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The new science and engineering management: cooperative research centers as government policies, industry strategies, and organizations

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Abstract Cooperative research centers (CRCs) are key mechanisms for national and subnational governments and private industry for achieving social and economic outcomes with science and technology. Despite growing policy and scholarly interest in the management and productivity of CRCs, their complex and variegated nature has led to limited and inconsistent understanding of CRCs. In this introduction to this *Special Issue* of *The Journal of Technology Transfer*, we discuss the impetuses for and embodiment of CRCs as government policies, industry strategies, and organizations and thus address a number of unexplored aspects of CRCs that are important to decision making for both policy and management. Of note, we discuss the lack of definitional clarity regarding CRCs and introduce criteria for distinguishing CRCs from other organizations. We conclude by introducing the article contributions, which are international in scope and address CRCs from multiple theoretical perspectives and levels of analysis, and by discussing areas for future research.

Keywords Cooperative research center · Science and technology policy · Technology transfer · Research collaboration

JEL Classification O31 · O32 · O38

1 Introduction to the *Special Issue*

This *Special Issue* of *The Journal of Technology Transfer* is focused on a growing and increasingly important vehicle for promoting technological innovation, commercialization

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and, ultimately, social and economic outcomes—a class of social and organizational technology we will refer to as "cooperative research centers" (CRCs). Although CRCs are not a new phenomenon, we believe our understanding of the true value and inner workings of these complex yet very adaptable organizations has been limited and inconsistent.

While a number of factors have contributed to this state of affairs, we believe that perhaps the biggest factor has been the scholarly community's tendency not to look beyond the disparate superficial labels we give our research centers and thereby fail to recognize that we are dealing with a core social and organizational phenomenon. As a consequence, we have tended to develop distinct literatures on a variety of centers including innovation centers, industry-university centers, engineering research centers, university research centers, industry consortia, and centers of excellence, among others, that emphasize differences while ignoring or downplaying the common conceptual, theoretical, policy, organizational, and management issues that affect all of these centers.

This is not to say that there are no important process, output, and outcome differences between different centers programs and models. In fact, the reality is quite to the contrary. As we believe the papers in this *Special Issue* illustrate, the CRC model is a versatile social and organizational innovation that can be structured in different ways and can produce different results under different circumstances. However, these differences have little to do the programmatic labels we give to centers and, instead, are contingent on a variety of factors including public policy goals and funding structures, differences between scientific fields and industry sectors, factors operating at various organizational levels, management differences, and the characteristics of the individual scientists and other stakeholders attracted to and involved in these centers.

Given this set of circumstances, the motivation for this *Special Issue* is two-fold. First, we would like to stimulate greater discussion within the policy and scholarly communities about which factors truly differentiate "types" of research centers. Thus, while we will offer our definition of CRCs below, we hope that this will be the beginning and not the end of a serious discussion in the literature that will lead to a more comprehensive typology of research centers. Second, we would like to contribute to the development of a more unified, coherent, and integrated theory and research-based understanding of the processes and outcomes of one type of center, namely CRCs.

Toward this end, in this introductory article we highlight the societal, policy, organizational, and related forces that led to the development and growth of CRCs; we define what characteristics distinguish a CRC from other types of centers and explain why the policy and scholarly community should be interested in CRCs; and, finally, we highlight some of the core issues and themes that are critical to gaining a better understanding of the processes and outcomes of CRCs. The collection of papers that follow illustrates how a variety of policy, organizational, and individual factors can affect CRC processes and outcomes.

2 Key drivers behind CRCs

Over the past several decades, a variety of forces including the increasing complexity of scientific problems, the need for a multidisciplinary perspective and for advanced and expensive equipment to solve these problems, the speed with which insights and discoveries must be made to exploit their commercial potential, and the importance of innovation to the health and vitality of regional, national and subnational economies as well as to broader social goals have changed the way science and research are conceptualized,

planned, and executed in both the private and public sector (Fagerberg et al. 2006). In our view, CRCs can be best understood as a social and organizational response to at least three far reaching developments that have changed innovation systems globally: the collectivization of research, the emergence of a cooperative paradigm for research guiding research policy in the US and abroad, and the development of open approaches to innovation by industry.

