Assessing the effectiveness of technology transfer from U.S. government R&D laboratories: impact of market orientation

Barry Bozeman and Karen Coker

Technology and Information Policy Program
The Maxwell School of Citizenship and Public Affairs
and L.C. Smith College of Engineering
Syracuse University
Syracuse, New York 13244

ABSTRACT

This study, based on a national survey of U.S. government laboratories, assesses the degree of success laboratories have had in transferring technology to industry, taking into account the laboratories' differing receptivity to market influences. Three success criteria are considered here, two based on self-evaluations and a third based on the number of technology licenses issued from the laboratory. The two self-evaluations are rooted in different types of effectiveness, "getting technology out the door," in one case, and, in the other, having a demonstrable commercial impact. A core hypothesis of the study is that the two types of effectiveness will be responsive to different factors and, in particular, the laboratories with a clearer market orientation will have a higher degree of success on the commercial impact and technology license criteria. Overall, the results seem to suggest that multi-faceted, multi-mission laboratories are likely to enjoy the most success in technology transfer, especially if they have relatively low levels of bureaucratization and either ties to industry (particularly direct financial ties) or a commercial orientation in the selection of projects.

1.INTRODUCTION

Technology policy came of age in the United States during the 1980's, at least insofar as new legislation is an index of significance. Congressional testimony surrounding the technology transfer legislation enacted in the early 1980's often characterized federal laboratories as sleeping giants from which rich R&D resources could be drawn to boost the U.S.'s competitiveness stance and to improve labor and employment conditions.[41] By redirecting government laboratories' activities to the active transfer of their technology and applied science to industry, it would be possible to revitalize the often criticized [47] laboratories and, at the same time, to enhance the likelihood of commercial benefit from the tax dollars underwriting the labs' research and technical activities.[21] For some government laboratories, this new breed of domestic technology transfer policy created an entirely new mission; for others it accelerated activities already well underway. In some instances, the movement of the laboratory from a single-minded focus on bench level science to a more external and market orientation affected significantly the organizations' cultures and routines.[33]

In the haste to address a perceived crisis in competitiveness and address the needs of industry, a great deal of energy has been invested in getting technology policy issues on the political agenda, building coalitions to bring the policies to fruition, and, more recently, implementing such policies as the Technology Transfer Act of 1986 or the Omnibus Trade and Competitiveness Act of 1988. The federal push has apparently had some effect. Roessner and Bean, reporting results from surveys of the large firms who are members of the Industrial Research Institute, indicate that industry is increasingly viewing the federal laboratories as a potential technology develoment partner.[29] However, as is so often the case in virtually every realm of public policy, there has been no commensurate effort to determine systematically the effectiveness of these new and accelerated technology transfer activities of government laboratories.[25] Much of the public discussion of the government role in technology transfer has been oriented to boosterism, perhaps as a prerequisite to political coalition building. Only a handful of systematic evaluative studies has been performed.[10] Even the more skeptical views of the potential of government laboratories in the technology transfer arena are more often based on personal opinion or direct personal experience than on systematic data.[22,25]

This study, based on a national survey of U.S. government laboratories, assesses the degree of success laboratories have had in transferring technology to industry, taking into account the laboratories' differing receptivity to market influences. Three success criteria are considered here, two based on self-evaluations and a third based on the number of technology licenses issued from the laboratory. The two self-evaluations are rooted in different types of effectiveness, "getting technology out the door," in one case, and, in the other, having a demonstrable commercial impact. A core hypothesis of the study is that the two types of effectiveness will be responsive to different factors and, in particular, the laboratories with a clearer market orientation will have a higher degree of success on the commercial impact and technology license criteria.

Before presenting the two models of technology transfer effectiveness and testing hypotheses about the determinants

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of effectiveness, the next section sets the context by presenting a brief overview of the policy initiatives that had led to the proliferation of U.S. government laboratories' technology transfer activity.

2. U.S. TEHCNOLOGY TRANSFER POLICY INITIATIVES

The first wave of technology transfer policy aimed at the general goal of making federal laboratories active partners in commercialization of technology. This was to be achieved through setting up technology transfer structures and requirements in the laboratories and by making changes in the treatment of federally-owned intellectual property.

