“Knowledge Value Alliances”: An Alternative to the R&D Project Focus in Evaluation

Juan D. Rogers
Barry Bozeman
Georgia Institute of Technology

The question of what the relevant entities or units of analysis for studying the dynamics of R&D are is central not only for adequate characterizations of the system of scientific and technological knowledge production but also for determining the correct focus for evaluation of R&D activities. Typically, R&D performance evaluations have focused not only on the wrong thing but have looked in the wrong place. Most evaluations have been project or program based. Often this focus is misleading. This article presents a “knowledge value” framework as an alternative focus for understanding and evaluating scientific and technical work. This framework consists of two core concepts: the Knowledge Value Collective (KVC) and the Knowledge Value Alliance (KVA). On the basis of the analysis of twenty-eight case studies of research activities, the authors present a typology of KVAs and conclude that they are a better object of evaluation than discipline-based projects.

When looking at more than one or two cases of knowledge production in science and technology, the observer is almost immediately struck by the relatively large variety of ways in which these knowledge-producing activities take place. There is neither a single pattern of organization of research teams nor a typical career path, nor a set of personality traits, nor a single motivating factor that characterize groups and individuals that produce scientific and technological knowledge, except, of course, for the awareness that the production and use of scientific and technological knowledge is at the heart of what they do.

The question of what the relevant entities or units of analysis for studying the dynamics of R&D are is central not only for adequate characterizations of

AUTHORS’ NOTE: The research was sponsored by the Department of Energy, Division of Basic Energy Sciences, Contract ER 45562. The views presented here are the case authors’ and do not necessarily represent those of the Department of Energy or Georgia Institute of Technology.

Science, Technology, & Human Values, Vol. 26 No. 1, Winter 2001 23-55

the system of scientific and technological knowledge production but also for determining the correct focus for evaluation of R&D activities. Typically, R&D performance evaluations have focused not only on the wrong thing but have looked in the wrong place. Most evaluations have been project or program based. Often this focus is misleading (Averch 1991; Bozeman and Melkers 1993; Cozzens et al. 1994; Kostoff, Averch, and Chubin 1994; Link 1996; Popper 1995). In seeking to understand 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, the *research project* is often the key focus.

While research projects sometimes give a distorted image of actual work patterns, the reason for evaluators' and managers' focus on projects is easy to understand. The organizational counterpart of a discipline focus is a project focus. Evaluations of research must begin somewhere and must entail some boundary rules, even if implicit ones. The project focus often is most convenient because it matches bureaucratic accounting schemes. R&D is often funded on a project basis, and 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 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, including social relations and social networks, to solve technical problems, generally with little regard to the bureaucratic accounting of resources.

This article presents an analysis of data from twenty-eight case studies of research sponsored by the Office of Basic Energy Science (BES) of the U.S. Department of Energy (DOE). Our objective is to consider the implications of these cases for rethinking our concepts of scientific work. We present a "knowledge value" framework as an alternative focus for understanding and evaluating scientific and technical work. We do not offer a set of techniques and/or indicators for ready application to R&D evaluation. Rather, we present a critical intermediate conceptual step in the evaluation process that, we believe, leads to refocusing the assessment of value creation in R&D. The case studies we present show a remarkable diversity in the pattern and meaning of scientific and technical work, a diversity not well explained by either a discipline or project focus. Many factors intrinsic to the content of research, such as the choice of research problems, the patterns of collaboration, the career paths of researchers, as well as institutional and organizational arrangements to carry out the work, seem more comprehensive when examined in terms of the actual collective relationships among knowledge producers and users—the focus of the knowledge value framework.

The article has two main parts: first, a theoretical section with the presentation of the knowledge value framework, and second, an empirical section with a typology of knowledge value alliances. In the theoretical section, we develop the two main concepts of our framework: the knowledge value collective (KVC) and the knowledge value alliance (KVA). These models of R&D activity are then compared with others available in the literature. The empirical section presents a constructed typology of KVAs based on our case study material. The section contains a discussion of research design and methodology followed by the five types of KVA we found, each illustrated with a specific case. The conclusion integrates the types into a dynamic structure suggesting possible paths of evolution between KVAs.

Theoretical Section: The Knowledge Value Framework

The Proposed Conceptual Framework

Recent studies of the production of scientific and technological knowledge in contemporary societies have acknowledged this diversity in the practice of scientific work and suggest that it may well be the single most important characteristic of these societies. Gibbons and colleagues (1994) maintain that there has been a transformation of the mode of production of knowledge. The traditional mode, mode 1, generated knowledge primarily within a disciplinary, primarily cognitive context. The new mode, mode 2, is characterized by its transdisciplinarity, its locus in the context of application and heterogeneity, and its heterarchical and transient organizational forms that are, at the same time, more socially accountable and reflexive (Gibbons et al. 1994, 3). These very general statements about the operations of science and research in contemporary contexts do find some support in our empirical investigations. However, we aimed at characterizing the dynamics of research activities with a more fine-grained framework that emerged from our data.

Following on work by Callon (1991, 1992, 1994a, 1994b, 1997) and Callon and Law (1989), in particular, but others as well (e.g., Liyanage 1995; Rappa and Debackere 1992; Elzen, Enserink, and Smit 1996; and especially Crane 1972), we argue 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 and impacts of that work. The building of artificial boundaries between the microworld of scientists and engineers and the macroworld of other scientists and engineers, commerce, and social institutions using 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.[1]

The knowledge value framework consists of two core concepts: the KVC and the KVA. In companion articles (Bozeman and Rogers 2000a, 2000b; Bozeman et al. 1997, 1998), we present a new framework for evaluating research based on these concepts. 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 of interest, the knowledge value focus is more fluid, less oriented toward discrete outputs, and 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 gives consideration to persons who are not scientists or engineers and who are not 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 those interactions rather than to the discrete outputs resulting from those interactions.

The knowledge value collective. A KVC is a set of individuals connected by their uses of a particular body of information for a particular type of application—the creation of knowledge (defined in terms of new uses of information [Bozeman and Rogers 2000a]). In this application, 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 is a physical embodiment of information).[2] 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.

The size of a KVC varies enormously from (in theory) a minimum of two (the original creator and a user other than the creator of information) to thousands or more. Typically, the size of the KVC will depend on such factors as general awareness of the body of knowledge, the breadth of its uses, and the skills required to obtain and apply information. There is no requirement that members of a KVC interact, know one another, or even be aware of one another; the only requirement is joint use of a body of information (and, in their use, creation of knowledge).

Our idea that there is a relation between the social structure of the collective of scientists in a field and its cognitive structure is central to the knowledge value approach but it is not a novel idea. Indeed, this notion has long permeated the sociology of science. Studies by Crane (1972), Hagstrom (1975), and Chubin (1985), among others, have attempted to relate the patterns of communication behavior among scientists to the practices and outcomes of their work. These studies assume that the choices made by scientists regarding communication with other scientists, career moves, and the publication of articles in refereed journals—in this view, the single most important output of research—at the individual level determine the characteristics of science at the collective level. This assumption has recently been challenged. Work by, among others, Joly (1997), Joly and Mangematin (1996), and Callon and colleagues (1991) shows that the characteristics of institutions and organizations add dimensions not easily explained simply by aggregating the behavior of individual scientists. In this regard, it is observed (Joly 1997; Bozeman and Wittmer 1996; Laredo 1997) that research groups pursue a variety of strategies and produce several types of outputs (e.g., publications, graduates, patents, instruments, techniques), which can be explained in part by the particular designs, structures, and interorganizational ties of the research groups' institutions. In short, the communication of information and the production of knowledge are complex activities, and scientific and technical knowledge is multidimensional. In this view, it is therefore 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 (Joly 1997; Crow and Bozeman 1998; Joly and Mangematin 1996; Faulkner 1994; Callon et al. 1991).

