Prometheus
Vol. 30, No. 3, September 2012, 261–289

RESEARCH PAPER

How do innovation systems interact? Schumpeterian innovation in seven Australian sectors

Robert Dalitz[a]*, Magnus Holmén[b] and Don Scott-Kemmis[c,d]

[a]*Centre for Industry and Innovation Studies, University of Western Sydney, Australia;* [b]*Department of Technology Management and Economics, Chalmers University of Technology, Göteborg, Sweden;* [c]*Centre for Innovation, University of Sydney, Australia;* [d]*Faculty of Business, University of Technology Sydney, Australia*

This paper analyses how and why different types of innovation systems interact through analysing seven Australian sectors. We find that there are sets of mechanisms or systems that 'articulate'; i.e. structure and shape the interaction among sectoral innovation systems and other types of innovation systems. Drawing on the Schumpeterian and evolutionary legacy, we contribute a theoretical explanation of how interaction among innovation systems influences innovation. First, this interaction enables and enhances variety creation by expanding the new combinations of knowledge and resources a firm can achieve. Second, it allows for more efficient and effective scaling up of useful knowledge recombination to achieve increasing returns. Empirically, this is supported in that the more successful sectors have active articulation systems with alignment with other systems, while weaker sectors have unplanned and patchy linkages. No simple model seems to explain successful articulation. However, important factors are active receptor firms with the motivation and capabilities to absorb and use resources from external systems, high quality and responsive education systems, and international linkages. Public research, labour markets, and intermediaries varied in importance.

Introduction

Innovation research sees innovation as essentially a firm level phenomenon, but one strongly influenced by surrounding systems that support learning and firm competition.[1] There is a group of standard frameworks used to understand these surrounding systems. These include national innovation systems (NIS; Lundvall, 1992; Nelson, 1993),[2] regional innovation systems (RIS; Cooke, 2000; Doloreux and Parto, 2005), technological systems (TS; Carlsson and Stankiewicz, 1991) and sectoral innovation systems (SIS; Malerba, 2002). Nations provide a natural system boundary because of institutional coherence within nations and the differences between them. Regions have been found to provide the milieu for much innovation. Technologies and networks among organisations are the basis of a great deal of competition and innovation. Sectors provide the *meso* level link between the firm level and the institutional or national level because they constitute the environment in which firms compete around particular product markets (McGahan, 2004; Malerba, 2005a).

*Corresponding author. Email: R.Dalitz@uws.edu.au

ISSN 0810-9028 print/ISSN 1470-1030 online

http://dx.doi.org/10.1080/08109028.2012.716275
http://www.tandfonline.com

Although each of these approaches has advantages, its usefulness for analysing or explaining economic progress within a nation, region or industry is by necessity limited by its particular empirical focus (e.g. Edquist, 2005; Dodgson *et al*., 2011). This becomes problematic in that innovation systems are known to be open systems, in which exogenous factors may at times be more significant than the factors endogenous to the system. A way to overcome this weakness would be to analyse how different innovation systems complement or hinder the development of each other and how actors interact or integrate work across different types of systems. Unfortunately, even though the relationship and interaction among different types of innovation systems is likely very important to economic development, it is little studied (Murmann and Homburg, 2001; Malerba, 2005b; Castellacci, 2009). A recent paper by Castellacci (2009) investigates the interaction between national and SIS using data from the European Community's Innovation Survey. Castellacci found that there are differences between countries in sectoral patterns and that there are interactions between each nation and its sectors. However, 'there does not exist any body of literature that systematically and explicitly investigates the mechanisms that link the *meso* to the macro level of innovation systems' (Castellacci, 2009, p.322).

Beyond these inter-level linkages, there is also a paucity of literature linking TS to the geographic domain of the NIS and RIS frameworks and to the economic domain of the SIS framework. From the perspective of distributed innovation over time, it is in the interaction of, at least, the national, regional, technological and sectoral domains that the dynamics and overall performance of innovation occurs (Nelson, 1994; Freeman, 2002; Coombs *et al*., 2003; Edquist, 2005). Following this logic, we argue that the path of economic development at any level is shaped by the array of other interacting systems it faces. Indeed, without understanding these linkages, innovation policy may miss the points of highest impact.

The problem lies in trying to understand such interactions. One way to do this is to go back and draw on the foundations of the innovation systems approach. One of the cornerstones of innovation systems is that innovations are created, diffused, imitated and used over time by interaction among a set of heterogeneous actors. Another basic assumption of the innovation systems approach is that competition and economic development are fundamentally evolutionary, or Schumpeterian, consisting of continuous interaction among firms creating and exploiting innovations, faced by competitive markets, generating waves of creation and destruction (Schumpeter, 1934; Moran and Ghoshal, 1999; Freeman 2004). These processes are neither simple nor teleological as they are based on a set of actors' differential motivations, aspiration levels, access to information, capabilities and ability to exploit increasing returns while being governed under some set of institutions.

This implies that one way to improve understanding how different types of innovation systems can interact, and how actors may integrate the work and knowledge of others outside their system, is to analyse how a particular innovation system relates to others from the perspective of the recombination of knowledge. Taken together, these Schumpeterian foundations suggest that systemic innovation needs to be understood from the perspective of variety creation through new combinations and how increasing returns by means of the reuse of knowledge affect selection. Systems of actors combine to increase the ability of firms to produce variety by expanding the availability of new combinations, allowing much wider search. We know search and innovation by firms draws on knowledge and resources outside their sectors (Klevorick *et al.*, 1995). This suggests that variety creation is promoted by crosscutting between innovation systems. On the other hand, the source of increasing returns boils down to the reuse of knowledge (Rosenberg, 1982; Langlois, 1999; Nightingale, 2000). If firms can reuse external players' knowledge, then novelties can become economically viable more quickly and to a greater extent. This may be through decreasing unit costs as a consequence of learning or increase in scale, the ability to solve increasingly complex problems or the ability to incorporate more complex resource bundles, or other similar situations where, over time, the scale and/or complexity of what firms can do increases more than inputs (Rosenberg, 1982; Nightingale, 2000). Again, this suggests that crosscutting among the various domains of systems of innovation may be crucial. External sources of useful knowledge for reuse can be within the nation or available globally. When some innovation begins to be successful, a system of actors can increase the scale and complexity of activities and resources involved in exploiting and advancing it much more effectively than a single firm. Systems of innovation are therefore powerful ways to augment the innovative abilities of a firm and the sector as a whole.

To address how different innovation systems interact, this paper analyses seven sectors; the Australian automotive, computer games, mineral exploration, oil and gas engineering, photovoltaics (PVs), wine and dairy sectors. We find emergent articulation systems (AS) of actors and structures that inform, shape and link crosscutting external systems to specific industry requirements and thus 'articulate' between levels and domains of innovation.[3] An AS allows an economically viable recombination of knowledge and resources, enhancing the variety creation and increasing returns performance in the sector. Examples of crosscutting include the public research and education systems and supply chains, as well as sector specific features that are external to the actual production and competitive process of the sector. A developed AS acts to augment the search and problem-solving capabilities of firms within a sector and allows the uptake of more complex and larger-scale resource bundles than firms can handle alone. The performance of the sectors that we studied corresponded with how well aligned each sector's commercial dynamics are with crosscutting systems. We find that Schumpeterian dynamics of variety creation and increasing returns provide a powerful lens on how and why articulation with crosscutting systems leads to better or worse performance.

Systems of innovation

The innovation systems concept was first proposed by Chris Freeman to an *ad hoc* Organization for Economic Co-operation and Development (OECD) group on Science, Technology and International Competitiveness (Freeman, 2004; Lundvall, 2004). The innovation systems concept is based on the empirical finding that innovation is a systemic phenomenon, not solely occurring in individual firms (Freeman, 1991). In his overview of innovation systems, Edquist (2005) provides a general definition: 'all important economic, social, political, organisational, institutional and other factors that influence the development, diffusion and use of innovations.' Unfortunately, as Edquist admits, this definition suffers from a 'conceptual diffuseness', which makes the innovation systems approach more of a framework than a theory. Although a Schumpeterian approach underlies the innovation systems framework, there appears to be little work linking empirical studies of systemic innovation to Schumpeterian economic theory. Moreover, innovation is primarily a firm level phenomenon because individual innovations are introduced by firms, yet the innovation systems approach works at levels above the firm. This critique naturally follows the problem of designing an analytic framework to study a system when the key actors in that system are active and deliberately try to influence the system's dynamics.[4] In performing an innovation systems analysis, and in reading one, careful attention needs to be paid to this issue.