The first piece of legislation which reflected the new concern over domestic technology transfer, the Stevenson-Wydler Technology Innovation Act of 1980, has the general objective of promoting technological innovation for U.S. economic, environmental, and social goals.[35] Stevenson-Wydler set the tone for much of what was to follow -- lengthy processes of policy formulation and enactment, difficulty getting full financing for the legislation, slow and limited implementation. Generally, the act proposed five major initiatives, the most important of which, at least for present purposes, are Section Nine, which instructed agencies, including the federal laboratories, to participate in technology development and transfer activities, and Section Eleven, which required most federal laboratories to establish an Office of Research and Technology Applications (ORTA). The functions of the ORTA's included assessing potential applications stemming from each research and development project in which that laboratory is engaged and disseminating information on federally - owned technologies with potential commercial application. The staffing and funding level for ORTA was left to the discretion of the laboratory with two exceptions: (1) each laboratory with an annual budget exceeding $20 million was instructed to employ at least one full-time professional to staff its ORTA; and (2) each federal agency which operated or directed at least one federal laboratory was to devote at least 0.5 percent of the agency's R&D budget to support technology transfer activities.

Stevenson-Wydler has been the target of much criticism. Many of the problems in implementing the Stevenson-Wydler Act stemmed from the fact that several of its provisions were not funded. Chapman notes that few of the ORTA's were staffed adequately to meet the objectives of the legislation and also points out that individual researchers are not necessarily the best judges of the potential commercial viability of their R&D output[11]. Another problem noted is that the act dealt only with technologies "already on the shelf" and did not promote innovation[33]. On the other hand, Stevenson-Wydler did at least improve the political standing of technology transfer activities by mandating the creation of ORTA's at all major federal laboratories.[19] The act also added technology transfer as a mission and attempted to motivate the national laboratories to become in tune with their external environments.[33]

The Bayh-Dole Act of 1980 proposed to promote innovation by allowing small business firms and nonprofit organizations to patent inventions arising from R&D funded with federal dollars[27]. The Act also encouraged small businesses to participate in federally supported R&D efforts and collaboration between commercial and nonprofit organizations, including universities. Particularly important is Section 202 which allowed nonprofit organizations and small business firms to retain title to federally funded inventions.

Neither the Stevenson-Wydler Act nor the Bayh-Dole Act is written to reflect the differing orientations of the laboratories.[7] Also, the purpose of promoting technology development is defeated partly because the pace of the patenting procedures for inventions made at government contractor-operated facilities has been discouraging.[28]

In 1982, the Small Business Innovation Development Act proposed to facilitate small businesses access to federal contracts. Particularly significant is Section 4 which required agencies with R&D budgets exceeding $100 million (for fiscal year 1982) to establish Small Business Innovation Research Programs (SBIR).[39] Under the SBIR programs, federal agencies were assigned the new task of awarding grants, contracts, or cooperative agreements to small businesses. In 1983, a Presidential Memorandum on Government Patent Policy directed agencies to allow (to the extent permitted by law) all contractors to claim rights to technologies developed under a federally funded grant, contract, or cooperative R&D agreement[1,18]. This memorandum extended to all contractors the rights given to small business and nonprofit contractors in the Bayh-Dole Act. In November 1984, Title V of The Trademarks-State Justice Institute-Semiconductor Chips-Courts Patents Act of 1984 refined the Bayh-Dole Government-Owned, Contractor-Operated (GOCO) exemption pertaining to the retention of title rights[40]. Section 501 allowed nonprofit (including university) -operated GOCO's which were not engaged in naval nuclear propulsion or weapons related R&D to retain title rights to technologies they developed. These laboratories also gained the right to license technology without having to go through the funding agency.

Whereas most of the policies flowing from the "first wave" of technology transfer legislation targeted behaviors and structures within specific laboratories, some of the "second wave" legislation set up broader, multi-organizational frameworks for enhancing technology transfer. In the second wave, cooperative R&D became more of a focus as a pathway to technology transfer.

