Assessing Economic and Social Impacts of Basic Research Sponsored By the Office of Basic Energy Sciences

Renewal of DE-FG02-96ER45562

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Summary

The research described in this renewal proposal examines the impact of government-sponsored R&D in the development and diffusion of "scientific and technical human capital." Scientific and technical (S&T) human capital includes the skills, know-how, "tacit knowledge," formal training and social/professional resources embodied in individual scientists. Economists measure human capital in terms of such surrogates as wages and market demand, but scientists and engineers ply their human capital routinely in their work. Generally, economists focus on formal educational attainment but pay no heed to human capital increments occurring *after* the award of the highest degree (Becker, 1993). Our concept focuses on the full range of human capital (including formal and informal training after the terminal degree) and the social capital-based professional and normative ties that shape scientists' work. Thus, S&T capital is that it is the reservoir of knowledge, both technical *and* social, scientists bring to their work.

Much of S&T human capital, especially that aspect that is interpersonal and social, is embedded in social and professional networks. These networks integrate and shape scientific work, providing knowledge of scientists' and engineers' work activity, helping with job opportunities and job mobility and providing indications about possible applications for scientific and technical work products.

We hypothesize that BES-sponsored projects and user facilities contribute significantly to the development and diffusion of S&T human capital and, thereby, the ***capacity*** of the nation to produce scientific discoveries, to innovate and to harness scientific and technological products to economic growth.

The proposed research seeks to:

1. Identify the S&T human capital components of selected projects and BES-sponsored user facilities;
2. To track the diffusion of S&T human capital, as embodied in the individuals involved in projects ("project graduates") and user facilities ("user facility graduates");
3. To examine the impacts of the work from projects and user facilities and to associate these impacts with development of S&T human capital;
4. To determine the linkage of "project graduates" (and "user facility graduates") to networks composed of the producers *and* users of science and technology and the capacity they bring to the networks.

The analysis is accomplished by gathering two types of data: (1) resumes and curriculum vitae from scientists who have been supported by BES-funded projects or participated in user facilities, and (2) responses from an Internet-based questionnaire examining scientific accomplishments, career trajectories and dynamics. Particular attention will be paid to network ties and communication patterns and to means of evaluating S&T human capital. **The chief research goal is to describe the role of projects and user facilities in enhancing the S&T technical human capital available to the nation's scientific and technical enterprise.**

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I. Introduction

The purpose of the research proposed in this renewal proposal is to build on the RVM work but with specific attention to an approach to evaluation that arose from our experiences in the first phase. Both in our theoretical papers (Bozeman and Rogers, 1998) and our empirical work (Bozeman, Rogers and Roessner, 1997; 1998), we concluded that one of the most important impacts of the BES-funded projects we examined was on the development and diffusion of "scientific and technical human capital."

What we mean by the term "scientific and technical (S&T) human capital" is skills, know-how, "tacit knowledge," formal training, and social/professional resources embodied in individual scientists. Economists measure human capital in terms of such surrogates as wages and market demand, but scientists and engineers ply their human capital routinely in their work. Generally, economists focus on formal educational attainment but pay little or no heed to human capital increments occurring *after* the award of the highest degree (Becker, 1993). Sociologists measure social capital as the "set of resources that inhere in …community social organization and that are useful for cognitive or social development" (Coleman, 1990, p. 3). Generally, sociologists focus on nontechnical communities' use of social ties. Our concept focuses on the full range of human capital (including formal and informal training after the terminal degree) and the social capital-based professional and normative ties that shape scientists' work.

By our usage, S&T capital is that it is the reservoir of knowledge, both technical *and* social, scientists bring to their work. Thus, theoretical knowledge explaining reactions in surface chemistry is S&T human capital. It can be transferred, as embodied in the individual, from one purpose or work site to another. It is an endowment that exists so long as the individual works and retains the knowledge and so long as the knowledge is viable. But there are many other elements of S&T human capital. Other examples include knowledge of testing procedures and results, ability to use and build equipment, knowledge of technology and technological processes, and knowledge about software and its uses. Finally, S&T human capital also has a social component. This includes, for example, knowledge about which individuals are expert on particular topics, social and professional contacts relevant to scientific and technological work, and contacts related to commercial development and use of scientific and technical products. At a most general level, S&T human capital is the entire range of knowledge of various types that permits scientists to succeed in their work.

