Craig Boardman · Denis O. Gray
Drew Rivers *Editors*

Cooperative Research Centers and Technical Innovation

Government Policies, Industry Strategies, and Organizational Dynamics

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Foreword

Understanding What We Can Do More and Better in Cooperative Research Centers

This book is a long overdue compilation of theoretical and empirical work on understanding cooperative research centers, mostly in academic settings. As such, it encompasses a wide range of foci, methods, and points of view. It will be a major helpmate for academic scholars in this field. It will also be useful for academic managers and public sector leaders who worry about how to make university research more responsive to a variety of stakeholders (including the private sector) and better able to leverage cross-disciplinary science. Finally, the selections will be useful for industry-based R&D managers looking for vehicles to engage university research and talent.

This volume is also timely for another reason, which is embodied in focused thinking about the nation's ability to be an innovative economic leader and a job creator for the many talented recent graduates who are currently less than fully employed. Some of the featured articles deal with that head on, all do by implication—for example by collecting and analyzing data on the varieties of how industry engages universities in the context of cooperative research centers and the benefits that derive from those relationships. For example, based on evaluation research conducted at some centers, we know that many of the graduate students who work on center-related projects end up with multiple job offers from industry partners (Scott et al. 1991). This is a positive outcome for all stakeholders. Moreover, access to bright students is a big plus for companies participating in centers.

To set the stage, several chapters comment on the scope or spread of cooperative research centers in universities and other settings such as government agencies, along with useful frameworks on how they are defined operationally and structurally. The opening selection by Gray, Boardman, and Rivers provides an excellent discussion of both population estimates as well as definitional issues and what's in

and what's not. These are good navigational aids for someone who is not familiar with the terrain.

For example, one of the more interesting definitional issues concerning cooperative centers is the nature and scope of private sector involvement therein. Since a presumed benefit of cooperative centers is their potential for impacting economic activity, at both the firm and industry level, one might have witnessed over the years a burgeoning of industry financial support of university research, with centers in the van of progress. In fact that has occurred at some institutions where the fraction of industry research sponsorship has climbed to 15–20% of total expenditures and where there are a relatively large number of cooperative centers; The Ohio State University, Georgia Institute of Technology, and North Carolina State University are examples of this phenomenon. Nonetheless, the fraction of university research that is industry-sponsored in the USA has held steady at around 6% for over decades. One of the potential benefits of this volume is that greater knowledge among industry leaders of how centers work, and the variance in the nature and scope of industry participation, might move the needle a bit on the scope of involvement.

One of the more interesting realities of the book is that this is the *first* summative amalgamation of theory-driven empirical research on the phenomenon of cooperative research centers, despite the fact that centers of this nature have been around for well over 30 years in the USA. Programs such as the Industry University Cooperative Research Center at NSF date from the early 1980s and were followed by many other models in the USA and elsewhere. So, what was the hard knowledge base that defined those programmatic innovations early in their history? In a word, not much and it was mostly experiential. During the era in which the centers programs were established at NSF, another organizational section was doing a review of the literature on innovation processes, which led to a volume that had significant readership for several years (Tornatzky and Fleisher 1990). What was mostly missing in the innovation and R&D management literature at that time was empirical studies on cooperative research. That has changed. This volume of studies represents a robust response to the need for empirical and theoretical understanding of the cooperative research phenomenon.

By way of contrast, in 1998 a guide for *Managing the Industry/University Cooperative Research Center* (Gray and Walters 1998) was commissioned by NSF, with each chapter addressing a practical problem of launching and managing an IUCRC. Looking at the citations at the close of each chapter, the ratio of "wisdom literature" to empirical research was pretty high. Interestingly, the work presented in the current volume—and within a growing body of work—would enable a much more informed guidebook—not a bad idea. This volume is a great start on that task.

The selections herein represent a rich multi-level analysis of how cooperative centers work, along with some empirically based insight into how they sometimes don't. Each chapter provides information on how interactions and exchange relationships among faculty, agencies, and industry participants are themselves nested within different options of organizational structures or processes.

One very interesting example of this is the implicit and explicit differences in processes and outcomes that accompany alternative financial and organizational roles for industry. For example, across different flavors of centers, industry organizational roles vary from interested advisor to key decision maker, with financial participation ranging from non-funder to majority funder. Across chapters and authors, industry readers will find useful information about these different approaches. So too will readers from state programs or non-profit organizations find useful information on how centers operating in different venues are organized and/or funded.