The Federal Technology Transfer Act of 1986, an amendment to Stevenson-Wydler, added cooperative R&D to the federal laboratories' role in technology transfer. Especially relevant is Section Two which encouraged federal laboratories to engage in cooperative R&D arrangements with state and local governments, industrial organizations, industrial development organizations, and nonprofit organizations including universities, and licensees of federal inventions.[16] This section allowed a federal laboratory to negotiate directly the sharing of funds, personnel, services, and property with the firm; the federal laboratory also may grant patent licenses or assignments rights to firms. Section Three established the Federal Laboratory Consortium for Technology Transfer, which was to be administered by the Director of the National Bureau of Standards. The Consortium's activities include developing and administering programs to teach federal laboratory employees about the commercializability of laboratory technology and innovations, providing on a per request basis assistance to federal agencies in technology transfer programs, and acting as a clearinghouse for requests for technical assistance from the federal laboratories.[32] Although the Federal Technology Transfer Act of 1986 did advance federal technology transfer, several issues remained unresolved. Most agencies, as well as the firms participating in the cooperative arrangements, have found it difficult to protect proprietary information which resulted from the agreement, especially when the federal agency had funded the research.[11]

Promulgated in 1987, Executive Order 12591, Facilitating Access to Science and Technology, required that DOE laboratories identify research areas key to national competitiveness and encouraged support for consortia and personnel exchanges.[1] The Order directed federal agencies with government operated laboratories to delegate authority to the laboratories to license, assign, or waive intellectual property developed under the cooperative arrangements.[19] Furthermore, this directive encouraged large businesses to obtain title to inventions which stemmed from joint research (unfortunately, it lacked specific guidelines outlining their rights to titles).[30]

The Omnibus Trade and Competitiveness Act of 1988 redesignated the National Bureau of Standards as the National Institute of Standards and Technology (NIST). In Part I of Subtitle B, commonly referred to as the Technology Competitiveness Act, NIST was the focus of restructuring in order to assist the private sector in capitalizing on advanced technology, especially through cooperative efforts among industrial, university, and government laboratories.[26] Section 5112 of Subpart A of the Technology Competitiveness Act designated functions for NIST. The newly structured agency would be responsible for assisting industry in technology development necessary to improve manufacturing processes and to facilitate more rapid commercialization. Other sections of the Act, few of which have been fully implemented, include Section 5121 of Subpart B which outlined major programmatic areas to be implemented by NIST. Section 5131 of Subpart C established NIST's Advanced Technology Program for assisting businesses in the commercial application of generic research results and the refinement of manufacturing technologies. ATP's functions were to provide advice for and participate in joint ventures, including collaborative technology demonstration projects which develop and test prototype equipment and processes.

The National Competitiveness Technology Transfer Act of 1989 seeks to improve technology transfer but also considers a number of national security issues.[23] The Act seeks to enhance U.S. national security by promoting technology transfer from GOCO's to the private sector and by enhancing collaboration between universities, the private sector, and GOCO laboratories in order to advance the development and commercialization of technologies with market potential. Section 3133 amends the Stevenson-Wydler Act by allowing directors of national laboratories to obtain title to and license intellectual property developed under these collaborative agreements. For five years, this section protects trade secrets, privileged or confidential commercial and financial information as well as data developed under joint research and development agreements. It remains to be seen how DOE and its contractors will negotiate on the licensing procedures. Other unresolved issues related to this act are how to favor U.S. firms over foreign ones and how to ensure equal opportunity to all firms interested in competing for licenses.[23]

The Small Business Administration Reauthorization and Amendment Act of 1990 has established a pilot Technology Access Program (TAP). The main purpose is to increase small business access to database services that provide technical expertise and business information. An early assessment indicates that the program has proven beneficial for the small firms participating.[2]

Though the legislation beginning in 1980 began haltingly, the cumulative impact of subsequent policy has been significant, perhaps enough so as to alter the government laboratories' general ways of conducting business. Certainly the message has been sent that Congress and the Administration expect that government laboratories, industry and universities are partners in U.S. technological competitiveness. The impact of that message is as yet difficult to judge. In the ensuing sections of the paper we seek to contribute some insight into the effects of technology transfer activities by examining concepts of government laboratories' effectiveness. Certainly this is not the entire picture, as the industry and university part of the triumvirate is not considered here; but government laboratories are particularly important to examine because they can be expected to respond to policy changes more quickly than actors from other sectors. While we present a variety of descriptive data about the effectiveness of government labs in technology transfer, the primary research question is whether laboratories that are more market-oriented are more effective in transferring technology.