Much of S&T human capital, especially that aspect that is interpersonal and social, is embedded in social networks. Networks and "invisible colleges" (Crane 1972; Chubin 1985) are the informal groups that integrate scientific work, provide knowledge of scientists' and engineers' work activity, help them with job opportunities and job mobility and provide indications about possible applications for scientific and technical work products. In addition to the informal, social resources of networks, there are also formal media that accomplish similar objectives. Thus, scientists looking for a new job can use social contacts or examine job newsletters; those seeking to find uses for products can rely on network contacts or can use formal and legal devices, those interested in understanding other scientists' work can either approach them informally or simply read publications. Scientific and technical human capital, thus, can be derived from either formal or informal media.

We hypothesize that BES-sponsored projects and user facilities contribute significantly to the development and diffusion of S&T human capital and, thereby, the *capacity* of the nation to produce scientific discoveries, to innovate and to harness scientific and technological products to economic growth. Most R&D evaluations (including our own previous study [Bozeman et al. 1998]) focus on the production and use of scientific and technical products (Bozeman and Melkers 1993; Cozzens et al. 1994). The proposed study focuses on the capacity developed from projects and user facilities. One part of this capacity is scientific and technical equipment, devices and infrastructure (Bud and Cozzens 1994). The even more important element is S&T human capital. Arguably, S&T human capital, usually unmeasured, has a deeper and longer-run benefit than do most discrete scientific and technical products.

The proposed research seeks to:

- Identify the S&T human capital components of selected projects and BES-sponsored user facilities;
- To track the diffusion of S&T human capital, as embodied in the individuals involved in projects ("project graduates") and user facilities ("user facility graduates");

- To examine the impacts of the work from projects and user facilities and to associate these impacts with development of S&T human capital;
- To determine the linkage of "project graduates" (and "user facility graduates") to networks composed of the producers *and* users of science and technology and the capacity they bring to the networks.[1]

II. Results of Department of Energy Support

Previous BES-funded work under the project title "Assessing the Impacts in Industry of Basic Research Sponsored by the Office of Basic Energy Sciences: An R&D Value Mapping Approach," sought to evaluate the impact on industry of public investment in basic research. This was to be accomplished using an innovative case study design intended to provide information about a broad array of R&D outputs. This approach, termed "R&D Value Mapping" (RVM) was to yield insight into not only the nature of the impacts but also the attributes of projects associated with impacts of particular types and magnitudes. At this point, the research is essentially completed and a final report will be delivered on time.

This discussion of the work under the initial DOE support is divided into the four major types of results: (1) Evaluation Methodology Results, (2) Empirical Results, (3) Theoretical and Conceptual Results, (4) Case Study Results.

1. Evaluation Methodology Results

One of the express purposes of the DOE-funded research was to develop new approaches to evaluating and understanding research results. This was accomplished by further development of the R&D Value Mapping (RVM) approach. The discussion of the method draws from papers published explaining the approach and its application (Bozeman and Kingsley, 1997; Kingsley and Bozeman, 1997).

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[1] This will not allow us to draw a direct link between the original projects or user facility activities and second order impacts on networks (there are too many other factors coming into play, including individuals' scientific and technical human capital development in other projects and other types of learning). But the knowledge of diffusion and linkages to networks is itself important.

The RVM method yields an inventory of benefits and empirical generalizations of the determinants of those benefits and has been applied in several studies (Bozeman et al., 1992; Bozeman and Roessner, 1995; Kingsley and Bozeman, 1997; Kingsley and Farmer, 1997; Kingsley, Bozeman and Coker, 1996). A particular advantage of the approach is that it not only provides an indication of the type and amount (though not a single numerical index) of value, but also gives insight into the reasons benefits are achieved. Thus, R&D value mapping (RVM) is useful for policy management strategies seeking to replicate success.