Several of the chapters comment on the processes via which cooperative centers enable innovation, particularly innovation that has commercialization potential and the policies and practices that enhance the likelihood thereof. Those observations are timely and appropriate. As described in the volume's entries, the centers phenomenon started in the early 1980s, with NSF as a primary locus. Also, in 1980 the Bayh-Dole bill was passed which enabled US universities to retain title to patented or otherwise protected inventions that emerged from government-sponsored research, with the important proviso that royalties and other revenues would be shared with faculty advisors.

Early in the post-Bayh-Dole era, the majority of commercialization deals involved larger established companies. However, that began to shift at an accelerated rate such that a healthy fraction of current licensing deals ended up involving startup or early stage companies. Consistent with this trend, today nearly 30% of memberships in the NSF IUCRC program are held by small firms. Moreover, in an interesting organizational anomaly, the Division at NSF that was the birth home for the NSF IUCRC program also was the locus of the fledgling version of the Small Business Innovation Research program, which became government-wide in the early 1980s. So, centers and entrepreneurship co-existed at the onset and are still policy and program bedfellows, and technology transfer lore has increasingly highlighted university startups that became rather successful (e.g., Google).

A parallel phenomenon over the past 10–15 years has been the massive growth of entrepreneurship curricular majors and minor (exceeding all other academic majors) along with the founding of several hundred entrepreneurship centers or institutes. This has, in turn, impacted how government-based programs construe their mission. In a recent agency example the National Science Foundation, the inventor and home of the largest number of center programs of various types, has within the last few months of 2011 founded an Innovation Corps program. This interesting organizational departure targets highly productive research faculty members and put them through what amounts to an entrepreneurship boot camp led by widely experienced Silicon Valley entrepreneurs. As a counterpoint datum, a recent survey from the Ewing Marion Kauffman Foundation indicated that 54% of 18–34 year-olds want to start a company or have done so.

These phenomena among stakeholders in the science, technology, government, and business communities foster discussion about where to place their bets in terms of public and private investment and how to better integrate such activities with existing programs. These concerns raise important questions as well as many

opportunities for cooperative research centers, many of which are addressed in the current volume. For example: What kinds of substantive questions are more likely to lead to innovations that have significant commercialization potential? How can the nature of industry involvement in centers be tuned so as to maximize innovation impacts and commercialization if that is the policy objective? We need to know the innovation ecosystem better, and how cooperative research as a key component, is part of the mix.

In fact, the nature of cooperative centers—their structures, processes, missions, and participants—holds great promise for being major contributors to innovation into the future. Their ability to conform more to a cluster-based conscious geography (see Chap. 12), to draw in research faculty who are interested in questions that cross boundaries (see Chap. 5), to address cross-sectoral questions (see Chaps. 3 and 4), and to attract cutting leading companies' participation suggests that the basic approach is robust for addressing these important challenges. As we understand more clearly the phenomena involved, we will all do better.

In summary, this is a volume that is practically useful, conceptually interesting, and important from a public policy perspective. Students of and practitioners in R&D, innovation, and cooperative relationships should read it closely.

San Luis Obispo, CA, USA Louis Tornatzky

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Finally, as we have strived to point out in this volume, the success of CRCs examined in this volume depends on the collaborative efforts of individuals from industry, universities, public research labs, and local and national government. This volume would not have been possible without the help and cooperation of countless individuals from these sectors and communities who care about the success of these cross-sector partnerships and shared their ideas and opinions about these novel organizational structures with us and the authors of individual chapters.

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Part I
Introduction

Chapter 1
The New Science and Engineering Management: Cooperative Research Centers as Intermediary Organizations for Government Policies and Industry Strategies

Denis O. Gray, Craig Boardman, and Drew Rivers

1.1 Introduction to the Volume

This edited volume is focused on enhancing understanding a particular type of intermediary organization – cooperative research centers (CRC). 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 and 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 research centers including innovation centers, industry-university centers, engineering research centers (ERC), university research centers, industry consortia, centers of excellence, proof of concept centers, among others, that emphasize differences while ignoring or downplaying the common conceptual, theoretical, policy, organizational, and management issues that affect all of these endeavors.

