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Theoretical Consideration of Collaboration in Scientific Research

Juan D. Rogers

Introduction

Collaborative research has grown significantly in recent times and has come to be considered one of the main features of contemporary science. It is reflected in the growth of co-authored papers (Hicks and Katz, 1996), in the division of scientific labor required by large experimental equipment (Knorr-Cetina, 1998), and in the assembling of multidisciplinary teams in research centers (Etzkowitz and Kemelgor, 1999). As a strategy in the pursuit of excellence in research, collaboration is not simply an alternative that can be selected or rejected among other paths to follow. It is inherent in the conduct of competitive research and found to a greater or lesser degree everywhere scientific research is conducted.

Recent times have seen an increase in the variety of arrangements and contexts in which research is conducted. Some studies emphasize the fact that stereotypes of the academic environment where scientists produce knowledge within the bounds of established disciplines is no longer applicable, if it ever was. A great proportion of the Nation's research effort is conducted in hybrid organizations that combine characteristics of the academic world, private industry, and government laboratories (Gibbons et al., 1994). In other words, various modes of collaboration are now inherent in the practice of science and not merely an option to be considered to increase the chances of success.

Collaborations to achieve excellence in research take place at the level of individual researchers and research teams, while most analyses of the competitiveness of research are aimed at the institutional level and take the university as the unit of analysis.[1] This chapter addresses the issue of the interactions between the two levels. The policies established by research universities will have an impact on the research arrangements and collaborations the researchers are able to set up (Katz and Martin, 1997). The chapter will show how understanding the main types of organizational arrangements and the dynamics of the practice of research can contribute to the design of institutional policies to increase competitiveness.

The chapter is organized as follows: the first section reviews some important studies on collaboration in research to show both its importance in contemporary science and the need for understanding the structural characteristics of collaborations in order to derive lessons for the management of research. The second section addresses the inadequacy of a "project" focus in understanding the organization of research. It proposes a new theoretical approach called the "knowledge value framework" and it presents this framework as well as a typology of the proposed units of analysis. A final section considers the implications of this framework for institutional strategies to increase competitiveness in scientific research via collaborative efforts.

PREVIOUS STUDIES ON COLLABORATION

Many reports have addressed the increasing number of collaborations in research, beginning with De Solla Price as long ago as 1963 and more recently with papers on international collaboration (Luukkonen et al., 1992). Hicks and Katz studied the growth of inter-institutional collaborations within the British system by examining over the years the rates of co-authorship (authors with different institutional affiliations). In 1981 the average number of articles with co-authors was 2.63 and by 1991 it was 3.34, with a linear increase of .08 ± .01. By now it is projected to be around 4 (Hicks and Katz, 1996, p. 390). If the trend continued, the number of collaborative articles must have exceeded the number of non-collaborative publications around the end of 1999. These authors see the increase in research collaborations as part of a general trend in science that is explained by the increasing need to pool resources, skills, and competencies in order to make significant contributions.

Ethnographic Studies and Structural Characteristics of Collaborative Research

The characteristics of collaborations in science have been studied with a microsocial, ethnographic focus (Knorr-Cetina, 1998; Zabusky, 1995; Schild, 1997). These studies reveal several aspects of the culture of "big science" in which these collaborations take place, since the research primarily examines fields in which large investments are necessary. Examples of these are high-energy physics experiments with particle accelerators (Knorr-Cetina, 1998); space science that requires telescopes, satellites, rocketry, and so forth (Zabusky, 1995); and polar research, with its use of ships and teams of people to run the expeditions for the research projects.

In a review of this literature, Chompalov (1998) points out that although these studies reveal the patterns of communication, the development of consensus, how conflict emerges and how it is resolved, and the process of decision making and the division of labor, they do not examine sufficiently the structural properties of these collaborations. Nor do they connect the patterns they find to the outcomes of the research. In other words, they do not pay sufficient attention to collaborations as goal-oriented arrangements. However, this is crucial knowledge for understanding the relation between collaborations and effectiveness or competitiveness in research.

Chompalov and Shrum (1999) then showed that among several structural dimensions of collaboration in science, the dimension of technological practices, taken as a single structural dimension, has the most predictive power with respect to outcomes such as success, trust, conflict, documentary practice, and stress. The notion of technological practices leads to a sharper typology of collaboration. This typology accounts for the various ways in which research collectives adjust their organization to the demands of the technical exchanges of the work. The significance of this finding lies in the fact that, from a management point of view, the interplay of knowledge or technical goals with the structural characteristics of the organizational arrangement is critical for the evolution of the research program.