2.1 The collectivization of research

Collectivization of research refers to the increasing reliance on large, interdependent, and increasingly complex teams of researchers to solve challenging scientific and technological problems (Ziman 1984). While the movement to team-based research began long ago within industrial laboratories (Whyte and Nocera 1956), it has more recently taken hold within our universities, government labs, and not-for-profit research settings (Gibbons et al. 1994; Etzkowitz and Leydesdorff 2000). Research that several decades ago might have been performed by an individual faculty member or by a small disciplinary team is now increasingly being conducted by large teams of researchers from various disciplines, aided by graduate students, post docs, technicians, and other specialists. This phenomenon has become sufficiently normative that scholars have begun to refer to it simply as "team science" (Stokols et al. 2008).

However, team science cannot flourish easily in an organizational vacuum, and academic departments and the discipline-focused research units found in government research enterprises are ill-equipped and to some extent antagonistic to the type of multidisciplinary, problem-driven, and strategically formed and focused research teams that are being organized to engage and solve complex problems. To a large extent, research centers are the organizational solution to the problems team science poses for disciplinarily and bureaucratically structured institutions like universities. CRCs provide structures and mechanisms that facilitate disciplinary and sectoral boundary-spanning, the management of large complex portfolios of projects, and that help support coherent and widely embraced strategies. However, these same structures and processes also present challenges for those who would manage these complex organizations and for the scientists who work in them (Boardman and Bozeman 2007; Gray 2009).

2.2 The emergence of the cooperative paradigm for research policy

The second force that has contributed to the development of CRCs is the changing perspective of government and its role in science and technology. While historically market failure has been the rule-of-thumb for government participation in and sponsorship of certain types of research and development, national and subnational governments in the US and abroad have increasingly emphasized a cooperative paradigm for research policy whereby government proactively (rather than only in response to externalities) harnesses scientific and technical capacities in universities and industry to fuel innovation by brokering the cooperative development of pre-competitive (Bozeman and Dietz 2001) and mission-critical (Boardman and Ponomariov, forthcoming) technologies. Although cross-sector cooperation has existed since the very beginning of modern technological enterprises (Prager and Omen 1980), this broadened definition of the government role in science and technology has led to public policies and institution building for the strengthening and formalization of research ties across the sectors.

In the US context, the impetuses for this redefinition include calls from policy makers, and more broadly from the public, for increased accountability in publicly-funded research (Guston 2000) and for enhanced competitiveness in the global marketplace (Geiger 1990; Link and Scott 2001). Another impetus has been the increasing complexity (discussed above, see Sect. 2.1) and expense of scientific and technical endeavors (Ziman 1994). The result has been national and subnational level strategies emphasizing not only CRCs, but additionally public policies aimed at facilitating and incentivizing problem-focused and/or commercially-relevant university research including tax incentives, financing, and proprietary modes of dissemination (e.g., patents, licenses) for publicly-funded research (e.g., the 1980 US Bayh-Dole Act).

Characterizations of publicly-funded research have been reflective of the cooperative paradigm for government participation in science and technology. Gibbons et al. (1994) delineate past from recent university-based knowledge production, with government playing a role in the transition towards "Mode 2" or problem-focused and cross-sector research in universities; Etzkowitz (1998); Etzkowitz and Leydesdorff (1998) in a series of influential articles examine at the organizational and individual levels of analysis of the "Triple Helix" and its role in promoting the "evolution of the ivory tower to entrepreneurial paradigm" (2002); Owen-Smith (2003) demonstrates the movement of universities and industry "from separate systems to hybrid order." Some of these characterizations specifically highlight CRCs. Tijssen (2006) identifies CRCs as fundamental policy mechanisms for promoting research environments that are facilitative of heightened cooperation between academic researchers and researchers in government laboratories and private companies; Bhattacharya and Arora (2007) characterize CRCs as the embodiment of "overlapping institutional spheres;" Bozeman and Boardman (2003) call CRCs in the US "the new national labs."