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 volume illustrate, the CRC model is a versatile social and organizational innovation that can be structured in a variety of different ways and produce different results under different circumstances.

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However, these differences have little to do the programmatic labels we give to centers. Instead, these differences are contingent on a variety of factors including public policy goals and funding structures, the nature of partnership relations, differences between scientific fields and industry sectors, and factors operating at the organizational level including management differences and the aggregated characteristics of the individual scientists and other stakeholders attracted to and involved with these centers.

Given this set of circumstances, the motivation for this edited volume is twofold. First, we would like to stimulate greater discussion within the policy and scholarly communities about what constitutes a CRC and whether one can identify factors that define meaningfully different "types" of CRCs. Toward this end, we will offer our definition of CRCs and factors that help define general types of CRCs in this introduction. 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 CRCs.

Thus, in this introductory chapter we attempt to accomplish a number of goals. Specifically, we highlight the societal, policy, organizational, and related forces that led to the development and growth of CRCs; we identify factors that help clarify what organizational arrangements are and are not CRCs while highlighting other factors that begin to form the basis for developing a meaningful typology of CRCs; we explain why the policy and scholarly community should be interested in CRCs; and finally, we highlight some of the core theories, issues, and themes that are critical to gaining a better understanding of the processes and outcomes of CRCs and how the individual chapters of the volume address these core theories, issues, and themes.

1.2 Key Drivers Behind CRCs

Over the past several decades, a variety of forces have changed the way science and research are conceptualized, planned, and executed in both the private and public sector. These factors include: 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 (Fagerberg et al. 2006). As a result, CRCs may be best understood as a social and organizational response to at least three developments that have changed innovation systems globally: the collectivization of research, the emergence of a cooperative paradigm for guiding research policy in the United States and abroad, and the development and implementation of "open" approaches to innovation by industry and other stakeholders.

1.2.1 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 studying these phenomena have begun to refer to it simply as "team science" (Stokols et al. 2008).

However, team science cannot flourish for very long without supporting organizational structures and processes, particularly when it is trying to take root within academic departments and discipline-focused government research enterprises that are ill-equipped and to some extent antagonistic to the multidisciplinary and more problem-driven approach towards complex problems. To a large extent, CRCs are the organizational solution to the problems team science poses for disciplinarily and bureaucratically structured institutions like universities (Etzkowitz and Leyessdorf 1998). CRCs provide structures and mechanisms that facilitate the management of large complex portfolios of projects, disciplinary and sectoral boundary spanning, and that help support coherent and widely embraced research strategies. However, as the more recent literature suggests (Boardman and Bozeman 2007; Gray 2009) and as several of the chapters in this edited volume illustrate, these same structures and processes also present challenges for those who would participate in and/or manage these complex organizations (see the chapter contributions to this edited volume by Sam Garrett-Jones, Tim Turpin, and Kieren Diment and by Donald D. Davis and Janet L. Bryant).

1.2.2 The Emergence of the Cooperative Paradigm for Research Science, Technology and Innovation 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 United States and abroad have increasingly emphasized a cooperative paradigm for Science, Technology, and Innovation (STI) policy. In this cooperative paradigm, 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 (Dietz and Bozeman 2005) 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) 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) (Gray 2011).

Characterizations of publicly funded research have highlighted the cooperative paradigm of 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, Leydesdorff, and others (Etzkowitz and Leydesdorff 1998, 2000) in a series of influential articles examine at the organizational and individual levels 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 STI 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."

The changing role of government in science and technology has elicited as much concern as enthusiasm. Much of this concern has been focused on the effects of government intervention in the scientific enterprise, and more specifically the negative effects of the cooperative paradigm, on the educational missions of universities (Slaughter and Rhoades 2004; Slaughter and Leslie 1997). However, the extent to which these concerns are warranted is open to debate (Baldini 2008; Behrens and Gray 2001) and is addressed by some of the chapters in this edited volume (e.g., the chapter contribution to this volume by Branco Ponomariov and Craig Boardman).