University/Industry Collaboration

Collaboration between academic science and industry has received much attention because it is believed to be the main channel for the flow of knowledge created in the universities to the profit-making sector. The often disputed but still widely held "linear" model of innovation provides the rationale for this belief. Challenges to the linear model have brought about a skeptical view of the actual contribution of academic science to market-oriented innovation (Forrest, 1991; Faulkner and Senker, 1995; Kline and Rosenberg, 1986). Most observers conclude that the knowledge inputs from academic science to the process of innovation represent only a small fraction of the knowledge resources that are actually brought to bear on the industrial innovation process (Faulkner and Senker, 1995, p. 36). However, collaborations between university researchers and industry do not seem to be decreasing. On the contrary, especially with the explosion of entrepreneurial ventures by academic researchers in the realms of biotechnology and information technology, the fundamental values of academic science may be undergoing a transformation to accommodate a new orientation toward the business of university research (Etzkowitz, 1989).

On the surface of things, it seems contradictory that the contribution of knowledge created in academic science to marketable innovations is small while both the role of knowledge in the economy and the frequency and variety of university-industry linkages are growing. Two factors seem to contribute to this apparent contradiction. On the one hand, with the greater emphasis on the role of knowledge in the economy, the diversity of sources and kinds of knowledge important for economic activities has also become evident. In this more complex picture, academic science is a component of varying relative importance. On the other hand, and more importantly for our purposes in this chapter, the importance of the organizational and material arrangements for the creation and use of knowledge has superseded the focus on knowledge as information (Callon, 1994b). Therefore, what matters most when analyzing contributions to innovation are the actual dynamics of the linkages between knowledge-related activities in universities and firms. This changes the focus from the input of knowledge produced by universities and elsewhere to industrial innovation to the various forms of collaboration between universities and industry. As will be shown in more detail below, the nature of these linkages is not an aside in the process of university research, but a dimension that seems more and more intrinsic to academic research efforts as the complexity of their knowledge goals increases.

Federal Lab/Industry Collaboration

The collaboration between federal labs and industry has not received quite as much attention as university-industry interactions. In the wake of shifting policy emphases toward commercial competitiveness, though, there has been a call for increased market relevance of the labs' research (Alic et al., 1992; Branscomb, 1993). As a result, several measures to increase the interaction between federal labs and industry were implemented beginning in the early 1980s (Crow and Bozeman, 1998, p. 181). A study of the industry perspective on these partnerships, paying special attention to the cases in which basic research was a significant component of the interaction, has shown that some traditional assumptions about the long-term nature of the payoff from basic research do not always apply. This is relevant to the issue of collaboration generally because some of the lessons are not peculiar to the environment of the government labs.

First, the study found that 16.4 percent of basic research projects led to marketed products in the brief time span of the collaboration, and another 19 percent had products under development. This result is noteworthy because it alone dispels the notion that basic research is an overhead investment with no real prospect of shortterm return. Second, role specialization helped increase the chances of success of the partnership. Interestingly, those projects in which both the federal laboratory and the company provided basic research were less beneficial in terms of product development and marginal benefit. One cannot directly infer from the data just why this is the case. But several explanations seem plausible and worthy of further exploration. First, joint basic research may require a higher level of cooperation and joint programming, resulting in increased coordination costs. Second, a lack of role segmentation may require a greater melding of organizational work habits and cultures. Since the companies and federal laboratories were likely to have quite different work cultures, with different incentives and rewards, closer cooperation on basic research may accentuate these differences. Our findings suggest that while it is beneficial for companies to contribute several technical roles to collaborative projects, more successful projects entail a smaller, more focused set of technical roles for federal laboratories. This may indicate a different set of requirements for appropriating and applying knowledge than those for supplying knowledge.

The findings provided here may have some implications for possible approaches to research collaboration in general. A fundamental finding is that the choice, at the outset of a project, of complementary technical roles is likely to lead to a shortened technology path. This study shows that some specific combinations of roles work better than others. The knowledge developed here may be applied as a first step in accelerating technology development.

