A SYMBIOTIC MODEL OF INNOVATION MANAGEMENT FOR COLLABORATIVE RESEARCH

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The proliferation of research collaborations amongst industry, university and public sector research organisations encourages and increases national innovative capacity. Innovation activities in research collaborations are governed by four major determinants that are critical for the transformation of new ideas generated within research organisations into commercial products, processes or user services. These determinants include the status of knowledge, organisational management factors, linkage mechanisms and market and user opportunities. Interaction between these determinants is important for an analysis of innovation clusters formed across different national research programs. This paper discusses the relationships between major determinants of innovation using a 'symbiotic' model which is similar to Michael Porter's 'diamond' model for competitive advantages of national industries. The model is applied to emerging 'innovation clusters' supported by the Cooperative Research Centres Program in Australia and is field tested at centre level for its explanatory viability. The discussion provides insights into improved management methods for innovation in collaborative research arrangements.

Keywords: Collaborative research, Cooperative Research Centres, innovation clusters, innovation management, symbiotic model.

INTRODUCTION

In his book, *The Competitive Advantage of Nations*,[1] Michael Porter uses a 'diamond' model to describe the necessary determinants of national industrial competitiveness. Porter identifies factor conditions (basic and specialised infrastructure, e.g., land, labour, capital, investment, institutions), home demand conditions (i.e., local market conditions and demand quality), the impact of related and supporting industries (vertically and horizontally linked industries promote the diffusion of innovation), and strategy, structure and rivalry as crucial reference points of his 'diamond'. Porter's model explains the determinants of national competitiveness in terms of mutually reinforcing factors to maintain competitiveness. In a previous work, Porter equated a firm's collection of activities with a collection of technologies.[2] The ability to maintain the competitive advantage of this 'collection of technologies' constitutes a core business strategy for many firms. Gaining technological advantage requires continuous involvement in innovative activities. All industries, whether traditional or modern, low or high research and development (R&D) intensive, require continuous monitoring of the status of their 'collection of technologies'. The competitive advantage of a firm or group of firms can be maintained by their positioning in technological competence. Competence can only be achieved when a continuing search for technological excellence and competitiveness is undertaken.

Technological innovations are widely accepted to be directly responsible for the maintenance of competitive advantage in firms. Innovative capacity is enhanced if various determinants contributing to innovation activities are constantly re-evaluated and strengthened. Innovation is generally described as an interactive process[3] involving knowledge generation, diffusion, and translation into market and technology related functions. This process is dynamic and responsive to the immediate environment in which firms operate. The significance of knowledge, management, linkages and market factors vary according to the operational activities of firms and the objectives of research organisations. These factors or innovation determinants can be arranged in a model similar to Porter's 'diamond' model. A major advantage of such a model as an explanatory tool for innovation management lies in its ability to encompass the disparate elements of collaborative research.

Research collaboration functions within an essentially hybrid structural framework based on university, industry and public research partnerships. Australia's Cooperative Research Centres (CRC) Program provides a unique opportunity to identify and monitor the characteristics and interactions of determinants of the innovation system. The CRC program has established 52 collaborative research centres[4] in six socio-economic areas with each centre receiving an average of 2 million dollars per annum over the next five to seven years. On one level, these centres contribute to critical technologies emerging in specific economic areas. On a broader level, they can also be seen as contributing to the formation of 'innovation clusters' or mutually supporting and sustaining systems of innovation in selected technology areas. Technological innovations attempted in centres vary according to the maturity of collaborations, knowledge production and technology utilisation activities. Some CRCs operate at the front end of knowledge production while others focus their activities in down-stream engineering development and design. This paper identifies and discusses the critical determinants involved in the management of innovations in collaborative research. The interactive nature of these determinants is discussed using an innovation model based on the symbiotic relationship between factors of technological advantage. The validity of this model is tested against data gathered from CRC applications and case studies of selected CRCs.

FORMATION OF INNOVATION CLUSTERS FOR INDUSTRIAL COMPETITIVENESS

The reasons for establishing a high profile collaborative research scheme such as the CRC Program are quite explicit. In the past, Australia's research system has concentrated on knowledge production activities without much success in the application and commercialisation of research. The national research system and innovation systems in general have undergone radical changes as breakthrough innovations require greater cross- and multidisciplinary inputs. Australia's small manufacturing base and existing institutional research arrangements are considered to be impediments to the development of a range of competencies required for innovation. As a result of a new focus on promoting and supporting complementary competencies, new organisational arrangements are emerging. They include research collaborations between industry and university, inter-firm joint ventures in research and innovation, university centres of excellence and collaborative research centres. These new organisational mechanisms raise numerous policy concerns regarding how best to share research resources, exchange of personnel and know-how, and how to apportion intellectual property rights.