1.2.3 Extra-Organizational Partnering and Open Innovation in Industry

Another impetus for the growing importance of CRCs is growing recognition in the private sector of the importance of extra-organizational sources for promoting technological innovation. Beginning in the final decades of the twentieth century, informal networks and more formal coordination were recognized as offering competitive advantage, whether by capturing knowledge and information flowing through networks (e.g., Powell 1990) or by acquiring complementary capabilities residing in the routines and processes of strategic partners (e.g., Prahalad and Hamel 1990). These perspectives maintained a focus on transferring knowledge and technology into the organization as a path to creating and exploiting value in the market, and marked a movement away from the "not invented here" approach to 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 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 an informal supplemental strategy, fueled by an appreciation of the value of organizational networks, to a primary driver for innovation.

Interestingly, one of the more important developments related to focus by industry on open innovation has been the rise in intermediaries and intermediary organizations (Chesbrough et al. 2006; Howells 2006), like CRCs. However, using intermediary organizations like CRCs to achieve open innovation goals creates a variety of challenges including insuring one has the absorptive capacity needed to exploit these transactions, being able to capture the payoff from what used to be considered spillovers, understanding and exploiting nontechnical behavioral additionality benefits, and effectively managing a variety of interorganizational relations (Chesbrough et al. 2006). The chapter contributions to this edited volume by James C. Hayton, Saloua Sehili, and Vida Scarpello and by Drew Rivers and Denis O. Gray address some of these challenges identified by the open innovation literature as they pertain to CRCs. The chapter by Irwin Feller, Daryl Chubin, Ed Derrick, and Pallavi Pharityal highlights some of the methodological challenges involved in documenting these impacts.

In our view, the joint influence of the collectivization of research, the cooperative paradigm for STI policy in governments, and the growth of open innovation strategies in industry have contributed to the growth of the social and organizational innovation embodied in the CRC. In fact, we believe it is the only STI policy mechanism that captures the benefits of all three of these innovation enabling developments.

1.3 Towards a Definition of CRCs

One of the factors that limits our understanding of CRCs is the lack of a widely agreed-upon definition. Because there is a diverse collection of intermediary organizations and a number of different types of organizations have been investigated under the "centers" label, understanding 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.

1.3.1 Programmatic Definitions of CRCs

Perhaps the earliest use of the phrase "cooperative research center" 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 ERC 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 inside and outside the United States (Lal et al. 2007; Coburn 1995) often include nonuniversity research performers and sometimes are organizationally independent of universities. For instance, Australia's long-standing Cooperative Research Centers program (founded in the early 1990s) defines a CRC as "an incorporated or unincorporated organization, formed through collaborative partnerships between publicly funded researchers and end users."[1] Similar, the Basque government in Spain sponsors a CRC program that supports a series of nonprofit 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 intermediary organizations (Chesbrough et al. 2006) that are publicly funded and that employ full-time researchers outside of

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

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

universities to achieve economic and social goals with science and technology for "end-users," be they private industry or the broader public. The chapter contributions to this volume by Jennifer Clark and by Bhavya Lal and Craig Boardman address this broadened notion of CRCs by assessing international practice for CRC mission, organization, and management.

1.3.2 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 comprise faculty members from more than one discipline or field, and engaged in problem-focused and/or commercially relevant research and development. Table 1.1 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 intermediary organizations, which has led to a great deal of confusion in the scholarly and STI policy communities. On one hand, any team-based research endeavor that takes place within an organized research unit may be characterized as a CRC; on the other hand, many center-type endeavors that appear to be truly cooperative but that do not use the term (e.g., numerous Centers of Excellence programs at the state level) 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 we described (see Sect. 1.2) and avoid many of the problems inherent in the programmatic and general university-centric definitions alluded to above:

> 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.

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*. Figure 1.1 provides a graphic representation of innovation-focused mechanisms that would not be considered a CRC because they lack at least one element specified in our definition of CRCs.

Table 1.1 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 semiautonomous 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 emphasize research strength, aimed at encouraging external funding bodies to support the research…	Zajkowski (2003, p. 206)

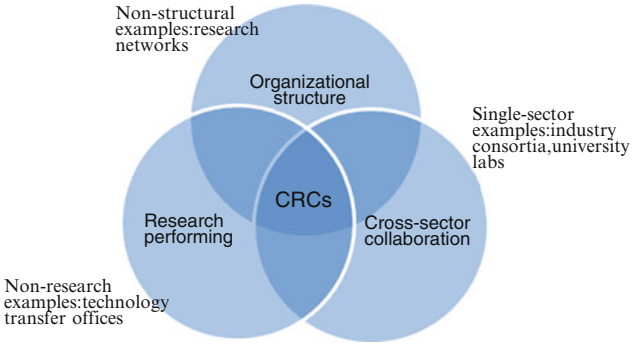

Fig. 1.1 Definitive characteristics of CRCs (and nonconforming examples)

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. 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 semiautonomous 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).