In capsule, RVM begins with one or more analytical models that track flows of knowledge and specifies possible outcomes of R&D projects. The outcomes are modeled in terms of sequences of events, depicted as a branching model. Each step in the model might be either the final outcome for the project or a preliminary stage to the next step. Thus, the sequences might include:

(step 1) project completed (yes, no), [if yes...]

(step 2) results disseminated outside the laboratory (yes, no), [if yes...]

(step 3) results used by an individual or organization not affiliated with the lab (yes, no), [if yes...]

(step 4) product developed from results (yes, no), [if yes...]

(step 5) product marketed (yes, no) [if yes...]

(step 6) outcomes [for example, sales from product, or other measures of benefits, costs, and disbenefits].

RVM involves measuring a variety of hypothesized project attributes (e.g. resources devoted to a project; the number of industrial participants; disposition of IPR) against the branched patterns of outcomes. By conceiving projects in terms of the progress of their results along certain branched alternatives, it is possible to develop predictive models of the factors related to project outcomes vis-a-vis those possible branched alternatives. Essentially, what factors relate to the ultimate path position, the final step, of the project?

RVM provides quantitative data from cross-case analysis. In some instances the measurement approach is similar to most quantitative studies. Thus, for each case, indicators are developed for such variables as amount of funding for the project, numbers of personnel devoted to the project and, on the benefit side, such variables as estimated monetary benefits and numbers of personnel receiving advanced training. Somewhat of a departure, however, is the attempt to use dummy variables (i.e. 0,1) to measure qualitative aspects of the cases. Thus, it is possible to quantify such variables as whether the lab's technology transfer office was involved in the project (0=not involved, 1=involved), whether a diffusion plan was developed at the outset of a project (0=developed later or not at all, 1=developed at outset), or whether the results of the project required the user to develop new manufacturing processes (0=not required, 1=required). By combining these variables, both the traditional interval-level variables and the dummy variables for the presence/absence of a project attribute, a series of causally relevant independent variables are developed.

These independent variables are then analyzed in terms of the sequential models developed at the outset. This assessment is made both in terms of the step reached in the branching model and the benefits (or disbenefits) that occur. RVM is similar to other case survey techniques whereby multiple coders score individual cases and resulting scores are subjected to inter-coder reliability analysis (Bullock & Tubbs, 1987, Larsson, 1993, Wolf, 1993). Case scores are then categorized for pattern-matching both within groups of cases and between case groupings.

Table One in the appendix, adapted from Bozeman and Kingsley, 1997, provides an approach to "locating" and assessing RVM in connection with other available R&D impact evaluation approaches.

2. Empirical Results

The product of an RVM analysis is a set of "maps" relating outcomes to project attributes. The approaches to developing case-based information included: (1) intensive on-site case studies; (2) review of documents and reports; (3) Internet-based survey. TheThest of cases chosen was determined by a combination of three factors- interviews with DOE program managers about projects and their effects, a desire to have a representative base of projects (which produced a sampling method documented elsewhere), and access. The latter factor turned out to have less impact than expected as the great majority of PIs contacted agreed to contribute data to the study.

After collecting the data (as described above), each of several outcome variables was employed as, essentially, a dependent variable. The independent variables provide an implicit set of hypotheses about possible relationships between project attributes and outcomes, but it is useful to make these assumptions more explicit. Figure 1 in the appendix provides the general outcome model. It is not viewed as exhaustive, but rather includes those variables, which could be obtained by the methods employed. Other possibly important variables are considered in the qualitative analysis of the case studies.

One of the initial motivations for this project was the view that *many of the most important impacts of public-funded R&D generally are not counted at all*. The tendency is to focus on the obvious or the easily measured. In order to remedy this narrow view, the case studies were employed to develop ideas from the researchers themselves as to the nature and importance of the impacts of their work. (See Tables 2 and 3 in the appendix).

The questioning in the RVM modeling is simple:

1. Did the project result in any particular activity or outcome?
2. What are the attributes of projects and how do they relate to the achievement of particular outcomes?

The analysis proceeds according to activity type. The activities include not only publication of articles and development of patents and licensing but support of students, technology assistance to industry, development of products, development of manufacturing techniques and processes, equipment sharing, development of algorithms and so forth. An illustration is provided indicating the relation of project attributes to a particular outcome [Figures 2 to 5 in the appendix]. Below is a summary of this analysis applied to a few of the possible outcomes.