Collaboration in technology innovation requires fundamental changes to the ways in which research and innovation are viewed by traditional institutions. Combinations of partners separated by functions and objectives do not necessarily share common views of the innovation process. CRCs provide an organisational model for the generation of knowledge in strategic areas and are a mechanism for linking research with specific industry development. In research collaborations, knowledge, however advanced, is produced according to market and user needs. CRC clusters, whether intentionally or not, are developing in such a way that they feed into existing research, innovation and market networks. Recently, Dr John Stocker, Chief Executive of the CSIRO, commented,

> The picture is not bad at all for Australia. If you look around you can see the preconditions for Porter's clusters in all kinds of areas. And there are more than a few diamonds glistening among the dross.[5]

Clusters of innovations are considered as an important source of dynamic growth.[6] Therefore generating the conditions for 'breeding' each innovation cluster can be regarded as the most effective policy goal of CRCs. This is particularly useful in the case of Australia where innovation policy has focused on fostering individual cases of innovation rather than breeding innovation clusters. This has meant that no strong institutional policies are in place for strategic intervention in organisational innovation processes.

The 52 centres currently established are multi-functional. Tasks included in their extensive briefs cover industrial research and development, education and training, technology transfer processes, marketing and commercial activities. Characteristics endemic to Australia's national research effort such as large public sector research establishments, small manufacturing base and previous generic research funding schemes have all contributed to centres forming 'clusters' in selected technology areas. Centres are creating critical threshold levels of linkages necessary for the creation of a beneficial technology environment for future involvement by small and medium sized research and industry groups. These technology clusters also provide opportunities for strategic alliances between two or more centres if problems of intellectual property can be overcome. While these clusters formed through the aggregation of centres are certainly not the industry clusters described by Porter, or the inter-company innovation networks outlined by Wissema and Euser,[7] they are nevertheless clusters of complementary research and innovative efforts which have the potential to coalesce into areas of economic significance. Even if the dynamism provided by strong competitive rivalries is absent, CRCs can provide the impetus for their own growth by engineering linkage mechanisms that result in inter-CRC and intra-industry interactions. Perhaps more importantly, cooperative research centres represent an opportunity for different sectors to learn how to cooperate and interact so that,

> Within clusters there is a dynamic process of interactive learning leading to the accumulation of such vital intangible capital as knowledge, skill, reputation and relationships. Goods and services production and knowledge production develop in parallel, each shaping the development of the other.[8]

Australia's national technological innovation advantage depends upon the continued recognition by government of the importance of nurturing these clusters by providing support and encouragement to build upon successful areas of research. Cluster density can be analysed using the determinants identified in the innovation model. An innovation cluster can develop as a mutually reinforcing system with stronger determinants reinforcing and balancing weaker determinants.

A SYMBIOTIC MODEL OF INNOVATION MANAGEMENT FOR COLLABORATIVE WORK

Innovative activities have been described utilising different models. Most refer to the difficulties of constructing a satisfactory model due to the complexity of interactions involved.[9] Many of these models fail to encompass the organisational, social and external interactions required for innovation. One reason for this failure is the consideration of innovation as a process rather than an interactive system. Prior to the 1980s, innovation theory utilised simple linear models of innovation known as 'technology-push' and 'market-pull' models. These models present the innovation process as a conditioned reflex to the stimulus of science discoveries or market needs. More recent models recognise the cumulative interactive or integrated nature of innovation[10] but still emphasize innovation activities in terms of sequential, parallel or simultaneous activities and stages which are self-contained within the innovation process.[11] Kline has included a systems component in the innovation process, bringing the external environment into consideration.[12] He recognizes innovation as a product of sociotechnical systems in his 'chain linked' model of innovation, identifying important feedback mechanisms and central flow paths for critical activities. A 'fifth generation' innovation model proposed by Rothwell is based on systems integration and networking coordinated by 'electronic toolkits'.[13] It is the first attempt to include strategic partnering and linkages as part of the innovation process. Strong linkages with leading edge customers, strategic integration with suppliers are linked to quality and management improvement concepts. Despite advances in the explanatory power of a number of models, many are limited insofar as they restrict discussion of innovation within organisational boundaries.