NIS came to the fore in the early 1990s (Lundvall, 1992; Nelson, 1993) because the nation state is seen as a natural system boundary, as most laws are national, and culture and history are typically strongly national in character. These factors are thought to make interactions stronger within nations than between nations. For example, Jacobides (2008) shows that institutions in different nations shape a particular sector differently in each nation. Although there is no commonly agreed definition of NIS (Niosi, 2002), there is a common focus on the institutional structures that develop and diffuse new knowledge, especially technological knowledge and technology itself (Freeman, 1987; Lundvall, 1992; Nelson, 1993; OECD, 1999). This focus on technology can be taken as a misjudgement as much innovation is non-technological, and some nations do not have industrial structures dominated by technological leaders (Dodgson *et al.*, 2011). Often the United States is used as a template for innovation analysis and a great deal of US economic development is based on world-leading technological development. In the case of other nations, a focus on technological development through R&D may miss the actual dynamics dominating that nation's innovation performance. For example, Teixeira and Fortuna (2010) claim that Portugal has limited linkages to enable absorption and use of external research knowledge.

SIS look at innovation in particular sectors (Malerba, 2002, 2005b), where a group of competing firms producing the same product has strong interactions and is influenced by a common set of institutions. SIS are based on three building blocks: (1) knowledge and technologies; (2) actors and networks; (3) institutions (Malerba, 2005b). Sectors are important as the competitive context that provides both a selection environment (markets) and knowledge infrastructure (Smith, 1997) around which firms innovate. A criticism of the SIS approach is that sectors are statistical abstractions that increasingly bear little resemblance to the competitive situation of firms (Dalziel, 2007; Cooke and de Laurentis, 2010). This critique is compelling if the standard industrial categories codes are assumed to equate to actual sectors. However, the real world experience is that a sector is the set of firms competing around products and services sharing inputs and environment (McGahan, 2004; Malerba, 2005a; Dalziel, 2007).

There are two other innovation systems approaches that require some exposition, the RIS and the TS frameworks. The RIS framework (Cooke, 2000; Doloreux and Parto, 2005) is focused on systemic innovation within a particular territory, typically sub-national. Many vitally important economic activities are localised and not readily discernible at the national level. A criticism of the RIS is that many activities are not simply local in nature and are part of much larger networks of activity. Wixted (2009) has shown distinct structures of activity in sectors across the world, with regions in nations playing roles in the global industry. The TS framework (Carlsson and Stankiewicz, 1991; Carlsson and Jacobsson, 1994) is defined as: 'networks of agents interacting in each specific area of technology under a particular institutional infrastructure' (Carlsson and Jacobsson, 1994, p.235). Technological systems, therefore, cut across sectors and are often international in scope. The TS framework is underpinned by the assumption that problem-solving among heterogeneous actors is coordinated by networks and a specific set of institutions. However, many important modern technologies have converged to become part of platform technologies (Cooke *et al*., 2010), which means the market and various forms of spill-over coordinate and govern activities in a manner that does not fit well within the TS formulation. Thus, the boundary and definition of a TS are likely to be contestable.

The above description of the innovation systems frameworks is brief, as is the discussion of criticisms of each framework. However, we contend that these frameworks represent an important domain of innovation, each with its own set of advantages and disadvantages. The NIS and RIS framework domain is essentially institutional; the SIS focuses on inter-firm competition in product markets and the TS focuses on the networks of technology development and exploitation. Thus, each framework has different issues at its heart and so combining these frameworks to produce a holistic understanding of innovation is inherently problematic. While several papers point to the interdependence of the various innovation system frameworks (e.g. Edquist, 2005; Malerba, 2006), each acts in a different domain and there is little work conceptualising how they relate to one another (Castellacci, 2009). Notwithstanding our appreciation of these frameworks individually, the fact that they are freestanding entities is a problem for anything described as 'systems' theory. Systems theory has long recognised that there are many interrelated systems in the social and economic world and that some systems are sub-systems of larger systems (Emery, 1969). Innovation systems, by their very definition, exist in the social and economic world and are sub-systems of the whole human 'system'. They are interconnected and interact to shape each other and the innovation performance of the actors involved. These systems interact and can be expected to shape each other. This paper explores how this interaction between domains of innovation occurs.

Methods

This paper is based on a cross-case analysis (Eisenhardt, 1989; Yin, 2003) of seven in-depth case studies in Australia; the motor vehicles, computer games, mineral exploration, oil and gas engineering, PVs and wine sectors. Each case study deals with the transformation of the sector and the interactions of the sector with external sources of knowledge and other resources. Each case study was carried out by a single researcher using interviews, available statistics and documents. The number of interviews per sector ranges from 10 to 60 and all were conducted between 2003 and 2005. The seven case studies were analysed with a modified SIS approach (Malerba, 2005a) and brought together for this paper. The analysis of each case included firms and other organisations, interactions among these actors, the division of international labour, national and sectoral institutions, the sectoral technology and knowledge base and their recent changes, opportunities and modes of appropriation. This analysis focused on how crosscutting systems interact with each sector. To ensure inter-interpreter validity, the cases have been documented and discussed in workshops over a period of three years.

The use of sectors as the prime unit of analysis was a consequence of our focus on economic innovation, which is a firm centric concept (Fagerberg, 2005), and sectors are the prime environment for firms. A sector is defined as the set of firms competing around a product, which share inputs and environment (McGahan, 2004;

Table 1. Delineation and selection of the sectoral case studies

Digital games	Mineral exploration	Motor vehicles	Oil and gas engineering	Photovoltaics	Wine	Dairy
Moderate international competitiveness	Increased international competitiveness	Increased international competitiveness	Increased international competitiveness	Poor international competitiveness	Increased international competitiveness	Increased international competitiveness
New sector	Established sector	Established sector	Emerged sector	New sector	Established sector	Emerged sector*
Non-geography	Geography	Non-geography	Geography	Non-geography	Geography	Geography

* The dairy sector has recently become prominent in international trade in commodities.

Malerba, 2005a). By placing the sectors in the regional and national context and observing how the sectors interact with TS, the interactions between domains of innovation can be studied. The researchers' focus is therefore on how the sector interrelates with other systems, as well as on the sector itself.

The selection of the case studies was based on three criteria (see Table 1). First, an *ex-ante* characterisation of the Australian actors' international competitiveness in the global sector was made to ensure that internationally successful and less successful sectors were included in the study. International competitiveness was measured in terms of export intensity, which increased in all sectors bar PVs. Second, sectors were chosen to include both new and old sectors. Third, sectors were chosen for their reliance on the particular location (geography) and ground (geology) of Australia. The rationale for this third criterion is that around 40% of Australia's exports are resource-related. Although not an adequate representation of Australia's economy, this selection does deal with much of Australia's trade.

We performed a cross-case analysis to find the connections between domains and levels of innovation and to find patterns that characterise performance. The aim of cross-case analysis is: 'to see processes and outcomes across many cases, to understand how they are qualified by local conditions, and thus to develop more sophisticated descriptions and more powerful explanations' (Miles and Huberman, 1994, p.172). Our seven cases are intended to provide a strong basis for theory building (Eisenhardt, 1989; Perry, 2001; Yin, 2003). Therefore, our research structure is designed to provide insight into the relationship between external systems and innovation in any particular sector.

We compared case studies. Each case was completed by one of the authors, with especial attention paid to elucidating if and in what ways the sector articulated with crosscutting systems and how crosscutting systems articulated into the sector. We then used the functions approach to innovation systems (Hekkert *et al*., 2007) to create a matrix of cases and features. The description for each cell was standardised and checked for consistency and validity by another of the team members. Patterns were sought rather than an overarching theory of AS. This analysis allows for identifying correlation between articulation characteristics and international success. However, despite longitudinal case studies where sequences of events were documented, the cross-case analysis cannot show if and how the AS caused international success. Rather, the data are limited to showing co-evolution.

Sectoral findings

Each of the seven sectors is discussed below in its own right and its connections to external systems, especially at the national level. The case descriptions are summaries rather than in-depth presentations of the quantitative and qualitative data.

Digital games

Digital games are games played on mass-market electronic hardware, such as personal computers, video consoles, dedicated handhelds and mobile phones. The digital games industry broadly refers to developers, publishers and distributors of computer games, producers of dedicated hardware and the suppliers of outsourced conceptual or technological work. Australian firms consist almost entirely of dedicated games developers and service providers, such as testing houses. Over the past two decades, the newly emerged games industry has exhibited double-digit annual growth rates and reached mainstream markets. The global sector is dominated by large North American, Japanese and European publishers, complemented with an elite club of independent, self-funded developers with proven intellectual property. The Australian games sector arose through enthusiasts and entrepreneurs starting companies to make games and finding niches in the global sector in the early 1980s. From an international perspective, the performance of Australian firms has been moderate, in that the sector is growing at around the same rate as the global sector and there are a number of viable firms with an effective sectoral infrastructure.

The sector's dynamics are now dominated by publishers using the studio model, focusing on sequels to successful titles. This model began in the 1980s and became dominant from the late 1990s. In the studio model, publishers develop games in-house or outsource the development work, but not the intellectual property rights, to external developers. Paired with double-digit rises in R&D and marketing costs during the last two decades, the studio model follows from appropriation being heavily skewed to a few international blockbusters in each type of game. This has reduced game shelf life and increased the focus on sequels. However, there are opportunities for new entrants because of technological changes in hardware, as well as in game design and game art.

