Project Summary

ASSESSING R&D PROJECTS' IMPACTS ON SCIENTIFIC AND TECHNICAL HUMAN CAPITAL DEVELOPMENT: Building "Knowledge Value Alliances"

Studies of innovations have already established the importance of close coupling of networks for knowledge transfer and success of innovations in the economy (DeBresson and Amesse, 1991; Callon 1992). They show that the flow of people from one organization, firm, or group to another is key in the process of knowledge exchange. However, there is not much systematic, detailed knowledge of the career paths of individuals and their relation with the contexts of research they come from and go to creating actual impact paths for the activities they leave behind.

The proposed research will address this issue by mapping the career paths of researchers against features of the research projects they worked in. Beginning with at least 20 projects in the U.S. and France, most from university settings but a few from government laboratories, the investigators will test several hypotheses about the connection between the characteristics of team-oriented R&D projects and the diffusion of scientific and technical human capital via the "projects' graduates."

The key research question is: "What characteristics of team-oriented R&D projects affect the long-term careers of persons involved in those projects and, in turn, the human resources capacity available for creating knowledge and spurring technology development?" Our case studies (e.g. Bozeman, et al., 1998) show that human resources development in R&D projects often provides opportunities for scientists, engineers and technicians to move into entirely new work contexts and specialties (including, among others, technology development in industry, equipment development, technique and craft, and new fields of science). Thus, the diffusion of human capital often sets new directions for scientific research and technology development. Our proposed research seeks not only to map these processes but also to determine the ways in which the management structure, content and linkages of R&D projects lead to different sorts of human resources and capacity outcomes.

Our research design is multi-field and multi-national. We focus on projects in two broad, multidisciplinary scientific fields and in two nations. Following our work with Department of Energy-funded projects, we examine energy and environmental projects, including both basic research projects and more applied projects. Following the recent research focus of our collaborators, a team of French researchers centered at the Ecole des Mines Centre de Sociolgie de l'Innovation, we examine research in biotechnology and life sciences.

The research will have two major components. In Phase I, we shall conduct intensive case studies of projects originating between three and ten years ago in order to learn as much as possible about the results, structure, management style, personnel and results of those projects. In Phase II, we use questionnaires and interviews to determine the career trajectories, level of human capital endowments, productivity and network linkages of "project graduates." This approach should permit us to understand the ways in which experiences in those focal projects have affected the career paths and contributions of participants.

Project Description

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Introduction

Studies of innovations (DeBresson and Amesse, 1991; Freeman, 1991; Callon 1992) have already established the importance of close coupling of networks for knowledge transfer and the ultimate success of innovations in the economy. They (Freeman, 1991; Faulkner, Senker, and Velho, 1995; Etzkowitz and Kemelgor, 1998) show that the flow of people from one organization, firm, or group to another is key in the process of knowledge exchange. However, there is not much systematic, detailed knowledge of the impact of early career participation in team-oriented research projects on later career choices, including movement into entirely new scientific fields and work contexts (Joly, 1997 and Mangematin, 1998 are recent contributions toward filling this gap). Our case studies (Bozeman, et al., 1998) suggest that publicly-funded R&D projects often have major impacts on scientific and technical human capital development, seeding "project graduates"[1] subsequent work, both scientific and commercial work.

The proposed research will address this issue by documenting and mapping the career paths of researchers that participated in focal research projects and then continued their work in other contexts, often in other sectors of the economy altogether. The research will show that far from being a random flow of individuals, often there are specific patterns that relate to the goals, strategies, and style of the research teams they passed through.

This research is important on at least two levels. First, it contributes to a dimension of the assessment of the impact of research that has either been treated abstractly or anecdotally, namely, the creation of capacity through basic research activities. The proposed work will draw from and contribute to continuing projects on the evaluation of R&D and impact assessment. It will take advantage of and build upon data gathered in numerous case studies of research sponsored by the Office of Basic Energy Science (BES) of the U.S. Department of Energy (DOE). And it will contribute to the overall study of scientific and technical human capital development by using a comparative framework taking into account various institutional settings, different fields of research, and an international dimension. The latter will be enabled through a collaboration with a prominent group of researchers centered at the Ecoles des Mines in France.

The second level of importance of this research will be determined by the contribution of empirically grounded knowledge of the ways in which flows of people constitute links between research and other activities in the economy across organizational and sector boundaries over time. It will offer maps of the legacy of research projects and teams in terms of the links to other innovation activities given by the "graduates" from the research groups. The importance of

[1] For simplicity's sake, we refer to all the members of a focal project as "project graduates," whether or not they have changed position or research focus.

scientists' and technologists' communications networks is well known. Early studies of "invisible colleges" (e.g. Crane, 1972), "diffusion networks" (e.g. Valente, 1995) and "technical systems" (e.g. Shrum, 1985; Callon, 1991, 1992) all demonstrate, in different ways, the value and workings of scientific and technical network. Our study seeks to build on this work by showing the relationship of career trajectories to movement into new networks, ones including scientific, technical and commercial participants.