Characteristics and Evolution of Research Units: The Knowledge Value Framework

In seeking to understand and evaluate research, two analytical foci have been predominant. Among scholars, a focus on disciplines often provides insights into the structure and processes of scientific work. Among managers and evaluators, however, the research project is often the key focus. While research projects sometimes give distorted images of actual work patterns, the reason for evaluators' and managers' focus on projects is easy to understand. The project focus often is most convenient because it matches institutional accounting procedures. R&D is often funded on a project basis. Thus, what begins as an accounting and fiscal control convenience often assumes a role as analytical arbiter. The complexity of research-in-practice encourages a focus on simple bureaucratic units, such as the project or program.

For all the convenience of these foci, they may belie actual work practices. In many cases, scientists working with multiple funding sources and multiple sponsors have little notion as to the particular patterns of resource flows. Scientists and engineers use resources generally with little regard to the bureaucratic accounting of the resources. This creates the problem referred to in the evaluation literature as the "additionality" problem (Buisseret et al., 1995). This problem arises when considering what contribution a particular intervention or input makes toward the research outcomes. Most of the time this difference is impossible to establish clearly because the project budget lines are not related directly to the outputs of research activities. Therefore, it is necessary to look at other features of the R&D activities in order to evaluate contributions and outcomes (Georghiou, 1998).

Following on work by Callon and his colleagues in particular (1997; 1994a; 1992), but others as well (e.g., Liyanage, 1995; Rappa and Debackere, 1992; Elzen, Enserink, and Smit, 1996; and, especially, Crane, 1972), researchers from the Georgia Institute of Technology, including the present author, have argued that the terms "R&D project" and "R&D program" fail to capture the inherent dynamism of the interchange between work in R&D laboratories and external influences on and impacts of that work. The building of artificial boundaries between the micro-world of scientists and engineers and the macro-world of other scientists and engineers, commerce, and social institutions that use the work of scientists and engineers produces blinders and, for those of us interested in actually evaluating impacts, leads to misplaced measures and dubious claims.

In a set of recent papers, (Bozeman and Rogers, 2000a, 2000b; Bozeman et al., 1998; Rogers and Bozeman, 2000) we have introduced a new theoretical framework for understanding the dynamics and outcomes of research.[2] The Knowledge Value framework consists of two core concepts: the Knowledge Value Collective (KVC) and the Knowledge Value Alliance (KVA). Whereas a focus on the R&D project limits the analyst temporally (usually by the official life of the project) and draws a de facto boundary around the persons, inscriptions, and social relations pertaining to the project, the knowledge value focus is more fluid. It is less oriented toward discrete outputs and is not subject to artificial time and organizational boundaries. One major difference between project evaluation foci and a focus on knowledge value interactions is that the latter considers persons who are not scientists or engineers, and who may not be officially parts of projects or work groups, but who nonetheless affect the interpretation and use of scientific work. A second difference is that a focus on knowledge value interactions brings attention to the sustained relationships among parties to these interactions rather than to the discrete outputs resulting from those interactions.

The two main concepts of the Knowledge Value Framework are premised on the fact that collaboration is inherent in contemporary research practice. They are designed to highlight the links between people who participate in research in various capacities and they provide for a more sophisticated understanding of the nature of collaboration in research. Most work focusing on the nature of collaboration relies on such indicators as co-authorship. Focusing on co-authorship, however, ignores the dynamics of the collaboration processes not directly linked to writing a research paper and also underestimates the costs associated with collaboration (Katz and Martin, 1997). The Knowledge Value Collective and the Knowledge Value Alliance are designed to capture the nature and dynamics of the many various modes of cooperation and collaboration that are frequently associated with research activities. We thus argue that the process of research produces certain value that a focus on discrete outputs alone is unable to reveal.

The Knowledge Value Collective

A Knowledge Value Collective (KVC) is a set of individuals connected by their uses of a particular body of information for the creation of knowledge (defined in terms of new uses of information [Bozeman and Rogers, 2000b]). In this process, the collective confers value to the information. It is a loosely coupled collective of knowledge producers and users (e.g., scientists, manufacturers, lab technicians, students) pursuing a unifying knowledge goal (e.g., understanding the physical properties of superconducting materials) but to diverse ends (e.g., curiosity, application, product development, skills development).

The KVC is composed of information/knowledge users who reshape information (knowledge, when actually used) into new packages of information (including technology, which we view as a physical embodiment of information). Knowledge consumers who do not reshape the knowledge but simply consume it without transforming it (e.g., read a newspaper report of a new technology, read a scientific paper, use a commercial software, drive a car) play an important role in innovation and knowledge creation by providing feedback. But "pure consumers" are not considered part of the KVC. Communicating information and producing knowledge are complex, multidimensional activities. Therefore, it is necessary to develop typologies of scientific organizations that account for the diversity of their goals, the strategies they pursue, and the variety of types of knowledge products that constitute their output (P. B. Joly, 1997; Crow and Bozeman, 1998; Joly & Mangematin, 1996; Faulkner, 1994; Callon et al., 1991).

