. 1988). Geroski,

[10] See http://www.daff.gov.au/content/output.cfm?ObjectID=D2C48F86-BA1A-11A1-A2200060B0A03878

using the same database has emphasised the inter-sectoral flow of innovations. The database covers 4378 'major'/ 'significant' innovations produced in the UK in the period 1945 - 1983. The innovations had to have been commercially successful and had to be thought by experts to have been a significant technical advance. "SPRU contacted about 400 experts (roughly five or six per sector) from research institutes, trade associations, universities, firms and government to list the major innovations produced during the period" (1994: 13). The list was subsequently checked with a second independent group of experts. The producing firm and the first user sector were identified in a follow up survey of the businesses that produced the innovations.

Figure 6: The Inter-sectoral Flow of Innovations in the UK

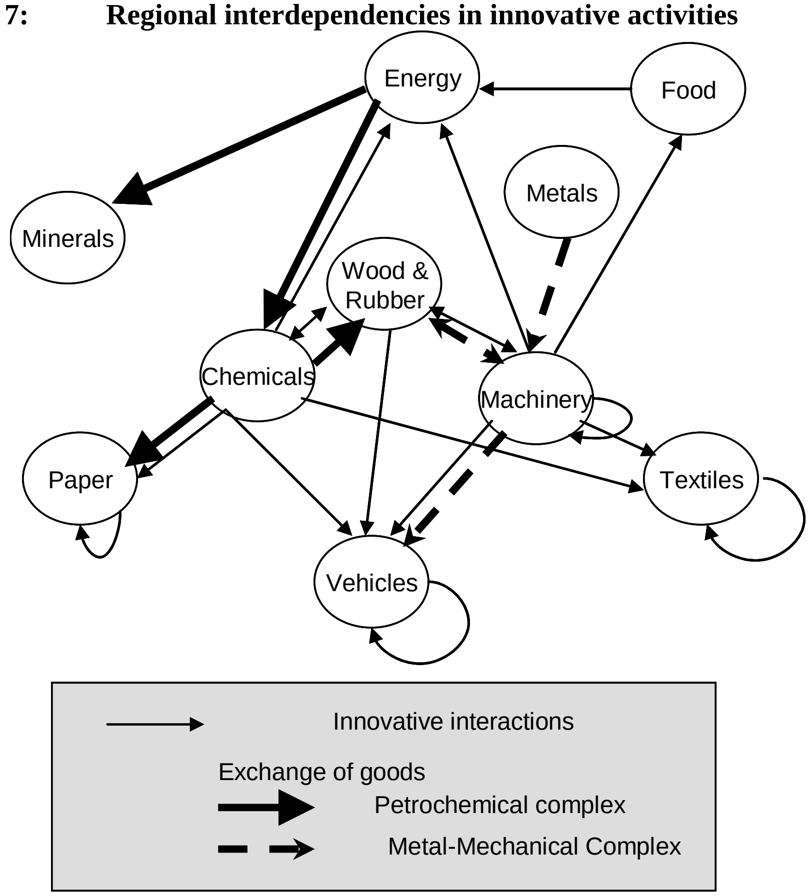


Source: redrawn from Geroski (1994: 19)

In this diagram (Figure 6) we can see a complex system of innovation interdependencies. A couple of primary 'sectors' – mechanical engineering and chemicals are key developers of innovations that flow onto a number of other sectors. Some sectors such as electronics and instruments are intermediate players, both benefiting from innovations generated elsewhere but also providing innovations to others. Finally, there are a range of largely 'recipient' complex integrating sectors such as auto, aerospace, paper, food and construction etc which are typically end points for a wide range of technological inputs.

Other surveys[11] of the producers and users of innovations have revealed similar patterns. Silvani *et al.* (1996), for example, have shown quite a similar pattern exists for the innovation interdependencies within just a single Italian region (Lombardy). Figure 7 reveals not only the innovation flows but also key flows of goods (combining an innovation producer-user matrix with standard input-output matrix data. Again, auto, paper, and textiles are recipient sectors, while machinery and chemicals are important innovation generating sectors. In this region the wood and rubber sector has important innovation interdependencies with the chemicals and machinery sectors.