Past Results and Next Steps: Laboratory Studies, Collaborations and Partnerships, and Individuals' Trajectories

The research we propose requires an understanding of the institutional settings and laboratory environments in which R&D projects occur and scientific and technical careers develop. The tradition of empirical studies of R&D laboratories (e.g. Andrews, 1979) flourished during the past decade and, as a result, considerable progress has been made in our understanding of the environments, structure and performance of R&D laboratories. Several researchers have contributed significantly to the study of the structure and environments of projects within R&D laboratories (e.g. Geisler, 1994; Roessner and Bean, 1990; 1994; Florida and Kenney, 1994; Berman, 1994; Lee, 1996; Joly and Mangematin, 1996). One multinational team of researchers collaborating in the National Comparative Research and Development Project (NCRDP) (see Crow and Bozeman, 1998, for a summary) was active throughout the decade, producing studies on such topics as commercialization of technology in U.S. federal laboratories (Bozeman and Papadakis, 1995; Papadakis, 1992; Bozeman, 1997); laboratories' technology transfer strategies and effectiveness (Rahm, et al., 1988; Bozeman and Coker; 1992); and even such management issues as bureaucratic red tape (Bozeman and Crow, 1991; Crow and Bozeman, 1989). At the same time as knowledge of instrumental topics emerged, the NCRDP studies focused on broader theories of laboratories and R&D projects, including the effects of "publicness" and government funding on the configuration of laboratories and products (Bozeman and Crow 1990; Crow and Bozeman, 1987).

While this NCRDP research shed light on the dynamics and performance of R&D laboratories, the studies were limited by their focus on discrete institutions (i.e. formally-defined laboratories) and discrete R&D projects. Such a formalistic approach provides insights into workings of formal bureaucracies but gives less knowledge about transactions spanning those bureaucracies. Focusing exclusively on formal organizations and projects fails to capture the dynamism of interchanges between work in R&D laboratories and external influences and impacts of that work. The building of artificial boundaries between a laboratory's scientists and engineers and the larger environment of other scientists and engineers, commerce, and social institutions using the work of scientists and engineers produces blinders. As Latour (1983, p. 143) observes correctly, "...the difference between the 'inside' and the `outside,' and the difference of scale between 'micro' and 'macro' levels, is precisely what laboratories are built to destabilize or undo."

Increasingly, researchers have looked beyond the confines of the individual laboratory to the "ecology" of the laboratory, R&D projects and groups of researchers. Lynn, Reddy and Aram (1996, p. 97) discuss the "innovation community framework," and seek to develop hypotheses about "organizations directly and indirectly involved in the commercialization of new technology." Callon's (1994; 1997) work on socio-technical networks likewise seeks to transcend organizational boundaries. The emphasis on networks by Callon and his colleagues (1997; 1994; 1992), in particular, but others as well (e.g. Liyanage, 1995; Rappa and Debackere, 1992; Elzen, Enserink and Smit, 1996; Crane, 1972) has been useful to break out of long established but not always useful analytical boundaries.

The study of innovations in sociology and economics has used network approaches for some time (Freeman 1991; DeBresson and Amesse 1991; Rogers 1995; Valente 1995). An early contribution of this work was the detection of the importance of "linkages" and "network coupling" that transcended the formal arrangements of institutions and organizations (Granoveter 1973). These studies have generally been of two sorts. On the one hand, they have aimed at characterizing the process of diffusion of innovations. On the other, they have tried to identify networks of businesses and entrepreneurs that are particularly successful in bringing innovations to fruition in the market. This includes attention given to collaborations and partnerships between public and private sector organizations and the conditions for their effectiveness (Fountain, 1998; Mangematin and Nesta, 1998; Rogers and Bozeman 1997; Faulkner, Senker and Velho, 1995). Several historical studies have documented the formation of these networks in particular industries over time (Galambos and Sewell, 1995; Hounshell and Smith, 1988; Hughes, 1983). A natural next step is to make use of these insights in the assessment of the impacts of research. A central aspect of the evaluation of research in the US has been the focus on the careers of individuals (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. We propose to use the same methodological assumptions that led to emphasizing networks to track the trajectories of individuals moving from one organization, team or group to another.

A focus on scientific and technical human capital development is not a new one, but most previous studies on this topic have not taken either an institutional or a network approach. A number of studies have pointed the way in understanding the formation of scientific and technical human capital (Weiss and Lillard, 1982; Diamond, 1984; Levin and Stephan, 1991). In general, these studies model utility functions for the life cycle of individual scientists, apart from network ties, and focus on income and research output measured by publications. In a recent review of economic approaches to the study of science, Stephan (1996) has argued that these human capital models fail to explain much of what is important to economics about researchers' careers. For example, they do not take into account cohort effects on publication output and, given the rather simplistic assumptions about the production of scientific knowledge, they do not model adequately the reward structure of research, which is necessary to understand their mobility. Recent work on the knowledge exchanges between firms has shown that what is lacking is a good understanding of the mechanisms by which organizations absorb knowledge (Mangematin and Nesta, 1998). Prominent among those mechanisms is movement between research contexts. By investigating the various paths that "projects' graduates" take during their careers, we will be able to answer some of these questions.