The Australian industry is small, with around 60 firms, primarily in Victoria and Queensland. Almost all Australian developers have become locked into the large international publishers by a fee-for-service model. The fee-for-service model for Australian firms has become dominant because no company has been able develop its own viable titles. At the same time, the larger Australian firms (ranging from 30 to 200 employees) have been successful in attracting offshore work, especially from North American publishers. Some small firms have entered the mobile games market and face a rapidly growing, but consolidating, industry.

The Australian games sector articulates with national and other systems primarily through educational systems and labour markets. Australian computer games firms innovate and learn because of their need to keep up with the global industry. The industry body is keen to improve linkages with the education system and to influence government policy to support capability upgrading. The Australian education system produces graduates with relatively high-quality skills in art, design and computer programming at both at the tertiary and vocational education and training (VET) levels. There are many more people who want to enter the industry than can be employed and, commonly, people address skills deficiencies by undertaking games-specific education. The relatively open immigration environment has been important in attracting experienced professionals, such as those with capabilities in running games companies. There are poor links to the research system because there is little relevant Australian research. The key linkages are to large global firms, because demand is dominated by major international game titles and technology suppliers with little scope for local market niches.

In Schumpeterian innovation terms, crosscutting systems are involved in variety creation in the sector by search through interpersonal networks and sectoral information dissemination structures, especially online and in conferences. Resource creation is primarily linked to skills development, with government support in the states of Victoria and Queensland. Crosscutting systems have little impact on problem solving. Increasing returns from articulation with external systems is principally associated with knowledge reuse by means of skills development, allowing access to a pooled labour market of talented workers. This reveals a narrow AS, with little dynamism and few intermediary organisations.

Mineral exploration

Mineral exploration comprises the systematic acquisition, processing and analysis of geologically interpretable data to assess if, and how, a mine should be created, reconfigured or terminated. The economic value of exploration comes from its decisive role in creating or improving mining and mining opportunities. Following deregulation and institutional convergence among nations, the sector is increasingly global, in that multinational mining companies and small independent explorers may explore for minerals around the world. Most exploration is carried out in countries with proven valuable geology and high institutional stability, including predictable exploration and mining rights. Australia and Canada are leading nations, with around 20% of the world's exploration expenditure. The division of labour in the industry consists of independent (junior) explorers, mining companies, geological surveyors who provide access to large scale data from geological surveys and a number of service providers, such as chemical laboratories and companies undertaking aerial geophysical surveys. In the last 30 years, Australia has created a number of organisations across all these activities, including the national geological survey organisation, Geoscience Australia, universities and the national research agency, CSIRO. Australia has the world's highest number of finds by small independent explorers. Underpinning this are rich public geological data and a high quality of reporting driven by rigorous regulations.

Recently, the explorers' focus has been on brownfield exploration of mature sites rather than risky greenfield exploration. This stems from an increasingly risk averse attitude of the miners who fund the exploration project and on the growing difficulty of finding economically viable deposits. Australia has been thoroughly explored in the past, which makes finding major new ore bodies less likely than in less explored nations. Furthermore, Australia has a much thicker regolith, the deep and weathered 'dirt' between fresh air and fresh rock, which often covers ore bodies, than many other nations. Consequently, Australian inventions and innovations have focused on the exploration of previously searched areas and on how to penetrate and model difficult terrain. The sector has shifted from surficial (two-dimensional) observations to subsurface data acquisition and analysis at multiple scales, a greater understanding of complex (e.g. weathered) terrains and increased emphasis on modelling geological processes. This has provided the Australian exploration sector with world leading capabilities.

The Australian mineral exploration sector emerged during the 1960s and took off during the 1970s as a response to domestic demand and the inability of foreign firms to analyse the Australian ground. The Australian mineral exploration sector articulates with national and other systems through a wide array of formal and informal linkages with regulatory, educational, research and geoscientific systems and with government. Australian exploration firms are able to acquire and develop leading mineral exploration technologies because they have the necessary resources and are supported by the large mining companies to find and absorb knowledge from around the world. Strong industry bodies form and maintain linkages with the knowledge infrastructure, government and other bodies with the aim of supporting improvements in mineral exploration. There are good linkages with human resources through the Australian education system and global labour markets. An array of public research bodies, cooperative research centres, universities, the CSIRO and others have close and ongoing linkages with the mining industry, including exploration. The firms provide significant funding and other support, while considerable resources are devoted to public sector research. Beyond this, public bodies, especially GeoScience Australia, offer a vital underpinning to mineral exploration, providing high quality public access to data on Australia's geology. The federal and state governments are strong supporters of mining and exploration, especially the Queensland and Western Australian governments. The mining and related industries are very important in Australia's terms of trade and so have significant leverage with government. Technology is supplied globally from many different sources; for example, the adoption of remote imaging technologies from NASA and the US Trident submarine fleet.

In Schumpeterian innovation terms, crosscutting systems are involved in variety creation in the mineral exploration sector by broad search through the public research system, industry bodies, technology suppliers and geoscientific bodies. Resource creation is also broad and strong, with new technologies being developed through public research, technology suppliers and mining firms, with public geoscientific bodies providing sector-wide knowledge bases, and the education and training system being closely aligned in skills provision. These actors allow the sector to solve very complex problems in entirely new ways of exploration and understanding of geographical information. This has led to increasing returns through knowledge reuse from many sectors (defence, agriculture, aerospace) and government agencies, allowing much more complex problems to be solved, allowing new ore bodies to be found and existing ones to be extended.

The motor vehicles sector

The motor vehicles manufacturing sector is a global industry dominated by multinational corporations, vehicle producers (producers) and suppliers of technologies, systems and components. The Australian sector had four global carmakers at the time of this research,[5] an array of mostly foreign-owned suppliers and a number of supporting firms, such as design houses, consultants, logistics and testing providers. Because of government policy and protection until the 1980s, the sector has the entire supply chain within Australia, mostly located in the states of Victoria and South Australia. Australia imports most of its automotive technology, with local innovation in styling and the ability to produce short runs of components and vehicles. The carmakers produce, by global standards, moderate volumes of large family cars. These cars are unusual internationally, being similar to executive vehicles, but at middling prices. Since the 1980s, government has been reducing protection and providing support for upgrading, forcing firms to become globally competitive and consolidating the sector. The sector has improved its international competitiveness dramatically by following the lean production approach (Womack *et al.*, 1990), moving from a minor exporter to regions adjacent to Australia to a global exporter of vehicles, parts and services. Locally made vehicles constitute a decreasing share of total domestic sales, but have increased exports, especially to the Middle East, which shares climatic conditions and many customer preferences. Some component producers have become tier-one international players and many other component and service suppliers export small volume niche products. Cheaper Asian suppliers have taken over some of the basic components that are cheap to transport. Supplier expertise has allowed increased exports of services supporting flexible, short-run production. Despite this success, the Australian industry still looks to overseas head offices to allow new product development, major capital investment and exports. For example, both Ford and GM Holden have limited remit to export because the Australian-made vehicles directly compete with US-made vehicles. The small Australian operations tend to lose fights for export rights.

The Australian motor vehicles sector articulates with national and other systems through dedicated automotive schemes and the education system. The carmakers' industry body is focused on influencing policy regarding industry support and trade, while the suppliers' body additionally focuses on supplier learning. As a result of the power of the sector, the Australian government's strongest manufacturing industry engagement is with the automotive sector, with a multi-billion dollar programme of support for R&D and car production. The sector has a very close relationship with the VET system, but a variable relationship with universities. The VET system is important in creating a pooled labour market and providing the skills necessary for continuous improvement. The automobile industry has patchy linkages with the public research system, mostly focusing on process research. Nevertheless, some top suppliers have close engagement with the public research system for technology development. The Australian-based carmakers source technology from their parents and suppliers. Ford and GM Holden have design facilities in Australia, Mitsubishi has redesigned an existing car for Australia and Toyota makes only minor changes to its Australian vehicles. The leading global suppliers often drive technology development and adoption throughout the world; thus, rapidly transferring technological developments. Intermediaries are important in company learning for some of the smaller suppliers, providing contract design, testing and development services, but unimportant for the large companies. For the large companies, the important sources of knowledge, including technology, are their parents and global supply chains. This mode of learning allows the Australian industry to increase product variety rapidly, at low risk and cost, on established base models.

In Schumpeterian innovation terms, crosscutting systems are involved in variety creation in the motor vehicles sector by search through supply chains and parent companies, public research for process (and some product) innovation and intermediaries for smaller firms, driven and supported by government policy. Resource creation occurs across the sector through the education and training system, technology suppliers and collaborative research in specific areas. These external systems and actors assist problem solving chiefly in technology adoption and continual improvement. This leads to increasing returns through the reuse of knowledge from multinational parent carmakers and suppliers, allowing the sector rapidly to adopt and adapt proven technology and design and to produce low-volume vehicles and components for niche markets.