Outcome: Scientific Publications. Six of the twenty-four project cases produced more than 100 publications to date. Regarding **project motivation**, one of the points almost all these projects have in common is a self-conscious desire to shape a discipline, sub-discipline, or field of science. This is not a motive for some projects, but is reported as one for five of the six projects producing unusually large numbers of published papers. By contrast, only one of the projects with 100+ articles has as a motive developing new technology (this despite the fact that nearly 60% of the >100 projects report technology development as a guiding motive. Half these high-producing projects report that equipment development or sharing is an important motivation in the project. In those projects not producing 100+ publications, equipment-related motivations are much less common (>15%).

One would expect that the **research focus** of projects with large numbers of scientific publications would be on basic research and, in fact, that is the focus of five of the six high producers. Even more interestingly, half of the 100+ article-producers who do not list technology development or technology transfer as a motive, nonetheless have patents and licenses from these projects. This is implies, perhaps, a bit of a mismatch between, on the one hand, R&D focus and intent and, on the other, outcome. *Put simply, high scientific producers often produce patents and licenses even if it is not a focus of the project or a major motivation.*

In sum, large-scale scientific production takes large-scale resources in terms of funding, equipment focus, personnel and time. So-called "little science" projects may produce high quality but they do not seem to have as much potential to either produce in great quantity or to produce sweeping changes in scientific disciplines and fields. These types of changes require large, stable infusions of resources.

Outcome: Patents and Licenses. Given the close relationship between patents and licenses, we consider the two together here. Eleven of the twenty-four projects have produced patents. There is little difference according to setting, with five university projects having produced patents and six government laboratory projects. Similarly, four of the projects with licenses are government laboratories, four are universities. However, when we consider **research focus,** *those projects with patents and licenses are even more likely than others to be oriented to basic research and less likely than others to be oriented to commercially-oriented applied research or technology development.*

Outcome: Technical Assistance. The work of laboratories on technical assistance to industry often goes unreported and, thus, are not credited. But industrial technical assistance is becoming an ever-more common activity. Indeed, half the 24 cases examined report significant activities pertaining to technical assistance to industry. Among these, five are government laboratories and seven are universities.

The reported **motives** for those projects engaged in technical assistance to industry are not highly dissimilar to other projects. As expected, they are somewhat more likely to report motivation to examine problems related to industry and to focus on developing new processes. The labs engaged in technical assistance are no more likely than others to report that their lab leadership encourages collaboration with other institutions.

The **research foci** for technical assistance-related projects are somewhat more oriented toward pre-commercial applied research and commercial applied research but no more strongly oriented than other labs toward technology transfer. As is the case for all the projects, there is a strong orientation to basic research.

With respect to **personnel**, projects involving technical assistance are somewhat more likely to involve personnel from a variety of the lab's divisions and much more likely to involve persons from outside the focal laboratory (11 of 12 involve outsiders, whereas only two of the remaining 12 projects involve outsiders). This implies that *technology assistance activities are particularly important, even more than technology transfer activities, in forging links with outsiders and working directly with people outside the institution.*

Outcome: Algorithms. Unlike many other activities supported by BES, the institutional setting makes a considerable difference. *Of the eleven producers of algorithms, eight are national laboratories.* The **research foci** of projects producing algorithms are distinctly different in that they tend to provide stronger emphasis than other projects on product development, technology transfer, and technical assistance. Projects developing software or algorithms are much more likely to entail CRADAs and to have licenses and patents. *From every standpoint, algorithm software production seems to be the major category of product development and application produced by BES funding.*

Outcome: Training Students. Nineteen projects report student training as a significant output and this includes eight government laboratories. Thus, the interesting question is the characteristics of projects that do *not* have student training as a component. A first characteristic is that they are all government laboratories.

Generally, the BES projects having no students tend to be smaller-scale and oriented almost exclusively to production of fundamental scientific knowledge. All of the projects without students began before 1990 and they are generally less likely to be funded at the $1 million level ore more and generally include less than ten scientific and technical team members.