One contribution of the proposed study will be to examine broader networks and linkages between producers and users of scientific and technical knowledge. The study of innovations deriving from scientific research has been dominated over the years by a "linear" model of the diffusion of knowledge from its creation to its application in technological arrangements and their commercialization. This model has been critiqued and is widely regarded to be unsatisfactory in accounting for the full social and economic impact of knowledge produced in research (Rosenberg, 1982; Bijker et al., 1987). However, new models, such as Kline and Rosenberg's "chain link" model (Landau and Rosenberg, 1986), have not yet been applied widely in comparative empirical studies of innovation. The proposed research seeks to fill this gap by working on multiple cases with a common framework and focusing on one of the major weaknesses of these models: the links and feedback loops created by the movement of people between scientific and commercial work context and networks.

"Knowledge Value Alliances": Interactions Among Scientists and Knowledge Users

a. The individual and collective levels

The relation between the career trajectories of individual researearrs and the the characteristics of team-oriented research projects in which they worked at various stages of their career is of fundamental importance to understand both the process of research and its impact through the development and diffusion of human capital. The proposed research seeks to establish patterns of such relations by following career trajectories of individuals who participated in selected research teams ("focal projects") and mapping them with respect to structural features of the teams.

Our work (Bozeman, et al., 1998; Rogers and Bozeman, 1998; Roessner and Bozeman, 1995; Bozeman and Kingsley, 1997) on the impact of research sponsored by DOE's BES, which included more than 30 case studies, led to the creation of a typology of research activities. The entry point for our empirical approach was each research team in a sample of teams that received funding from BES. The assessment of the impacts of their actual research activities, however, led us to conclude that the unit producing the impacts was larger. The research team mentioned in a particular BES proposal was generally found to be part of an alliance. It included other research teams in various levels of collaboration, members of private industry in advisory or collaborative roles, program managers and/or administrators of funding or umbrella institutions, and other participants generally considered not to be researchers. The importance of recognizing the ties to these other participants stemmed from the fact that they clearly played epistemically relevant roles. In other words, their participation had an impact on the actual content and direction of the research (For a similar analysis of the social process of innovation in a historical case study see Carlson 1991).

The interaction between members of the alliances examined in our case studies (Bozeman, et al., 1998), who generally belonged to different institutions, could be considered informal. However, 'informal' should not be equated with 'intractable' or 'unknowable' as many references to activities not governed by institutionalized hierarchies seem to suggest. In all cases, there were common goals and shared patterns of accountability, which may or may not be backed by contracts or other documentation, that were recognized by all participants and served to guide and unite the collective effort.

We termed these entities "Knowledge Value Alliances" because they are united by a common knowledge goal and because they were responsible as a unit for the observed impacts. A Knowledge Value Alliance (KVA) is an institutional framework binding together a set of directly interacting individuals, from multiple organizations, each contributing resources in pursuit of a set of mutually acknowledged goals for knowledge production and use (Rogers and Bozeman, 1998). Inherent in the KVA concept is the objective of generating multiple uses of knowledge and multiple *types* of use (e.g. technology development, skill enhancement, understanding fundamental phenomena). The KVA originates with either a formal alliance agreement (e.g. contract, CRADA) or an informal, but mutually recognized, set of compatible goals. It terminates when resources are no longer brought to activities pertaining to the common knowledge goal (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; there must be links, however, among the members of the respective institutional representatives (those designated in the alliance agreement). The KVA acts as a selection mechanism parsing specialized information (e.g. understanding of phenomena, understanding of technologies' product possibilities, skill in equipment operation or processes) for multiple knowledge uses.

Our work (Rogers and Bozeman, 1998) on these cases led us to develop a typology of

Knowledge Value Alliances. Since this typology serves as a starting point for developing ideas and hypotheses for the proposed research, we provide some examples here. It is important to note, however, that this is only a starting point and one explicit objective of the proposed research is to refine ideas about the workings of Knowledge Value Alliances and to, ultimately, develop empirical measures pertaining to their formation, change and influence on career trajectories. In the proposed study we are interested in determining ways in which KVAs affect human capital development and, in turn, lead to the emergence of new career trajectories and, in some instances, new KVAs.

b. Types of Knowledge Value Alliance

We detected various patterns of KVA with different combinations of knowledge goal and arrangements of actors and resources reflected in the following typology of KVAs. It is based on the combination of knowledge goal and the shape of the institutional and organizational arrangements. One of fundamental dimensions of this typology has to do with the career paths of individuals who participate in the research activities in various capacities.

1. Single-Sector Sporadic Exchange System

Many basic science projects focus on a set of fundamental questions, which often, but not always, fall squarely within the confines of a scientific discipline and are pursued in an academic curiosity driven atmosphere. At the same time, these projects have *potential* uses that are extra-academic (e.g. applications in industry enabled by the specialized and appropriable human capital endowments of graduate students). The main point is that multi-institutional relationships that exist alongside the explicit project objectives are significant enough to consider the ensemble a KVA. But in this type of KVA, these interactions remain peripheral to the main activities of the project.

Several university-based projects, mostly small, but some quite large, fall under this category. Regardless of the size of the project, the KVA is still simple, not developed in terms of the number of uses for its knowledge products and having, therefore, relatively few inter-institutional relations.

An interesting feature of the Single-Sector Sporadic Exchange cases was that they did not necessarily follow the discipline-oriented pattern of scientific reproduction. Often doctoral students working on dissertations that were components of the research activities pursed trajectories far-removed from the project, including work in industry relying on technical skills developed in the original project.