In comparison to previous theories, this proposed model based on the concept of Porter's 'diamond' model describes innovation as an evolving system rather than a process. The model is useful for synthesizing social, organisational, economic and technological aspects of innovation into an interactive and cross-sectoral system and takes into account information flows and collaboration amongst involved individuals and groups. The driving forces of the system have four major determinants and these are critical to the success of an innovation (Figure 1). They are 'knowledge status'; 'organisational management'; 'linkages, diffusion, strategic alliances'; and 'market and user opportunity'. Major characteristics of the model are:

- All determinants are important for an innovation to occur; no hierarchy of priorities exists for the development of determinants.
- Each determinant can interact with others to mutually support the strength of determinants. As a result innovation can emerge from all points in the integrated system.
- Innovation may be derived from the strength of one of these determinants. This determinant can drive the development of the others. For example, the 'market opportunity' determinant can contribute to 'market pull' innovation whereas strengths in the 'knowledge status' determinant can result in 'technology push' innovation.
- Innovation may be inhibited as a result of weaknesses in one determinant which can break down information flow patterns of the system.
- All determinants need to be considered in terms of an interactive system rather than individual processes within each determinant. Each determinant, however, is inter-linked through information exchange processes.

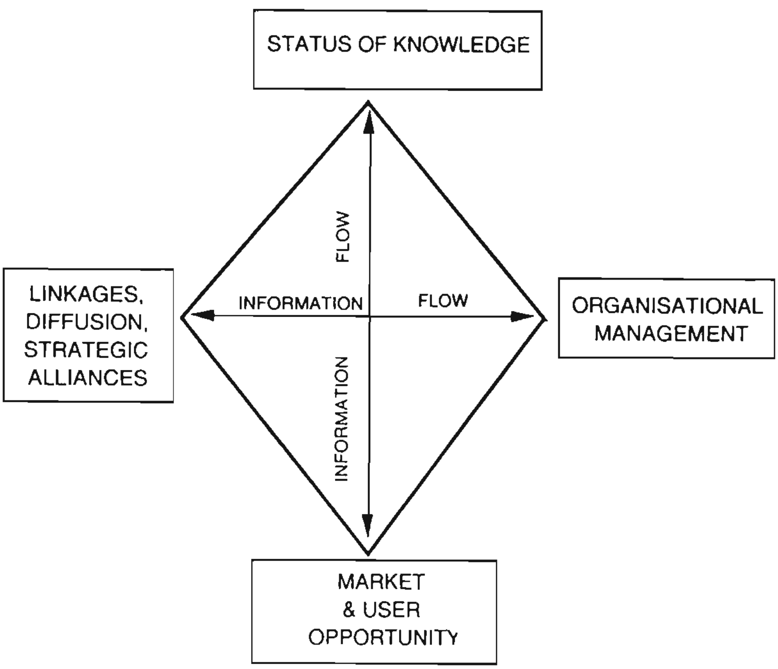

Figure 1. Determinants of technological innovation in collaborative research.

Unlike Porter's 'diamond' model, this new model of innovation requires threshold levels of strengths for each determinant. While determinants can function independently, they need to interact with other determinants in order that they develop as a mutually reinforcing system. The model of innovation described in this paper is similar to Porter's 'diamond' model insofar as it identifies four major factors of competitive advantage. However, these factors are applied to determine the success of managing innovation in collaborative research arrangements. The model can be described as a 'symbiotic' model of innovation management because the determinants disseminate their influence over the other determinants. The result is a system where the stronger factors can drive the innovation system.

The first determinant, 'status of knowledge', refers to both scientific and technological knowledge. Technological innovations are knowledge-based and encompass all forms of knowledge ranging from 'tacit' to 'explicit' forms.[14] As new technologies are increasingly science-dependent,[15] state-of-the-art knowledge is a key determinant of national innovative capacity. Companies can now acquire their knowledge from a variety of sources without necessarily developing it in-house. Knowledge can either be created, or 'borrowed', through joint ventures and cross licensing arrangements. Improving the efficiency of internal knowledge accumulation has become a significant corporate strategy. Business firms recognise that knowledge accumulation determines the effectiveness, scope and speed of external technology sourcing required to achieve national advantage in technological competitiveness.[16] The knowledge determinant in the model can be strengthened by systematically undertaking or drawing upon basic, applied and experimental development work. There are also other forms of knowledge associated with engineering and production processes that firms may acquire through proprietary sources and networking.

There are significant opportunities for sharing complementary or specific types of knowledge between CRC participants and, on a wider level, CRC clusters. The idea of sharing complementary knowledge is not new. Japanese companies like Nippon Steel have approached the problem by creating specialised information and communications companies which create portfolios of organisational intelligence leading to competence building through joint ventures and joint technology development.[17] A high degree of advantage in technological innovation can be gained by engaging in a combination of joint ventures, collaborations, and cooperative research that allows external sourcing of knowledge. In CRCs, knowledge production activities are organised according to basic, strategic basic, applied research and experimental development work. Each CRC exhibits an active knowledge function that relates to the overall mission of the CRC as well as discrete projects within the centre.