Oil and gas engineering

The oil and gas engineering sector comprises activities related to creating systems for extracting and processing hydrocarbons. This includes a number of upstream and downstream services, such as search for, and proving of, gas deposits, conceptual design, detailed engineering, project management of assessment, extraction and transport of hydrocarbons. Patterns of innovation in oil and gas engineering are shaped by the need for high efficiency in extractive operations and geological expertise to improve the economic (and technical) lifespan of existing resources. Australian oil and gas engineering firms tend to specialise in areas not currently served by the major international oil and gas engineering firms, using the idiosyncrasies of the major Australian deposit in the North West Shelf (NWS) off Western Australia, and deep Australian expertise in resource areas.

Gaining major contracts for oil and, especially, gas depends on the ability to provide certainty to the buyer in terms of reserves and the capability to produce for the contract length, usually a decade or more. This requires appropriate and substantial infrastructure, stability of institutions and government and access to suitable capabilities and technology. The scale of contracts is such that government is usually involved and suppliers need to understand the customer (often China). The Australian oil and gas engineering sector was, and is, primarily focused on off-shore deposits. Oil and gas engineering activity has moved from the relatively accessible oil deposits in Bass Strait, Victoria, to very remote and very large deep-water gas deposits in the NWS. The high cost of development of the NWS gas fields required joint ventures between major multinationals and Australian firms. Exploiting remote off-shore deep-water oil and gas reserves requires different skills, machinery and equipment, driving major managerial and technological shifts. Technologically, the trend has been toward modular design of plants, an increasing division of labour, including a growing role for outsourced specialised services in technology, project management, systems integration and maintenance. A combination of global and local expertise and technology providers was required to meet these requirements, where Australian firms tended to fill niches directly relevant to the distinctive NWS situation. Each project requires the assembly of a unique team, with generic skills in oil and gas extraction and transport and specific capabilities for the NWS. Australian service firms arose to fill specific niches and some have grown globally, based on their specialised technical skills and managerial expertise in deep sea situations.

The primary sources of knowledge, expertise, finance and technology are found in the international oil and gas industry rather than nationally. Articulation with national systems is through a wide array of formal and informal linkages with the regulatory, educational, research, geoscientific and government systems. The firms are large, sophisticated and well resourced, as is the public infrastructure. There are good human resources linkages through the Australian education system and global labour markets. An array of public research bodies, cooperative research centres, universities, the CSIRO and others have close and ongoing linkages with the sector. The firms provide significant funding and other support, while the public sector has considerable resources devoted to oil and gas research. The federal and state governments are strong supporters of oil and gas, especially the Western Australian government, through regulation, infrastructure and support for individual projects. Oil and gas exports are very important to Australia's trade performance and give the sector great sway with government.

In Schumpeterian innovation terms, crosscutting systems are involved in variety creation in the oil and gas engineering sector by broad search through the global oil and gas sector, public research system, industry bodies, technology suppliers and geoscientific bodies. Resource creation is strong, with solutions to specific problems being developed through public research, technology suppliers and oil and gas firms, with public geoscientific bodies providing an underpinning knowledge base. As this sector essentially sells problem solutions, the augmentation of its problem-solving abilities for complex and difficult issues involving the NWS, and similar deep sea situations, is vital. This has led to increasing returns through knowledge reuse and much more complex problems to be solved in the exploitation of deep sea oil and gas reserves in Australia.

Photovoltaics

PV cells convert light directly into electrical power. The PVs sector encompasses the manufacture and design of cells and modules of connected solar cells. Although advances still focus on increasing cell efficiency, increasing production efficiency has become important since the mid-1990s. This has coincided with an increase in the applications for PVs and their integration into on-grid systems. Three markets have emerged: (1) modules connected to the electric utility infrastructure (on-grid); (2) stand-alone customer specific remote area PV systems (RAPS) off-grid modules; (3) markets for equipment and components for industrial use. For on-grid applications, the high cost of PV electricity requires subsidies and 'green' legislation to encourage viable markets. Off-grid applications rely on PVs being cheaper than alternative ways of generating electricity and this market has historically been strong in the remote parts of Australia. Equipment and component production relies on large-scale industrial applications emerging, which essentially means on-grid applications. The sector's learning is moving from being based on laboratory processes to large-scale industrial production. As on-grid markets have grown, large German and Japanese producers have emerged as the dominant players, both with government support. Australia was one of the early leaders in developing commercially viable PVs and had early production and user markets. This lead has fallen away as Australian government policy reinforced traditional energy sources, making on-grid PVs not commercially viable. Essentially, there has been strong, if erratic, support for the production of renewable energy rather than for renewable technology. Australia is left with world-leading PV research and educational capabilities, but little PV production.

The current remnant Australian PV sector articulates with national and other systems in research and education, but has little industrial impact. Australian PV production is limited, without leading edge producers large and capable enough to absorb and use commercially the leading edge Australian PV research. Nor have there been firms with an interest in doing so. A combination of low levels of capability in the firms, weak entrepreneurial attitudes and the focus of government support was responsible. Many of the Australian PV production firms were university spin-offs, interested in intellectual property rights rather than the production of PVs. Other Australian firms focused on the RAPS market and did not produce for the on-grid mass market. Government policy supported commercialisation of public PV research and RAPS, but not production and export of PVs. This contrasts with strong Japanese and German government support for PV production and the uptake of the technology by large established multinational firms, mainly microprocessor firms in Japan (with similar underpinning product technology) and chemical firms in Germany (with a similar underpinning process). Since this early period, other nations, such as China, have aggressively targeted the PV production market. Thus, the industry is now dominated by global players producing PVs for a global market.

The early Australian lead in PV development, and ongoing public PV research, has left a public research infrastructure that works with foreign producers and provides global PV educational services.

In Schumpeterian innovation terms, crosscutting systems have little involvement in the PV production sector. There are strong capabilities in the public research and education system for search, resource creation and problem solving, but they are little used by the sector because of the lack of receptor firms capable of using and willing to use these crosscutting systems. Reinforcing this is the focus of government policy, supporting electricity production through PVs, but not production of PVs themselves. Increasing returns from knowledge reuse in PV production from articulation with crosscutting systems is thus limited.

The wine sector

The wine sector comprises vineyards growing grapes and wineries producing wine. The sector is located in south east Australia (New South Wales, Victoria, South Australia and Tasmania) and the southerly part of West Australia. During the last three decades, wine demand has changed globally from bulk wine toward premium wine (Rabobank International, 2003). The branded premium wine segment dominates the production and export of Australian wine. Traditionally, wine was produced from single vineyards using customary production technology and techniques and sold to local consumers or through specialist exporters. This required close interpersonal relationships, but not sophisticated marketing or logistics, while variable taste in each wine was expected and accepted. Branded wine is sold in large volume through chain retailers to mass market consumers who expect consistent taste, high-quality branding and competitive price, while the retailers demand excellent logistics and support. These very different business models require different approaches to winemaking and Australia has been at the forefront in branded wine development.

The Australian wine sector articulates with national and other systems in a coordinated and holistic way. Wine firms, government and industry bodies interact through formal co-funded structures and pervasive interpersonal networks. The large firms have the capabilities to absorb and utilise most advanced knowledge, while the smaller firms leverage the system that translates advanced wine knowledge into practice. This system to assist firm learning comprises industry bodies, the public research and education systems, state and federal governments and innovation intermediaries. Underpinning this system is a co-funding arrangement, whereby the industry voluntarily imposes a levy on itself and the government matches this funding. The funding provides the resources for the transmission of this knowledge through various education channels; publications, events and other mechanisms to all firms in the industry. The industry has voted to increase its levy on itself to further bolster the system. The education system's role in this is coordinated, but differently at various levels. Universities coordinate with researchers, companies and industry bodies. VET has a central industry-funded body to develop training packages and support transferable skills and qualifications nationwide. VET links directly into the extension system of state governments, federally funded programmes and the (industry-owned) Australian Wine Research Institute (AWRI). There are fluid labour markets, which facilitates knowledge transfer. The public research system has two main universities, the AWRI and the Cooperative Research

Centre (CRC) in viticulture. The nature of the funding and governance arrangements of the AWRI and CRC mean that the industry has a major role in guiding research. The AWRI offers a problem-solving service to all Australian winemakers, which even the largest firms use on occasion. The research and education systems draw on knowledge from the wider microbiology and agricultural systems. Government provides matching funding, trade facilitation and supports the Australian Brandy and Wine Corporation in regulatory oversight. Australian regulations are strict, but conducive to experimentation, unlike competing European regulations. The wine show system provides a venue for publicly showing and assessing the results of new knowledge and reinforcing norms of continual improvement. Wine firms learn about technology and methods from other sectors, such as the brewing, fruit juice and dairy sectors. Various intermediaries, especially technical consultants, provide expertise to the smaller players and act to disseminate knowledge throughout the industry.