As with many government policies and programs, the changing role of government in science and technology has elicited as much concern as enthusiasm. Much of this concern has seemed focused on the effects of government intervention in the scientific enterprise, and more specifically the effects of CRCs, on the educational missions of universities (Slaughter and Rhoades 2004; Slaughter and Leslie 1997). However, whether and the ways in which CRCs and related activities are affecting traditional university missions like education remains very much an open empirical question (Baldini 2008).

2.3 Extra-organizational partnering and open innovation in industry

Another impetus for the growing importance of CRCs is the recognition of the importance of extra-organizational sources in promoting technological innovation. The culmination of this trend has been the relatively recent emphasis within industry on an "open innovation" strategy.

According to Chesbrough et al. (2006), open innovation is an alternative to the old internally focused and vertically integrated model of industrial innovation. More specifically, open innovation is a "paradigm that assumes that firms can and should use external ideas as well as internal ideas and internal and external paths to market, as they look to advance their technology" (p. 1). Within the open innovation paradigm, the use of external knowledge from various sources including other established firms, start-ups, entrepreneurs, government labs, and universities (both locally and abroad) has moved from a supplemental to a primary driver for innovation.

Interestingly, one of the more important developments related to the increased focus on open innovation has been the rise in intermediaries and intermediary organizations (Chesbrough et al. 2006), like CRCs. However, operating in an open innovation mode

creates new challenges including how to capture the payoff from what used to be considered spillovers, insuring one has adequate absorptive capacity, and effectively managing interorganizational relations (Chesbrough et al. 2006).

In our view, the joint influence of the collectivization of research, the cooperative paradigm for research policy in governments, and the development of open innovation strategies in industry has contributed to the development of social and organizational innovation, embodied in the CRC. In fact, we believe it is the only S&T mechanism that captures the benefits of all three of these important developments. Before introducing the contributions to this *Special Issue*, we feel it is important to delineate the CRC from other types of organized research units.

3 Towards a definition of CRCs

One of the factors that limits understanding of CRCs is the lack of a widely agreed-upon definition. Because a number of different types of organizations have been investigated under the centers label, understanding of the effects and processes of CRCs has been inconsistent. While a number of definitions can be found in the literature, all have their deficiencies. For instance, the most widely circulated definitions appear to be linked to specific government-funded centers programs that use the terms "cooperative" and/or "center" in their title, rather than to a general class or type of organization.

3.1 Programmatic definitions of CRCs

Perhaps the earliest use of these terms in connection with organized research was for the NSF's Industry/University Cooperative Research Centers (IUCRC) Program that was piloted in the early 1970s and formally established around 1980 (Gray and Walters 1998). According to Tornatzky et al. (1982), an IUCRC is a "university-based, typically interdisciplinary program of research supported jointly by a number of companies." This definition could easily apply to a number of other government-funded center programs (e.g., the NSF Engineering Research Centers Program). But following this definition, CRCs are limited only to centers that are university-based, involving departmental faculty (typically on a part-time basis) and student researchers, and jointly funded by industry.

However, CRCs outside the US (Lal et al. 2007) and supported by subnational units of government (Coburn 1995) often include non-university research performers and sometimes are organizationally independent of universities. For instance, Australia's long-standing Cooperative Research Centres program (founded in the early 1990s) defines a CRC as "an incorporated or unincorporated organisation, formed through collaborative partnerships between publicly funded researchers and end users" (sic).[1] Similar, the Basque government in Spain sponsors a CRC program that supports a series of non-profit associations that perform cutting edge research with full-time scientists (rather than in universities with departmental faculty) with an explicit expectation of technology transfer to other sectors.[2] Other CRC programs abroad with missions of transfer that are government-supported yet generally independent of universities and departmental faculty can be found in Japan (e.g., MEXT), Germany (e.g., Fraunhofer Institutes), and throughout Western Europe and Asia. These conceptions broaden the definition of CRCs to include

[1] See www.crc.gov.au/, accessed December 2009.