The second determinant, organisational structures and management styles, provides a framework for approaching innovation within organisations. Previous research has identified three organisational models adopted for innovation in Australian Cooperative Research Centres.[18] They can be described as 'Research', 'Corporate' and 'Integrated' organisational types. Structures adopted have an impact on the types of innovations attempted: they determine the way in which work processes are organised; they provide mechanisms for the way in which intellectual property issues are resolved and bear directly on the outcomes of innovative activities. Appropriate management approaches can facilitate complementary skills, provide equitable access to resources and provide an integrated overview of the progress of innovation functions. Advantages to be gained from engaging in collaborative research emanate from an accumulated ability to make efficient choices between alternative paths for innovation as new opportunities arise rather than from particular innovations.[19] Flexibility in management structures enables the organisation to allocate sufficient time for engaging in refinements to, and improvements upon, innovations. The expertise gained during their manufacture and production is thereby accumulated for future use.[20]

Forms of organisational management also impact directly on the management of resources for innovation. Down-stream innovation development work involves raising venture capital and determining when to allow pilot plant and prototype development. A number of specific policy initiatives to address some of these management issues include the establishment of an Australian Technology Group, the Pooled Development Funds or provision of equity capital to small and medium sized companies, the 150 per cent tax incentive scheme, the Advanced Manufacturing Technology Development Program and other mechanisms for commercialisation of research.

The third determinant deals with linkages, diffusion mechanisms and strategic alliances. Linkages provide the means for introducing, promoting and sustaining innovations between participating institutions and firms. Innovations require complementary inputs from other research disciplines, technologies and techniques.[21] In particular, access to supplementary networks based on purchasers, suppliers and manufacturers is important for sustaining the dynamism of the innovation process. Complex interactions and networking lies at the heart of innovation clusters. Networks act to facilitate technology adoption choices and influence the historical paths taken in the innovation process.[22] Development of linkages and knowledge diffusion processes facilitate the formation of clusters and speed the innovation process within clusters. Some countries have acted on this knowledge by developing national programs to strengthen and stimulate linkages and diffusion processes and also to encourage strategic alliances. For example, Germany has created technology transfer centres and institutes, joint research programs or 'Verbundtorschungs-programmes', established more than fifty innovation centres since 1981 and implemented specialised schemes like the TOU (Technology-Oriented Enterprise) Program. Each of these measures has created a fertile environment for the development of institutional linkages to stimulate innovations. The Fraunhofer Society and its thirty institutions can be loosely compared with Australian CRCs in that they provide extensive opportunities for networking and linkages for knowledge transfer. However, while the Fraunhofer institutions undertake contract research for industry and government and operate to subsidise the research costs of smaller firms, Australian CRCs are specifically aimed at building innovation capabilities based on the longer term interests of their major partners. The utility of forming strategic alliances with other innovation centres is already recognised by some CRCs. One is developing a strategic alliance with a similar centre overseas while two additional centres have named other CRCs as supporting partners.

A fourth dimension lies in identification of market and user opportunity. Industrial firms are geared towards identifying market potential and are accustomed to evaluating commercial opportunities in the early stages of innovation. This is still an area in which universities have much to learn. Many innovations fail due to an overestimation of market potential or, in the case of some university research, no estimation at all. Markets play a significant role in generating the feedback required for undertaking improvements to innovations. Misreading these cues can add years to product development thereby losing technological advantage. Goldman and Nagel accurately observe that technological innovation is 'driven by extra-technical value judgements' which are the 'prerogative of management'.[23] Most problems in developing research to the market stage involves solving problems which are not necessarily based on resolving knowledge or technical questions. Innovation does not end with 'discovery'. It is an interactive process where new actors can step in at the threshold of production or use.[24] Often innovative efforts are linked with areas outside the core business activities of firms. For example, offering improved methods for using company products as an after-sales service provides an additional dimension to innovation. Products are now continually upgraded so that producers are able to build and improve upon products by 'learning by doing'[25] and users are able to develop critical knowledge necessary for effective product utilisation through 'learning by using'.[26] Consideration of market opportunity influences the manner in which commercialisation is handled within a firm or joint venture. Speed to market is often given greater consideration than proprietary ownership.

The model's determinants are combined through information flows. Information flow mechanisms promote technology diffusion, bind competitive strategies and reinforce the strength of each plane in the model. A useful starting point for the CRC Program would be to study the techniques and strategies of Japanese *sogo shoshas*, trading companies devoted to acquiring, processing and coding product and market intelligence, technical and scientific information. If CRCs develop as closed information systems they may eventually harm their industry partner's ability to compete and therefore the long term viability of the CRC itself.