Focusing on the collectives of researchers, technologists, and the users of the knowledge they produce is not only indispensable for understanding the dynamics of science, but it is also a better way to assess the value of scientific research. This contrasts with standard methods that focus on particular outputs of their work. Even when collectives are evaluated, the entire range of activities associated with the creation and application of knowledge is rarely seen in connection with each other. This range of activities should include overlapping collectives of scientists, technologists, technicians, entrepreneurs and marketing professionals, and production engineers.

The knowledge value alliance. In addition to the KVC, we consider the KVA. Indeed, the latter is the chief focus of this article. In a sense, the KVA is a more structured and more tightly coupled subset of the KVC.

A KVA 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 (e.g., technology development, skill enhancement, understanding of fundamental phenomena). The KVA originates with the activation of a knowledge compact, usually, although not necessarily, through a formal alliance agreement (e.g., contract, cooperative research and development agreement [CRADA][3]) and ends when resources are no longer brought to activities pertaining to the knowledge compact (or when resources are no longer shared among parties). The KVA is an interactive group, but there is no necessity that each member interact directly with each other member; however, there must be links among the members of the respective institutional representatives (those designated in the alliance agreement). The KVA acts as a selection mechanism managing and distributing specialized information (e.g., understanding of phenomena, understanding of technologies' product possibilities, skill in equipment operation or processes) 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, and programs, arises from the fact that the latter do not capture the diversity and heterogeneity of knowledge production we found in the 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 in- spection, they are artificial units that exist only for the purpose of securing resources for a larger set of research activities that has dynamics of its own. If the value creation of research is mainly gauged by measuring the payoff at the project level, then most of the activities the actors put their energy into simply go unnoticed, resulting in 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 even though there is a cognitive and/or strategic unity to the research work that does not correlate with the arrangement into teams and projects. Similarly, research programs are often administrative units that reflect the jurisdiction of managers rather than the relevant dynamics of the knowledge production process.

Of course, there still is much high-quality research that is done by relatively unconnected teams that work, under a single institutional umbrella, on projects reflected quite accurately in their grant proposals. However, it is our contention that phenomena that do not fit this mold are rapidly growing in importance and that, in many cases, the ones that do are simply in a stage that can be quickly superseded 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 advisers or partners, and other participants that would not be considered members of a research team.

The unifying knowledge focus is not simply inferred from contacts and references to informal communication, as a disciplinary pattern would suggest. One or more formal instruments almost 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 provision of resources for the work but also address possible conflicts of interest that may arise from the multi-institutional endeavor. Most of the cases where university-based principal investigators were the main participants had a combination of grant agreements with the U.S. Department of Energy, consulting contracts and/or licensing agreements with one or more private firms, and industry advisory boards that included firms that were more indirectly involved. The knowledge focus was identified and specified in the various instruments implementing the agreements so that it was quite clear that all the members were after the same set of knowledge goals. But at the same time, the various participants pursued a diversity of interests and uses. In other words, academic researchers maintained a degree of autonomy and openness in their intellectual pursuits. Private firms were able to appropriate portions of the work for their purposes and had firsthand access to trained graduates. And the government agency either fulfilled its facilitator role by supporting industry-relevant research and training or, in some cases, actually participated through its managers 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 we describe might suggest the increasing importance of applied research as opposed to basic science (Gibbons et al. 1994). However, this is not necessarily the case. The pursuit of intellectual goals and possible economic benefits of research are present in almost all of our cases and not easily separated out into distinguishable activities. 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 2000b). Most cases we analyzed show that significant epistemic and economic risks are taken in the context of KVAs.

Comparison of KVAs with Other Models of R&D Activity

The inadequacy of the classical concept of a research project as the unit of analysis was one of the motivating factors for devising a new framework. Table 1 contains the results of comparing the notion of a KVA with that of a research project as well as other concepts that have been suggested in the literature for studying the production of scientific and technological knowledge.

The main difference between a KVA and a disciplinary project, even when the latter may adequately describe some of the research activities, is the fact that a KVA comes into being when an agreed upon unifying knowledge focus is associated with multiple types of use. In general, disciplinary projects are oriented toward a single type of use, the publication of results, and only indirectly related to other uses such as the training of students and possible applications, which are rarely considered part of the project itself. Disciplinary projects, when they exist as such, are much simpler and more homogeneous social and epistemic entities.

Other concepts that have been proposed to study complex situations in R&D are technical systems (Shrum 1985), technological programs (Callon, Laredo, and Mustar 1997), and technoeconomic networks (Callon 1992). The notion of a technical system was proposed by Wesley Shrum to study large-scale technological endeavors that entail interorganizational relations in the process of innovation. The Manhattan project and the Apollo program are typical cases of large-scale innovation that this framework is designed to address. Technical systems differ from KVAs in very specific ways. First, they are by definition large, which is not necessary for KVAs. Second, technical systems are almost always initiated and managed by government with significant participation of universities and industry via contracts and grants. Third, the knowledge focus of technical systems is ultimately technological with rather concrete outcome specifications (i.e., a nuclear weapon, put a man on the moon), which require bureaucratic control to successfully implement them. KVAs may lack such structures and specification of outcomes without losing their focus and identity.

Technological programs are tools for the management of public R&D policies mainly in the context of the European Union (Callon, Laredo, and

(text continues on p. 34)

Table 1. Comparing Knowledge Value Alliances with Other Frameworks

	Knowledge Value Alliance	*Discipline-Based Project*	*Technological Programs*
Institutional actors	By definition, multi-institutional	Single or multiple institutional actors	Generally multi-institutional
Organizational style	Generally nonhierarchical	Hierarchical (principal investigator, postdoc, graduate students)	Some components are hierarchical, others nonhierarchical
Use focus	By definition, multiple-use types	Usually single-use type (e.g., contributing to fundamental science)	Multiple, but formal emphasis on industrial uses
Effectiveness criteria	Highly diverse (e.g., impact of scientific publications, developing new technical process)	Somewhat diverse (e.g., impact of scientific publications, supporting graduate students)	Diverse, but less academic
Resource base	By definition, multiple	Single or multiple	Multiple, but highly oriented toward public funds
Choice process for R&D foci	Negotiated, selected focus is constitutive	Semiautonomous	Negotiated, but with formal mechanisms to channel technology policy objectives
User network	Multiple uses, highly diverse, often fragmented	Generally, fewer uses and use types, less diverse users, less fragmented users	Multiple uses; however, preferred uses are industrial
Communication norms	Open or closed (proprietary)	Open	Open or closed
Size and scope of enterprise	Generally large, but not necessarily	Generally small, but not necessarily	Generally large
Initiating instrumentality	"Knowledge value covenant" reflected in contracts, grants, cooperative research and development agreements (CRADAs), or similar instruments	Single investigator or institution, either formal (e.g., grant) or informal (e.g., indirect support from home institution)	Policy identified target, generally an industry segment; formal institutional partnerships and mandates