[2] See http://www.ikerbasque.net/research_centers/cics.html, accessed January 2010.

organized research units that are publicly-funded and that employ full-time researchers outside of universities to achieve economic and perhaps social goals with science and technology for "end-users," be they private industry or the broader public.

3.2 General definitions of CRCs

Beyond government agencies and programs sponsoring CRCs, there have been a number of scholarly attempts to define CRCs, with most early definitions using the traditional academic department as a comparator (e.g., Becker and Gordon 1966; Ikenberry and Friedman 1972). More recent attempts have been aimed at differentiating CRCs from other extra-departmental research units, and these attempts posit particular attributes as common across CRCs. Upon review of these attempts, one could conclude that CRCs are funded by external stakeholders, organizationally distinct from academic departments, affiliated with universities and comprised of faculty members from more than one discipline or field, and engaged in problem-focused and/or commercially-relevant research and development. Table 1 includes a selection of these definitions.

Despite these common elements, seldom have these or any other definition been applied in the literature. The result has been a failure to demarcate CRCs from other research units and programs, which has led to a great deal of confusion in the scholarly and policy communities. On one hand, any research endeavor other than individual investigator grants may be characterized as CRCs; on the other hand, many center-type endeavors that appear to be truly cooperative do not use the term (e.g., numerous Centers of Excellence programs at the state level) and may not be included.

Given these circumstances, we would like to propose a definition of a CRC that is consistent with the social and organizational forces described above (see Sect. 2) and thus is broader than programmatic and university-centric definitions:

> A cooperative research center (CRC) is an organization or unit within a larger organization that performs research and also has an explicit mission (and related activities) to promote, directly or indirectly, cross-sector collaboration, knowledge and technology transfer, and ultimately innovation.

Table 1 Selected general definitions of CRCs

Definition	Source
"What have here been typified as 'centers' were often intended to facilitate interdisciplinary investigations…their participants largely remained rooted in established departments; the research undertaken… was supported by outside agencies for nonacademic reasons"	Geiger (1990, p. 10)
"[A center] is a semi-autonomous research entity within a university that operates independently of academic departments… [they] typically involve multidisciplinary teams of researchers, a portfolio of research projects… and sometimes have access to some significant piece of equipment and/or facilities"	Gray et al. (2001, p. 248)
"We define [a center] as a formal organizational entity within a university that exists chiefly to serve a research mission, is set apart from the departmental organization, and includes researchers from more than one department"	Bozeman and Boardman (2003, p. 17)
"A 'centre' may be seen as a strategic device intended by its institutional hierarchy to emphasise research strength, aimed at encouraging external funding bodies to support the research…"	Zajkowski (2003, p. 206)

Based on this definition, we believe CRCs to have three essential characteristics. At a fundamental level, a CRC is an organization or organized research unit, albeit a specialized one. Accordingly, CRCs must *engage in research* and *exhibit organizational formality*. At a more specific level, CRCs are cooperative, thus they also must *promote extra-organizational and cross-sector collaboration and transfer*.

First, the criterion that CRCs conduct research as a primary though not as an exclusive activity is required to exclude entities that primarily facilitate collaboration or transfer, like university external liaison and technology transfer offices. Thus, entities that do not conduct research should not be considered CRCs. However, CRCs may engage in numerous other activities that are related to their research missions, like educating students, providing technical assistance, and facilitating business formation.

Second, CRCs must exhibit a minimum level of organizational formality. While "team science" may be a necessary ingredient for a CRC, additionally there must be an explicit attempt to organize researchers in the interest of aligning individual behaviors with CRC mission and goals, including but not limited to the discrete research objectives of the CRC. Organizational formality may materialize by the presence of some degree of structure, strategy, specified roles and responsibilities, managerial policies and procedures, and/or monitoring and control systems (Gray and Walters 1998; Corley et al. 2006). While we do not adhere to program-based definitions of CRCs, traditional research collaborations (i.e., amongst individual investigators) and loosely coupled networks of investigators (Howells 1990) should not be considered CRCs.