The Knowledge Value Alliance

In addition to the KVC, we consider the Knowledge Value Alliance (KVA). In a sense, a KVA is a more structured and more tightly coupled subset of a KVC. A Knowledge Value Alliance is an institutional framework binding together, in a "knowledge covenant," a set of directly interacting individuals from multiple institutions, each contributing resources in pursuit of a transcendent knowledge goal (the basis of the covenant). Inherent in the KVA concept is the objective of generating multiple uses and multiple types of use of knowledge, for example, the contemporary production of knowledge for technology development, skill enhancement, and understanding of fundamental phenomena. The KVA originates with the activation of a knowledge compact, usually, though not necessarily, through a formal agreement (e.g., a contract or Cooperative Research and Development Agreement, or CRADA), and it terminates when resources are no longer brought to the activities pertaining to the knowledge compact. The KVA is an interactive group but it is not necessary that each member interact directly with every other member. There must be links, however, among the members of the different institutions participating in the alliance agreement. The KVA acts as a selection mechanism parsing specialized information for multiple knowledge uses.

The need to postulate the existence of an entity such as a KVA, rather than continue to explain knowledge-production activities by referring to research teams, projects, or programs, arises from the fact that the latter do not capture the diversity and heterogeneity of the knowledge production we found in case studies. The difficulties are many. For example, the boundaries of research projects are often misleading. They may seem identifiable and bounded in research proposals and budget documents. But frequently, upon further inspection, the research projects are artificial units that exist only for the purpose of securing additional resources for a larger set of research activities that has dynamics of its own. Measuring the payoff of research at the project level can miss most of the activities the actors put their energy into, and it can produce a very distorted picture of the knowledge-production process. Research teams change in ways that are frequently unrelated to individual projects. Their members can be working on more than one team and on more than one project. The cognitive or strategic unity of the research work does not necessarily correlate with its arrangement into teams and projects. Research projects are often administrative units that reflect the jurisdiction of managers rather than the relevant dynamics of the knowledge-production process.

Of course, much high-quality research is done by relatively unconnected teams under a single institutional umbrella, on projects that are reflected quite accurately in their grant proposals. However, research endeavors that do not fit this simpler mold are rapidly growing in importance. In many cases, the projects that do fit the simple model are in early stages that can be quickly outgrown once the uses of their work begin to multiply.

The main focus of a KVA is the pursuit of knowledge, and that pursuit brings all the participants together. In this, it is similar to any scientific pursuit such as disciplinary research teams or projects. However, the multiple-use focus of the KVA highlights the epistemic relevance of program managers, industry advisors or partners, and other participants that would not traditionally be considered members of a research team.

The unifying knowledge focus of a KVA is not simply inferred. One or more formal instruments always accompany informal interactions and connect multiple resource streams to the diverse scientific and technical activities establishing a "knowledge value covenant." These include grant proposals, contracts, CRADAs, and licensing agreements. These instruments not only establish the allocation of resources for the work but also address possible conflicts of interest that may arise from this multi-institutional endeavor. The combination of all of these establishes the unity of the knowledge focus on the one hand, and allows for the diversity of interests and uses of the various participants on the other. In general, academic researchers wish to maintain a degree of autonomy and openness in their intellectual pursuits. Private firms need to appropriate portions of the work for their purposes and have firsthand access to trained graduates. And government agencies either fulfill a facilitator role or actually participate in setting the research agenda based on policy goals.

The description of KVAs so far raises the question of the type of research they generally perform. The collaborative and interactive patterns described here might suggest the increasing importance of applied research as opposed to basic science (Gibbons et al., 1994). However, this is not the case. Furthermore, cases in which the researchers declared basic research as their main knowledge goal almost always had more patents and licenses among their outcomes than cases in which applied research was the main activity (Bozeman and Rogers, 2000a). Most cases we analyzed showed that significant epistemic and economic risks were taken in the context of KVAs.