Outcome: Technology Processes and Manufacturing Techniques. Only four of the twenty-four projects resulted in new technology processes or manufacturing techniques, three at government laboratories and only one at a university. Regarding the **project motivation,** the chief difference in these four projects is a stronger orientation toward most commercially-relevant motives including working on problems to industry, developing new processes and developing new technology. But, interestingly, *each of the four included shaping the field or discipline as a very important motive. This is perhaps best explained by the fact that the processes developed contribute to the ability of scientists working in the field to perform new studies and tests. These processes are not "near market."* Some examples of the processes developed are new sensors, processing of lube oils and recovery evaluation techniques, a reflectance monitor (which won a 1997 R&D 100 award and is now being commercialized).

Outcome: Equipment Sharing. While the projects involving equipment sharing are equally likely to be located in universities or government labs (four in each setting), they otherwise tend to be quite distinct from other projects. In terms of **project motive**, they are more likely to be oriented to problems relevant to industry, to the development of new technological and manufacturing processes and to the development of interorganizational ties. They differ in that *none of these projects report motivation by internal pressures for grants or for funding diversification (implying that equipment-based, equipment-sharing attributes give rise to stability).*

The findings from the RVM analysis are more extensive than can be considered here and, moreover, are available in a project paper (Bozeman, Rogers and Park, 1998). The summary provided here should give some insight into the RVM approach and the results one obtains in its application.

3. Conceptual and Theoretical Results

Much of the important work in the project has involved developing conceptual and theoretical schema relevant to understanding the impacts of scientific and technical work. Indeed, the most revolutionary outcome of our work has been a fundamentally different approach to evaluating impacts of science and technology. The conceptual contributions are summarized here in terms of each of the major conceptual papers prepared during the project.

a. Barry Bozeman and Juan Rogers, "Knowledge Value Collectives: A Theory of Knowledge for Research Evaluation". The paper presents an alternative approach to valuing knowledge, one that relies less on economic prices or shadow prices than on the range and repetition of uses of scientific and technical knowledge, a "use-and-transformation approach." A key concept is the "knowledge value collective," a set of individuals connected by their uses of a particular body of information for a particular type of application: creation and use of scientific and technical knowledge. The paper argues that innovation cannot be assessed independently of the collective arrangements of skilled people, their laboratories and instruments, social networks, resources and institutions. Most evaluations focus on R&D outputs, we argue that the dynamics of research collectives- their "health," longevity, breadth, ability to create new applications- is often more important. The paper outlines the concept of the knowledge value collective and related knowledge value alliances (a more formalized working group). We contrast the knowledge value collective, which we feel is a more realistic focus for evaluation, with the more traditional unit of analysis, the scientific discipline. The general idea is illustrated through an application using the material from one our in-depth case studies.

b. Barry Bozeman and Juan Rogers, "Information Use as a Criterion for Knowledge Value." This paper is in some respects an application of the first. The paper focuses more specifically on evaluation and compares a use-and-transformation approach to R&D evaluation to a more traditional economic approach. The paper provides alternative approaches to actually measuring knowledge value collectives and their dynamics and provides dimensions (e.g. growth-decline, fecundity, impacts of scientific and technical human capital). The paper discusses the approach in connection with new evaluative demands now underway through the Government Performance and Results Act.

c. Juan Rogers and Barry Bozeman, "Modeling the Creation of Knowledge Value: Comparisons and Types of Knowledge Value Alliances." In a sense, this is an empirical paper because it takes the concepts and ideas developed in the two papers discussed above and uses the RVM cases studies to develop a taxonomy. From the case studies, we observed several basic structures for performing science and labeled them (e.g. "Enabling Star System," "Multiple-Sector Mutually Adapting System"). The purpose was to determine the relationship of project resources and organizational variables to the outcomes obtained in projects. Each element of the taxonomy is illustrated with a case study.

4. Case study results and management/evaluation implications

A prerequisite to the RVM study was the development of extensive case studies. At this point, some sixteen full-blown case studies, based on one or more site visits, have been performed. Each of these resulted in a monograph (see appendix).