2. Multiple-Sector Mutually Adapting System

The creation of spin-off companies to exploit the results of research is a familiar development in the R&D projects. Our cases in molecular biology and software engineering fields are particularly prolific in this regard. We detected a peculiar dynamic in cases we studied where the process did not simply entail the commercial exploitation of a scientific result. They showed a mutual co-adaptation of basic research and an industry sector that occurred with the formation of an intermediate industry segment. The latter conducted commercial R&D and marketed products that altered the technology base of a large industry sector. At the same time, the agenda for basic research was 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 one illustrative case, an ensemble of university researchers, spin-off company, and chemical industry clients was inter-connected by a virtual "traffic" in "project graduates" and facilitated by the catalytic participation of the public research program manager. This resulted in scientific results linking a research team and industrial user over a long period of time and with growing mutual impact. The links created by the movement of individuals changing jobs maintained actual "feedback loops" between sectors that were integral to the strategies and the impact of the research activities.

3. Enabling Star System

These are cases in which the research nucleus has a few researchers that have developed unique expertise in an area that can be developed in many different directions, typically associated with experimental arrangements or special instruments. A case in NMR spectroscopy is typical of this group. A single PI developed relations with numerous researchers and with private firms to apply NMR spectroscopy in different fields, such as solid state characterization, study of proteins, catalysis, microelectronics, to name a few. Collaborators and students worked as independent groups only linked through the main PI on different applications. Results of research as well as variations of the experimental techniques and instruments were developed for commercialization as well. Students continued their careers both in academic research in the fields of application of NMR spectroscopy and in industry. The "star" structure functions as a multiplier of impacts through "project graduates" because they continue their academic or industry careers in the areas of application rather than in the core area.

4. Organized Expanding Knowledge System

In some cases a multi-institutional effort was launched to develop and lead an entire sub-discipline of science, such as combustion, complex carbohydrates or plant biology. The knowledge goal is broad and there are several research efforts developing in parallel within a single institution. A center housed either in a university or a national laboratory is created and, for the most part, resident scientists carry out the research effort. However, as the first results are achieved and uses begin to multiply, the center becomes a reference for scientific efforts elsewhere with several of its researchers taking significant responsibilities in organizing conferences, chairing the program committees, leading the editorial boards of new journals created for the sub-field, and so on. At the same time, the center becomes 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.

An important feature of Organized Expanding Knowledge Systems is that they represent significant portions of entire sub-disciplines of science and have a variety of relations with the rest of the academic community, government agencies and industry for it to qualify as a KVA. The centers are the seedbed for generations of researchers that go into all activities related to the sub-field. The tracking of all the individuals going through one of the centers established for a longer period is a large-scale problem and it will be necessary to take a sample of the entire network for a manageable sized study.

5. Organized Converging Knowledge System

These cases are similar to the previous group in that there is significant growth of formal organizations and institutions as the pursuit of the knowledge goal advances. However, the main difference is in the nature of that knowledge goal. In the previous group it was expansive in order to develop an entire new field of knowledge. In these cases the knowledge goal becomes more and more specific and narrowly focused.

The typical case here is "Rolling-Assisted Biaxially Textured Substrates (RABiTS)" at Oak Ridge National Laboratory (Norton et al. 1996). The pursuit of the superconducting wire shows the correlation between convergence toward certain superconducting alloys and the establishment of an administrative apparatus that facilitated the complexity of the various knowledge uses. What characterizes these cases is that various streams of basic science converge on a single result or cluster of results that is perceived by many to be of great epistemic and economic importance. As this happens, efforts get more organized and formalized in order to achieve that goal. As the knowledge goal gets specified in more detail an administrative apparatus is set up to facilitate the needed exchanges between scientists, between institutions, and between sectors.

The “RABiTS” case is typical of this sort of KVA. As the focus converged on the specifications of the superconducting wire, many of the norms followed by actors in their own realm were suspended in order to achieve the common goal. For example, scientists were asked to 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 in order to both comply with accountability requirements and avoid disclosure to non-members of the alliance. The formal administrative arrangement was directed mainly at shielding the research from the distracting effects of these pressures while maintaining the cross-sector relations.

In sum, we have been able to identify a number of work patterns, management structures, network ties and cross-institutional linkages among these cases and to use this information to view recurring patterns. These patterns, which we describe as Knowledge Value Alliances, seem to have significant implications for understanding the scientific and technical human capital impacts of projects and their impacts on career trajectories, maintenance of networks and formation of new networks.

Research Design and Operations

a. General approach

The key research question is: “How do characteristics of team-oriented R&D projects affect the long-term careers of persons involved in those projects and, in turn, the human resources capacity available for creating knowledge and spurring technology development?” Our case studies (e.g. Bozeman, et al., 1998) have shown that the training and human resources development in R&D projects continues to seed new work in fields encompassed by the project. But they also demonstrate the often remarkable ways in which persons trained in team-oriented R&D projects take their abilities into entirely new contexts (including, among others, technology development in industry, equipment development, technique and craft, and new fields of science not encompassed by the original project). This diffusion of human capital often sets new directions for research and technology. Our research design seeks not only to map those processes but also to determine the ways in which the management structure, content and linkages of R&D projects lead to different sorts of human resources and capacity outcomes.