(continued)

Table 1. Continued

	Knowledge Value Alliance	*Discipline-Based Project*	*Technological Programs*
Incentive alignment	Multiple incentives, may or may not be aligned	Fewer, better aligned incentives	Multiple incentives, but industrial competitiveness is constitutive
Connection to knowledge value collectives (KVCs)	Multientry, often multi-KVC	Narrower entry, often single KVC or discipline-only	Multientry, multi-KVC

	Knowledge Value Alliance	*Technical Systems*	*Technoeconomic Networks*
Institutional actors	By definition, multi-institutional	Multi-institutional, distribution of the interorganizational arrangement is key	By definition, multi-institutional
Organizational style	Generally nonhierarchical	Hierarchical, centrally managed	Overall network is nonhierarchical
Use focus	By definition, multiple-use types	Well-defined technological system with preestablished specifications	By definition, multiple-use types
Effectiveness criteria	Highly diverse (e.g., impact of scientific publications, developing new technical process)	Meet specifications for technological system (e.g., man on the moon; atomic weapon, etc.)	Highly diverse, mainly oriented toward capturing intermediate results toward a successful innovation
Resource base	By definition, multiple	Multiple, but highly oriented toward public funds	By definition, multiple
Choice process for R&D foci	Negotiated, selected focus is constitutive	Public policy priorities	Focus is emergent, not a priori
User network	Multiple uses, highly diverse, often fragmented	Mainly government, any other by spin-off	Variable, from single to multiple. Technoeconomic network (TEN) includes the user network

Communication norms	Open or closed (proprietary)	Core closed, periphery open	Open or closed
Size and scope of enterprise	Generally large, but not necessarily	Large	Variable, from small to large
Initiating instrumentality	"Knowledge value covenant" reflected in contracts, grants, cooperative research and development agreements (CRADAs), or similar instrument	Government-sanctioned technology objective	Variable, but strongly oriented toward government intervention
Incentive alignment	Multiple incentives, may or may not be aligned	Multiple incentives, alignment is main administrative problem	Multiple incentives, may or may not be aligned
Connection to knowledge value collectives (KVCs)	Multientry, often multi-KVC	Multientry, multi-KVC	Multientry, multi-KVC

Mustar 1997; Laredo 1997). They differ from technical systems in three ways. First, they are subject to formal time constraints. Second, they fit into a preexisting market rather than create a new one. Third, rather than support individual actors that contribute pieces of the technical system, they are directed at supporting an industry segment by contributing to the development of the set of skills necessary for competitive advantage (Callon, Laredo, and Mustar 1997, 14).

The main difference between a technological program and a KVA is that the former is a management tool for public R&D policy, whereas a KVA emerges in the pursuit of a knowledge goal. A technological program is a "top-down" approach to achieving general R&D goals, and a KVA is an entity that emerges from the bottom up as a particular knowledge goal is pursued. A technological program is intended to foster the formation of KVAs in the areas that were chosen as policy objectives. But even in this case, it is mostly oriented toward industrial competitiveness, while KVAs include, but are not restricted to, competitiveness situations.

The notion of a "technoeconomic network" (TEN) was proposed by French sociologists to evaluate and/or study technological programs and other R&D activities (Callon et al. 1991; Callon, Laredo, and Mustar 1997). They are similar to KVAs in that they attempt to describe the heterogeneous collaborations between actors with different institutional backgrounds in the knowledge production process. Therefore, both KVAs and TENs are multi-institutional and oriented toward multiple uses. However, TENs are not evaluated as such, and therefore, effectiveness criteria are not provided except that the size or "length" of a network is evidence of its ability to produce successful innovations. The notion of a TEN is proposed as a way of capturing the intermediate steps toward a successful innovation to provide tools for continuous evaluation of such policy instruments as technological programs. The single knowledge focus that acts as an "attractor" in the formation of a KVA is absent in a TEN. TENs preexist the emergence of knowledge goals. A full comparison between all these notions along 12 dimensions is provided in Table 1.

Empirical Section: Types of Knowledge Value Alliance

Methodological Remarks

To ensure adequate representation, the cases we studied were selected via stratified sampling of the universe of research activities that receive funds from BES. Four strata were identified according to two dimensions: level of

BES funding (above and below $500,000 a year) and whether they were housed in a government lab or not. In all cases, research activities had been ongoing for three or more years to ensure that they had a chance to have results and produce outputs. Almost all cases had other sources of funding besides BES, and in many of them, the history of research activities predated the award of the first BES grant. Therefore, the sample of cases is not significantly biased by its connection to BES, and the cases could have been selected from a more general pool of publicly funded research.

A constructed typology of KVA was developed from the cases.[4] The types were identified by observing features of the social and organizational structure and of the knowledge pursuits or epistemic features present in the cases. Variation in the organizational structure was indicated by features such as the number of participants and variety of their roles, the level of funding and number of sources of funding, the number of interactions with other entities (e.g., collaborations, technical service, advisory membership), and the number and variety of activities crossing sector boundaries (government, industry, university). The complexity of the knowledge pursuits of a case was indicated by features such as the number of different strands of research, variety of its outputs, variety of fields and activities of graduates, relationship between breadth of research and breadth of the field, and inter- and/or multidiscipline.

In all the cases we studied, researchers declared that their main knowledge goal was to conduct basic research. However, they varied in the degree to which basic research activities were accompanied by other knowledge goals. These included developing possible commercial applications, making incremental contributions to their field, creating new or transforming existing foundations of their field, making fundamental contributions in several fields (both interdiscipline and multidiscipline), and specific technical goals (e.g., hot superconducting wire).

The types are not simply the result of quantitative variation along the organizational structure complexity and knowledge goal complexity axes, although, as we show in the conclusion, the cases do vary in that way as well. The interplay of organizational and epistemic features suggested distinct combinations for each type.

Case Data Analysis and KVA Typology

Careful analysis of our cases revealed five distinguishable types that had different combinations of knowledge production activities and goals, and social-organizational structures:

1. Single-sector sporadic exchange system
2. Multiple-sector mutually adapting system
3. Enabling star system
4. Organized converging knowledge system
5. Organized expanding 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, the number of people involved as researchers, and 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 fit 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, and training of 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.

Single-sector sporadic exchange (SSSE) systems can be quite large. We found some cases in which the level of funding was quite significant, three to five times the average level of funding of the smaller ones, with coprincipal investigators and many graduate students. However, the KVA was still simple, not very developed in terms of the number of use types and, therefore, relatively few boundary crossing links. In other words, their activities are almost completely contained within a single sector, which in our cases is almost always the academic sector. If there are interinstitutional relationships, they occur with other groups similar to their own. Figure 1 represents this type of KVA. The figure is a map representing the combination of knowledge goals and activities and the social structure against the background of three basic components of an input-output model (resources, knowledge-producing system, and impact field). The arrows represent the direction of flows of knowledge and resources. Solid lines indicate features always found in this type, and dashed lines represent those that may sometimes, but not always, be present. So, for example, in an SSSE, funding always comes from several sources in portions that are well correlated to specific research activities