Sharing knowledge and technological information has become pivotal to the success of collaborative ventures in the 90s. Stakeholders in cooperative research enterprises must be aware of their competitors technology and market strategies to avoid pursuing 'dead end' research or bearing the costs of trialing product and process innovations previously tested and discarded by competitors. Information on its own, however, has little commercial utility. Stuart MacDonald observes,

> In its pure form, it is no more attractive to industry than the raw results of much university research. Of much more use is a blend of technological information with information relating to the more prosaic concerns of the firm. ... Informal networks have the flexibility to cope with this demand: formal collaborative agreements may not.[27]

Methods for translating information into specific actions and operations depends on the type and level of innovative functions required. Those innovations which relate to product development generate and require different patterns of information flow to those undertaken in process development. Rothwell identifies the exchange of electronic data between innovators, suppliers, R&D collaborators and customers as the basis for strategic networking and evidence of the changing nature of the innovation process in the 90's.[28] An important outcome of this change is that knowledge and information are now constituted differently. Customers, suppliers, manufacturers and researchers have become interdependent and now trade in vastly different sets of information than they would have a decade ago. The importance of human interaction and personal networks to the innovation enterprise cannot be underestimated.

The catalyst for achieving technological innovation advantage in this symbiotic model can come from any one of the determinants. A 'market pull' strategy towards innovation would be focused on early recognition of favourable market conditions and opportunities and would then be followed by the responsiveness of the other determinants. Similarly, a 'technology push' strategy can come from advantages generated by the status of knowledge. Each determinant in this model is contingent on the state and performance of the others. Naturally, the strength of one determinant can also strengthen the advantage of others. The role of information technology, in particular, is important in drawing all these factors together. Information technology acts as a translation mechanism of messages from one determinant to another and increases the efficiency of all determinants.

APPLICATION OF THE MODEL TO INNOVATION CLUSTERS

The term 'innovation cluster' in the context of CRC programs refers to a collection of collaborating organisations consisting of groups of researchers, research programs and projects based on complementary research objectives within a specific socio-economic area. Australian innovation clusters are both structural and knowledge-based with the potential to become technology sharing networks. The symbiotic model of innovation can be applied to each cluster with the result that a congruence of innovations is evident in complementary industry areas.

In this paper, the strength of each determinant in the model is applied to collaborative research clusters developed in the Australian CRC Program. Evidence from two sources is utilised:

- Formal applications to the Program, and
- Case study material based on interviews with key personnel.

Case study data are drawn from structured interviews with representatives of the major partners involved in selected CRCs. This material is used to ascertain the respondents opinions of the model in relation to their involvement in innovation activities of CRCs. Executive directors, research leaders and leading industry personnel, who are responsible for the management of centres, were asked to comment on the model in terms of their involvement in their CRC. Their views on technological innovations, in general, were also considered.

Fifty two CRCs are clustered into six major areas: Mining and Energy, Information and Communications Technology, Manufacturing Technology, Agriculture and Rural Based Manufacturing, Environment, and Medical Science and Technology. Agriculture and Rural Based Manufacturing has acquired the highest number of centres (13) with the smallest at seven centres for both Medical Sciences and Mining and Energy areas. Interactions within and between clusters are inevitable yet little has been made of the potential national advantages of CRC innovation clusters. For example, the Agriculture and Rural Based Manufacturing and Environment areas have clusters based on strong interactive functions which are not confined within the research categories utilised. In case study interviews conducted with key personnel, centre representatives identified other CRCs they judged to be engaged in research of direct interest to their centre. These connections were not necessarily in the same cluster or same socio-economic area in which their own centre was located. If Australia is to fully realise potential areas of technological advantage these linkages need to be made and recognised at a more formal level.

The strength of the model's determinants varies according to a range of criteria. The knowledge determinant can be defined in terms of basic research, strategic basic research, applied research and engineering development and design activities attempted within centres. These variables provide an insight to the focus in knowledge status adopted by centres and the maturity of innovative activities undertaken within a CRC. For example, some centres like the CRC for the Antarctic and Southern Ocean Environment operate predominantly in basic and strategic basic research. Other centres like the CRC for Materials Welding and Joining concentrate in applied research and engineering development.

The organisational management models adopted in CRCs influence methods of project selection, knowledge development strategies, knowledge transfer and diffusion, researcher autonomy and management strategies for commercialisation. Different organisational cultures, particularly the influence of partners who dominate by virtue of funding or staffing levels, affect the management styles adopted in innovation. 'Corporate' approaches locate business management and development above the research and education functions in the organisational hierarchy. Organisational structures contain a high level of representation from industry; place an emphasis on commercialisation and have specialised advisory and evaluation committees to guide research to market-driven industrial applications. According to evidence available from applications and interviews, less than a third of existing CRCs adopted this approach reflecting Australia's historical predisposition towards traditional forms of research management. In contrast, just over 40 per cent of centres have adopted a 'Research' style of organisational management which is based on a flatter organisational structure where key researchers enjoy a high degree of autonomy and are less likely to be coordinated into teams answerable to a Manager. This model places an emphasis on research rather than business or commercialisation functions with industry partners playing a secondary role to research leaders. A third of CRCs have adopted an 'Integrated' style of management which balances research, education and commercial functions at the same organisational level. This approach places a greater emphasis on processes facilitating networking between units within the organisation.