Types of Knowledge Value Alliances

Analysis of the data used in the case studies revealed several types of KVAs.[3] These types differed in the particular relation between the knowledge-creation activities and goals, and the social structure of the KVA. In all the cases we studied, researchers declared that their main knowledge goal was to conduct basic research. They varied in the degree to which basic research activities were accompanied by other knowledge goals. These goals included developing possible commercial applications, making incremental contributions to their field versus creating new or transforming existing foundations of their field, making fundamental contributions at the boundaries with other fields (inter-disciplinarity) or in emerging fields with contributions from several established ones (multi-disciplinarity), as well as a range of intermediate technical goals varying in specificity.

The social structures of the KVAs varied in complexity. A simple structure would resemble the classic university-based research team led by a principal investigator (PI) with a few graduate students and postdocs. More complex structures would include collaborations with teams in other institutions, consortia, or councils created to share resources and ideas or data, and to provide administrative support for multiple, expanding research goals, or very specific but difficult technical goals. In all cases we were careful to determine when the formal or informal organizational arrangement included links across the sector boundaries, i.e., between the locus of research activities and other government, industry, or academic institutions generally considered not to have an influence on the knowledge-creation activities. Examples of these links are the involvement of program managers from funding agencies, technology transfer officers, corporate councils, and industry representatives or collaborations across these boundaries.

Careful analysis of our cases for variation in these two dimensions—organizational complexity and knowledge goal—revealed five distinguishable types of KVAs that exhibit different combinations of knowledge-production activities and goals, and social-organizational structures. They are the Single-Sector Sporadic Exchange System, the Multiple-Sector Mutually Adapting System, the Enabling

Star System, the Organized Expanding Knowledge System, and the Organized Converging Knowledge System.

Single-Sector Sporadic Exchange System

The cases belonging to this type are the simplest. Most of them are small in terms of the level of funding and the number of people involved both as researchers and as members of the array of relations that form the alliance. Several university-based projects in our set fall under this category. However, a fair characterization of the activities and organizational arrangements shows that they are more complex than they seem at first sight. Many basic science projects focused on a set of fundamental questions, which may or may not have fallen squarely within the confines of a scientific discipline. But they were clearly pursued in an academic curiosity-driven atmosphere and had, at the same time, potential uses that were extra-academic. The latter included possible applications in industry, only conceivable in the long term. They also included training graduate students with skills that industries were interested in, for work in fields that were sometimes only indirectly related to the actual scientific questions addressed in their theses. The relevance of the research was sometimes determined by government agency interests or other factors. The main point is that multi-institutional relationships that existed alongside the knowledge goal were significant enough to consider the ensemble a KVA. However, these interactions remained peripheral to the main activities of the principal investigators.

The main outcomes of this type of KVA are incremental contributions to fundamental science and training students. Frequently, but not always, there are ties with industry via small grants in exchange for information on highly qualified graduates or privileged access to interesting research results via presentations for industry or consulting. However, these interactions are not systematic nor on a regular basis and do not have a significant influence on the research agenda. Research collaborations may occur, but are of the unstructured, informal type with colleagues in the same field. The formality of these collaborations rarely goes beyond common authorship of proposals and papers.

Multiple-Sector Mutually Adapting System

The creation of companies to exploit the results of research is a very well-known development in the R&D system in the last couple of decades. The molecular biology and software engineering fields are particularly prolific in this regard and are said to be transforming the nature of academic institutions (Etzkowitz, 1989). We detected a peculiar dynamic in the cases we studied. The process did not simply entail the commercial exploitation of a scientific result. Rather, it involved a mutual coadaptation of basic research and the formation of an intermediate industry sector. The latter conducted commercial R&D and marketed products that altered the technology base of a large industry sector. At the same time, the agenda for basic research was itself affected by the interactions between university teams and the intermediate industry sector. This was not a simple reorientation toward marketable applications. It involved altering the formulation of basic research questions. An important phenomenon was the circulation of people who graduated out of university research, worked in industry for some time, both in the intermediate sector and the main industrial sector, and then returned to research in the university. In these cases, the program manager of the agency that funded the university research often played a significant role. The manager monitored the division of intellectual labor in the field under his or her supervision and facilitated the management of conflicts of interest so that publicly funded research could be conducted in the context of close interactions with private industry. Thus, the ensemble of university researchers, a spin-off company, and clients from the large industry sector, together with circulating graduates from the research team and a catalytic, public research program manager, constituted a knowledge covenant by which research and industry tracked each other over a period of time with growing mutual impact.