However, it is important to recognize that the range of organizational formality across CRCs can vary significantly. On one end of the continuum are semi-autonomous organized research units or virtual organizations embedded within larger organizations (Friedman and Friedman 1982) that may have an emergent strategy, a small portfolio of projects, scientists borrowed from across departmental boundaries, and possess no facilities or offices of their own (like the many university-based CRCs that are sponsored by various government agencies). At the other end of the continuum are large scale CRCs that are relatively autonomous organizations, have well defined structures, strategies, formalize relations between participating individuals and institutions, and possess their own facilities (like many Federally-Funded Research and Development Centers). As some of the papers included in this volume will point out, there has been little systematic inquiry into organizational variation across CRCs.

Last, given the centrality of cross-sector collaboration to the cooperative paradigm for research policy that led to the earliest CRCs (described in Sect. 2.2), our definition limits CRCs to centers that are focused on joint research or other interactions between universities, industry, and/or government participants with the purpose of technology and knowledge transfer. The focus of the collaboration can be direct and structured as is the case with CRCs at the NSF requiring industry partners, or it can be indirect and informal as is the case with CRCs at the NIH focused on particular diseases (e.g., cancer) which do not require industry partnerships but outline as goals knowledge transfer facilitating the commercial development of technologies for disease detection and intervention.[3]

Given the focus within the cooperative paradigm for research policy on using public resources to promote innovation, commercialization, and ultimately social and economic outcomes, this means that CRCs will be predominantly public sector or publicly-funded organizations (or units within larger organizations). While most of the examples in the literature involve public-private sector exchanges, public collaborations with non-profit

[3] See http://grants.nih.gov/grants/guide/rfa-files/RFA-HD-09-027.html.

organizations can also be found.[4] In the US, CRCs are typically based in universities though increasingly they can be found in government agencies (Boardman and Ponomariov, forthcoming). However, international models (Lal et al. 2007) and state-level models in the US (Coburn 1995) demonstrate CRCs oftentimes to be standalone public entities that are organizationally distinct from universities and government. While industry-based research consortia focused on mitigating risk in a particular area of inquiry or development may include university partners, this sort of endeavor is not a primary mission or goal of CRCs.

Each of the contributions to this *Special Issue* address organized research units that meet the criteria we have laid out for CRCs. Our intention in presenting criteria is not to stamp out a definition for future research and policy, but rather to generate discussion in the interest of developing greater coherence in both practitioner and scholarly treatments of CRCs and hopefully lead to the development of a more comprehensive typology of centers. Next, we briefly make our case for the social and economic importance of CRCs. The following section (Sect. 5) introduces the contributions to this *Special Issue*.

4 Why CRCs matter

Although CRCs are not a new phenomenon, there are a number of reasons why we believe it is both important and timely to provide a detailed analysis of the policies, processes, and outcomes of CRCs.

CRCs have grown in number. While due to the lack of a common definition it is impossible to come up with an accurate estimate of the number of CRCs in existence, according to the *Research Centers and Services Directory* there are almost 16,000 university-based and other non-profit research centers in the US and Canada, more than 8,000 government-based research centers in the US and Canada, and over 13,000 non-US research centers in 160 countries.[5] While this source is admittedly not complete, the *Directory* lists 37,000 research centers worldwide. How many of these centers meet the criteria for CRCs presented above is not clear.[6] However, given the increasing emphasis on cross-sector collaboration by the public sector and the open innovation paradigm by the private sector, we believe the number of research centers that meet our definition of a CRC (see previous section) is substantial and growing.