Last, given the centrality of cross-sector collaboration to the cooperative paradigm for STI policy that led to the earliest CRCs (described in Sect. 1.2.2), our definition limits CRCs to centers that are focused on joint and/or cooperative 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 sponsored by 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 STI 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 nonprofit organizations can also be found.[4] In the United States, CRCs are typically based in universities though increasingly they can be found in government agencies (Boardman and Ponomariov 2010). However, international models (Lal et al. 2007) and state-level models in the United States (Coburn 1995) demonstrate CRCs oftentimes are standalone public entities that are organizationally

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

[4] For example, a long-standing independent nonprofit 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.

distinct from universities and government. While industry-based research consortia exhibit organizational formality, conduct research and facilitate within-sector collaboration, if they do not include a formal mechanism to secure research from universities or other public sources, they would not meet our definition of a CRC.

Each of the contributions to this volume address organized research units or intermediary organizations that meet the criteria we have laid out for CRCs. Our intention in presenting criteria is to generate discussion in the interest of developing greater coherence in both practitioner and scholarly treatments of CRCs.

1.4 Towards a Typology of CRCs

As we suggest above, although we believe there are a small set of characteristics that help define the organizational form we call CRCs (see Fig. 1.1), one of the other qualities that make CRCs so valuable is the heterogeneity they exhibit across these characteristics. By taking on different profiles in terms of their organizational structures, research and technology development agendas, and interactions across sectors, CRCs can and have been used to achieve knowledge creation, technology transfer, commercialization, economic, and human capital development goals for private firms and for local, regional, and national units of government. However, we feel strongly that the organizational form must be tailored to the desired outcome.

Clearly, both public and private sector interests would benefit from having a typology that highlights variation across CRC characteristics and relates it to various goals, outcomes, or longer term impacts. Motivated by similar objectives, scholars have attempted to develop typologies for various boundary-spanning or intermediary organizations that are either much broader or much narrower than our definition of CRCs. For instance, some have offered broad typologies or at least morphologies for "science-industry collaborations" (Carayol 2003; Tierlinck and Spithoven 2010), "research partnerships" (Hagedoorn et al. 2000), and university-based organized research units which include "university research centers" in addition to traditional departmental labs and other hybrid units (Bozeman and Boardman 2003). However, because of the lack of definitional consensus we discussed earlier, a definitive typology of CRCs does not currently exist. We believe there is enough overlap among the existing typologies and also sufficient theory and research on CRCs to begin the development of a CRC typology.

Our goal in proposing a typology is twofold: to provide an interim tool for policy makers, program managers, and private sector interests interested in designing new or optimizing the effectiveness of existing CRCs, and to stimulate additional theory building and research on the processes and outcomes of CRCs. Toward these ends, our typology is based on what we interpret as objective and potentially measurable characteristics of CRCs that either theory or research suggest will result in (a) variation across the three defining characteristics of CRCs (i.e., cross-sector, research performing, and organizational structure; revisit Fig. 1.1) and therefore are (b) related to different objective and potentially measureable CRC processes and outcomes.

So we *begin* our typology of CRCs with two dimensions: higher education-based vs. non-higher education-based (or university-based vs. not), and bilateral vs. network collaboration format. We start with these two dimensions because they represent major differences across CRCs that are easily validated and that theoretically and empirically are known to lead to substantial differences in our three defining characteristics for CRCs (Fig. 1.1). For example, CRCs based in a university can be very different than CRCs that are not university based (e.g., government-based CRCs) in terms of their research and cross-sector collaborations and therefore in terms of their organizational structures and overall governance. The same can be said of networked vs. bilateral CRCs—the former typically having many loosely connected and therefore informal institutional partners including multiple firms, government labs, and university labs and the latter limited usually to two or at most a few "nodes" (e.g., a particular university lab, and a particular firm) tied to one another by way of formal and project-specific contracts.