Figure 7: Regional interdependencies in innovative activities



Source: redrawn from Silvani *et al.* (1996: 266)

[11] See Debresson *et al.* 1996:35

With these findings in mind, the analysis of Cesaratto *et al.* (1996), based on similar data to Silvani *et al*., is quite interesting. These authors categorise industries into a quite a different format than has typically been developed, although principally reinforcing the emergent understanding of the technological division of labour and the interdependencies. Their taxonomy groups industries into *design based capital goods*, *investment based intermediate goods innovators*, *complex innovators*, *marketing oriented innovators*, *cost oriented consumer goods innovators*, *construction*, and *services and consumption*.

Such analysis, however, rests on the availability of information on the users and producers of innovations - a type of question yet to be included in standard innovation surveys such as the European CIS series. Even when available, such surveys are typically not interested in the flow of innovations between the different institutional structures of university, government labs and business.

A discussion of indicator development for these purposes is provided in the following section.

5. Measuring knowledge ecologies

Breaking down and analysing the different parts of a system and attempting to put indicators alongside them is not an easy task. Further, using the knowledge ecologies perspective would not replace existing indicator reports. The existing reports have the advantage that they present large amounts of detailed data and the categories adopted avoid double reporting. How then do we go about investigating the creation and use of knowledge? Smith (1994) has already discussed some of these issues. Links, he says, are the most difficult part of the problem. To identify them, three methods have been used in the past: interviews about interactions, patent citations, and interviews about the use of university research. The classic interview techniques, however, simply quantify the amounts of information gathered from various sources, according to Smith. To gain the level of detailed information that today's policy makers and program designers need new approaches. We suggest three methodologies, in order of their ease of implementation and systemic coverage – but none of them are truly easy.

1. Harmonizing statistical classification systems and creating R&D matrices

2. Technology mapping

3. Sectoral innovation mapping

4.1 Research and development matrices

There are a number of barriers in moving towards a R&D collections strategy that meets the needs of policy makers and analysts in this field. First, data from all the different institutional silos must be collected using the same classification system. The Australian standard research classification system already achieves this. In this case, business R&D is collected by industry classification as well as both detailed research fields and socio-economic objective. This facilitates analysis of categories where industry, government and university are currently conducting research or being funded extramurally. Second, there must be a move beyond single dimensional data tables to relational data. This second shift is the most problematic both in terms of resources and statistical confidentiality which is of utmost importance to statistical agencies.

Such matrices have been produced in the past[12] for Australia (and currently for Austria), for product field data, but there is no evidence that they are widely available across the OECD countries. Selecting here (Table 3) just a few example industries from Australia, which also appear as interesting from Figures 1 and 2 the range of activities which industries invest in is quite revealing.

[12] When the Australian Bureau of Statistics collected product field data it matched the data with industry information.

Table 3: Australian Industry R&D performance by Product Field 1997-98.

Product Fields	Food, beverages & tobacco	Motor vehicle & other transport	Metal product
Agriculture, forestry, fisheries & hunting	15,707,000		43,000
Mining			56,647,000
Food, beverages and tobacco	130,488,000		
Textiles, clothing and footwear			
Wood, wood products			147,000
Paper, paper products			
Petroleum refining			
Pharmaceuticals & veterinary products	762,000		
Rubber & plastic products			3,134,000
Other industrial chemical products		178,000	1,285,000
Non-metallic mineral product			
Basic iron and steel			71,282,000
Basic non-ferrous metals		1,911,000	94,995,000
Fabricated metal products		2,096,000	62,530,000
Industrial machinery and equipment	9,553,000	1,278,000	15,031,000
Computer hardware			
Electronic equipment			2,505,000
Other electrical appliances			3,580,000
Photographic, professional and scientific equip			
Motor vehicles and parts		343,391,000	2,944,000
Ships and boats		49,261,000	
Railway rolling stock and locomotives		13,659,000	
Aircraft		4,889,000	
Other transport equipment		3,284,000	
Other manufacturing	11,384,000	2,122,000	6,023,000
Computer software			
Construction			
Other n.e.c.			
Electricity, Gas and Water	18,000		
Transport & Storage Services		1,201,000	
Telecommunication Services			
Total other industries	5,988,000	8,952,000	10,322,000