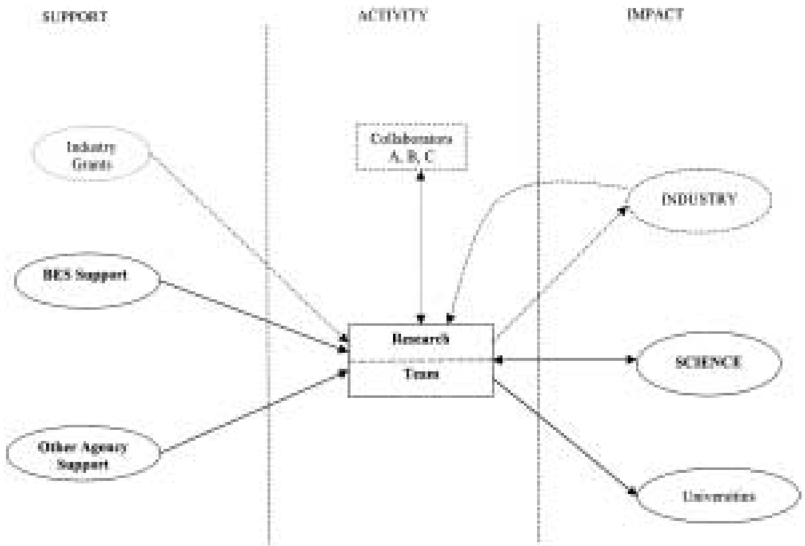

Figure 1. Single-sector sporadic exchange system.
NOTE: BES = Office of Basic Energy Science.

that the principal investigators are careful to keep distinct. Their relation with program managers of funding agencies is not very close and is generally limited to the established channels of proposal submission and review. The main outcomes are incremental contributions to fundamental science and training of 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 neither 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 articles.

Case in Point: "The Metabolism of Hydrogen by Extremely Thermophilic Bacteria"

The main goal of this set of research activities is to identify and characterize the properties of a peculiar class of anaerobic microorganisms called *thermophiles* that have the property of growing optimally near and above 100 °C. The principal investigator, Michael Adams, began working in this field at the

University of Georgia in 1987. He had started his career at Exxon, working on enzymes to metabolize hydrogen and nitrogen gas. This background was ideal for studying thermophilic organisms because these microorganisms contain some of the enzymes Adams had studied. It also required growing the bacteria in large scale (400 liters), something he had done at Exxon, and it was related to energy, which was of interest to both Exxon and BES. Adams and his collaborators found that these organisms' enzymes contain metal, tungsten, whereas other organisms' enzymes that live at lower temperatures contain molybdenum. Adams's team and collaborators were able to determine the crystal structure of these enzymes and other main characteristics, which until the late 1980s were almost unknown.

Adams receives funding from both BES and the National Science Foundation (NSF) and, much like other SSSE cases we studied, distinguishes clearly between the lines of work supported by each sponsor. The research program is not really a small one, either in terms of its levels of funding or number of researchers. It involves two continuing collaborations with researchers at North Carolina State University, the University of Washington, and Oak Ridge National Labs. The lab currently includes about twenty active researchers, including several postdocs and graduate students. However, it has limited interactions with nonacademic entities. It receives funding from government agencies, BES and NSF. There seems to be little feedback to the agenda of these entities via their relation with program managers. They occasionally interact with business corporations mainly to provide samples or related products from their lab facilities. Commercially relevant developments can be envisioned but have not been pursued actively to date. This system could easily develop into a multiple-sector mutually adapting (MSMA) system and on to an enabling star system (ESS), our second and third types. The applications of knowledge of enzymes and specialized large-scale organism cultivation facilities show potential for multiple knowledge fronts and the possibility of a spin-off company or common academy-industry forum.

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 thought to be transforming the nature of academic institutions (Etzkowitz 1989). We detected a peculiar dynamic in cases we studied in which the process did not simply entail the commercial exploitation of a scientific result. They also showed a mutual coadaptation of basic research and an industry sector that occurred with the formation of an intermediate industry segment. The latter

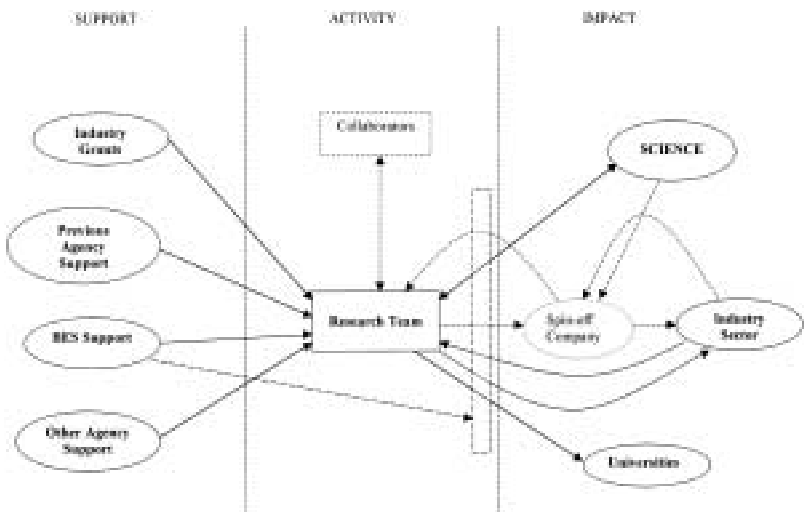

Figure 2. Multiple-sector mutually adapting system.
NOTE: BES = Office of Basic Energy Science.

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 affected by the interactions between university teams and the intermediate industry sector. This was not a simple orientation toward marketable applications. It was an alteration of the formulation of basic research questions through the circulation of personnel that graduated out of university research; worked in industry for some time, both in the intermediate segment and the main industrial sector; and returned to research in the university. In these cases, the program manager of the agency that funded the university research played a significant role. He or she monitored the division of intellectual labor in the field under his of 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. In sum, the ensemble of university researchers, spin-off company, clients from the large industry sector, together with a virtual "traffic" in graduates from the research team and the catalytic participation of the public research program manager, resulted in a knowledge covenant by which research and industry tracked each other during a period of time with growing mutual impact. Figure 2 is a graphic illustration of this type of KVA.

Other cases in this type may show a mutually adapting dynamic determined by strong exchanges between researchers, private industries, and government agencies 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. The research activities are directly relevant to industry through its findings, the generation of data, or experimental techniques. At the same time, the commercial interests and the experiences and needs of industry significantly shape the research agenda through the exchanges that take place in the specially created forum. However, 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 continues to develop according to epistemic, educational, and other priorities of the team. The results of research are often patented or licensed as they are integrated into the commercial strategies of industry.

Case in Point: "Synthesis and Optimization of Chemical Processes"

The Synthesis and Optimization of Chemical Processes case analyzes the stream of research led first by Larry Evans, from around 1976 to 1991, and then by Paul Barton, from 1992 to the present, and carried out at the Massachusetts Institute of Technology (MIT). The main concerns of this research are the flows of energy in industrial chemical plants. It seeks to develop systematic methods to synthesize industrial chemical processes and provide optimal solutions for the required overall energy flows. The visible products of this research are specifications and software packages that implement the methods and algorithms to reach optimal solutions.

The origins of this stream of research can be traced back to the second half of the decade of the 1970s when DOE sponsored a significant amount of work in alternative fuels due to the energy crisis. Soon the emphasis on energy crisis priorities began to wane and DOE discontinued support for this line of work. Evans and his team had developed a simulator to optimize energy flows in chemical plants and wanted to continue developing their ideas and programs, including their relationship with the industries interested in the results of their work.