Our research design is multi-field and multi-national. We focus on projects in two broad, multidisciplinary scientific fields and in two nations. Following our work with Department of Energy-funded projects, we examine energy and environmental projects, including both basic research projects and more applied projects. Following the experience and institutional knowledge of our French research partners, we examine research in biotechnology and life sciences. Most of the projects will be drawn from university research because, compared to publicly sponsored-research at government laboratories, university projects are more likely to develop a wider array of cross-organizational ties and are more likely to involve graduate students and post-docs (and, thus, often have greater human capital development potential). However, at least four of approximately 20 projects examined will, for comparison's sake, be centered at government laboratories.

The research steps (followed by each partner in each country) include:

Step One. Our data gathering will begin by focusing intensely on about twenty research projects, ten in France, ten in the U.S., ten in environment and energy research, ten in biotechnology and the life sciences. The choice of particular projects will be determined by the need to ensure variance on the variables of interest in our chief hypotheses (discussed below). Our experience in previous case studies will be used to select cases that seem useful in developing typologies of projects and Knowledge Value Alliances. While we will examine some projects considered ad aart of earlier DOE/BES funded projects, we shall also consider projects funded by the NIH, U.S. EPA, DOD and other agencies with either energy/environment or life science/biotechnology foci.[2] The French collaborators will have chief responsibility for selecting the French projects (though we shall consult closely with them in selection of the cases from both countries). Elaboration of case selection criteria and methods will be an early task in the finalization of the research design.

Step Two. After selecting projects, we will write synoptic case histories of each project, focusing particularly on the human resources components of the project, the mobility and career trajectories of those associated with the projects. Since we are explicitly interested in outcomes that have occurred as personnel move from the initial focal project to new settings and new research and technology tasks, we will focus on projects that began no less than three and no more than ten years before our own beginning point. We expect that projects older than ten years may have insufficient "footprints" for us to follow and projects less than three years old would likely have limited turnover and diffusion of human scientific capital. As part of these case studies, we shall further develop a taxonomic approach to understanding the structures of the projects with respect to their network ties and their scientific and technical human capital development aspects.

Step Three. Relying on the data developed in Step Two, we shall contact each member of the original project team, including PIs and associated researchers, post-docs, graduate students, technicians, consultants, research partners from other organizations, industrial and other users (if they received training from the project), and undergraduate students. Using a combination of telephone interviews, mailed questionnaires, and a web-based questionnaire, we will develop an extensive profile of the individuals' scientific and technical careers. These profiles will include not only research trajectories but also charts of the subjects' networks of personal contacts and interactions with scientists, technologists and users (especially industrial users) of scientific knowledge and technological products and processes.

Step Four. The data resulting from the interviews and web questionnaire will be entered into a data base and hypotheses will be tested about the relation of the original projects and the subsequent career trajectories and impacts of the individuals, including their network associations.

b. Hypotheses

Our chief hypothesis is that features of the initial projects will systematically affect the trajectories and network ties (both scientific and commercial) of scientists and technologists who are "project graduates." Following our earlier work (e.g. Crow and Bozeman, 1998; Rogers and Bozeman, 1998), we will develop typologies of projects based on research teams' approaches to managing scientific work, the focus of their work (e.g. basic, applied, technical assistance) and

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[2] Due to extensive previous work with R&D laboratories and funding agencies and due to the explicit interest registered by some agencies and investigators, we expect no difficulty in gaining access to sufficient number and types of projects.

researchers' interactions with funding agencies and scientific and commercial user communities. The data will be employed to validate typology development and to test specific hypotheses apart from the typologies. Many of these hypotheses are derived from the proposers' preliminary findings (Bozeman, et al., 1998; Rogers and Bozeman, 1998).

We divide our hypotheses into two sections, one focusing on the focal projects, the second on the career trajectories and ties of scientists and others associated (of, generally, previously associated) with the projects. Given our human capital focus, we shall focus especially on four broad variables: (1) the breadth and diversity of focal projects' scientific and technical outputs; (2) the diversity of their linkages and network memberships; (3) the projects' research management structures and managerial strategies; (4) their sources and magnitudes of funding and stability of resources.

1. Hypotheses about the Focal Projects

1.1 Projects more oriented to basic research will have (a) a broader set of network linkages and cross-institutional ties, (b) a more diverse set of scientific and technical products.

This hypothesis is derived from our earlier and somewhat unexpected findings that basic research projects are more likely to generate commercial ties and products than are projects (Bozeman, et al., 1998) and cooperative research agreements (Bozeman and Rogers, 1997) that set out with more applied goals.

1.2 Projects with more stable resources and "core funding" will have (a) a broader set of network linkages and cross-institutional ties, (b) a more diverse set of scientific and technical products.

Several of our case studies (e.g. Bozeman and Roessner, 1996) have indicated that projects with more stable funding tend to broaden their scientific and technical focus.

1.3 Projects with broader and more diverse linkages will tend to have a PI (or another major actor in the project) who plays an entrepreneurial role, complete with a set of explicit entrepreneurial strategies for "marketing" the project's research products and/or for placing project personnel (especially graduate students and post-docs) in new positions.