In Schumpeterian innovation terms, crosscutting systems are involved in variety creation in the wine sector through both basic and applied public sector research and technology development by public actors and suppliers. Resource creation by crosscutting systems is focused on skills and technology development and uptake. Problem solving is assisted by heavy industrial influence in pubic research and educational, with governmental policy and programmes supporting universal access to this high-level problem solving, with technical intermediaries being important for small firms. This leads to increasing returns through knowledge reuse, whereby the sector improves the quality of wine and its productivity and is better able to target global mass branded wine markets, along with niches in Australia and internationally.

The dairy sector

The dairy sector comprises dairy farms, the production of milk-based goods and specialist suppliers to these firms. Although the dairy industry in all countries is highly regulated for health and trade protection reasons, Australia has become one of the most deregulated dairy producers. This has driven rationalisation in the industry and support for capability development and innovation. However, high levels of intervention by the EU and the US, to protect domestic producers, continue to distort global dairy markets. Although trade in dairy more than doubled from 1986 to 2001, only 7% of world milk production is traded. Australia accounts for about 2% of world milk production and over 11% of all internationally traded dairy products. In 2008–9, more than 40% of Australia's annual milk production was exported, mainly in the form of milk powder and cheese to Asia. But export products are increasingly specialised and customised to address customer and end-use applications.

The main dairy producers are large multinational firms, typically foreign owned, supplied by (often cooperative) dairy firms. In Australia, farmer-owned cooperatives currently account for about 50% of milk processing, concentrated in whole milk. Over time, the importance of more processed, branded and widely traded consumer dairy products and industrial ingredients has increased, especially in Asia. Small firms and the producer-owned processing cooperatives lack the scale and capital to undertake the innovation required to capture these new opportunities. International dairy producers have filled this niche, leading to increased concentration and foreign ownership. There is increasing collaboration between dairy manufacturers and food processors, to support innovation in packaging and distribution.

The dairy manufacturing segment is changing in line with consumer tastes, the search for higher value-added products, new applications of by-products and the growth of markets for ingredients to the processed food industry globally. Patterns of innovation have evolved from solving quality and distribution problems to cost reduction and product development as competition has increased. Innovation is based on increasingly detailed knowledge of the properties of milk ingredients, of dairy products and the needs of specific markets and customers. The need for scale economies because of deregulation and new markets has led to innovation in product development, production technology, packaging and global marketing. Thus, a much wider range of knowledge (process engineering, chemical engineering, microbiology, instrument engineering, software, food technology and marketing) is required at increasing levels of competence.

Supporting the industry are governments at the national and state levels, Dairy Australia (the industry body) and an array of research agencies. At the national government level, the policy focus has been on framework conditions. Statutory levies fund R&D and knowledge dissemination, and mechanisms of consultation, coordination and diffusion (extension) are either well established or have been created to develop the capabilities that the Australian dairy sector lacked. This has led to increasing division of labour within Australia in research, specialist services and knowledge dissemination groups with close links to users. The Victorian state government has been very active, supporting the establishment of organisations and mechanisms for research, extension and education and Victoria is now where two-thirds of the industry is located. The international division of labour in dairy is limited because of the low percentage traded and strict regulation.

In Schumpeterian innovation terms, crosscutting systems are involved in variety creation in the dairy sector through basic and applied public sector research and technology development by public actors and suppliers. Resource creation is focused on technology development and uptake, especially for increasing scale and new products. This array of actors allows more complex problem solving than individual firms can achieve, especially in developing new products for new market niches. This leads to increasing returns through knowledge reuse, where the sector is able to operate at a larger scale and serve new markets, either in Asia or for new dairy-based products.

Analysis of results

A number of researchers have approached innovation systems through the lens of the functions or activities they perform (Edquist, 2005; Bergek *et al*., 2008). Hekkert *et al*. (2007) have developed a functions approach, which we use in analysing our cases. They think that innovation systems approaches tend to be static, to default to structural analyses and to focus too much on the macro or meso level and hence aggregate performance, although we know that change at the micro level is critical in enabling innovation. Hekkert *et al*.'s approach has a strong focus on technological change and on the analysis of emerging TS. They propose seven functions of an innovation system, as summarised in Table 2. We use this approach because trying to perform cross-case analysis through common factors, such as

Table 2. Functions of an innovation system

Function	Components
Entrepreneurial activities	Business experiments through the formation of new ventures and the diversification of existing firms Creates opportunities for learning about technologies, markets, regulation, competition
Knowledge development/ Learning	Learning through searching (e.g. R&D), licensing, hiring, doing, etc.
Knowledge diffusion through networks	Information exchange to facilitate learning; exchanges that develop shared agendas
Guidance of the search	Patterns of demand Regulation and policy Trajectories and regimes Perceived sources of opportunity
Market formation	Policy created niches for early application Market segment that form early adoption
Resource mobilisation	Financial capital and human capital
Legitimacy and countering resistance to change	Advocacy

supply chains and the education system, produces a complicated and weak examination. The functions approach offers a more comprehensive analytical lens.

We performed cross-case analysis using the innovation systems functions approach and comparing across cases, as shown in Table 3. Each of the cells in Table 3 shows how the sector AS interacts with a specific innovation systems function. It is clear that more active articulation between the sector and external systems corresponds to better performance in the sector. In cross-case analysis between sectors, the success of the AS depends on the alignment of the AS to the factors underpinning commercial success for the firms in the sector. Sectors perform better where there are organisations and mechanisms assisting articulation that are tailored to the specific competitive context of the sector.

Firms with the requisite capabilities and resources, and a desire to exploit external systems to improve innovation performance, were necessary for an active and successful sector and AS. We have termed the type of firm that receives and uses external knowledge a 'receptor firm'. In the agricultural sectors, analogues to receptor firms were found in organisations that digested and transformed advanced knowledge into a form useable by farmers and wine and dairy producers. This involved a range of mechanisms co-funded by industry and government. In all cases where there were active AS, there were organisations and mechanisms assisting the transfer of external knowledge to firms in a useable form. Often these organisations and mechanisms involved skills development, but technology transfer and trade promotion were also common. Another finding was that the global industry is fundamental to the workings of each sector. Most nations are not the dominant source of knowledge and resources for the nation's industries. Thus, NIS are structured by the global division of labour and knowledge. This last finding may be influences our case selection as we considered only internationally traded sectors.

A striking feature of Table 3 is that government and the public sector are strongly involved in most industrial sectors and are central to successful sectors. One important finding is that education is important in all the sectors that have

Table 3. Analysis of articulation systems by innovation systems functions

Sector Function	Digital games	Mineral exploration	Motor vehicles	Oil and gas engineering	PV(production)	Wine	Dairy
Entrepreneurial activities	Skilled immigration supports entrepreneurship and firm creation Open economy allows access to global markets	Large mining firms and financiers provide support Government facilitates exploration	Government schemes force and support international competitiveness and experts in niche areas	Government facilitates oil and gas sector Firms use systems to augment entrepreneurship in core areas	Little support for PV production Support for commercialisation of public research PV education and training is exported	Government support for exports and industry strategy Public research and skills development systems facilitate innovations in product and process	Government support for exports and industry strategy Public research assists in new product development and increases in scale
Knowledge development/ Learning	Skilled immigration Education and training system emerged providing skills Access to global industry through web and conferences	Public research supports new techniques Public research, education and training systems support gaining competence in new activities Large mining firms support explorers and own R&D	Public research assists process and some product innovation Education and training assist incremental innovation Firms mainly use parent companies and suppliers for learning	Public research and geoscientific bodies assist knowledge base in deep sea Skilled immigration supports capabilities Education system assists competence Global industry provides base knowledge and capabilities	Little learning in PV production, but strong in PV technology	Firms actively engage through industry bodies with comprehensive public support for R&D, education and training for commercial use of knowledge Active technology suppliers	Firms actively engage through industry bodies with comprehensive public support for R&D, education and training, for commercial use of knowledge Active technology suppliers

(*Continued*)

Table 3. (*Continued*)

Sector Function	Digital games	Mineral exploration	Motor vehicles	Oil and gas engineering	PV(production)	Wine	Dairy
Knowledge diffusion through networks	Strong diffusion through publishers, suppliers and knowledge sharing events Strong interpersonal networks, but weak industry bodies	Strong through public research and industry bodies	Strong within large multinational firms, and supply chains. Weak sector wide interpersonal networks	Strong through public research and industry bodies	Strong knowledge networks in technology and research but poor in PV production	Very strong interpersonal networks, publications, extension and events Fluid labour markets	Strong through public research, industry bodies, and extension services
Guidance of the search	Clear signals from publishers and technology developers	Clear signals from mining companies Government and geotechnical bodies provide support	Niche demand leads firms to search for proven technologies and methods	Firms seek knowledge specific to NWS problems Public geotechnical bodies provide support	Government incentives for research commercialisation and RAPS Firms not seeking PV production knowledge	'Industry owned' research and industry bodies guide search into branded wine Regulations allow experimentation.	Research and industry bodies guide search toward scale and new products Regulations allow experimentation
Market formation	International publishers create market Little government involvement.	Government support of exploration for, and exploitation of, ore bodies	Government programmes support production volumes and sales of Australia-made cars	Very strong government support for sale of oil and gas leading to support for services	Little government support for PV production	Large-scale sales to major retail chains and creation of niche wines Government and industry active in creating exports	Deregulation led to national market Government supports growing exports to Asia New dairy products such as probiotics