Source: ABS (2000).

The interesting feature of this data (see also Appendix Figure) is that it reinforces the Figures 6 and 7 but from the reverse direction. The earlier figures revealed that there was a flow on of innovations from particular industries to user industries. Table 3 suggests (food and transport columns) that the 'user' industries also invest in R&D in product fields related to the innovation supplier industries. Metal industries carry out research and development activities across a wide spectrum of product fields. Combining these two data sources begins to give statistical support to the complex relations between sectors that have been observed in case studies. The possibilities of using product field data, limited as it currently is, has not been used for deepening our understanding of the processes of absorptive capacity (see Lane, Koka and Pathak 2006). A greater focus on the flow of innovations between producers and users within innovation surveys would also be very helpful.

4.2 Technology mapping

In recent years it has become more commonplace for industry segments to identify their future knowledge requirements through formalised technological foresight and mapping exercises. Through the publications that arise from such exercises it is possible to begin to understand the complexities of what might otherwise be thought of as an industrial sector. Industry, government and academia have been collaborating on a technology roadmap for the UK road transport industry.

The key technological priorities that they have reported (Foresight Vehicle 2004: 6) are:

Environment

- CO2 reduction
- Conservation of resources
- Health, pollutant reduction
- Waste, re-use and recycling

Safety

- Accident prevention
- Accident effect mitigation

Choice

- Vehicle design
- Vehicle manufacturing

Mobility

- Access and use of the system
- Infrastructure development

Security

- Vehicle and occupant security
- Prevention of vehicle use in acts of terrorism

Economics

- Manufacturing cost reduction
- Flexible manufacture
- Cost of ownership

This range of topics includes both incremental innovation as well as basic research to develop human–vehicle interaction systems which require "detailed behavioural studies of drivers are highlighted as necessary so that systems can be designed to given an appropriate response' (p45). However, even this list of technological frontiers, understates the breadth of knowledge upon which private transport systems rest. Geels (2002: 1258) suggests that transport systems are more than purely technological systems (Table 4).

Table 4: The sociotechnical configuration in personal transport

First tier category	**Second Tier categories**	**Third Tier categories**
Culture and symbolic meanings (e.g. freedom and individuality)		
Finance rules, interest rates, insurance premiums		
Industry structure (car manufacturers, suppliers)		
Regulations and policies (e.g. traffic rules, environmental standards, car taxes, parking fees)		
Maintenance and distribution networks (e.g. repair shops, car sales & show rooms)		
Markets and user practices (mobility patterns, driver preferences)		
Road infrastructure and traffic systems		
Fuel infrastructure (e.g. petrol stations, oil refineries)		
Vehicle artefact		
	drive train	engine
		transmission
		wheels
	suspension	
	body	material
		structural configuration
	accessories	
	control systems	brake system
		steering system

Foresight exercises, such as that conducted in the UK for the auto segment have been done for a large number of industrial sectors [13] across the last decade or so. The analysis presented in such foresight activities reinforce the survey driven results on the complex technological interdependencies between various sectors that were presented in an earlier section of this paper. The foresight-based technology roadmaps are *forward looking* results of consultative processes combining the knowledge of leading expertise in various fields. They are based in examining the technical barriers that exist today and the resources and innovations needed to make significant improvements. A retrospective mapping approach would require similar processes but be interested in finding out how we got to where we are now. Who was involved, how much R&D was involved etc?