The path toward commercialization of the simulator was clearly in view at this point but could not be housed entirely within the institutional framework of MIT. Evans, then, decided to start a business to pursue the commercialization of the simulator and its future versions. As a result, Aspen Technologies Inc. was founded in 1981 while Evans was still a professor at MIT. The company developed the simulator for commercialization and also developed plant control versions of the software that could not only simulate the energy balance conditions but also introduce integrated control loops to control the plant once it was implemented.

The fundamentals of the Aspen technology were used by other commercial enterprises that were founded to provide competing products. Therefore, the impact of the original research into energy balance sheet simulation was not simply a single spin-off company to commercialize the product but an entire industry segment that provided a family of products, which varied in sophistication, price, and completeness.

The BES program manager, Oscar Manley, played a significant role in this case. He administered a coordinated program awarding grants in complementary areas to promote the development of interlocking research that would have maximum impact on industry.[5] He regularly gave feedback and facilitated linkages with the chemical industry so that the research would be governed by both the intellectual interests of the researchers and the needs articulated by industry. After the start-up period of the enterprise, Manley suggested that Evans develop a partnership effort with the Idaho National Engineering Laboratories. BES would fund it to continue the research component of plant energy integration and batch process modeling and optimization. The collaboration began in 1985 and continued for about ten years.

The problems they addressed in the first period of BES funding were general-interest expert systems problems that had no direct applications to industry problems of interest to Aspen Technologies. They were in the area of energy integration to balance the uses of energy in a chemical process. The main uses of energy in these cases are for heating and/or cooling material to the temperatures required for each stage of the process. Later, the emphasis shifted to modeling batch processes and the overall design problem of plants to implement the batch processes. The feasibility of the latter result was clear when the use of their models in a plant simulator achieved results very similar to those used in plants that been subjected to very long processes of optimization. A design package based on these methods promised to achieve in a single iteration what took years of field adjustments in the plant. The savings in production costs of the chemical plants using these software packages range from tens to hundreds of millions of dollars a year.

The great impact of this research and, using the vocabulary of our "use-and-transformation" approach, an indication of the multiplicity of uses of this case is evident in two more types of linkage with industry. First, the career paths of students who participated in this research show that graduates in this field are in great demand both for the companies that develop commercial software based on the results of basic research and in the chemical industry at large to apply the software intelligently to the particular cases of a plant or a firm. Second, Evans also has a very large consulting portfolio and is able to bring particular case studies or new problems from industry for students to work on in their theses. This feedback channel was supplemented with a striking pattern of personnel exchange in that graduating students have been hired by competitors of Aspen Technology in the same industry segment or by firms in the chemical segment and later hired back either by Aspen Technologies or returned to research work. The communication network of graduates plus the actual career path returning to the MIT-Aspen center has maintained this stream of research in very close connection with the relevant industrial sectors magnifying its impact potential enormously.[6]

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 very different directions, typically associated with experimental arrangements or special techniques and instruments. Many contemporary experimental or instrumental techniques are based on specialized knowledge that is not directly related to the actual systems studied with those techniques. The expansion of the applicability of the instrumental methodology requires the advancement of fundamental knowledge of the basic components of matter. This leads to research programs with special features because the agenda of research moves on many fronts at the same time. On one hand, the core instrumental knowledge is pursued as a fundamental science endeavor. On the other hand, what would count as applications of the instrumental techniques are basic research programs in themselves, in which various fields of science are advanced with the important contribution of those instruments. However, "application" here is the use 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, occurs in the fields where the techniques are applied rather than in the principal investigator's specialty. Collaborators and students work as independent groups in different fields, only linked to each other through the principal investigator. Industrial relations are pursued also, first, in developing commercially the instruments based on the knowledge at the center of the researchers' work. Second, the fields of application often have components of interest to industry. Funding patterns also follow this "star" structure. One main funding source for research, in our case BES, supports 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 is also mirrored by enough commitments by industry through a number of smaller grants, licensing, and patents to diversify the resource base and bring the industrial

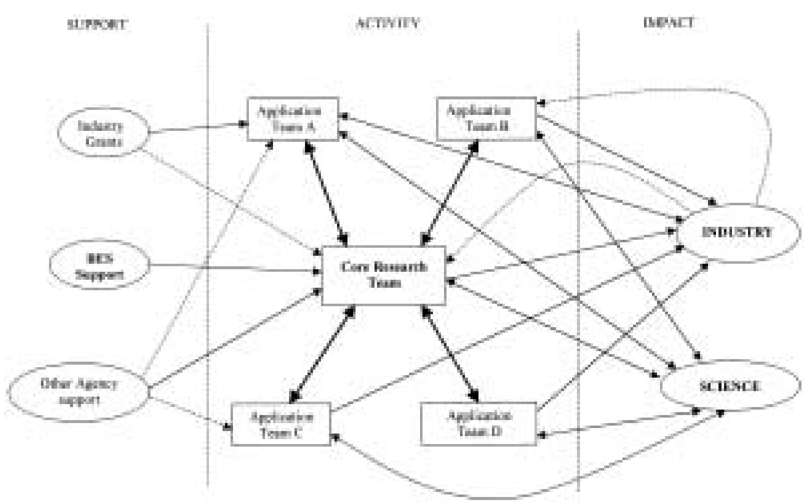

Figure 3. Enabling star system.
NOTE: BES = Office of Basic Energy Science.

partners closer in the "knowledge covenant." Students continued their careers both in academic research in the fields of application of instrumental knowledge and in industry in almost equal proportion. Figure 3 illustrates the "star" structure of this KVA. The various collaborations and flows of knowledge, people, and resources are symbolized by the arrows.

Case in Point: "Nuclear Magnetic Resonance Spectroscopy"

The Nuclear Magnetic Resonance (NMR) Spectroscopy research program is conducted under the leadership of Alex Pines at the University of California, Berkeley. This case is another example of a basic research effort with a very diverse collection of outputs and impacts. The research team works on fundamental principles of NMR and at the same time develops numerous techniques, instruments, and applications that on several occasions have spanned several disciplines including chemistry, engineering, materials science, and biology.

NMR makes use of the fact that spinning nuclei are charged particles in movement and generate magnetic fields. When irradiated with external electromagnetic energy, the interactions will follow patterns that depend on the local environment in the sample. Materials are subjected to radio frequency radiation of known characteristics. After interacting with the material, the energy absorbed and emitted is analyzed to detect its frequency patterns, which contain information about the characteristics of the material.

NMR has three main features that make it a valuable tool for laboratory analysis. First, NMR is able to focus on individual atomic sites through the nuclei. This contrasts with optical spectroscopy, which can visualize only whole molecules. Second, NMR can show the relationships between atoms in different sites. These are structural relationships concerning the relative position of atoms in a sample. Dynamic relationships concern the relative motion of atoms. NMR can reveal these relationships because they produce characteristic frequencies in the spectrum. Finally, NMR is noninvasive and nondestructive. The interactions of spinning nuclei with radio frequency energy occur without altering the fundamental characteristics of the material.

The advantages of NMR come at a price set by several inherent drawbacks. These are low sensitivity, poor resolution, and weak selectivity. The main knowledge contributions of this stream of research involved overcoming some of these drawbacks of NMR while maintaining its advantages and, therefore, extending its use to a broader range of materials. In the process, contributions are made to the basic science of fundamental particles and new instruments were developed that have enabling features in other fields of research.