CRCs are important elements of government innovation strategies globally. Although individual investigator grants continue to comprise the bulk of public monies allocated to research by institutions like the NSF and NIH, CRCs increasingly constitute key mechanisms for the strategic use of science and technology to address social and economic problems, particularly problems not easily addressed unilaterally by academic departments, government labs, and private companies (Feller et al. 2002, Stokols et al. 2008). Although there are no definitive statistics on this phenomenon, over the years, CRCs have

[4] For example, a long-standing independent non-profit CRC working with government as well as business is the Southwest Research Institute in San Antonio, Texas. Founded in 1947, the center conducts research and development on a contract basis for government and industry clients in the US and abroad and emphasizes as a core mission the creation and transfer of technology in engineering and the physical sciences; see http://www.swri.org/swri.htm.

[5] See http://library.dialog.com/bluesheets/html/bl0115.html, accessed December 2009.

[6] The figures for CRCs are most likely lower than those reported in the *Directory*. A discussion with a technical representative from the parent company, Thomson Gale, revealed that for an organization to qualify as a research center, it must conduct research and not be an academic department.

grown in number and in terms of their share of the federal R&D budget (Hall 2004). We have seen this growth in large part owing to the cooperative paradigm for research policy discussed above, but more specifically because of the increased emphasis by policy makers on extracting social and economic returns from research. The terminology used to convey this emphasis has been varied—including funding strategies for research and development (at the NSF, NIH, and other agencies with core science and technology components) that is "transformative," "translational," "paradigm-shifting," "blue-sky," "high risk-high yield," etc—and CRCs, rather than traditional individual investigator awards, increasingly are how such strategies are implemented (Block and Miller 2008). While the term "cooperative research center" is not always used, virtually every developed and developing country as well as many subnational units of government employ CRCs as part of their science and technology strategies. CRCs seem likely to play an important role in the new and emerging innovation strategies being deployed to combat the effects of the recent recession.

Knowledge about CRCs has been limited and inconsistent. We believe at least four factors have contributed to this state-of-affairs. First, although research on CRCs has been growing, the amount of scholarly attention paid to this topic has been relatively modest and lags behind comparable topics, such as research parks and policy interventions aimed at promoting entrepreneurship (e.g., university patenting) and transfer (Siegel et al. 2001; Siegel et al. 2003). Case in point, to the best of our knowledge, this issue of *The Journal of Technology Transfer* will be the first special issue devoted to CRCs. Second, as we have pointed out above in some detail, the extant literature on CRCs is fragmented, at least in part due to a lack of definitional clarity. Third, CRCs are inherently complex and therefore a challenging phenomenon to understand. There seems consensus across the literatures on collectivization, research policy, and open innovation (see Sect. 2) that we are still struggling to understand the nature and effects of developments like CRCs. Due to the variegated nature of these impetuses for CRCs, the potential for heterogeneity across CRCs is great. There are differences across national and subnational models as well as across and within jurisdictions, sectors, and funding agencies. Insofar that CRCs constitute responses to scientific and technical demands that are varied, they necessarily vary in their resources, level of sponsorship, organization and membership, management and operations, technologies and life cycles, and objectives and goals. Finally, as a number of the papers in this issue point out, extant research on CRCs has often not been sophisticated enough in terms of research design, measurement procedures, and methods for data analysis to address these challenges. Scholarship has generated mostly case-based and practically no general knowledge of CRCs, perhaps because a large proportion of this research is spun from evaluation efforts for a particular CRC or CRC program.

5 Understanding CRCs

The motivation for this *Special Issue* has been to frame research and discussion of CRCs by presenting a series of articles addressing CRCs from multiple levels of analysis and from multiple stakeholder and theoretical perspectives. The articles included here examine CRCs as government policies, industry strategies, and as organizations and embedded organizational units. CRCs' internal management and processes, scientific productivity, economic impacts, and educational and outreach outcomes are addressed.