In our discussion of the two *starting* dimensions of our typology, we discuss how these may lead to different variants of the three defining characteristics of CRCs outlined above; we also address briefly the implications of inter-quadrant variation for CRC performance and outcomes. We conclude our discussion of the typology by addressing *intra*-quadrant variation across the three defining characteristics of CRCs: organizational structure, industry interactions, and research performance, e.g., for university-based CRCs engaging in network- or consortial-style collaborations.

Typology Dimension 1: Higher education-based vs. *non-higher education-based CRCs.* While the overwhelming majority of CRCs receive some if not most of their funding from local, regional, or national government sources, they do vary on which sector they are embedded within. Some CRCs are part of and/or directly connected to a higher education institution or university while others are considered a government and/or not-for-profit organization (or part of one). The former includes industry-serving university research centers (Cohen et al. 1994) while the latter includes what Tierlinck and Spithoven (2010) called pubic research centers (government or nonprofit) such as many of the government-funded centers of excellence found around the globe.

These two types of CRCs tend to look very different, have different operational strengths and weaknesses, and lend themselves to different kinds of outcomes (Lal et al. 2007). Specifically, according to Tierlinck and Spithoven's (2010) research in Belgium, public research centers were more likely to be oriented toward practical knowledge, to be prepared to respond quickly to industry requests, possess complex and sophisticated facilities and embrace large-scale research missions, and have a professionalized research staff and project management infrastructure than higher education-based CRCs. These authors examine the impact of this difference on the "installment" of science-industry collaboration (e.g., creation of new collaborations), and found that regionally funded public CRCs have a greater impact in this domain than university-based CRCs. They also suggested these types of arrangements are more likely to meet the needs of firms that are interested in assistance related to immediate commercialization, and we agree.

However, higher education-based CRCs are likely to have their own advantages. For instance, higher education-based CRCs that possess world-class faculty are more likely to provide a basis for transformational and even translational research outputs and outcomes. They are also much more likely to produce behavioral additionality in the form of faculty involvement with industry (Boardman 2009) and significant science and technology human capital impacts (Bozeman and Dietz 2001). At the same time university-based researchers are also more likely to experience role conflict and role ambiguity (Boardman and Bozeman 2007), which Garrett-Jones and colleagues show in their chapter contribution to this volume can be disruptive to center performance.

Typology Dimension 2: Bilateral vs. *network-based CRCs.* In his empirically based typological paper on science-industry collaborations, Carayol (2003) identified five types of collaborations that were based on four distinct dimensions. We believe at least one of those dimensions, bilateral vs. network-based (or consortial) collaborations has great relevance to CRCs. According to Carayol, bilateral collaborations take place between one researcher or research organization and another while a network-based collaboration entails a consortium of research partners that operates collectively. According to Carayol's findings, network or consortial collaborations look and operate very differently from bilateral collaborations. Network arrangements that necessitated the sharing of intellectual property rights (IPR), tended to have substantial public funding, and conducted research that was much more fundamental or basic. At least one study, specifically examined goal differences between these two types of collaborative arrangements. When asked about the importance of various goals for their collaborations, both faculty and industry respondents who were involved in a bilateral collaborations rated patent and product development as their top two goals and general knowledge expansion as their lowest rated goal (Gray et al. 1986). In contrast, faculty and industry participants involved in a consortial or network-based research collaboration both rate general knowledge expansion as their top goal and patent and product development as among their lowest goals. Our own research has demonstrated this effect in fairly dramatic fashion (Boardman 2009).

Thus, we believe there are a number of operational and outcome implications for CRCs based on whether they adopt a bilateral or network-based model. First, the bilateral form will be much easier to engage firms in and to manage,[5] particularly for firms where exclusivity of IPR is important. Empirical support for this position is presented in the chapter on member recruiting by Drew Rivers and Denis O. Gray. On the other hand, because research that is more applied and directed toward patents and product development can sometimes present conflicts for faculty who are committed to more fundamental research and open dissemination of findings, a bilateral format would certainly cause more conflicts (than a network-based CRC).

[5]One exception may be consortia explicitly organized around developing industry standards, where firms have a vested interest in reaching some consensus on design standards. The research organization serves as a mediator in this case.