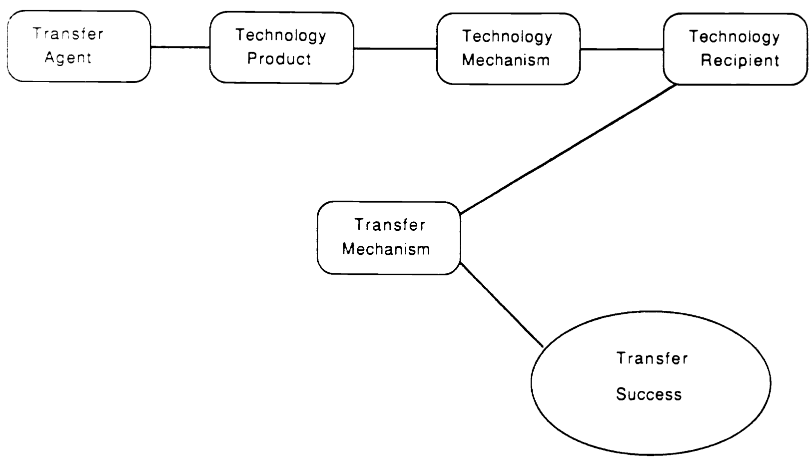
3. MODELS OF TECHNOLOGY TRANSFER EFFECTIVENESS

Assessing technology transfer effectiveness is complicated by the fact that it is difficult to determine when and under what circumstances technology (or applied science, or know-how, or technological processes) has been transferred, much less transferred successfully. Is technology transferred when the technical good is adopted in another organization? When the good is licensed? When it has a commercial impact?

Following previous research[7], we suggest that there are two dominant models of technology transfer especially relevant for evaluating technology transfer effectiveness. The "Out-the-Door" model assumes that transfer itself equates with success. Once the technical good has been adopted by another organization, then an instance of successful technology transfer has been accomplished. A representation of the Out-the-Door model is provided in Figure One. A transfer agent (for present purposes a government laboratory) makes available a technological product (or process, or software), through some intellectual property mechanism (patent, license, copyright), to a technology recipient (usually a private firm). The transfer mechanism is acquired and in the process results in a limited form of transfer success- that is, a technical product has been demonstrably transferred from one organization to another.

FIGURE ONE

OUT-THE-DOOR TECHNOLOGY TRANSFER EFFECTIVENESS



The use of the Out-the-Door model as a conceptual underpinning for evaluating technology presents obvious problems. What if the technology transferred has no beneficial effect? What if it lies dormant in the adopting organization? But despite these obvious drawbacks, the Out-the-Door model is worth our attention. In the first place, it is clearly in use and influences current thinking about technology transfer success.[36] Persons responsible for technology transfer, and their superiors, sometimes count instances of technology transfer and assume those numbers are a useful surrogate indicator of success. And there is some logic to this assumption. If technology transfer is conceived as a probability distribution with success "parameters," then increasing the instance of transfer increases, cetirus paribus, the likelihood of successes. Thus, the input to success becomes a surrogate for the output. If this logic seems dubious, it is nonetheless the same logic that is the basis for a great deal of science and technology policy, particularly the expectation that increasing R&D spending will increase innovation. Another practical reason for embracing the Out-the-Door model is that it is conceptually much tidier than most other approaches. It is usually possible to measure an instance of technology transfer, it not determine its effects.

The "Market Impact" model of technology transfer success is conceptually much more satisfying, if practically much more problematic. The Market Impact model considers technology transfer success in terms of whether the transferred product or process is commercially viable and contributes to the recipient firm's profitability. Figure Two presents an elemental conceptualization:

FIGURE TWO

MARKET IMPACT OF TECHNOLOGY TRANSFER

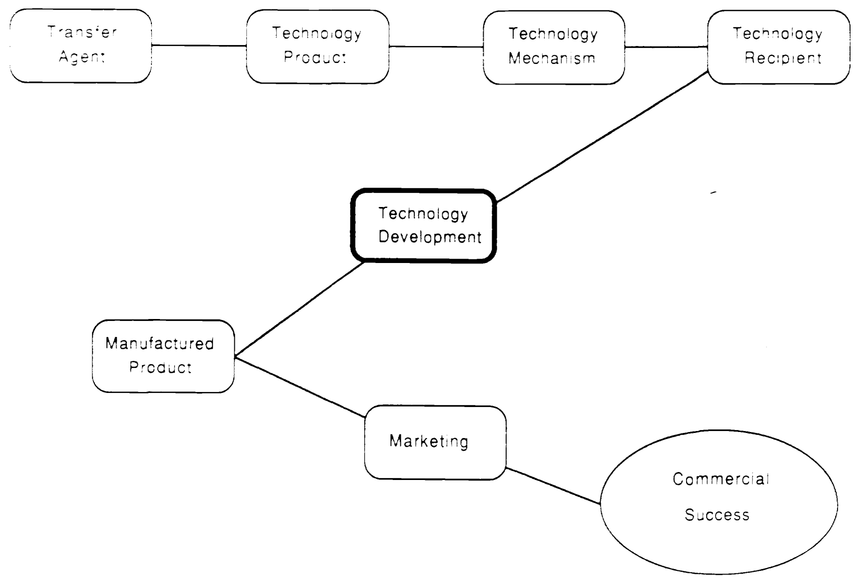


Figure Two is, essentially, appended to Figure One, implying that success only becomes a possibility with transfer. Once the technology is transferred, further technology development is usually (not always, thus the darkened line) required, the product must be successfully manufactured and successfully marketed (neither of which can be assumed) and, if developed, manufactured, and marketed successfully will prove a commercial success-- **if** the product meets or induces a market demand.

The Market Impact model is not only more stringent in terms of success criteria it imposes but is also much more exacting in its evaluation requirements, at least from the standpoint of evaluating the contribution of the technology transfer to the commercial success. If the problem with the Out-the-Door model is that it "underidentified," the problem with the Market Impact model is that is "overidentified." That is, there are many elements, each of which interact, and little possibility for determining the discrete and independent contribution of any single element. Thus, for example, if a venture fails, it is possible that the technology transferred was of little value. But it is also possible that the technological product had great value but had its potential squandered by bad marketing or poor manufacturing or, in general, poor business judgment. In the latter circumstances one could, perhaps, fault the government laboratory for choosing a poor licensee, but not on any other account.

In sum, the Market Impact and Out-the-Door models each present certain difficulties as a normative criterion for evaluation. But by using both models, a technology transfer effectiveness study increases its likelihood of being both valid and realistic.

4. DETERMINANTS OF TECHNOLOGY TRANSFER EFFECTIVENESS: HYPOTHESES

Having considered two concepts of effectiveness- instance of transfer and commercial impact of transfer-- we turn now to hypotheses about the determinants of effectiveness. Depending upon one's perspective, there is either a great deal of literature relevant to gauging technology transfer effectiveness or almost none. There is a wealth of impressions, opinions, and anecdotes about technology transfer success and its causes. There is an impoverishment of empirical evidence. In addition to examining the impact of market-orientation (discussed below), we consider three other factors often alleged to affect technology transfer success: the size of the laboratory, the level of bureaucratization and "red tape," and the diversity of missions. Each of these is discussed in turn.

Hypothesis One The size of the laboratory, measured in terms of total personnel, will be positively associated with out-the-door technology transfer effectiveness and with the number of technology licenses from the laboratory, but will not be significantly associated with the commercial impact of the technology transferred.

The possible effects of size is one of those instances where sense is on more than one side. On the one hand, it seems that technology transfer might require certain scale of human resources (and related) inputs as a prerequisite for effectiveness. But, on the other hand, smaller laboratories might be expected to be better able to work one-on-one with users and to have the type of organizational climate that would produce the type of informal atmosphere, flexible, nonbureaucratic atmosphere in which it is widely assumed that commercial enterprise flourishes. Our expectation is that scale effects will be required for sheer numbers of transfer (out-the-door) and licenses but not for commercial effectiveness.

Hypothesis Two Diversity of laboratory missions will be positively and significantly associated with each of thethree types of transfer success-- out-the-door,commercial impact, and number of licenses.

We expect that laboratories with a greater diversity of missions (e.g. not just technology transfer, but technical assistance, applied research, development) will be more effective because they will have a wider assortment of technological inputs and will have less difficulty in bringing science and technology to a stage where successful transfer is likely. To some extent, the diverse missions support one another. True, there is also some potential for such diverse laboratories to be working at cross-purposes and to dispute the flow of resources into various missions, but overall we feel that the effects of diversity on technology transfer will be beneficial.