5.1 CRCs as national and subnational policies

In the US, the proliferation of CRCs has been the hallmark of policies intended to alter the norms and boundaries of academic research (Owen-Smith 2003), predominantly by facilitating technology transfer across the sectors. CRC programs came to the fore in the US and abroad during the competitiveness crises of the 1970s and 1980s. The establishment of the Industry/University Cooperative Research Centers (IUCRC) and Engineering Research Centers (ERC) programs at the NSF, for example, was in many ways a response to US economic competition with Japan (Suh 1986). Many of the CRCs in Europe and Asia were established similarly by government to help national industries compete in the global economy (Bozeman and Boardman 2004). Yet, most studies of CRCs focus on organizational aspects and scientific and commercial outcomes (see below) rather than the policy implementation functions that these research units help to fulfill. An exception includes a small part of the literature on "public research organizations" in Europe and Canada, which includes some direct assessment of the public policy functions of CRCs (e.g., Atkinson-Grosjean et al. 2001; Sanz-Menendez and Cruz-Castro 2003; Busom and Fernandez-Ribas 2008).

Though all of the articles in this special issue have implications for national and subnational policies, two explicitly address CRCs as policy mechanisms. David Roessner, Lynne Manrique, and Jongwon Park (SRI International) address the economic impacts of CRCs, specifically NSF ERCs. The authors highlight heterogeneity across ERCs and warn against the use of standardized performance criteria, uniform timetables for impact evaluations, and exclusive reliance on quantifiable data. Jennifer Clark (Georgia Institute of Technology) assesses the neglected topic of policy coordination across tiers of governance via CRCs. Noting that national and subnational policy frameworks for technology transfer and economic development oftentimes fail to address the importance of physical proximity (or the lack thereof) among researchers and participants in CRCs, she conducts a cross-case comparison of CRCs in the US and Canada. Her paper illustrates the ways policy outcomes may be influenced by the spatial distribution of scientific and technical production. In our view, these contributions address key issues faced by science and technology policy makers for the implementation and evaluation of CRCs as policy.

5.2 CRCs as organizations

Much of the scholarly research directly or indirectly addresses CRCs as organizational and interorganizational phenomena (Siegel et al. 2001). Like broader organizational studies, this literature spans multiple levels of analysis, though most often assessments of CRCs occur at the programmatic and individual levels with limited study of populations of CRCs (Gray 2000).

At the individual level, past study ranges from basic descriptions of researchers participating in CRCs, for instance in terms of their personal and professional characteristics (e.g., Corley and Gaughan 2005), to predictive assessments of individual behaviors in CRCs, including patenting (e.g., Moutinho et al. 2007), publishing (e.g., Ponomariov and Boardman 2010), industry involvement (e.g., Boardman 2009a), and broader collaboration patterns (e.g., van Rijnsoever et al. 2008; Boardman and Corley 2008). Other individual-level assessments have focused on unintended outcomes, such as role strain and shirking in CRCs (e.g., Boardman and Bozeman 2007) and intraorganizational competition among individual collaborators in CRCs (e.g., Carayannis and Alexander 1999). This component of the literature on CRCs employs a number of perspectives, including widely-used

approaches from management and organizational studies such as the resource-based view of collaboration, sociological approaches like role theory and social capital theory, and from economics human capital theory and game theory. Some assessments (Boardman 2009a) employ multiple perspectives to frame individual-level behaviors in CRCs.

Two of the contributions to this *Special Issue* examine how organizational factors affect individual-level responses to CRCs. Sam Garrett-Jones (University of Wollongong), Tim Turpin (University of Western Sydney), and Kieren Diment (University of Wollongong) examine how department-based researchers perceive the costs and benefits of participation in centers and how these perceptions are affected by center structures and management practices. Beth Coberly (North Carolina Department of Health and Human Services) and Denis Gray (North Carolina State University) conduct a multivariate analysis to explore university, CRC, and individual-level antecedents to faculty satisfaction in NSF IUCRCs. While the challenges associated with managing faculty in CRCs are well-documented, these studies mark important contributions by assessing across multiple centers the institutional and structural correlates to these challenges.