With the "innovation" as the unit of analysis, this technique was introduced in the 1970s in the classic studies "TRACES" and "Hindsight" and has been applied more recently by a team at SRI.[14] In many ways the process for developing such retrospective maps is similar to the process for developing the future oriented roadmaps. For example, the SRI team that applied the technique recently went through the following steps:

- **Decomposition**. Distinguishing the "intrinsic" technologies unique to the innovation from "supporting" technologies, and from the larger sociotechnical system within which the innovation occurs.
- **Library Search** of online databases using keyword strategies to identify all major published works on the technologies.
- **Bibliometrics** including co-citation and patent analysis
- **Institutional Analysis** to identify the major companies, federal labs, federal agencies, universities, and other organizations that played a significant role in the development of intrinsic technologies, using both literature-based and interview-based information

[13] The Canadian equivalent of this work is conducted through Auto21 http://www.auto21.ca/home_e.html . A broad range of activities are conducted in the UK http://www.foresight.gov.uk/. US Department of Energy's 21st Century Truck project (2000).
[14] See http://www.sri.com/policy/csted/reports/techin/ and http://www.sri.com/policy/csted/reports/sandt/techin2/welcome.shtml for a review of these classics and a recent application of the technique.

- **Patent Analysis** involving searches of the standard patent databases available at federal government repository libraries.
- **Personal and Telephone Interviews** with the people identified as key contributors to each major intrinsic technology were conducted.

4.3 Sectoral innovation process monitoring

Both technology roadmapping and retrospective tracings have usually been carried out as special studies. An exception is the roadmap done for the semi-conductor industry by Sematech, which is updated regularly. In neither case has the intention been to provide regular information to policy makers to inform their choice and design of innovation policies. However, some of the methodological elements of those processes could be applied to the task of regular monitoring of innovation at sectoral level.

We turn now to describing what such a process might look like and how it could produce insights that would be useful for national policymaking. We will first address the methodological task and then suggest a way of organizing such an effort. Malerba (2004) defines a sector as "a set of activities that are united by some related product group for a given or emerging demand and that share some basic knowledge" (9-10). He defines a sectoral system of innovation as "a set of agents carrying out market and non-market interactions for the creation, production, and sale of sectoral products" (2004, 10). Each sectoral system has three building blocks: knowledge and technology; actors and networks; and institutions (that is, the rules of the game). Actors in the system interact through "processes of communication, exchange, cooperation, competition and command and their interaction is shaped by institutions." They key problem for an indicator constructor in monitoring such systems is to relate the building blocks to innovation outcomes.

We propose that multi-method case studies are the best methodological approach to monitoring innovative capacity and innovation itself at sectoral level. Each sectoral study would use multiple information sources and approaches to characterizing the knowledge and technology in the system; its actors and networks; and the institutional context. Sector-specific sources could be used, such as existing roadmaps. Patent and publication data can contribute, both as indicators of the size of contribution of actors to the technology and knowledge base and as indicators of networks and flows of knowledge, both within the sector and between sectors. . Surveys on R&D expenditure may be able to contribute to the characterization, if the definitions used there align closely enough to the boundaries of the sector; and if this condition holds, innovation surveys could provide one estimate of innovation rate. This estimate could be compared with publication-based and patent-based analysis of rates of technological change. Focus groups and interviews with industry experts could also be used periodically to provide a qualitative check on any quantitative analysis with partial indicators.

The key issue is how the studies of individual cases would add up to inform national policy. The answer lies in case study methodology itself (Yin), where individual cases contribute to the understanding of a general phenomenon through replication logic. The SSI literature provides theory-based hypotheses about how the characteristics of innovation systems are related to rates of innovation itself. At a general level, that literature postulates that higher levels of interaction will be related to higher levels of innovation through stimulating learning, and that institutions (rules of the game) that foster learning will also be conducive to innovation. Following Yin's approach, each sectoral case study in a monitoring system would form a test of the hypotheses derived from the literature, either confirming or suggesting revisions. National policy makers would both learn something from each case study and from the comparison of cases about the rules of the game they set and about the effectiveness of their other investments, especially in research at government laboratories and universities.