Other cases in this type may show a mutually adapting dynamic without generating a spin-off company. An alternative is the formation of a corporate council where exchanges of personnel, data, algorithms, and software implementations occur. In this scenario, the research activities are directly relevant to the industry sector through its findings, data, or experimental techniques. At the same time, the commercial interests, experiences, and needs of industry significantly shape the research agenda through the exchanges that take place in the specially created forum. In this system the research does not proceed primarily to serve the needs of the private companies that, strictly speaking, are not clients of the research team. Research thus continues to develop according to the epistemic, educational, and other priorities of the team. The results of research are nonetheless of interest to industry and are often patented or licensed as they are integrated into the commercial strategies of industry.

Enabling Star System

These are cases in which the research nucleus has a few researchers who have developed unique expertise in an area that can be developed in many different directions. These cases are typically associated with special experimental arrangements, techniques, and instruments. Many contemporary experimental or instrumental techniques are based on specialized knowledge that is not directly related to the actual systems that are studied with those techniques. Some of these cases involve special instrumental knowledge that has its own theoretical underpinnings. The expansion of the applicability of the instrumental methodology requires the advancement of fundamental knowledge. This leads to research programs with special features because the research agenda moves on many fronts at the same time. On the one hand, the core instrumental knowledge is pursued as a fundamental science endeavor. On the other, what would count as applications of the instrumental techniques are themselves basic research programs. However, "application" here means the application of results of basic research in one area to a basic research endeavor in another field rather than the application of scientific results to commercial technology.

The organizational structure that we found in such cases is set up to pursue collaborations in the fields of application. In our cases, most of the educational contribution of the KVA, for instance, occurred in the fields in which the techniques were applied rather than in the principal investigator's specialty. Collaborators and students work as independent groups in different fields, linked to one another only through the main principal investigator. Industrial relations are pursued also. First, the instruments are commercially developed based on the knowledge at the center of the researchers' work. Second, the fields of application themselves often have components of interest to industry. Students continued their careers both in academic research in the fields of application of instrumental knowledge and in industry in almost equal proportion.

Funding patterns also follow this "star" structure. One main funding source for research may support the central instrumental research program and many of the students in the applications. Principal investigators collaborating in each field often write independent proposals for the problems pursued in their field. The diversity of the research program may also be mirrored by commitments by industry through a number of smaller grants, licenses, and patents, which diversify the resource base and bring the industrial partners closer in the "knowledge covenant."

Organized Converging Knowledge System

These cases exhibit significant growth of their formal organizations and institutions as the pursuit of the knowledge goal advances. As the organization's size and complexity increase, the knowledge goal becomes more and more specific and narrowly focused. The growing importance of the specific knowledge goal requires the increasing organizational support. It generally is a high-stakes goal that puts significant competitive pressure on the KVA. The narrow focus of the knowledge goal does not mean that it represents a straightforward scientific problem. Rather, we saw a correlation between convergence toward a technical goal and the establishment of an administrative apparatus that could manage the complexity of the various use-and-transformation relations.

What characterizes these cases is that various streams of basic science converge on a single result or cluster of results that is perceived by many to be of great epistemic and economic importance. As this happens, efforts get more organized and formalized in order to achieve that goal. As the knowledge goal gets specified in more detail, an administrative apparatus is set up to facilitate the needed exchanges between scientists, between institutions, and between sectors. The leading individuals in these systems often were not research principal investigators but technically savvy administrators who were able to facilitate the exchanges between the members of the various teams as well as shield their work from the external pressures of competition and resource acquisition. The self-regulating aspect of basic research agenda setting was temporarily superseded by a more complex and sizable organizational effort that simplified the short- and medium-term research pursuit for the researchers.

Organized Expanding Knowledge System

In some cases a large-scale effort was launched to develop and lead an entire sub-discipline of science, such as combustion, complex carbohydrates, or plant biology. The knowledge goals were broad and several research efforts developed in parallel within a single institution. The organizational arrangement was generally based on a center created for that purpose and housed either in a university or a national laboratory. Most of the research was carried out by resident scientists. However, with the achievement of the first results and the multiplication of uses, the center became a reference for scientific efforts elsewhere. Several of its researchers then took significant responsibilities in organizing conferences, chairing program committees, leading editorial boards of new journals created for the subfield, and so on. At the same time, the center became the main hub for relations with government agencies that fund most of the research within the center as well as elsewhere, and for relations with industry. In all of these cases, the contribution to science by the KVA has been of great impact, to the point of creating a clean break and a new direction of research in the particular field.