While there was a great deal to be learned from each of the individual cases (too much to be reviewed here), the entire set of cases, examined together, provided several practical lessons about the results of BES-funded projects. Many of these results have practical management implications. These broader results were reviewed in our Advisory Board presentation (1998). The practical lessons discussed at that time pertained to (among other factors): (1) PI's strategic uses of BES funding and the particular value of stable funding; (2) the fecundity of basic research for technology development and human capital development purposes; (3) the unplanned, informal emergence of new institutions and new organization designs for accomplishing interdisciplinary scientific work; (4) the special role of user facilities and the variety of contributions made by different sorts of user facilities.

III. Proposed Research

The RVM research findings underscored the importance of BES funding on the careers of scientists and the long-term ability to contribute to scientific and technical goals of various sorts and over the entire career life span. While discrete outputs of projects remain important, these capacity-building aspects are even more important. The proposed research builds directly on the earlier RVM work but focuses more on long-range capacity rather than near-term impacts.

There is a substantial body of work on communities of scientists that includes studies on the patterns of communication and social structures within disciplinary boundaries (Hagstrom 1975, Crane 1972, Chubin 1985, Hargens 1988). These studies did not consider the relation between the various types of knowledge in each discipline and the structural patterns for each community. When this question is raised explicitly, it leads to different models of scientific development that show the importance of the mobility of scientists across disciplinary boundaries (Mulkay 1975). The results of our previous work confirm this and suggest that tracking the careers of individual researchers taking into account their migration not only from place to place but also into new fields or areas of knowledge is necessary to understand the creation of capacity in science and technology.

Available studies on the careers of scientists have been concerned mainly with the issues of stratification (Cole and Cole 1973), gender differences (Zuckerman and Cole 1975, Fox 1994, Reskin 1978b, Rossiter 1993) and cumulative advantage (Merton 1988). A central aspect of the evaluation of research in the US has been the focus on the careers of individuals (Diamond, 1984; Stephan and Levin, 1997; Stephan, 1996; Levin and Stephan, 1991). However, for evaluation purposes, individuals are considered completely independently of the research groups and context in which they work or have worked. Careers of individual scientists have also been studied from an institutional point of view as they relate to the he titutions and social structures of the academy and the disciplines (Long 1978; Long et al. 1979; McGinness et al. 1982). This body of work does not address the issue of the creation of capacity or value as publicly funded projects give rise to various patterns in the career trajectories of scientists and engineers.

IV. Methods and Research Procedures

The proposed research seeks to: (1) identify the S&T human capital components of selected projects and BES-sponsored user facilities; (2) track the diffusion of S&T human capital, (3) examine the impacts of the work from projects and user facilities and to associate these impacts with development of S&T human capital; (4) determine the linkage of "project graduates" (and "user facility graduates") to networks composed of the producers *and* users of science and technology and the capacity they bring to the networks. The research design described here permits us to achieve these research objectives.

Research Steps

1. Selection of Projects and User Facilities. The study begins by selecting the projects and user facilities that pose the *beginning point* for data collection. (Since our study has as much to do with scientific career development and trajectories, the choice of "entry point" is not as vital as it would be for a project-centered study). Building on our earlier BES-sponsored work (Bozeman, et al., 1998), we shall select at least four projects examined previously. Informal discussions have already begun and participation agreements have in some cases already been obtained. In addition to the four projects, we shall also examine in a more comprehensive fashion four BES-sponsored user facilities or centers. We anticipate that two of these will be the Combustion Research Facility and the Michigan State Plant Biology Center, the other two will depend upon access and informal discussions with officials knowledgeable about the facilities.

2. Data Inventories

a. **Project output.** In many instances we already have a set of the outputs (e.g. articles, patents, awards) from projects and user facilities (Bozeman, et al., 1998). For those projects/facilities we examine for the first time, we will need a comparable set of outputs.

   We do not have extensive information about the output of user facilities and a major aspect of the study will be to document various types of output for user facilities (in much the same was as accomplished in the R&D value mapping study).

b. Inventory of "Project Graduates" and "User Facility Graduates." Since ours is a study of career trajectories, we must develop an inventory of all PI's, post-docs, faculty researchers/collaborators, industry users/collaborators associated with either the project or facility. In some cases we will already have a complete inventory of research and technology products from the project. In cases where we do not, such an inventory will be necessary.