The variety of possible uses of NMR spectroscopy led to a fairly large number of collaborations. These included researchers from the University of California San Francisco Medical School; several divisions of the Lawrence Berkeley Laboratory, such as the Biology and Medicine Division; Cornell University's Department of Mathematics; the Solid State Physics Institute of the University of Stuttgart; Exxon; the U.S. Naval Research Lab; Mobil Oil; and Monsanto. Interestingly, the patterns of these collaborations all center on Pines's research. Many of his students and research associates are in fields other than chemistry and continue their work in their own field. Therefore, the impact of the research program in science has two axes: one continuing the work on NMR effects and the other into biology, electronics, and materials science via the enabling effect of the spectroscopy techniques. Similarly, the industry connections are in two dimensions. On one hand, instruments are developed and marketed for use by other researchers. On the other, the techniques contribute to industry's own R&D pursuits, such as oil field exploration.

Organized converging knowledge system. These cases present significant growth of formal organizations and institutions as the pursuit of the knowledge goal advances. However, as the organizational size and complexity increases, the knowledge goal becomes more and more specific and narrowly focused.

The importance of the specific knowledge goal is what requires the increasing organizational support because 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 is a straightforward scientific problem. There was a correspondence between convergence toward the technical goal and the establishment of an administrative apparatus that facilitated 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 are perceived by many to be of great epistemic and economic importance. As this happens, efforts get more organized and formalized 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 and shield their work from the external pressures of competition and resource acquisition. The self-regulating aspect of the 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. Figure 4 illustrates these systems indicating the correlation between growth of organizational structures' size and complexity with a narrow knowledge focus. The peculiar role of the program administrator is indicated with a dotted line and circle.

Case in Point: "Rolling-Assisted Biaxially Textured Substrates (RABiTS)"

The RABiTS case examines research on high-temperature superconducting wires carried out at Oak Ridge National Laboratory (ORNL). Deposits of YBaCuO (YBCO) on textured substrates have promise for enabling high-field electric power devices at liquid nitrogen temperatures. This case also is an excellent example of national laboratory research activities successfully teaming multiple divisions within the lab. The RABiTS case has strong scientific implications, including publications in *Science* and other top rank journals, but also strong commercial implications, including partnerships with 3M, Southwire, and a number of other firms.

This case illustrates a type of KVA in which a growing set of resources and administrative arrangements are put in place to pursue a narrowly focused knowledge goal. As the focus converged on the specifications of the superconducting wire, many of the norms followed by actors in their own realm were suspended to achieve the common goal. For example, scientists were asked to

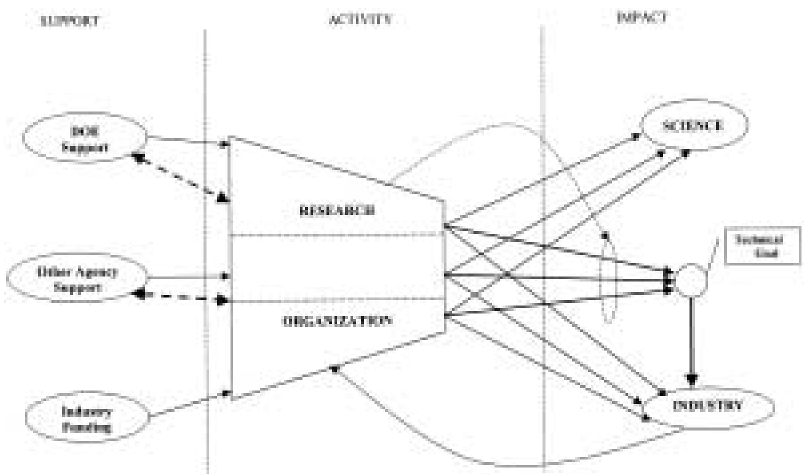

Figure 4. Organized converging knowledge system.
NOTE: DOE = U.S. Department of Energy.

postpone their plans for publication even though they ran significant risks as professionals due to internal and external competition. Reporting by components of the federal lab also had to be handled carefully to both comply with accountability requirements and avoid disclosure to nonmembers of the KVA. The formal administrative arrangement was directed mainly at shielding the research from the distracting effects of these pressures while maintaining the cross-sector relations.

The development of this KVA was triggered by an existing network of informal contacts between researchers at ORNL and other colleagues. Rosa Young, a former ORNL researcher at a private company, contacted her colleagues at ORNL to perform certain measurements that required specialized equipment and techniques she knew existed at the lab. From these contacts, a collaboration via an early ORNL CRADA was proposed and signed in 1991 to work on the superconducting materials. From then on, a variety of ORNL scientists worked on solving problems related to developing an adequate substrate for a superconductor. Goyal and Paranthaman worked on alignment of a thallium-based superconductor and its deposition on silver. Christen and He focused on processing a rolled nickel substrate and later worked on depositing cerium oxide as a YBCO-compatible buffer layer. By early 1995, the ORNL scientists agreed that they had developed a layered superconductor that had desirable attributes, including a critical current density of 80,000 amperes per square centimeter. By the end of 1995, many major technical problems seemed to have been solved or at least ameliorated; an adequate buffer layer and substrate seemed within the team's grasp. Further improvements to the buffer layer led to critical current measurements of 300,000 amperes per square centimeter by April 1996 and 900,000 later in the same year.

As the research effort gained momentum and the contributions of the three teams were clearly relevant to each other, an administrative structure was put in place, under the direction of Bob Hawsey, to maintain the coordination and focus of the research. Interestingly, the administrative role of Hawsey was very important in facilitating the communication of technical matters between the teams. At the same time, the findings of each group had publication potential independently of the success of the superconducting wire prototype. However, for patenting purposes and the possibility of future commercialization, the contributions of all three were interdependent. So, to ensure the laboratory's intellectual-property position, the researchers agreed, after considerable discussion, to take the unusual step of agreeing not to release scientific findings until patents had been filed. This was not an easy decision and required several meetings. Of interest is that it was not at all easy to attract the interest of ORNL technology transfer and licensing personnel because, according to John Budai, there was little likelihood that a product would be developed within about a year or so. However, once the technology transfer office was on board, a patent application was filed, facilitating the team's efforts to frame its interaction with industry.

Industrial development of the superconducting wire and substrate depends largely on the ability to scale up in size, and the ORNL team is working with industry to accomplish that objective. The team is working, via CRADAs, with both small businesses and such larger players as 3M and Southwire. Although industrial funding is still at a modest level, there is some funding and other in-kind contributions. The work with industry transcends ORNL. Currently the team is working with several universities (including the State University of New York at Albany, Stanford University, the University of Illinois, and the University of Tennessee), as well as with other national laboratories, particularly Los Alamos National Laboratory.

This case clearly involves multiple uses of information generated within the various teams that comprise the KVA and outside it altogether. It also led to multiple uses of the information it produced, not only for the succession of findings in the various lines of research pursued within the KVA and the potential applications to industry but also for the conclusions that were drawn at Oak Ridge and elsewhere in DOE for the management of this type of R&D enterprise and its implications for lab-industry relations. The peculiar role of the project manager as a nontechnical facilitator for the interaction of research groups reflects the multiple dimensions of use and its implications for value creation. He was the mediator of the communication of information that led to new uses that were not on the agenda of the researchers taken separately.