The determinants responsible for linkages, diffusion and strategic alliances are influenced by the level of participation of partners. The involvement of industry associations, the numbers and composition of partners involved in centres, previous histories of collaborative experience are all factors which contribute to developing networks, linkages and strategic alliances. The extent of involvement of core and supporting partners in each cluster can be used as a proxy for determining the strength of linkages, diffusion and strategic alliances.

The impact of the market opportunity determinant depends on the type of innovative products attempted within centres and the importance ascribed to this factor by centre management. CRCs with highly defined products are generally active at the market-end. Those centres emphasizing process and systems development are less inclined to possess clear market strategies. In a study of development stages and success factors associated with Industry-University Cooperative Research Centres funded by the US National Science Foundation, critical issues for the initial and intermediate stages of centres included 'technical leadership', 'meetings with industry' and 'understanding industrial concerns'.[29] Most CRCs are facing these issues now. The way in which centres approach 'market opportunity' is determined by their relationship with industry in the initial and intermediate stages of centre development.

The strengths of the model's determinants vary according to cluster and a range of criteria (Table 1). The matrix indicates that some clusters such as Agriculture and Environment have relatively strong knowledge production advantages and are dominated by a 'Research' style of management. These clusters show a high level of activity in basic and strategic basic research indicating that they are proactive in knowledge production. These sectors are also characterised by lower numbers of core partners although Agriculture has strong peripheral support from supporting partners indicating the historical influence of agricultural R&D corporations. The philosophy of institutions in these clusters is that once a knowledge base is established, there will be ample opportunity to attract industrial partners. In comparison with other clusters, these sectors have smaller numbers of core industry partners.

As the Program matures, centres are beginning to provide a formal basis for interaction between CRCs. Unlike previous rounds, the third round of the Program produced applications which identified other CRCs as supporting partners. For example, the CRC for Sustainable Cotton Production named a number of established CRCs as potential partners with which they could network. The Research Data Network CRC, also created in the third round, will integrate some of the research programs of two other CRCs, the CRC for Distributed Systems Technology and the CRC for Advanced Computational Systems with its own research. Evidence suggests that some centres are building strategic alliances with other centres to consolidate their international standing and reputation and to gain corporate access to knowledge competence. These interactions form the basis for complex inter- and intra-institutional linkages which lay at the heart of what can be described as 'innovation clusters'.

Table 1. Innovation Management Determinants in CRC Clusters

Innovation Cluster	Knowledge Status				Organisational Factors			Linkages/ Commercial Partners		Market Potential		
	B.	*SB.*	*App.*	*Exp.*	*Corp.*	*Res.*	*Int.*	*Core*	*Support*	*Prod.*	*Proc.*	*Sys.*
Mining& Energy	0	3	2	2	2	2	3	9	25	2	4	1
Information & Communications	0	4	3	0	3	2	2	36	13	1	4	2
Manufacturing Technology	0	2	1	5	3	3	2	29	19	4	3	1
Agriculture & Rural Manufacturing	0	3	10	0	3	7	3	17	43	8	5	0
Environment	3	3	3	0	0	6	3	9	3	0	4	5
Medical Science & Technology	0	2	4	0	1	2	4	16	5	4	3	0
TOTALS	**3**	**17**	**23**	**7**	**12**	**22**	**17**	**116**	**108**	**19**	**23**	**9**

Note: The following symbols denote: B - Basic research, SB - Strategic Basic research, App - Applied Research, Exp - Experimental Development, Corp - Corporate, Res. - Research, Int. - Integrated, Support. - Supporting Partners, Prod. - Product, Proc. - Process, Sys. - Systems

Information and Communications and Manufacturing Technology clusters are active in applied and experimental development research. An important feature of these clusters is the large number of industries as core partners. Linkages are strongly represented with a high level of industry partnerships. These clusters also have a greater tendency to adopt a corporate style of management. Clusters with 'Corporate' or 'Integrated' management approaches in preference to a 'Research' style of management are characterised by strong product driven markets and objective driven knowledge base development. Medical and mining clusters illustrate a wide spectrum of strengths generally concentrating on specific development objectives.