Again, we do not have extensive information about individuals who have visited and used the user facilities and simply compiling lists and relating (below) to career trajectories should prove useful in and of itself.

c. Career Data from Resumes. After obtaining a list of individuals (project graduates/facilities graduates) we shall contact each of them in order to obtain information about current occupation and location as reflected in resumes or curriculum vitae. Previous research has indicated that the professional's resume is an excellent source of data related to accomplishments, career change, and project and institutional affiliation. Use of resumes greatly facilitates the formidable task of developing a database of several hundred BES-sponsored scientists and engineers and their colleagues. Our primary use will be to understand career patterns and the diffusion of S&T human capital. To do this we will construct a "career trajectory database" which will begin with the information from resumes and be supplemented with questionnaire-based data.

Using this data, we can code, among other possibilities, the degree of substantive migration, the movement among sectors (industry, government, university), the rapidity of job change, the status of university jobs, the job type (e.g. post-doc, faculty). Each of these is important to understanding the diffusion of S&T human capital from projects.

d. Citation and patent data. The resumes will, presumably, be adequate for beginning a citation and patent database that can be used to examine communication and collaboration patterns among persons in the database.

3. Survey data. Project/user facilities graduates for whom we have a resume will be asked to provide questionnaire-based data. In most instances, this will be accomplished with an Internet, web-based survey. Our earlier experience (Bozeman, Rogers and Park, 1998) indicated that this format was easy for technically-trained individuals to use and, in the very few instances where that was not the case, it was easy enough to provide a hard copy version (a copy of the web-based questionnaire used in previous research is included in the appendix). The survey will be focused on information related to the respondents' history with the project/facility from which they "graduated" and reasons for particular career choices. We will also examine continued ties to members of the original project. Most important, we will use the survey information to begin determining membership in informal networks of scientists and users of science and technology.

It is not useful for us to develop questionnaire instruments at this time, but Table Five provides an illustration of the type of information we can develop to help us understand network ties and communication patterns.

4. Network Analysis

Much of the study will focus on the respondents' (project graduates) professional ties as reflected in activities of informal networks. Thus, as a result of data accumulated from citations and co-citations, collaboration patterns, and the data from questionnaires, we will have an excellent indication of respondents' professional interactions, both formal and informal. This data will allow us to plot networks indicating the existence of interaction and communication ties within networks and the flow of S&T human capital from one context and network to another.

In addition to the standard network variables (e.g. density, centrality, strength of ties) we will analyze the substantive foci or specialties of the network in order to determine proximity to the original project from which the respondent "graduated."

Expected Results and Utility for BES

We expect that the results of BES-funded projects and user facilities add up to much more than the sum of project outputs. In particular, projects and facilities contribute enormously to what we call S&T human capital- the combination of scientific skills and person-to-person ties available to scientists. Our study should accomplish the following:

1. The S&T human capital of hundreds of scientists will be measured and traced back to projects or facilities funded by BES.
2. The flow of S&T human capital will be measured, producing not only a picture of the contribution of projects to S&T human capital available to other scientific and technical purposes but, at the same time, information about the dynamics of scientific careers.
3. From an evaluation standpoint, the results will indicate which projects/facilities are associated with what type of S&T human capital, possibly providing a better idea of the *long-range* benefits of projects to scientific careers and, in general, the nation's scientific capacity.

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VII. Publications and Presentations from DOE-Supported Work (1996-98)

1. Papers published or submitted for publication

Barry Bozeman and Hans Klein, "Government's Role in Performing Research," chapter in Chris Hill (ed.) *Science and Technology Policy in the U.S.: A Time of Change* (London: Longman), forthcoming.

Barry Bozeman and Hans Klein, "The Case Study as Research Heuristic: Lessons from the R&D Value Mapping Project," *Evaluation and Program Planning*, forthcoming.

Barry Bozeman and Monica Gaughan, "Models of Scientific Careers: Using Network Theory to Explain Transmission of Scientific and Technical Human Capital," to appear in *International JouJoul of Technology Management*.