Our previous case studies (e.g. Rogers and Bozeman, 1997) showed vast differences among projects according to the presence or absence of a strong "network entrepreneur." Those projects including a boundary-spanning (Allen, 1977) (as opposed to an entrepreneur whose domain was chiefly limited to the scientific specialty) tended not only to have more linkages but also more durable and intense ones.

1.4 Projects with a greater variety of sources of research funding will tend to have (a) a broader set of network linkages and cross-institutional ties, (b) a more diverse set of scientific and technical products. This relationship will be mitigated by the presence of one stable source of funding; projects with funding diversity and no stable funding will not have broader ties and more diverse products; projects with funding diversity and at least one stable source will have more diverse products and broader network ties.

Diversity of funding sources can be either a blessing or a curse. If the diversity is related to a continual search for new resources because others have "dried up," the impacts will generally be negative in terms of the range (and perhaps the quality) of products and ties. If the diversity reflects researchers' successful entrepreneurial strategies and builds on leveraged, stable funds, the effects will be salutary.

2. Hypotheses about Human Capital and Capacity Impacts

Our chief interest is not in the focal projects themselves but in the human capital and R&D capacity impacts of the projects. As a result of our interviews and questionnaire data derived from projects' "graduates," we will be able to test a number of hypotheses concerning the nature of projects that lead to greater diffusion of scientific and technical human capital. In this respect, we are interested in a number of dependent variables, including: (1) project graduates' employment sector; (2) their salaries relative to career span and to type of work (this permits us to test hypotheses developed from the traditional literature on human capital [e.g. Becker, 1962; Ehrenberg, 1991; 1992]); (3) their ties to networks associated with the focal projects' work focus and to new scientific, technical and commercial networks; (4) sustained interaction with other graduates of the focal project; (5) project graduates' productivity (measured in publications, citations, patents, and income); (6) composition and content of project graduates' current work output (whether scientific, commercial, or both).

Our current plan (subject to revision with finalization of the research design) is to develop a multidimensional index of "scientific and technical human capital." This index will be derived from the variables specified above and, subject to empirical validation, the index will be "higher" in cases where productivity measures are higher than the average and where the number and expansiveness of network ties and interactions are greater. The hypotheses below are related to the index we expect to develop but it is possible that hypotheses will need to be disaggregated since some components of the index may prove orthogonal.

In general, we expect that individuals will place higher on the index of scientific and human capital if the focal projects with which they are associated have the following characteristics. *Each of these is a preliminary hypothesis about diffusion and impacts of scientific and technical human capital*:

1. The focal project was led by a "high productivity" PI (measured in terms of citations, patents, awards and affiliations), controlling for age and career level;
2. The focal project had diverse research and technical products;
3. The focal projects had diverse and extensive network ties and users;
4. The focal projects included persons from multiple disciplines and specialties;
5. The focal projects had longer duration;
6. The focal projects had greater funding and stable of funding;
7. The focal projects had core funding for at least one source;
8. The focal projects had more personnel and personnel from more than one institution.
9. The focal projects were strongly oriented to basic research and fundamental discovery .
10. The focal projects had a high "exit rate" for graduate students and post-docs (i.e. relatively short-term duration in the project and then placement in a new position).

As a minimum, we shall disaggregate our index according to scientific and technical vs. commercial productivity levels of project graduates. After testing these hypotheses, we expect to develop a number of propositions about the processes for forming and sustaining KVAs. We shall examine the typology of projects and KVAs (already begun in Rogers and Bozeman, 1998; Bozeman, et al., 1998) to evaluate the potential of various types with respect to the development of scientific and technical human capital.

c. Research Methods and Statistical Approaches

Our study includes both qualitative and quantitative elements. The case studies of the focal project are chiefly qualitative and will result in approximately 20 case studies, one for each focal project. The proposers have considerable experience conducting case studies (Bozeman and Fellows, 1988; Crow and Bozeman, 1992; 1998) and contributing methodological innovations in case study methods (e.g. Bozeman and Kingsley, 1998; Bozeman and Melkers, 1993; Crow, Bozeman, Meyer and Shangraw, 1988; Kingsley, Bozeman and Coker, 1996; Bozeman and Klein, 1998; Bozeman and Roessner, 1996).

The tradition of case studies generated in the search for impacts of science on technology first brought general attention to the methods application for science studies (e.g. Sherwin & Isenson, 1967). More recently, rigorous, theoretically-framed case studies have become increasingly common in science studies and R&D policy (e.g. Logsdon & Rubin, 1985; Gray, Johnson, & Gidley, 1987; Brown, Berry, & Goel, 1991; Brown, Wilson, & Franchuk, 1991).

Yin (1984; 1989) has summarized the major strengths and limitations inherent in all case study designs. Strengths include (1) the ability to reveal a rich detail of information that highlighting the critical contingencies among the variables, (2) exploring topics for which theory is not well developed and, (3) promoting researchers' learning, including contributing to subsequent research designs. We feel our study will take advantage of each of the strengths, especially the ability to use the case study to shape the second quantitative phase of the research. The chief limitations identified by Yin relate to a frequent lack of rigor in case studies and an inability to make cross-case comparisons. Given that our intent is to use the case studies to develop a conceptual framework and typologies (see McKinney, 1961) and to enable the second phase of the research, we anticipate no significant problems with rigor or cross-case comparison.