Hypothesis Three Degree of bureaucratization and "red tape" is significantly and negatively associated with each of the three types of technology transfer success.

Both anecdotal and research evidence[19,3] suggests that red tape and bureaucratic control mechanisms can be a major impediment to technology transfer effectiveness. Particularly when red tape is measured in terms of it's effects on delays, it seems to have the impact of stifling technology transfer. Most observers feel that technology transfer occurs best in a fluid organizational environment that includes a high degree of work autonomy and an ability to cut through red tape to quickly serve the needs of both transfer agents and technology recipients.[20,17]

Hypothesis Four The market orientation of the laboratory is significantly related to market impact of technology transfer, but not to out-the-door measures or to number of licenses. Specifically, laboratories with a greater market orientation are more likely to prove successful in the commercial impact of technology transfer.

The reasoning behind this hypothesis is straightforward- market ties may not be important in just producing more instances of technology transfer, but if the transfers are to enjoy any commercial impact then a market orientation is important. There is some evidence that government and university laboratories with more of a market orientation are more successful in transferring technology but, for the most part, this is one of those "obvious" propositions that has never been tested.

5. STUDY METHODS AND PROCEDURES

Data for this study are taken from the master database of the National Comparative R&D Project (NCRDP). Begun in 1984, the NCRDP is an on-going study of the technical enterprise in the United States and other industrial nations, involving more than 25 researchers in a variety of universities and government agencies in the U.S., Japan, and the Republic of Korea. The project has developed in three phases. Based on survey data and 30 in-depth case studies, Phase I, the prototype phase, began as a study of R&D performance in more than 250 U.S. energy laboratories.[6] Phase II set as its goal developing a profile of the structure, behaviors and environments of a representative sample (n=935) of the entire U.S.[3,4,5]. Designed as a panel study, Phase III sought data from all government labs, all respondents from Phase II, and focused intensively on technology transfer and cooperative R&D.

The data examined here are from Phase III and based on responses to a questionnaire mailed in June and July, 1990, to directors of laboratories involved chiefly in physical science and engineering research. Somewhat different versions of the mailed questionnaires were sent out according to laboratories' sector: university, industry, government and "generic" (for nonprofit, hybrid or indeterminant sector). About 75% of the questions were common to all questionnaires. The data used here are entirely from the government laboratory sub-sample (n=189). However, not all of the 189 government laboratories are examined here as 39 reported no involvement in technology transfer; thus the effective "n," not considering possible missing data, is 150, or a little less than half of all the government laboratories in the U.S. (with more than 25 employees).

The measures are operationalized from responses to the Phase III NCRDP questionnaire. Laboratory directors were asked to fill out a (branched) section of technology transfer only if their laboratory was involved in technology transfer, defined as "the transfer of physical devices, processes, 'know how' or proprietary information from your laboratory, to either business or government, either U.S. or foreign."

There were three major approaches to measuring technology transfer. A first measure was number of licenses [variable name: T-LICEN]. Directors were asked: "During calendar year 1989, about how many technologies, if any, were licensed by your lab or lab employees?" One measure of success related to the lab's ability get organizations to use their technology [variable name: T-DOOR]: "From the standpoint of 'getting technology out the door' (getting others interested in using your lab's technology), how would you evaluate the lab's success during the past three years? Please rateon a 0-10 scale where 10 is excellent, 5 is average, and 0 is totally ineffective. The market impact [variable name: T-MARKET] of technology transfer activities was measured in the following manner: "From the standpoint of commercial impact on the organizations receiving the technology, how would you evaluate your lab's technology transfer success during the past three years?" [Scale specified was same as above].

In terms of the independent variables for the study, bureaucratization and red tape were measured in two very different ways. One perceptual item [variable name: BUREAU] asked the respondents to indicate level of agreement or disagreement on a four-point Likert scale with the statement: "I think there is more 'bureaucracy' slowing things down in this laboratory than in other labs I know about." In order to develop a more concrete indicator of "red tape," respondents were asked to indicate how much time was taken, on average, for a series of core laboratory activities include hiring, firing, getting approval for research projects or various size, purchasing equipment of various costs, circulating research papers and findings and publishing research. Since it is not convenient to use all these items (due to degrees of freedom problems) and since they are highly intercorrelated, one measure, amount of time taken to hire new full-time personnel [variable name: REDTAPE] is taken as a measure of red tape.