The multiple-method, multiple-case study approach does not fit well organizationally with current indicator units, which tend to be centrally organized and depend on national-level statistical surveys. Indicator units would need to be capable of some organizational innovation themselves to incorporate this approach. Sector-level organizations themselves or sector-related government agencies might need to be partners in the case study strategy, and in the process of learning lessons across the cases. A more collaborative approach of this sort might have the advantage for central decision makers of increasing interest in the results.

6. Conclusions, implications and future research

The broad goal of this paper has been threefold. First, we wanted to remind the reader that one of the key findings of innovation systems research has been that significant inter-sectoral technological interdependencies underpin many industries. Second, if we want to discuss the relations between academia, industry and government then we need data that is better suited to identifying the technological and institutional interdependencies. Third, we wanted to show that although R&D expenditure data has been overrated for what it might tell us about the innovation process in general, it has been under-rated and under-developed as a source of information on embedded technological requirements of various industrial activities. In this paper we have highlighted a number of ‘industry’ examples (food and auto) where both the data and case studies have shown that they rely upon either integrating innovation from a range of other industries or are embedded in wider societal value systems of infrastructure and resources. However, the data suggests that there are a number of other sectoral systems that fit this category and others (mechanical engineering) where the dynamics might be very different.

As it turns out, R&D is a key starting point for understanding the complexities of modern knowledge economies as the R&D classification schemes can better reflect the wide range of knowledge and technology oriented activities. Innovation-relevant bibliometrics, patent analysis and innovation surveys must all be embedded in industrial classifications and therefore potentially misinterpret the role of government and university research in many sectors. These research institutions may provide an infrastructural platform upon which the narrower economic interests of companies can operate.

This last point directs us to the possibility of re-evaluating in a constructive sense our taxonomies of technology (high tech etc) and the knowledge economy. In the interim however, an urgent task is to explore a re-design of science, technology and innovation indicators presentations to derive greater public policy benefit. Current approaches to indicator presentation make it difficult for policy makers to understand the systems that they are modifying. For example, 'low tech[15]' industries are knowledge intensive, and are frequently part of 'high tech' systems, and both scholars and policy-makers should be aware of their significance for growth. If the term the 'knowledge economy' is to have any real significance then it must take such processes and activities into account, not only as bearers and users of knowledge, but also as drivers of change.

It is possible that the reconfiguration of available data will prove to be difficult, but Sandven and Smith point us in the direction of why we must try.

> The basic reason is that many theories about innovation or about its effects, for example theories of economic growth, really concern propositions about systems or populations. This means that the testing of these propositions should not be based on the generalisation of a few examples, such as those drawn from case studies. There is an enormous amount of extremely valuable case studies that have enriched our understanding of innovation, but these studies simply do not cover all relevant sectors or technologies; on the contrary, many of the innovation case studies of the past twenty years are focused on a relatively small group of R&D-intensive sectors of the economy. The result is that many innovation theories, particularly when extended to dynamics and growth theory, have only a tenuous link with economy-wide evidence. Since we are interested in the characteristics, structure, and dynamics of populations and natural systems as a whole, we need data that reflects the entirety of a population of firms. (1998: 11).

[15] See for example Hirsch-Kreinsen *et al.* 2003.

References

ABS (1998) *Australian Standard Research Classification 1998.* Canberra, Australian Bureau of Statistics catalogue no. 1297.0 available at www.abs.gov.au

ABS (2000) *8104 Research and experimental development: Business Enterprises Australia*. Canberra: Australian Bureau of Statistics - consultancy service.

Barnett, W. (1990) 'The Organizational Ecology of a Technological System' *Administrative Science Quarterly* Vol 35 (1): 31-60.