The Dynamics of KVAs

Table 1 shows the five types of KVAs using the two-dimensional matrix of organizational features and epistemic characteristics. The location of the five KVA types on the table suggests paths of evolution of the peculiar combination of knowledge goals and organizational structures that might occur over time. This possibility is inferred from the historical data of the cases themselves. At critical junctures, various uses of the research activities created opportunities for new strategic directions in the KVAs. One of our cases in the category of MSMA developed new links with industry and a new direction for research as a result of the outcome of prior research which was no longer of interest to the sponsors, as well as a new emphasis on commercially relevant research. A KVA with new organizational and epistemic features emerged. The SSSE type, located in the upper left-hand corner, could be the initial state of most basic research activities. The types of uses and links that develop may then lead to an evolutionary path in any of three directions. A high-stakes or highly prized specific knowledge goal may lead to increasing administrative support in the direction of an OCKS (horizontally along the top row of the table). A diversification of knowledge interests pursued with loosely coupled (interdisciplinary and/or multidisciplinary) collaborations would lead in the direction of ESS (vertically along the first column).

The Knowledge Value Framework can provide research administrators with a tool to assess the impacts of the research they sponsor. The administrators will be able to see beyond those impacts that are revealed by the misleading categories of individual research projects and budget lines. The framework shows that collaborations in research lead to important payoffs and institutional dynamics that cannot be explained by simply examining and adding individual ties. A very significant value of the KVA framework is that it shows how certain collaborative R&D activities create a capacity for the next stages of research. These later stages may involve broader knowledge goals that extend or transform a field, and that bring an institution to national prominence, or they may involve a transition to more focused, high-risk technical objectives that could transform an industry.

IMPLICATIONS FOR INTER-UNIVERSITY COLLABORATION

The net effect of inter-institutional collaboration is an increase in the capacity for conducting research. The main components

Table I: Typology of KVAs

Knowledge Goals Number/Complexity	Organizational Size/Complexity: *Small*	*Medium*	*Large*
Small	Single-Sector Sporadic Exchange (SSSE) System		Organized Converging Knowledge System (OCKS)
Medium		Multiple-Sector Mutually Adapting (MSMA) System	
Large	Enabling Star System (ESS)		Organized Expanding Knowledge System (OEKS)

of the capacity for research are "scientific and technical human capital" and the infrastructure in space and equipment needed by researchers to conduct their work. By "scientific and technical (S&T) human capital" we mean the sum total of personal skills and noneconomic resources the scientists or engineers bring to their work (Bozeman, Dietz, and Gaughan, forthcoming). S&T human capital includes not only the individual human capital endowments included traditionally in labor models (e.g., Becker, 1962; Shultz, 1963), but also the individual scientist's tacit knowledge (Polanyi, 1962; Senker, 1997), craft knowledge, and know-how (Bidault and Fischer, 1994). S&T human capital further includes the social capital (Bourdieu, 1986; Coleman, 1988) that scientists inevitably draw upon in framing research and technological questions, creating knowledge, and developing social and economic certifications for knowledge.

The description of KVAs given above shows that a simple aggregation of people and materials will not suffice to achieve increased capacity. There is more to the nature and dynamics of collaboration than meets the eye. The nature of academic institutions makes for some interesting possibilities when we consider collaboration across organizational boundaries. Academic researchers have a degree of autonomy that does not exist in other contexts and, therefore, they are able to develop their research programs in a very entrepreneurial manner. At the same time, the allegiance of academic scientists is not to their institutions alone. They also have a primary interest in the development of their discipline or emerging field, making the strategic goals of universities and researchers, at times, orthogonal. Research administrators must try to develop their institution and allocate resources across field boundaries, while researchers are building a reputation in their own field.[4] Building research infrastructure under these conditions involves difficult choices and negotiations because facilities and equipment are often very specialized and very expensive, putting pressure on scarce resources. When infrastructure is developed to be shared across campus it may not be a fully satisfying solution for any one unit.

Under these circumstances, collaborations between universities can be even more frustrating because the universities are, at the same time, potential competitors for retaining the very researchers the collaborations employ. An example of such frustration in inter-university collaboration was the effort to develop a national research network during the 1960s and 1970s. During those years, the disparity in access to high-speed computer resources among universities across the country led to discussions on distributing access more evenly via a national network (Brown et al., 1967; Greenberger, 1974). NSF and EDUCOM supported these efforts for over a decade but the difficulties in creating a framework for competing institutions to collaborate at first proved to be too great. About 15 years after the initial proposals, the first collaborative network was born with BITNET in 1981. It was hailed as an example of how universities could engage in cooperative activities.