Organized expanding knowledge system. In some cases, a large-scale effort was launched to develop and lead an entire subdiscipline of science, such as combustion, complex carbohydrates, or plant biology. The knowledge goals were broad and there were several research efforts developing 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, and 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 the program committees, leading the 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 relations with industry. In all these cases, the contribution to science by the KVA has been of great impact to the point of creating a clean break and new direction of research in the chosen field. Figure 5 shows the correlated growth in the goals and impacts of the research with the organizational apparatus created to support those activities.

Case in Point: "The Combustion Research Facility at Sandia-Livermore"

Combustion research was not a new phenomenon when the idea of the Combustion Research Facility (CRF) was born. In fact, research on the topic of combustion had been going on for some time at different universities and labs scattered around the nation. Since combustion provides 90 percent of a nation's energy and has serious effects on the environment, economics, and productivity, it was widely viewed as a topic worth investigating. Many began to feel that a concentrated effort would produce more efficient and effective results. Thus, the CRF was conceived—a unique, multidisciplinary facility established to conduct a wide range of basic and applied research and development. In 1978, the final approval to build a CRF was received, and the facility became operational in 1980.

The CRF is located at Sandia National Laboratory, in Livermore, California, close to the high-tech industries of Silicon Valley and several prominent universities. Not only does CRF have its own resident research programs, but it is also a user-based facility that offers office space, equipment, and expertise

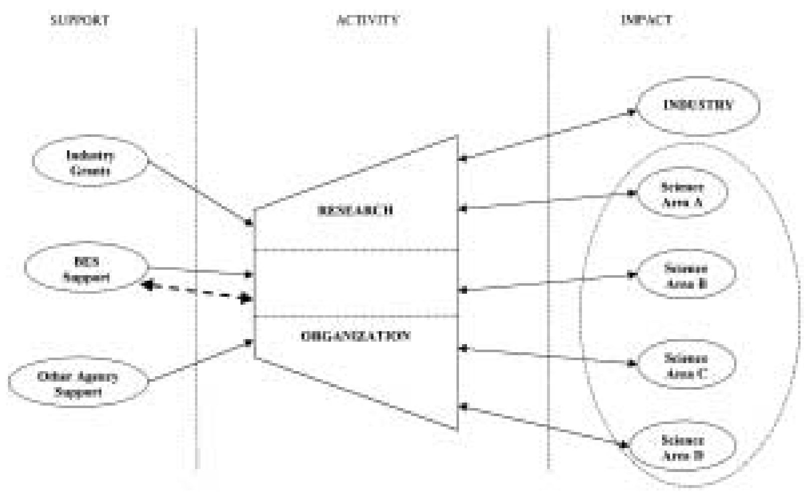

Figure 5. Organized expanding knowledge system.
NOTE: BES = Office of Basic Energy Science.

to professors, industry members, and researchers from all over the world. The facility is specially equipped to provide for laser-based diagnostics, combustible and toxic gas handling, computer-controlled safety, and the technical support capabilities required for state-of-the-art combustion research activities.

The staff at the CRF is divided into seven different departments, namely, Computational Reactive Processes, Reacting Flow Research, Combustion Chemistry, Chemical Sensor Sciences, Industrial Combustions and Processes, Combustion in Engines, and Diagnostics and Remote Sensing. Each of these groups has a manager and about five principal investigators. The direction of each group at any one time depends on the topic and the people involved. Some are much more basic (such as Combustion Chemistry) and others are much more applied in nature (such as the Combustion in Engines group), although any group can be involved in any combination of both basic and applied research. However, all the work is aimed at expanding the field of combustion research.

In the past two decades, CRF has become the internationally recognized leader in all facets of combustion research. The peculiar institutional arrangement that combines in-residence research programs with the user-facility setup has put CRF at the center of a world network of research on combustion. It represents a typical case of increased organizational effort to lead or dominate a complete subfield of research.

Conclusions

The analysis of several cases of research sponsored by BES of DOE shows that the organizations and arrangements for fundamental research are very diverse. We believe these cases are typical of publicly funded research generally. Most of our cases had more sources of funding, and the importance of BES support varied. Furthermore, the research activities in many instances predated the award of BES funding. Therefore, even though we entered this universe of research activities via BES, the sample, albeit small, is a good representation of publicly funded fundamental research activities.

Table 2 shows the five types described in this article using the organizational features and epistemic characteristics with which we constructed the typology as dimensions to suggest a unified representation. The location of the types in 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. For example, our MSMA system case in point developed new links with industry and a new direction for research as a result of both the outcome of prior research, which was no longer of interest to the sponsors, and a new emphasis on commercially relevant research. A KVA with new organizational and epistemic features emerged. The upper left corner of the table, occupied by the SSSE type, could be the initial state of most basic research activities.[7] The types of uses and links that develop may 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 organized converging knowledge system (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).

Our analysis also shows, first, that fundamental research occurs in conjunction with numerous other activities in several different combinations. It is not surprising that it is conducted in close connection with educational activities. However, it is also interesting to note that it may be intimately related to commercially relevant activities without significantly changing its characteristics of fundamental research.

Second, we suggest in this article that what all of these arrangements have in common is that they are held together by a “knowledge covenant” that allows the heterogeneous entity we have called a “knowledge value alliance” to attain a temporary unity and stability to achieve certain epistemic goals.

Table 2. Typology of Knowledge Value Alliances (KVAs) along Epistemic and Social-Structural Dimensions

Knowledge Goals Number/Complexity	*Organizational Size/Complexity*		
	Small	*Medium*	*Large*
Small	Single-sector sporadic exchange (SSSE)		Organized converging knowledge system (OCKS)
Medium		Multiple-sector mutually adapting (MSMA)	
Large	Enabling star system (ESS)		Organized expanding knowledge system (OEKS)

Third, we compared this notion with other models for studying research and showed that the KVA captures some important dynamics of the research process that competing models have not. Notably among them is the temporary unification of goals and strategies that mediates significant impacts of research that are not evident in the formal accountability mechanisms, such as the granting and reporting process, but are not simply emergent in an undirected process.

Finally, this article presented a typology of KVAs that captures some of the patterns that were observable in the case data. The typology reflects the interaction between cognitive structure, strategies, and goals and the organizational patterns that are set up to mediate them.

We conclude that the KVA is the main generator of uses of research, under the generalized notion of uses adopted in this framework, and should be the main subject of impact analysis in a "use-and-transformation" approach to evaluation.

Notes

1. The full development of our theory of knowledge value is presented in Bozeman and Rogers (2000a). In this article, we compare our notion to economic perspectives on value and show how these lead to inappropriate R&D evaluation schemes.

2. We distinguish between information and knowledge. The following are our working definitions: (1) *information:* descriptors (e.g., coded observations) and statements (e.g., language-based synthetic propositions) concerning empirically derived observations about conditions and states of affairs in the physical world and the real of human behavior; (2) *knowledge:* information put to use in furtherance of scientific understanding (i.e., empirically based, generalizable explanation of states of affairs and behavior) or in the creation, construction, or reshaping of technological devices and processes (Bozeman and Rogers 2000a).

3. A cooperative research and development agreement (CRADA) is an instrument created by U.S. law to enable the participation of government labs in R&D cooperative activities with private industry that may have commercial outcomes.