Bender, G. (2006) *Peculiarities and Relevance of Non-Research-Intensive Industries in the Knowledge-Based Economy. Final Report of the Project "Policy and Innovation in Low-Tech – Knowledge Formation, Employment & Growth Contributions of the 'Old Economy' Industries in Europe – PILOT.* www.pilot-project.org

Bradley, R. (2000) Technology Roadmap for the 21st Century Truck Program A Government-Industry Research Partnership at http://www.osti.gov/hvt/21stcenturytruck.pdf

Cesaratto, S., S. Mangano, and S. Massini (1996) 'New Dimensions on Division of Labor: The case of Italy (1981-85)' in DeBresson, C. (ed) (1996) *Economic Interdependence and Innovative Activity*. Cheltenham: Edward Elgar.

Cooke, P., Kaufmann, D., Levin2, C., and Wilson, R. (2006) 'The Biosciences Knowledge Value Chain and Comparative Incubation Models' *Journal of Technology Transfer*, 31: 115–129, 2006.

Cooke, P. (2006) 'State, Markets & Networks in Knowledge Economy Value Chains' presented at the *DRUID Summer Conference* 2006 June 18 - 20, 2006, Copenhagen.

Debresson, C., G. Sirilli, P. Kaminski, S. Xu, and N. Vernardakis (1996) "Some surveys of Innovative Activity" in DeBresson, C. (ed) (1996) *Economic Interdependence and Innovative Activity*. Cheltenham: Edward Elgar.

Department of Energy (2000) *Technology Roadmap for the 21st Century Truck Program*. http://www.doe.gov/bridge

DEST [Department of Education, Science and Training] (2002) *National Research Priorities* http://www.dest.gov.au/sectors/research_sector/policies_issues_reviews/key_issues/national_research_priorities/default.htm

Foresight Vehicle (2004) *Foresight Vehicle Technology Roadmap: Technology and research directions for future road vehicles.* http://www.foresightvehicle.org.uk/

Geels, F.W. (2002) 'Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study', *Research Policy* Vol 31: 1257–1274.

Edquist, C., M. McKelvey (eds) (2000) Systems of innovation: growth, competitiveness and employment. Vol. I. and Vol. II., Cheltenham: Edward Elgar.

European Commission [Directorate-General for Research Knowledge-based economy and society Competitiveness, economic analysis and indicators] (2003) *Third European Report Science & Technology Indicators 2003: Towards a knowledge-based economy,* Luxembourg: Office for Official Publications of the European Communities, 2003

Geroski, P. (1994) *Market Structure, Corporate Performance and Innovative Activity.* New York: Claredon Press – Oxford

Industry Canada (2002) Achieving Excellence Investing in People, Knowledge and Opportunity http://www.innovationstrategy.gc.ca

Hirsch-Kreinsen, H. D. Jacobson, S. Laestadius and K. Smith (2003) *Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges* available at: http://www.pilot-project.org/index.html

Kaloudis, A., T. Sandven, and K. Smith (2005) ‘Structural change, growth and innovation: the roles of medium and low tech industries, 1980-2002’ presented at *Low-Tech as Misnomer: The Role of Non-Research-Intensive Industries in the Knowledge Economy.* Brussels 29 - 30 June, 2005.

Lane, P., Koka, B. and Pathak, S. (2006) ‘The Reification of Absorptive Capacity: A Critical Review and Rejuvenation of the Construct’ *Academy of Management Review* Vol. 31 (4): 833–863.

Leontief, W. (1936) ‘Quantitative Input-Output Relations in the Economic System of the United States’, *Review of Economics and Statistics*. Vol 18 (3): 105-125.

Leydesdorff, L., W. Dolfsma, G. Van der Panne (2006) ‘Measuring the knowledge base of an economy in terms of triple-helix relations among ‘technology, organization, and territory’’ Research Policy 35 (2006) 181–199

Malerba, Franco, ed. (2004) Sectoral Systems of Innovation. Cambridge: Cambridge University Press.