University consortia, created to share the costs of large scientific instruments, such as telescopes and particle accelerators, have also been successful. And success in one enterprise has then been leveraged in others. This was the case, for example, for the regional university consortia that allowed for the implementation of the three-tiered architecture of the NSFNET. This constituted the catalyst that catapulted the Internet as a global information infrastructure (Rogers, 1998).

However, the nature of the two levels of collaboration, actual research activities represented by the KVAs and the institutional context represented by the universities, highlights the first two consequences for collaboration as a possible strategy for competitiveness. First, inter-institutional collaborations will have small chances of success unless there is goal alignment between the level of KVAs and the institutional level. Second, because boundary-crossing arrangements are occurring at both levels at the same time, a scheme for the appropriation of the benefits of collaboration by all the participants must be devised. The creation of research centers with multiple institutional partners housing diverse research teams (or constituting the central reference point for several KVAs) is one such scheme. It allows the KVAs to grow and pursue multiple knowledge goals with their dedicated resources while attaching their success to the name of the center in a sort of "branding" process.

CONCLUSION

A consideration of KVAs suggests that viewing a collaboration as a mere pooling of resources does not suffice. This type of cooperation tends to create zero-sum games in which the participants increase their lot only at the expense of other members of the collaboration. Research programs or KVAs have multiple goals and these change over time. Successful collaborations tend not only to have common goals but also a clear division of labor or distribution of technical roles. Competitiveness strategies must be designed to pursue specific goals that are monitored and renegotiated over time. They must also include an explicit distribution of technical roles to be played by the participants.

The first two consequences emphasize that research collaborations should seek to obtain specific results with clearly defined roles for the participants. However, the most significant payoff of collaboration may not be the achievement of the original objectives of the partnership. The value of successful collaborations accumulates as the participants learn to work with one another and discover the potential to leverage the initial successes in new and more ambitious enterprises. This leads to two more consequences for collaboration as a strategy. First, the ability to sustain collaborative activities over time and diversify their potential is an indicator of increased competitiveness as well as a means. Second, one of the most important forms of value creation through collaborations is the development of social capital (Fountain, 1998).

The idea that collaborations are indicators of research competitiveness is consistent with the observation that cooperative activities are an inherent element of contemporary scientific research. What the two lessons together bring to the fore is that collaboration cannot be coherently construed as a strategy of the "have-nots" to reduce the advantage of the "haves." The KVAs that evolve successfully cannot be confined to disadvantaged institutions, even if they originate there. Their successful evolution will network these institutions into the mainstream of research in their field and their collaborations will include partnerships with the most reputable teams and institutions.

This logic is important for a program such as EPSCoR. On the one hand, it means that an increase in competitiveness at the national level integrates the state or region at issue into the overall system in ways that may not be reflected by specific indicators such as percentage of national R&D budget going to the state or region. On the other hand, it means that collaborations generate increased capacity available for the pursuit of various knowledge-related goals that must be leveraged for the benefits to accrue. Interestingly, one of the impacts of the EPSCoR program, according to a recent evaluation (NSF, 1999), is the legacy of inter-university collaborations in the EPSCoR states that is now leveraged to pursue new objectives. Sometimes the increased social capital that this capacity represents may come about with the apparent loss of leading researchers who decide to move to another institution. Healthy and productive KVAs are a sign of this integration process. The region or state may still benefit from that researcher's work even if he or she has relocated. However, the focus must be on the capacity at the systemic level for this potential to be appreciated and leveraged.

ENDNOTES

1. The search for collaborative strategies in the context of the National Science Foundation's EPSCoR (Experimental Program to Stimulate Competitive Research) program, for instance, is directed at designing ways in which universities may cooperate to increase their chances of obtaining federal support.

2. The research for this section was conducted with the sponsorship of the Office of Basic Energy Science, Department of Energy, under contract ER45562. The content of this section draws heavily on a previous paper co-authored with Barry Bozeman (Rogers and Bozeman, 2000).

3. The methodology used to construct this typology is discussed in Rogers and Bozeman, 2000.

4. Even interdisciplinary or multidisciplinary efforts become institutionalized into emerging fields with disciplinary characteristics when they prove to be fertile research areas. So the fluidity of a research area without disciplinary trappings is only a temporary phenomenon.

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