The overall picture indicates that Australian research clusters tend to operate at the research end with weaknesses in experimental development, engineering and production. A large majority are driven by a 'research' style of management or adopt an 'integrated' style with less emphasis on corporate management approaches which are closer to the market end. The number of core industry or commercial partners exceeds the number of supporting industry partners for most clusters with the exception of Mining and Energy, Agriculture and Rural Manufacturing areas. In general, the presence of greater numbers of supporting partners suggests that the potential exists for involving more Australian companies at a later date in subsequent development stages. A number of industry partners prefer to operate at some distance rather than make a full commitment to CRC activities in the early stages. Product and process innovations are the major objectives for most CRCs with systems development occurring primarily in the Environment cluster. The latter results from CRCs aimed at developing a service function that only indirectly supports market development.

The apparent strengths in one pole of the model can act to reinforce the other poles. Clusters which function at the end of the knowledge spectrum operate with less industry linkages, are less likely to organise their activities along corporate lines and are concerned with development of longer term impacts to systems and processes. These operational phases change as the phase of innovation matures or shifts from one phase to another. For example, a research oriented cluster may shift its focus as a result of greater industry involvement and as knowledge becomes mature and shifts towards the market end.

INDUSTRY PERCEPTIONS OF THE INNOVATION MODEL

The symbiotic model of innovation is useful for explaining the processes and structural characteristics of collaborative research. The nature of CRC collaboration is that industry, university and research partners contribute to various functions of the innovation process. Centres have structured and adopted discrete programs for research, education and commercial development which support and facilitate the completion of the innovation process. Inputs to various functions of the innovation process are ultimately determined by the relative skills and resource contributions of each partner. Partnerships are bound by agreements for resource commitments, specific financial contributions and methods for sharing research outcomes. An early assessment of the nature and extent of capabilities and contributions can provide a strong basis for future collaboration in the innovation process.

The innovation capacity of CRCs was gauged by interviews with key personnel in four centres. The new innovation model was presented to interviewees to ascertain their opinions on the relative importance of each determinant and in relation to the current development of their CRC. The opinions expressed reflect the way in which key players understood the innovation process and their perception of the relative significance of each determinant. These opinions are also a reflection of how each participant viewed their organisation's strengths and contribution to innovations attempted in centres. Interviews were carried out with personnel directly involved in work processes or management of CRCs. The sample is limited for practical reasons, however, the opinions expressed are those of leading Australian industrialists, executive directors, research program leaders and managers. As such, these views are indicative of a trend in collaborative research and a useful analytical tool to verify functions of the innovation process. The results of interviews are presented in Table 2.

Table 2. Opinions Ranked by Relative Importance of Model Determinants

CRC Partners *Organisation Type*	**Knowledge** *Rank*	**Management** *Rank*	**Linkages** *Rank*	**Market** *Rank*
Industry A1	3rd	4th	1st	2nd
Industry A2	2nd	3rd	1st	4th
Industry B1	1st	3rd	2nd	4th
Industry B2	1st	2nd	4th	3rd
Industry C3	1st	3rd	2nd	4th
Industry D1	2nd	3rd	4th	1st
Industry D2	2nd	4th	3rd	1st
Industry D3	2nd	4th	3rd	1st
Industry D4	1st	4th	2nd	3rd
Research Inst. B1	1st	4th	3rd	2nd
Research Inst. C1	1st	4th	3rd	2nd
Research Inst. D1	1st	4th	2nd	3rd
Research Inst. A1	1st	4th	3rd	2nd
University A1	1st	4th	3rd	2nd
University A2	1st	2nd	3rd	4th
University B1	1st	2nd	3rd	4th
University D1	1st	3rd	2nd	4th
University D2	1st	3rd	2nd	4th

All respondents agreed that all four determinants were important in describing the innovation process of collaborative research attempted in CRCs. None of the interviewees denied the importance of any of the determinants presented, and all expressed opinions regarding the role each determinant had to play in the completion of the innovation process within CRCs. A number of important observations can be drawn from the data:

- A common trend can be extrapolated from the way in which industries, research institutions and universities have responded to the model's determinants.
- Responses vary within sectors and amongst representatives of specific sectors involved in particular CRCs. As a result, perceptions of the importance of determinants can have different rankings. These variations reflect the internal capabilities of an organisation and the type of activities performed, as well as the organisation's ability to form strategic alliances and network with other institutions.
- Generally, industry representatives perceived the importance of market and knowledge factors, ranking them higher than management and linkages. However, depending on the type of centre, linkages and management can also be rated highly.

- Respondents from public sector research institutions tended to rank knowledge and market determinants highly as perceived capabilities and tended to rank management and linkages lower.
- Respondents from universities viewed knowledge as a strong determinant followed by linkages or the management determinant. They generally ranked market opportunity as the weakest component or did not recognise its importance.
- Distinct differences in ranking the importance of determinants was observed amongst respondents from the three sectors examined.