Marburger, J. (2006) ‘Keynote Address’ presented at “*Blue Sky II 2006” What Indicators for Science, Technology and Innovation Policies in the 21st Century?* Ottawa: September 25 - 27, 2006.

National Science Board (2002) *Science and Engineering Indicators 2002.* Virginia, NSF.

National Science Board (2004) *Science and Engineering Indicators 2004*, Virginia: National Science Foundation.

National Science Foundation (2002) Science and Engineering Indicators 2002, Virginia, NSF.

OECD (2001) *Science, Technology and Industry Scoreboard 2003: Towards a Knowledge Based Economy.* Paris: OECD.

OECD 2002 *Frascati Manual 2002: Proposed Standard Practice for Surveys on Research and Experimental Development.* Paris, OECD.

OECD (2003) *Science, Technology and Industry Scoreboard 2003.* Paris: OECD.

Pavitt,, K. (1984) ‘Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory’, *Research* Policy 13 (6) (1984).

Phaal, R. (2002) *Foresight Vehicle Technology Roadmap Technology and Research Directions for Future Road Vehicles, London.* Department of Trade and Industry, www.dti.gov.uk

Robson, M., J. Townsend and K. Pavitt (1988) ‘Sectoral Patterns of Production and Use of Innovations in the UK: 1945-1983’ *Research Policy.* Vol 17: 1-14

Sandven, T. and Smith, K. (1998) ‘Understanding R&D Intensity Indicators - Effects of differences in industrial structure and country size’ *IDEA Paper series* 1998-14 Oslo: STEP Group.

Silvani, A., F. Cancemi, C. DeBresson and X. Hu (1996) ‘Innovative self-sufficency or regional interdependence: Lombardy and the Rest of Italy’ in DeBresson, C. (ed) (1996) *Economic Interdependence and Innovative Activity*. Cheltenham, Edward Elgar.

Smith, K., (1997), "Economic infrastructures and innovation systems", in C. Edquist (ed.) Innovation Systems: Institutions, Organisations and Dynamics London: Pinter, pp. 86-106.

Smith, K., (2000) “What is the ‘knowledge economy’? Knowledge intensive industries and distributed knowledge bases” Australian Expert Group in Industry Studies Working Papers 2000-03 Sydney: AEGIS University of Western Sydney.

Smith, K., (2002) “What is the ‘knowledge economy’? Knowledge intensity and distributed knowledge bases” *INTECH Discussion Paper Series* 2002-6 Maastricht: United Nations University.

van Hulst, N.; Olds, B. (1993) ‘On high tech snobbery’ *Research Policy*, Vol. 22, pp. 455-462

Wixted, B. (2005) *Systems of Innovation Beyond Borders: Linked Clusters and the Role, Scale and Spatial Structure of Extra-Territorial Interdependencies*. unpublished thesis currently being examined– should become available at http://library.uws.edu.au/adt-NUWS/public/adt-NUWS20060407.100831/

Wixted, B. and Cozzens, S. (2006) ‘Of Triple Helixes, Classification Schemes and Knowledge Value Chains’ presented at *“Blue Sky II 2006” What Indicators for Science, Technology and Innovation Policies in the 21st Century?* Ottawa: September 25 - 27, 2006.

World Trade Organization (2003) International Trade Statistics 2003, Geneva: WTO.

World Trade Organization (2003) International Trade Statistics 2003, Geneva: WTO.

Zhu, D., Porter, A., Cunningham, S. Carlisie, J. and Nayak, A. (1999) "A Process for Mining Science & Technology Documents Databases, Illustrated for the Case of "Knowledge Discovery and Data mining", Cienciaa da Informacao, Vol. 28, No. 1, p. 1-8., 1999.

Appendix Figure 1: Australian Industry R&D by Product Fields 1997-98 (AUD)