The second phase of the study, building on the case studies of focal projects, will entail building a data base pertaining to the "project graduates," their productivity and career trajectories. The chief means of doing so will be telephone-administered interviews and an Internet-based survey. The researchers have had considerable experience with telephone and mailed interviews as a result of the work of the National Comparative Research and Development Project (summarized in Crow and Bozeman, 1998), as well as national survey-based studies funded by the NSF, the U.S. EPA, and the Department of Energy. More recently (Bozeman, et al., 1998) the researchers have pioneered the use of web-based surveys on the Internet (see Bertot and McClure, 1996, for an assessment of the potential of web-based surveys).

Once the data are gathered from the Phase II analysis of the "project graduates," an SPSS data base will be built which will permit analysis. The creation of human capital productivity indices will chiefly be accomplished by using factor analysis to determine the dimensional properties of the data and the likelihood of developing a useful single index.[3] We hope to use factor analysis, and attendant factor scores, because of the techniques' value in studying network structures. The network analyses we shall perform are more within the tradition set by science studies (e.g. Shrum and Wuthnow, 1988) and science communication (e.g. Crane, 1972; Allen, 1977) than network analysis techniques developed independent of application (e.g. Burt, 1982; Wasserman and Faust, 1994). Thus, our chief purpose is less to develop network models than a set of variables pertaining to

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[3] It is anticipated that we will perform a comparison of the results of an oblique (pattern reference) factor analysis and an orthogonal (varimax rotation) factor analysis to determine the "distortion" occurring by imposition of an orthogonal solution. By this means, as well as examining the factor patterns between the unrotated principle components and the varimax rotation, we will be able to determine the utility of a factor analysis approach to deriving the index. If the empirical results fail to reduce the data to indices that have desired statistical properties and face validity, we will (dependent upon the results) either employ multidimensional scaling techniques or abandon the search for a more general index and treat each of the major human capital variables separately in a series of OLS or logit equations.

networks which can, in turn, be used in the study of human capital. We expect that our hypotheses will be tested using a series of regression analysis models (including not only OLS but, when required by the structure of the dependent variables, logistics response models).

Structure of Collaboration with French Colleagues

The proposed project is directly linked to research being performed by a group centered at the Ecole des Mines in Paris, under the direction of Phillipe Laredo (see Appendix for summary of French collaborators' research, recently funded by CNRS and letter stating intent to collaborate).

The U.S. and French colleagues have a long history of active communication. After recognizing similarities between U.S. work in the National Comparative Research and Development Project and the French work on profiling French laboratories, the two teams have stayed in close correspondence. As the project members of the NCRDP were producing studies of R&D laboratories in the U.S. and other countries (e.g. Papadakis, et al., 1994; Crow and Nath, 1990; Bozeman and Pandey, 1994), a group of French researchers centered at the Ecole des Mines produced empirically-based studies (Joly and de Looze, 1996; Joly and Mangematin, 1996; Laredo, 1995 ; Callon, et al. 1992) quite similar in nature and also aimed at expanding knowledge of the relationships between laboratories and their enacted environments. While these studies were not coordinated with the NCRDP research, the convergence of findings was striking.

Joint interests led to the intent to collaborate. The French team (Laredo, Joly, Mangematin) met with a group of Georgia Tech and NCRDP researchers (Bozeman, Klein, Rogers) in Paris (May, 1996) and in Atlanta (March, 1997) to discuss relationships and concurrence of past work and possible collaborative projects. This proposal is one of the products of that collaborative work.

The current research proposal is for fully collaborative research among a team of French and U.S. researchers who are already quite well acquainted and who have begun working together. The research will be joint in every respect. After agreeing last year to collaborate on this research we have been in close touch, including a visit by the French research team to Georgia Tech and, most recently, a visit by Bozeman and Rogers to Paris. Bozeman and Laredo were co-organizers of a Workshop on R&D Impacts (see Appendix) held at the Ecole des Mines, in Paris this past July. After the workshop, Bozeman and the French rh rarch team, including Phillipe Laredo, Pierre-Benoit Joly and Vincent Mangematin, discussed at length the specifics of this research proposal. The French team now has funding from CNRS and other sources that will permit their participation in both the French and U.S. sites.

We are currently exploring a visiting researcher position at Georgia Tech for Vincent Mangematin and one of his doctoral students, Valerie Edel. Ms. Edel is in the preliminary stages of her dissertation research on the career paths of researchers and their relation to the research institutions in which they work and was a participant in the recent workshop in Paris. (We shall be meeting with Prof. Mangematin in the U.S. in October to finalize plans for the visiting arrangements, which include Bozeman co-chairing, with Prof. Mangematin, Ms. Edel's dissertation which would be part of this project).

If this proposal is funded, the French and U.S. partners will meet as soon as possible to finalize the research plan and develop specific coordination approaches. At that time, we shall choose the research projects that are the focus of the study and we will develop a time schedule for U.S. researchers' visits to France and French researchers' visits to the U.S. That timetable will be a function of the schedule for site visits to the focal research projects.