The results of this opinion survey can only be indicative due to the small sample size. The views expressed may not be applicable universally, however, they reflect the opinions of an influential group of people who will determine the future of CRC collaborations. The results reveal important trends in the manner in which each sector views the innovation process in each CRC. A divergence of views amongst different sectors and between partners within each sector is noted. Understanding the underlying reasons for diverging views is useful in order to develop a common framework for fruitful collaborations. Differing views invariably related closely to the capabilities and background of each partner. Even within the same industry sector, different industry partners perceived innovation capability differently on the basis of their relative strengths.

The opinion of respondents needs to be considered against the type of collaborative research centre in which they are involved. While some centres are active at the market end, others operate at the research end. The Australian Photonics CRC, one of the leading centres now in full operation, has three nodes with each node involved in leading edge technology areas. All of the CRC's nodes had previous histories of collaboration with industries and high levels of industry participation in their research work. One of the industry partners in this CRC commented that the 'knowledge status' determinant was less important with respect to innovations attempted in this CRC and rated market and linkages as strong determinants. However, another industrialist in the same CRC whose work involved the supply of services, commented that market opportunity and knowledge status were strongly represented but that linkages, diffusion and strategic alliances were the weakest aspects. The research conducted in the Australian Photonics CRC relates directly to suppliers, users and producers of technology. Therefore, the second interviewee identified the absence of strategic alliances with manufacturers of devices as a major constraint for furthering innovation within the centre. After less than a year of operation, the importance of developing a circle of supporting industries which could manufacture the devices and products of the centre had already been identified by this industry partner who was concerned that this fact was not being recognised by the other partners. The strength of each determinant of the model was therefore closely linked with the strategic outlook and mission of each organisation involved in the collaborative research.

The application of each determinant in the model to innovation depends on the stage of maturity for each determinant. For example, the group involved in the CRC for Cochlear Implant, Speech and Hearing Research already had a well defined product based on a history of previous research. The respondent identified organisational management and linkages as the critical determinants for creating innovation advantage. Traditions of collaborative research in small companies suggest there is a distinct difference in the way in which innovation advantage is rated. Small companies clearly seek avenues to increase their knowledge status determinant but are also strongly driven by market signals. Therefore, the smaller companies viewed the knowledge factor, organisational management and market opportunity factors as important determinants for realising successful innovations. Representatives from larger companies, like those involved in the CRC for Materials Welding and Joining, viewed organisational management and linkages as major determinants of success in innovation. There was general consensus that large companies were more able to access knowledge, however, equitable processes of organisational management were regarded as difficult to achieve particularly in down stream innovation development. The inability to change production planning schedules of large companies for testing research, or simply not being given access to pilot plant facilities required for commercial testing as a result of departmental rigidity were regarded as major difficulties faced by research departments in large companies.

Although the clusters formed in the CRC Program are based on taking an idea through the entire innovation process into markets, formation of venture capital, investment, marketing and management are also determinants of how successful these clusters can become. Without an understanding of risk capital formation, investment and management, those CRCs focussed largely on research excellence run the risk of underestimating or disregarding market signals. As the Executive Director of the CRC for Distributed Systems Technology explained, 'many good ideas can fall flat because of an overconfidence in the market situation'.[30] Several interviewees were able to identify definite strengths and weaknesses on the basis of the model's determinants. The strengths identified could be used to manage innovation within CRCs. It is vital that each organisation involved in collaborative research consider each determinant in terms of stages of development for particular innovations. The symbiotic model is an evolving system and the strengths of each determinant can vary according to the stage and type of interactions.

CONCLUSIONS

The development of the symbiotic model provides researchers with a mechanism for looking at innovation as a system of interacting and complementary processes based on four major determinants. These determinants are useful for understanding the complex interactions encountered in collaborative research and innovation. Their strengths, as perceived by participants in the collaborative process, promote completion of innovative activities. The strength of one determinant, however, will not necessarily ensure completion of the entire innovation process. All four determinants need to be developed to a threshold level so that each innovation can coalesce with others into a cluster. This model, although tested mainly for its viability on research collaborations, is useful for explaining the way in which innovation functions as a evolving system. It integrates both internal and external interactions that determine innovation activities. Determinants that may be regarded as critical for one organisation may not be critical to another. These divergent perceptions are important for collaboration to work and to enhance innovation at a systems level. Different approaches to the management of innovation are essential for tailoring a hybrid organisational form to the collaborative task in hand. The ability to view innovation according to the determinants described also provides a systematic may in which innovative activities can be evaluated and developed within an organisation.

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