(*Continued*)

Table 3. (*Continued*)

Sector Function	Digital games	Mineral exploration	Motor vehicles	Oil and gas engineering	PV(production)	Wine	Dairy
Resource mobilisation	Skills through education and training and immigration	Strong and expert financial markets Strong education and training system Fluid labour market	Finance and operational remit from parent companies. Strong education and (especially) training system	Strong and expert financial markets Strong education and training system Strong and fluid labour markets, often international	Weak support for PV production	Active financial sources for winemaking. Strong and pervasive education and training system with fluid labour markets	Strong and expert financial markets (large firms) and government programmes for small dairies Strong education and training system
Legitimacy and countering resistance to change	Strong and growing social acceptance Government advocacy in Victoria and Queensland	Effective advocacy by industry bodies and strong government support at multiple levels	Effective advocacy of various levels of government Government policy driving sectoral change	Effective advocacy by industry bodies and strong government support at various levels	Strong advocacy of research commercialisation and RAPS, weak for PV production	Strong industry bodies and government support at all levels	Strong industry bodies and government support at all levels

become successful. However, the form of this relationship varies greatly by sector. For example, mineral exploration requires university-level skills in geotechnical areas, while motor vehicles require VET of workers to support continuous improvement. Innovation in all the resources sectors relies heavily on Australia's strong research, education and training systems. The motor vehicles sector has patchy links with public research and is strongly driven by specific policy and programmes exposing it to international competition and supporting production and R&D. Public research created leading edge research in PVs, and government supported off-grid applications, but focused incentives on technology and electricity production rather than PV production. Digital games is the (partial) exception to this pattern, with the only important governmental support coming from an immigration policy supporting skilled migration and an education and training system that provided good quality, if not initially specialised, workers. In world-leading sectors, government has a role in assisting articulation between the sector and crosscutting systems. Beyond these overarching features, there is no clear pattern in the characteristics of articulation between sectors and the national level. In some (but not all) successful sectors, public research is extremely important. The role of innovation intermediaries appears to be important for smaller firms and some sectors are themselves intermediaries for production sectors. Government tends to be active in various ways in all of our sectors, but in different ways in different sectors.

Our cross-case analysis shows that Schumpeterian dynamics within a sector can be strongly affected by articulation with external crosscutting systems. The results also show that effective articulation is not always evident. Where external systems are closely aligned to the sector's commercial dynamics, firms are able to search more broadly, to take advantage of more complex resources and solve more difficult problems, leading to increasing returns and competitive success. The common external systems are the public research and skills development systems, suppliers and technical intermediaries (for small firms); these are partly linked directly to the sectors, but in many ways their role goes beyond any individual sector. However, our results also show the need for mechanisms that disseminate knowledge in a useable form. This knowledge dissemination role is commonly played by industry bodies, education and training organisations, and leading (receptor) firms. This is in line with Edquist's (2005) argument that competence (human capital) building is vital to innovation systems. In systems where competitive dynamics are aimed at global leadership, a wide range of external systems is used across the range of activities. In other sectors, such as motor vehicles, where the firms focused on niche activities and technological leadership is of less importance, narrow AS occur, focused on production and skills. Where no active receptor firms are involved, alignment between external systems and the sector does not occur and Schumpeterian innovation is less dynamic, at least within our sample. Overall, the effect of external systems on increasing returns within sectors in our research follows from the strength of articulation between a sector and external crosscutting systems. Where articulation is strong and closely linked to competitive dynamics, external systems become part of the sector's innovation dynamics.

Discussion

Our research clearly shows that sectors and crosscutting systems link together. The better and more active the alignment between the crosscutting systems and the competitive drivers in a sector, the better the performance in terms of international competitiveness. The most common crosscutting systems we observed in action were those of education and training, public research, supply chains and innovation intermediaries. These interactions occurred both within the nation and also internationally.

Our results indicate that articulation consists of sets of actors and mechanisms that structure and shape the interaction among sectors and wider systems. More active sets are more systemic, incorporating industry into wider systems on the one hand and wider systems (e.g. public research) into sectors on the other hand. In these instances, we may speak of ‘articulation systems’. However, a sector does not need a wide-ranging set of strong crosscutting mechanisms to be successful, as illustrated by the motor vehicles sector. Some sectors have such limited articulation to external systems that interactions cannot be considered systemic.

Australia’s pattern in the observed articulation between sectors and other systems reflects strengths in Australia’s knowledge infrastructure and industrial and trade structure. Certain sectors share a common infrastructure for their AS, creating a platform for innovation (e.g. Cooke *et al*., 2010). The two agricultural sectors, wine and dairy, share a common national infrastructure of institutions, governance structures, research and education systems and relationships with government aimed at supporting agricultural sectors to compete in international markets. Similarly, geological industries, such as mineral exploration and oil and gas engineering, take advantage of the strong research and education base, public geoscience organisations and supportive governments. These geological sectors have large firms that employ people to absorb and use advanced knowledge and technology. These articulation structures allow the absorption and use of knowledge and capabilities from outside each sector and around the world, while supporting indigenous innovation and development. Crosscutting creates a cumulative pattern of growing strength within the trajectory of the sector’s innovation. This leads to improved performance, which, in turn, provides greater resources for the crosscutting systems (educational and research especially), which then are able to assist the sector to advance. Because the various knowledge bases cut across sectors, the crosscutting systems can attain a scale not possible within any individual sector. The knowledge bases are useful because they are not just ‘imported’ into the sectors, but are adopted to fit the specific problems of firms in the sector. Thus, Australia’s resources specialisation in trade can, partially, be explained by established and strong AS that support continual advance. Conversely, our other three cases are all exceptional to some extent.

The non-resource based industries each face different situations. The motor vehicles sector has large, technologically sophisticated firms that depend on rapid adoption and adaptation of internationally proven technology. They source proven new knowledge internationally and interact in Australia only in specific areas. Consequently, the AS in the automotive sector is much narrower than that in the resource-based sectors. The games sector has had little support until recently, but has some linkages with a specialised education system and immigration to recruit experienced staff. The other new sector, PVs, lost its early world-leading position because government policy supported public research commercialisation and not PV production. Nowadays, the PV research groups export education and their expertise. These sectors indicate that AS tend to interact in specific areas related to their competitive needs and that the underlying beliefs of government and industry toward innovation are important.

The empirical findings indicate that articulation becomes successful when the activities that cut across innovation domains augment the commercial abilities of firms in that they can reuse and recombine resources and knowledge created outside a specific system (regardless of the delineation of the system). This interaction and integration of knowledge and resources involves creating common understanding, because firms tend to 'speak a different language' from researchers, educators and others who provide potentially valuable inputs. Sometimes this occurs through specific bodies, sometimes through institutional mechanisms or interpersonal networks. Once understanding occurs, crosscutting systems can align their outputs and timing of work to the innovation needs of the specific sector. Full articulation means firms align their innovation activities to the crosscutting systems. The use of power, in various forms, was important in aligning systems, sometimes through sectors lobbying government to create organisations and/or programmes to assist the sector in using crosscutting systems.

The observed effectiveness of articulation among innovation systems can be understood from a capability perspective: a minimum level of capability in absorbing and using external resources is required by the firms and other actors involved. This requires that the players are willing and able to adjust their activities to one another. Generally this involves well-resourced, technologically sophisticated firms with advanced capabilities and a strategic orientation toward innovation, those we term 'receptor' firms. However, in the agricultural sectors, where small farmers and wine and dairy producers may not have suitable capabilities, public systems to digest and transform external resources into a usable form are vital to sector performance. These systems act as analogues of receptor firms and involve special research, educational and strategic agencies, often with co-funding from industry and government.

There are many actors and mechanisms that act to assist alignment and articulation between a sector and other systems. Active and capable receptor firms and industry bodies are able to leverage schemes to create effective articulation, even in the absence of supportive government. Where they can make a profit, private sector suppliers and intermediaries perform this articulation function. Governments can do many things to create effective articulation, but our research suggests that articulation should be industry-driven to reflect actual rather than assumed innovation. Because governments tend to have a certain orientation toward interaction with industry and nations have an established industrial structure and business culture, we can expect successful articulation to have particular national patterns, supporting strong areas. Logically, this could include being good at establishing new sectors.

We infer from the Australian example that the pattern of a nation's economic development is significantly derived from the pattern of AS in the nation's industrial structure and business culture, its knowledge infrastructure and the philosophy of government toward industry and innovation. Teixeira and Fortuna (2010) give some support to this contention in claiming that the limited linkages enabling absorption and use of external research knowledge characteristic of Portugal have shaped that nation's economic development.