Because a key function in the management and operation of CRCs is the coordination of researchers with diverse institutional affiliations, disciplinary backgrounds, and goals, many organizational interpretations of CRCs occur at the organizational level of analysis and in particular focus on interorganizational activities and processes to facilitate scientific productivity and outcomes like transfer. However, most of these studies address the organizational characteristics not of CRCs but of the private firms partnering with centers, including (among other factors) firm structure and culture (e.g., Gopalakrishnan and Santoro 2004), size and technology (e.g., Santoro and Chakrabarti 2002), and geographical proximity to CRCs (e.g., Santoro and Gopalakrishnan 2001). This points up an important gap in our understanding of CRCs as organizations. There is little general knowledge of structures and management practices within CRCs and how these facilitate or not particular types of contributions from center participants, with exceptions being Toker and Gray's (2008) assessment of workspace design and Gray's (2009) study of strategic planning in IUCRCs and also Carayannis and Alexander (1999) work on "intelligent organizational interfaces" for CRCs and research collaborations more broadly.

One of the contributions to the *Special Issue* addresses the gap in understanding of CRCs as organizations. Donald D. Davis (Old Dominion University) and Janet L. Bryant (Personnel Decisions International) use leader-member exchange theory to frame an analysis of relations between NSF IUCRC directors and university leaders and demonstrate with survey and interview data the importance of these relations to center performance. In our view, this contribution addresses two fundamental realities for the management of university-based CRCs, at least in the US. First, these centers are embedded within larger institutions (universities) upon which they are reliant for resources, including but not limited to department-based faculty. Moreover, this type of CRC is relatively constrained in terms of the structural and managerial options available for inducing contributions from boundary-spanning participants towards center goals (Boardman 2009b), and thus relies on center leadership to forge university relations to acquire not only the resources but also the legitimacy required to ensure center performance.

5.3 CRCs as business strategies

Industry collaboration and funding are vital to many CRCs both in the US and abroad. There has been much focus on the benefits that private companies derive from partnering

with CRCs, such as access to upstream modes of knowledge production (Feller et al. 2002) and firm use of such knowledge (Russo 1990), access to graduate students for placement in industry jobs (Feller et al. 2002), technology transfer and commercialization (Santoro and Chakrabarti 2002), and firm spending on in-house research and development (Adams et al. 2001). However, there has been little study of the conditions under which private companies opt to partner or not with CRCs. Given the increasing importance of an open-innovation strategy, this appears to be a critical oversight.

The contribution to this *Special Issue* authored by James Hayton (Bocconi University), Saloua Sehili (African Development Bank), and Vida Scarpello (University of Florida) addresses this gap by analyzing multiple predictors of private companies' decisions to join CRCs with panel data from more than 500 firms in more than 100 industries over a twenty year period. Though some prior work addresses the decision by private companies to renew membership in CRCs (e.g., Gray et al. 2001), the authors draw upon a number of theoretical frameworks and consider a relatively wide range of centers in the interest of arriving at more general conclusions about the environmental conditions and firm-specific contingencies that are antecedent to firm participation in centers.

6 Closing remarks and future research

It is important to acknowledge that given the constraints of a single *Special Issue* the coverage reflected in the following papers is necessarily limited. For instance, the issue does not include a paper on one of the most important and neglected (from a research standpoint) CRC stakeholders—the students and post docs who do much of the research performed in CRCs. From an outcome perspective, none of the papers takes a serious look at the extent to which CRCs lead to the production of qualitatively different and perhaps superior "scientific and technical human capital" (Bozeman et al. 1999) when compared to traditional settings for training and experience in research. From a process perspective, another important but neglected area includes general examination of the organizational structures and personnel management practices of CRCs, which study of private firms focused on research and development demonstrates as fundamental to innovation outcomes (Souitaris 1999; Laursen 2002; Laursen and Foss 2003; Cano and Cano 2006), but provides little guidance for CRCs. Other gaps and unaddressed questions are highlighted in the individual article contributions. Having acknowledged these limitations, we hope that the current issue will serve as a catalyst to other researchers to expand understanding of these critically important collaborative vehicles for promoting technological innovation and ultimately social and economic development.

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