4. For a classic discussion of constructive typology in theory development, see McKinney (1966).

5. For a treatment of portfolio management of publicly funded R&D, see Bozeman and Rogers (2000b).

6. An analysis of the "linkage field" created in this case is provided in Rogers (2000).

7. The origin of a line of work will have a conventional aspect to it. So, for example, a younger researcher may leave a larger knowledge value alliance (KVA) to start his or her own independent research work. The feature of the latter activities may then look like a single-sector sporadic exchange (SSSE) system, but it will be clearly related to its "parent" KVA. Later it may take on momentum of its own. For evaluation purposes, it could be either an impact of the parent KVA or a new activity in its own right.

References

Averch, H. 1991. The practice of research evaluation in the United States. *Research Evaluation* 4:130-36.

Bozeman, B., and J. Melkers, eds. 1993. *Evaluating R&D impacts: Methods and practice*. Boston: Kluwer.

Bozeman, B., D. Roessner, J. Rogers, and H. Klein. 1997. *The R&D Value Mapping Project: Annual report, 1997*. Report to the Department of Energy, Office of Basic Energy Sciences. Atlanta: Georgia Institute of Technology.

Bozeman, B., and J. Rogers. 2000a. A "Churn" model of scientific and technical knowledge value: The *non*-economics of science. Manuscript submitted for publication.

———. 2000b. Strategic management of government-sponsored R&D portfolios: Project outputs and "scientific and technical human capital." *Environment and Planning C.: Government and Policy.*

Bozeman, B., J. Rogers, D. Roessner, H. Klein, and J. Park. 1998. *The R&D Value Mapping Project: Final report*. Report to the Department of Energy, Office of Basic Energy Sciences. Atlanta: Georgia Institute of Technology.

Bozeman, B., and D. Wittmer (1996). Technical roles and success of federal laboratory-industry partnerships. Presented at the EASST/4S Conference: Signatures of Knowledge Societies, 10-13 October, Bielefeld, Germany.

Callon, M., J. P. Courtial, P. Crance, P. Laredo, P. Mauguin, V. Rabeharisoa, Y. A. Rocher, and D. Vinck. 1991. Tools for the evaluation of technological programmes: An account of work done at the Centre for the Sociology of Innovation. *Technology Analysis & Strategic Management* 3 (1): 3-41.

Callon, M., P. Laredo, and P. Mustar. 1997. *The strategic management of research and technology.* Paris: Economica International.

Callon, Michel. 1991. Techno-economic networks and irreversibility. In *A sociology of monsters: Essays on power, technology and domination*, edited by John Law, 132-61. London: Routledge.

———. 1992. The dynamics of techno-economic networks. In *Technological change and company strategies*, edited by R. Coombs, P. Saviotti, and V. Walsh, 72-102. London: Academic Press.

———. 1993. Variety and irreversibility in networks of technique conception and adoption. In *Technology and the wealth of nations*, edited by Dominque Foray and Christopher Freeman, 232-68. London: Pinter.

———. 1994a. Four models for the dynamics of science. In *Handbook of science and technology studies*, edited by Sheila Jasanoff, Gerald Markle, James Petersen, and Trevor Pinch, 29-63. London: Sage.

———. 1994b. Is science a public good? *Science, Technology, & Human Values* 19 (4): 395-424.

———. 1997. Analysis of strategic relations between firms and university laboratories. Presented at the Conference on the Need for a New Economics of Science, February, University of Notre Dame, Indiana.

Callon, Michel, and John Law. 1989. On the construction of sociotechnical networks: Content and context revisited. *Knowledge and Society: Studies in the Sociology of Science Past and Present* 8:57-85.

Chubin, D. 1985. Beyond invisible colleges: Inspirations and aspirations of post-1972 social studies of science. *Scientometrics* 7 (3-6): 221-54.

Cozzens, S., S. Popper, J. Bonomo, K. Koizumi, and A. Flanagan. 1994. *Methods for evaluating fundamental science*. Report prepared for the Office of Science and Technology Policy. Washington, DC: RAND, Critical Technologies Institute.

Crane, Diana. 1972. *The invisible college*. Chicago: University of Chicago Press.

Crow, M., and B. Bozeman. 1998. *Limited by design: R&D laboratories in the US national innovation system*. New York: Columbia University Press.

Elzen, B., B. Enserink, and W. A. Smit. 1996. Socio-technical networks—How a technology studies approach may help to solve problems related to technical change. *Social Studies of Science* 26 (1): 95-141.

Etzkowitz, H. 1989. Entrepreneurial science in the academy: A case of the transformation of norms. *Social Problems* 36 (1): 14-29.

Faulkner, W. 1994. Conceptualizing knowledge used in innovation: A second look at the science-technology distinction and industrial innovation. *Science, Technology, & Human Values* 1 (4): 425-58.

Gibbons, Michael, Camille Limoges, Helga Novotny, Simon Schwartzman, Peter Scott, and Martin Trow. 1994. *The new production of knowledge: The dynamics of science and research in contemporary societies*. London: Sage.

Hagstrom, W. O. 1975. *The scientific collective*. New York: Basic Books.

Joly, P. B. 1997. Chercheurs et Laboratoires dans la Nouvelle Economie de la Science. Presented at the Conference on the Need for a New Economics of Science, February, University of Notre Dame, Indiana.

Joly, P. B., and V. Mangematin. 1996. Profile of public laboratories, industrial partnerships and organisation of R&D: The dynamics of industrial relationships in a large research organisation. *Research Policy* 25 (9): 901-22.

Kostoff, R., H. Averch, and D. Chubin. 1994. Research impact assessment: Introduction and overview. *Evaluation Review* 18 (1): 3-10.

Laredo, P. 1997. Technological programs in the European Union. In *Universities and the global knowledge economy: A triple helix of university-industry-government relations*, edited by Henry Etzkowitz and Loet Leydesdorff. London: Pinter.

Link, A. 1996. *Evaluating public sector research & development*. New York: Greenwood.

Liyanage, S. 1995. Breeding innovation clusters through collaborative research networks. *Technovation* 15 (9): 553-67.

McKinney, J. 1966. *Constructive typology and social theory.* New York: Appleton-Century-Crofts.

Popper, S. 1995. *Economic approaches to measuring the performance and benefits of fundamental science*. Report prepared for the Office of Science and Technology Policy. Washington, DC: RAND, Critical Technologies Institute.

Rappa, M. A., and K. Debackere. 1992. Technological collectives and the diffusion of knowledge. *R&D Management* 22 (3): 209-20.

Rogers, J. D. 2000. Software's "functional coding" and personnel mobility in technology transfer: Linkage fields between industry and publicly funded research. *International Journal of Technology Management*.

Shrum, Wesley. 1985. *Organized technology: Networks and innovation in technical systems*. West Lafayette, IN: Purdue University Press.

Juan D. Rogers is Assistant Professor of Public Policy and Associate Director of the Research Value Mapping Program at Georgia Tech. His research focuses on the organization of R&D, R&D evaluation, and the institutional dimensions of the Internet. Recent publications include "Software's 'Functional Coding' and Personnel Mobility in Technology Transfer: Linkage Fields between Industry and Publicly Funded Research" in International Journal of Technology Management *and "Internetworking and the Politics of Science: NSFNET in INTERNET History" in* The Information Society.

Barry Bozeman is Professor of Public Policy and Director, Research Value Mapping Program, Georgia Tech. His research focuses on R&D evaluation, technology transfer, and organization theory and design. His most recent book is Limited by Design: R&D Laboratories in the U.S. National Innovation System *(written with Michael Crow).*