Barry Bozeman and Gordon Kingsley, "The Research Value Mapping Approach to R&D Assessment," *Journal of Technology Transfer*, 22, 2, (1997) 33-42.
(Note: This paper was awarded the Technology Transfer Society's Lang-Rosen Award for research excellence).

Barry Bozeman and Dennis Wittmer, "Technical Roles and Success of Federal Laboratory-Industry Partnerships," *Research Policy*, revised, resubmitted for publication.

Barry Bozeman, "Commercialization of Federal Laboratory Technology: Results of a Study of Industrial Partners," in R.P. Oakey (ed.), *New Technology-Based Firms in the 1990s, Volume 3* (London: Paul Chapman Publishing Limited), 1997, 127-139.

Barry Bozeman and Gordon Kingsley, "Charting the Routes to Commercialization: The Absorption and Transfer of Energy Conservation Technologies," *International Journal of Global Energy Issues*, 9, 1/2, 1997, pp. 8-15.

Gordon Kingsley and Barry Bozeman, "Commercial Interactions with Federal Laboratories," *Materials Technology*, forthcoming.

Juan Rogers and Barry Bozeman, "Basic Research and the Success of Federal Lab-Industry Partnerships," *Journal of Technology Transfer*, 22, 3, (1997) 37-48.

Juan Rogers, "Researcher mobility as a way to transfer scientific knowledge," to appear in a special issue the *International Journal of Technology Management.*

2. Professional conference presentations, symposia

Barry Bozeman, "Knowledge Value Collectives and R&D Evaluation," invited lecture, Workshop on R&D Evaluation, Ecole des Mine, Paris, France, June, 1998.

Barry Bozeman, "Empirical Results from the R&D Value Mapping Project," invited lecture, University of Copenhagen, September, 1998.

Barry Bozeman, Monica Gaughan and Jongwon Park, "Scientific and Technical Human Capital and R&D Evaluation," paper prepared for presentation at the Annual Meeting of the Institute for Operations Research and Management Science, Seattle, October, 1998.

Barry Bozeman and Juan Rogers, "Research Value Mapping Project Overview," Advisory Board, Office of Energy Research, June, 1998.

Barry Bozeman and D. Wittmer, "Technical Roles and the Success of Federal Laboratory-Industry Partnerships," paper presented at the EASST/43S Conference: Signatures of Knowledge Societies, Bielefeld, Germany, October, 1996.

Juan D. Rogers and Barry Bozeman, "Knowledge Value Communities: The Proof is in the Putting," paper presented at Society for the Social Studies of Science Annual Conference, University of Arizona, Tucson, Arizona, October 23-26, 1997.

Juan D. Rogers, "Models of the Creation of Knowledge Value," invited lecture, Workshop on R&D Evaluation, Ecole des Mines, Paris, France, June, 1998.

Juan D. Rogers, "Career Paths as Inter-Sector Feedback Loops in R&D," paper prepared for presentation at the Annual Meeting of the Institute for Operations Research and Management Science, Seattle, October, 1998.

Juan D. Rogers, "Knowledge value networks: A use-and-transformation approach to R&D valuation," paper prepared for presentation at the 20th annual research conference of the Association for Public Policy Analysis and Management, New York, October 1998.

3. Technical Working Papers and Papers to be Submitted for Publication

Barry Bozeman, Juan Rogers, and Jongwon Park. 1998. "Research Value Mapping Analysis: Quantitative Case Studies of Basic Energy Sciences-Funded Research Projects." RVM Technical Working Paper. Submitted for publication.

Barry Bozeman and Juan Rogers. 1998. “Knowledge Value Collectives: A Theory of Knowledge for Research Evaluation." RVM Technical Working Paper. Submitted for publication.

Barry Bozeman and Juan Rogers. 1998. “Information Use as a Criterion for Knowledge Value.” RVM Technical Working Paper. Submitted for publication.

Juan Rogers and Barry Bozeman. 1998. “Modeling the Creation of Knowledge Value: Comparisons and Types of Knowledge Value Alliance.” RVM Technical Working Paper. Submitted for Publication.