Systemic articulation assists Schumpeterian innovation by allowing firms to search broadly and comprehensively, create and exploit complex resource bundles and to gain increasing returns through solving complex problems and increasing the scale of resources. This occurs because crosscutting provides firms with access to external resources by linking them to knowledge and resource generating systems and making the outputs of these systems specific to their needs. Articulation also enables the uptake of complex resource bundles by providing the problem-solving capabilities firms when they are needed. Articulation systems accelerate and enhance learning throughout a sector. In other words, they amplify absorptive capacity (Cohen and Levinthal, 1990), the ability of firms to find, absorb and use external knowledge. Conversely, linkages to firms allow crosscutting systems to gain access to resources. Once systems are aligned with one another, all gain – as long as the alignment can be supported.

Linking the various innovation systems concepts

Although there is no defined relationship between innovation domains, there is conceptual overlap. An innovation system is located in some physical space, whether sub-national, national or international. Institutional architectures, physical and knowledge infrastructures, industry structures and populations confine activity within these locations. Economic innovation occurs in settings where firms serve markets that act as the focus of activity; competitive, innovative and institutional. Sectors have certain firms producing, customers buying, intermediaries, suppliers and other actors, with a particular geographical configuration and using particular technologies. Finally, any innovation system must have certain core technologies to enable innovation to take place. These technologies are produced by groups of actors with certain relationships, geographical configurations and relations to various sectors. Each domain of innovation systems thus overlaps the others.

In line with this, our research suggests that the various domains of innovation characterised by the NIS, RIS, SIS and TS frameworks can interact, and at times act jointly. All of our sectors articulated with external systems to augment the innovative ability of the sector. This produced an overlap where the NIS, RIS, TS and SIS domains worked together. Where an AS exists, it coordinates activity in areas of overlap between the innovation in the sector and in crosscutting systems. However, it is likely that only specific areas of each system become involved in articulation with other systems.[6] This denotes a number of important features of AS. An AS is specific to the situation and closely correlated in structure and dynamics to the competitive drivers and entrepreneurial mindset of the firms in the sector. This is not to say that firms drive all activity: firms are often reliant on crosscutting systems for resources and so their activities are shaped by these crosscutting systems. We found that firms, sectors and crosscutting systems shaped one other in the sectors we studied and so can presume that this is a general feature of the entire innovation picture. This conjecture suggests that the innovation performance of nations, regions, sectors and firms is shaped by how the systems in various innovation domains interrelate. Often both researchers and policy makers focus on specific systems, assuming interaction with other systems is either outside the scope of attention or is a natural by-product of the existence of self-interested actors. If AS augment the performance of firms and sectors, then both researchers and policy makers need to pay attention to this interaction with other systems. We suggest articulation between systems may provide policy makers with great leverage while avoiding the picking winners approach. Once in place, articulation arrangements are reinforcing as each actor gains from the interaction.

Conclusion and implications

The starting point of this paper is that, despite knowing that different innovations systems interact, this interaction has not been systematically studied. Yet it is in the interaction of national, regional, technological and sectoral domains that the dynamics and overall performance of innovation occurs (Nelson, 1994; Freeman, 2002, Coombs *et al*., 2003; Edquist, 2005).To analyse the nature of linkages among sectoral, national and technological innovation systems, we studied the empirical results from seven case studies of Australian sectors.

Drawing on Schumpeterian and evolutionary legacy, the paper identified two main principles to explain this type of interaction and integration. These consist of new combinations and recombinations of existing knowledge and resources outside sectors. The reuse of the old makes much variety creation economically viable. To explain this, we refer to Moran and Ghoshal (1999), who showed that, for economic progress to take place, actors must combine knowledge and resources to recognise and exploit opportunities. However, if innovations are to be launched, someone must have a need, someone must recognise the opportunity to fulfil this need and someone must have the motivation and the ability to carry these things through. There is little likelihood that a single actor will recognise an opportunity and have the motivation and the ability to carry it through. However, mechanisms allowing specialised actors to be involved in knowledge recombination increase the likelihood of innovating greatly. While Moran and Ghoshal explained how firms as integrators and combiners of knowledge require market exchanges to be successful, our paper makes the more general point that there can be other types of transfers and exchanges enabling variety creation. From the present perspective, this means that firms can economise by drawing on the work of actors in other systems. Indeed, it seems that most entrepreneurial opportunities are based on the work of others (Buenstorf, 2007). This is simply because human cognition, energy, time and labour are limited. This should not imply that knowledge recombination and subsequent innovation will be linear or path-dependent. Knowledge recombination can be of any type, even if it commonly follows existing paths.

We use Schumpeterian innovation theory as an analytical lens for innovation systems research. Currently, innovation systems research offers little theoretical basis to understand why systems work as they do. This paper argues that a more explicit Schumpeterian or evolutionary focus would greatly assist. By articulating with external systems, firms can increase their variety creation through recombining knowledge from diverse sources they would not otherwise be able to access. Useful knowledge recombination can then be expanded by leveraging external systems to access resources normally beyond the firm. Understanding variety creation through new combinations and increasing returns through the reuse of knowledge deepens our understanding of systemic innovation. Knowledge recombination lies at the heart of innovation (Schumpeter, 1934) and, by articulating into external systems, firms can recombine knowledge that is beyond their own learning ability (variety creation). Once useful new knowledge is found through recombination from external sources, firms can increase the economic impact of this knowledge by leveraging these external systems.

This Schumpeterian lens leads inexorably not only to firms using external systems to assist in their innovations (and so to systemic innovation), but also to the systems involved, co-evolving and changing together in a dance of creative destruction. We suggest that this perspective provides a theoretical foundation for understanding how innovation systems interact. Perhaps more importantly, the notion of Schumpeterian dynamics underpinning the interaction between various systems may explain the dynamics driving systemic innovation in general. If so, we have at least addressed the problem of the innovation systems approach being under-theorised and conceptually diffuse (Edquist, 2005).

This paper discovered systems that articulate between the various levels and domains of innovation, where more active and systemic AS are associated with better performing sectors. Although we did not find a magic formula for successful articulations systems, we did find that they need to be attuned to the commercial drivers of each sector. This indicates that government needs to provide generic crosscutting systems, such as education and training and research, and also that government can support industry's access to these systems. The various innovation systems frameworks provide the building blocks for such policy analysis and AS provide the cement to bond the various aspects together.

That we found better AS are associated with better sectoral performance provides impetus to policy recommendations to improve articulation between sectors and other systems. We argue that this is important as the articulation level is a middle ground for policy, falling into neither the picking winners camp, nor the market camp (Fuchs, 2010). A picking winners approach runs a number of risks. First, the process may be flawed, leading to waste of government resources. Second, the picked firm or sector may become reliant on government support and so never become a net positive contributor to the nation. Third, given limited resources, picking winners precludes supporting other technologies, regions or sectors.

On the other hand, a pure market approach also has limitations. First, emerging sectors are unlikely to have the resources to develop the infrastructure required to sustain growth. Second, large established firms and sectors are likely to use their strong position to block the emergence of new competing activities (as was the case in the manufacture of PV cells in Australia). Third, firms become embedded in their established architectures of operation and search patterns and can find difficulty mobilising the resources required for significant change.

Before there can be beneficial articulation, there must be good quality crosscutting systems, such as education and training and research systems. Once such crosscutting systems are in place, other systems can be developed. Firms use these external systems to gain access to new combinations and to enhance increasing returns. Thus, these systems need to contain 'redundant' variety. That is, the crosscutting systems must contain knowledge and resources that firms have not yet needed or cannot justify developing for themselves. We propose that a key factor to successful policy is active industry support for articulation. Therefore, policies that encourage industry involvement in strategy and resourcing are required, especially co-funding arrangements to ensure industry has a vital interest in the success of these arrangements. Our research found that receptor firms (or analogues) are essential for effective AS, extending innovation policy into the culture and resource base of firms and sectors. The strategies of the core firms in each sector co-evolved with AS and strategies aiming at world leading performance and innovation tended to be associated with broader and more active AS. Non-public actors and systems, such as supply chains and technical consultants, are also vital.

Our work has limitations, in the AS concept itself and in case selection. The AS concept is a bridging one between domains of innovation systems and so cannot stand alone in the way that NIS, RIS, SIS and TS do. An AS only has meaning given a sector with a particular geographical and technological configuration. Thus, although AS link the various domains of innovation systems, one cannot expect actors or configurations to be important in the way we might expect in other frameworks. All of the sectors we selected are trade-focused and our research did not address untraded parts of the economy. Our cases are limited in the coverage of services, which now constitute the largest part of a developed economy. Looking at only Australia will bias the general understanding of AS.

There are several implications for future research from this paper, especially understanding the differences between AS in other countries, the characteristics of good AS, how different types of sector, the technological regimes and the complexity of their knowledge base affect the setup of AS and differences between developed and developing countries. Research on other nations is required to discover the differences among countries in the pattern of AS. Study of a broader range of AS would reveal the characteristics of good AS. If we can determine what characterises better articulation between sectors and national systems, then better policy can be formulated.