Coordination of the project will be facilitated by continuing researchers' close correspondence on electronic mail and by establishing a joint-use Internet web site for the project.

All data will be posted on the web site (which will become public after the completion of the research and after appropriate steps have been developed to ensure confidentiality).

We anticipate that the results of the project will be a number of research papers co-authored by the French and U.S. teams. Project results will be presented at a second Workshop on R&D Impacts that will be organized in the U.S., perhaps in Atlanta, and will include many of the participants from the initial workshop.

Milestones: Summer 1999-Fall 2001

Year One:

- Meet with French colleagues to finalize research design and select focal projects
- Further develop taxonomic models via literature review
- Develop substantive knowledge of research fields of projects
- Begin case studies

Year Two:

- Interim meeting with French collaborators
- Conclude case studies in U.S. and France
- Analyze case study results, including development and validation of typologies
- Glean case results for discrete variables to be entered into data base as independent variables predicting project graduates' trajectories, productivity and network ties.
- Develop plan for gathering data from project graduates.
- Begin data gathering from project graduates.

- Year Three:
  Finish gathering data from project graduates in U.S. and France.
  Finish data base development.
  Perform analysis of project graduates network ties, scientific and technical human capital and productivity.

mine relationship of trajectories, ties and human capital to focal projects.

- Produce final report and papers.
- Conduct workshop with French collaborators

Budget Information

(1) **Travel.** Travel, both national and international, represents a significant portion of the budget for the proposal. This is required because much of the work involves case studies, often requiring multiple visits of at least two persons (all case studies will be conducted by teams of two) to each of twenty sites. The international travel expenses will be devoted chiefly to field research in France with French colleagues (as well as to two planning trips and a conference or workshop near the end of the project).

(2) **Consultant.** The consultant, Monica Gaughan, was added for two reasons: her knowledge of network analysis and theories (which was a chief methodological focus in her dissertation) and because she is fluent in French. While each of the French collaborators is fluent in English, having a member of the U.S. contingent fluent in French will prove valuable. Ms. Gaughan was a participant in the Public Sector R&D Workshop conducted in Paris this summer and, at that time, participated in discussions and plans for the proposed research project. The fact that she has a position at a local university (Emory) facilitates coordination.

(3) PI. The P.I. has a limited amount of time listed in the budget. This is *not* a reflection of the amount of time he will spend on the project. The reduced time is motivated by a desire to provide some money to support course release for the Co-PI and, in general, a need to devote as much of the projects resources as possible to the costs of the field research. As a research center director, the P.I. does not have the same release time needs as other faculty because his course load is reduced in expectation that considerable time will be devoted to conducting research.

Results of Prior NSF Support

Barry Bozeman

During the past five years, the P.I. was supported under contract No. 9220125, Research on science and Technology Program. The study was budgeted at about $85,000. The final report for this projected is dated January, 1995: B. Bozeman, Maria Papadakis and Karen Coker, *Industry Perspectives on Commercial Interactions with Federal R&D Laboratories*. Results included:

Doctoral Dissertation:
Karen Coker, *Geographic Dispersion and Technology Transfer*, Syracuse University, The Maxwell School, Department of Public Administration, 1995.

Publications and Conference Papers:
J. Rogers and B. Bozeman, “Basic Research and the Success of Federal Laboratory Partnerships, *Journal of Technology Transfer*, 22, 3, 1997.

B. Bozeman and D.Wittmer, “Technical Roles and Success of Federal Laboratory-Industry Partnerships,” invited to resubmit to *Research Policy*, 1998.

B. Bozeman, “Commercialization of Federal Technology,” in R.P. Oakey (ed.), *New Technology Based firms in the 1990s*, Vol. 3 (London: Paul Chapman Publishing), 1997.

G. Kingsley and B. Bozeman, “Commercial Interactions in Industry-Federal Laboratory Technology Developments,” *Materials Science*, 18, 3, 1997.

B. Bozeman and M. Papadakis, “Firms’ Objectives in Industry-Federal Laboratory Technology Development Partnerships,” *Journal of Technology Transfer*, December 1995.

M. Crow and B. Bozeman, *Limited by Design: R&D Laboratories in the U.S. National Innovation System*, New York: Columbia University Press, 1998 (Chapters six and seven).

Juan D. Rogers

The Co-PI was supported during the 1995-96 academic year by a Doctoral Dissertation Improvement Grant, contract No. 9423145, in the Science and Technology Studies Program. The amount of the grant was $5,000 and research was conducted under the direction of the PhD adviser, Gary Downey at the Science and Technology Studies Program, Virginia Polytechnic Institute and State University.

Results from this work are the following:

Doctoral Dissertation:

Implementation of a National Information Infrastructure: Science and the Building of Society. Virginia Polytechnic Institute and State University, May 1996.

Publications and Conference Papers:

“Science and the Politics of Internetworking: NSFNET in Internet History,” *The Information Society*, 14(3), in press.

“The Role of the Research Community in Creating and Shaping the Internet.” Seminar presentation at the Max Plank Institute for the Study of Societies, Koeln, Germany, July 15, 1996.

"Characterizations of Internet History: Toward a Multistranded Account," presented at the 1995 Annual Meeting of the Society for the Social Studies of Science, Charlottesville VA, 18-22 October 1995.