Notes

1. We define innovation as 'the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations' (OECD, 2005).
2. National systems of innovation (NSI) has identical meaning.
3. We use the term 'articulation system' throughout this paper although our results indicate that in some sectors articulation with crosscutting systems is not systemic.
4. There is a natural 'double hermeneutic' (Giddens, 1987) involved in analysing innovation systems, whereby the theories of innovators of the systems in which they are embedded affect these same systems. Analysis of innovation systems, including our own analysis, suffers from this problem.
5. General Motors Holden (US), Ford (US), Toyota (Japan) and (until 2008) Mitsubishi (Japan).
6. For example, the Australian motor vehicles innovation system has patchy links with the Australian research system, while certain Australian researchers have strong links with international motor vehicles producers, but weak links within Australia.

References

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. and Rickne, A. (2008) "Analyzing the functional ynamics of technological innovation systems: a scheme of analysis", *Research Policy,* 37, pp.407–29.

Buenstorf, G. (2007) "Creation and pursuit of entrepreneurial opportunities: an evolutionary economics perspective", *Small Business Economics,* 28, pp.323–37.

Carlsson, B. and Jacobsson, S. (1994) "Technological systems and economic policy: the diffusion of factory automation in Sweden", *Research Policy,* 23, pp.235–48.

Carlsson, B. and Stankiewicz, R. (1991) "On the nature, function and ccomposition of technological systems", *Journal of Evolutionary Economics,* 1, pp.93–118.

Castellacci, F. (2009) "The interactions between national systems and sectoral patterns of innovation: a cross-country analysis of Pavitt's taxonomy", *Journal of Evolutionary Economics,* 19, pp.321–47.

Cohen, W. and Levinthal, D. (1990) "Absorptive capacity: a new perspective on learning and innovation", *Administrative Science Quarterly,* 35, pp.128–52.
Cooke, P. (2000) "Regional innovation systems, clusters, and the knowledge economy", *Industrial and Corporate Change,* 10, pp.945–74.
Cooke, P. and de Laurentis, C. (2010) "Trends and drivers in the knowledge economy" in Cooke, P., De Laurentis, C., MacNeill, S. and Collinge, C. (eds) *Platforms of Innovation: Dynamics of New Industrial Knowledge Flows*, Edward Elgar, Cheltenham.
Cooke, P., de Laurentis, C., MacNeill, S. and Collinge, C. (eds) (2010) *Platforms of Innovation: Dynamics of New Industrial Knowledge Flows*, Edward Elgar, Cheltenham.
Coombs, R., Harvey, M. and Tether, B. (2003) "Analysing distributed processes of provision and innovation", *Industrial and Corporate Change,* 12, pp.1125–55.
Dalziel, M. (2007) "A systems-based approach to industry classification", *Research Policy,* 36, pp.1559–74.
Dodgson, M., Hughes, A., Foster, J. and Metcalfe, S. (2011) "Systems thinking, market failure, and the development of innovation policy: the case of Australia", *Research Policy,* 40, pp.1145–56.
Doloreux, D. and Parto, S. (2005) "Regional innovation systems: current discourse and unresolved issues", *Technology in Society,* 27, pp.133–53.
Edquist, C. (2005) 'Systems of innovation: perspectives and challenges' in J. Fagerberg, Mowery, D. and Nelson, R.(eds) *Oxford Handbook of Innovation*, Oxford University Press, Oxford, pp.181–208.
Eisenhardt, K. (1989) "Building theories from case study research", *Academy of Management Review,* 14, pp.490–5.
Emery, F. (ed.) (1969) *Systems Thinking*, Harmondsworth, Penguin.
Fagerberg, J. (2005) 'Innovation: a guide to the literature' in Fagerberg, J., Mowery, D. and Nelson, R. (eds) *Oxford Handbook of Innovation*, Oxford University Press, Oxford, pp. 1–26.
Freeman, C. (1987) *Technology Policy and Economic Performance. Lessons from Japan*, Pinter, London.
Freeman, C. (1991) "Networks of innovators: a synthesis of research issues", *Research Policy,* 20, pp.499–514.
Freeman, C. (2002) "Continental, national and sub-national innovation systems – complementarity and economic growth", *Research Policy,* 31, pp.191–211.
Freeman, C. (2004) "Technological infrastructure and international competitiveness", *Industrial and Corporate Change,* 13, pp.541–69.
Fuchs, E. (2010) "Rethinking the role of the state in technology development: DARPA and the case for embedded network governance", *Research Policy,* 39, pp.1133–47.
Giddens, A. (1987) *Social Theory and Modern Sociology*, Polity Press, Cambridge.
Hekkert, M., Suurs, R., Negro, S., Kuhlmann, S. and Smits, R. (2007) "Functions of innovation systems: a new approach for analysing technological change", *Technological Forecasting and Social Change,* 74, pp.413–32.
Jacobides, M. (2008) "Playing football in a soccer field: value chain structures, institutional modularity and foreign expansion", *Managerial and Decision Economics,* 29, 2–3, pp.257–76.
Klevorick, A., Levin, R., Nelson, R. and Winter, S. (1995) "On the sources and significance of interindustry differences in technological opportunities", *Research Policy,* 24, pp.185–205.
Langlois, R. (1999) 'Scale, scope and the reuse of knowledge' in Dow, S. and Earl, P. (eds) *Economic Organisation and Economic Knowledge: Essays in Honor of Brian Loasby*, Edward Elgar, Cheltenham, pp. 239–54.
Lundvall, B.-A. (ed.) (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, Pinter Publishers, London.
Lundvall, B.-A. (2004) "Introduction to *Technological Infrastructure and International Competitiveness* by Christopher Freeman", *Industrial and Corporate Change,* 13, 3, pp.531–9.
McGahan, A. (2004) *How Industries Evolve: Principles for Achieving and Sustaining Superior Performance*, Harvard Business School, Boston, MA.
Malerba, F. (2002) "Sectoral systems of innovation and production", *Research Policy,* 31, pp.247–64.
Malerba, F. (2005a) "Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors", *Economics of Innovation and New Technology,* 14, pp.63–82.

Malerba, F. (2005b) 'Sectoral systems: how and why innovation differs across sectors' in Fagerberg, J., Mowery, D. and Nelson, R. (eds) *Oxford Handbook of Innovation*, Oxford University Press, Oxford, pp. 380–406.

Malerba, F. (2006) "Innovation and the evolution of industries", *Journal of Evolutionary Economics,* 16, pp.3–23.

Miles, M. and Huberman, A. (1994) *Qualitative Data Analysis: An Expanded Sourcebook*, Sage, Thousand Oaks, CA.

Moran, P. and Ghoshal, S. (1999) "Markets, firms, and the process of economic development", *Academy of Management Review,* 24, pp.390–412.

Murmann, J. and Homburg, E. (2001) "Comparing evolutionary dynamics across different national settings: the case of the synthetic dye industry, 1857–1914", *Journal of Evolutionary Economics,* 11, pp.177–205.

Nelson, R. (1993) *National Innovation Systems: A Comparative Analysis*, Oxford University Press, Oxford.

Nelson, R. (1994) "The co-evolution of technology, industrial tructure, and supporting institutions", *Industrial and Corporate Change,* 3, pp.47–63.

Nightingale, P. (2000) "Economies of scale in experimentation: knowledge and technology in pharmaceutical R&D", *Industrial and Corporate Change,* 9, pp.315–59.

Niosi, J. (2002) "National systems of innovations are 'x-efficient' (and x-effective)', *Why some are slow learners', Research Policy,* 31, pp.291–302.

OECD (1999) *Managing National Innovation Systems*, Technical Report 50649, OECD, Paris.

OECD (2005) *The Measurement of Scientific and Technological Activities: Oslo Manual Guidelines for Collecting and Interpreting Innovation Data*, OECD, Paris.

Perry, C. (2001) "Case research in Marketing", *Marketing Review,* 1, pp.303–23.

Rabobank International (2003) *Wine Is Business – Shifting Demand and Distribution: Major Drivers Reshaping the Wine Industry*, Food & Agribusiness Research, Utrecht.

Rosenberg, N. (1982) *Inside the Black Box: Technology and Economics*, Cambridge University Press, Cambridge.

Schumpeter, J. (1934) *The Theory of Economic Development*, Harvard University Press, Cambridge MA, Cambridge.

Smith, K. (1997) 'Economic Infrastructures and Innovation Systems' in Edquist, C. (ed.) *Systems of Innovation: Technologies, Institutions and Organizations*, Pinter, London, pp. 86–106.

Teixeira, A. and Fortuna, N. (2010) "Human capital, R&D, trade, and long-run productivity. Testing the technological absorption hypothesis for the Portuguese economy, 1960–2001", *Research Policy,* 39, pp.335–50.

Wixted, B. (2009) *Innovation System Frontiers*, Springer-Verlag, Berlin.

Womack, J., Jones, D. and Roos, D. (1990) *The Machine That Changed the World*, Macmillian, New York.

Yin, R. (2003) *Case Study Research: Design and Methods*, Sage Publications, Thousand Oaks, CA.