Laboratory directors were asked to indicate which of nine missions their lab is involved in, including basic research, pre-commercial applied research, commercial applied research, development, providing technical assistance to government agencies, providing technical assistance to the lab's parent organization, providing technical assistance to private firms and industrial organizations, technology transfer to government organizations, and technology transfer to business. Respondents indicated, in each case, whether the mission is the "Single Most Important," "Important," "Somewhat Important," a "Mission of Little Importance," or "Not a Mission." Using these items, a measure of mission diversity was created [variable name: MISSDIV], by first creating a dummy variable for each ("Not a Mission" and "Mission of Little Importance"= 0, all else= 1) and the adding the values. The number of people working in the laboratory is conceived as a potential explanatory variable, due to expected scale effects, but also as a control. Arguably, both level of bureaucratization and degree of mission diversity could be expected to interact with size. Given the skewness of the distribution, variable is measured as the log of the total employees of the laboratory [variable name: LOGPER].

The commercial impact measures are quite different from one another. One is R&D funding from contracts with private firms or nonprofit organizations as a percentage of the government laboratory's total R&D budget [variable name: RDIND]. The other is a self-report of the extent to which commercial benefit is an important factor in the lab's choice of projects [variable name: COMMPROJ]. Specifically, a four-point Likert scale response to the item: "Assessments of the commercial benefits of my unit's R&D output often have a significant effect on selection of research projects."

These measures described above were used in regression models, a first including all the variables except the two indicators of commercial impact, a second including introducing the commercial impact variables.

6. RESULTS

Before testing the hypotheses presented above, it is useful to examine some descriptive data. Table One provides the number of licenses for the government laboratories. The table shows that about half the laboratories issued no licenses in 1989, several issued between one and five, and just a handful of labs are extremely active, issuing 20 or more licenses.

TABLE ONE
DISTRIBUTION OF GOVERNMENT LABS BY NUMBER OF LICENSES IN 1989

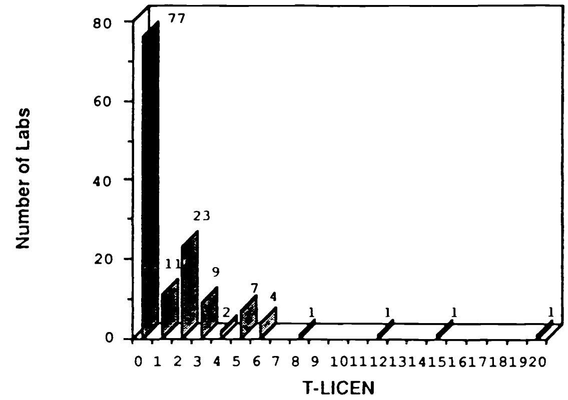


Table Two depicts the self-rated success of laboratories in "getting technology out the door." A small percentage is very successful (9 or 10) and a similarly small percentage is clearly unsuccessful (1 or 2), with a mean success rating of 6.04. Table Three provides the same information for the commercial impact of technology transfer and shows a roughly similar distribution but somewhat less positively skewed and with a lower mean rating of 5.2.

TABLE TWO
DISTRIBUTION OF GOVERNMENT LABS BY OUT-THE-DOOR SUCCESS

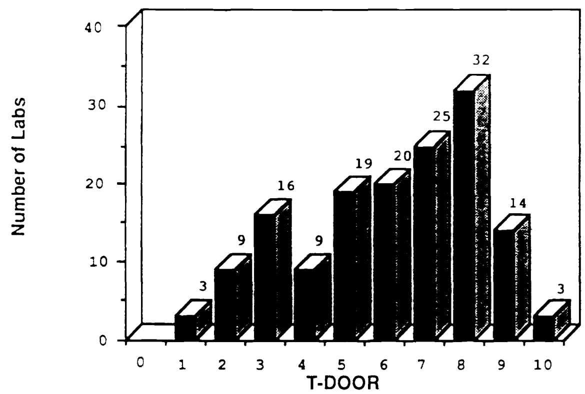
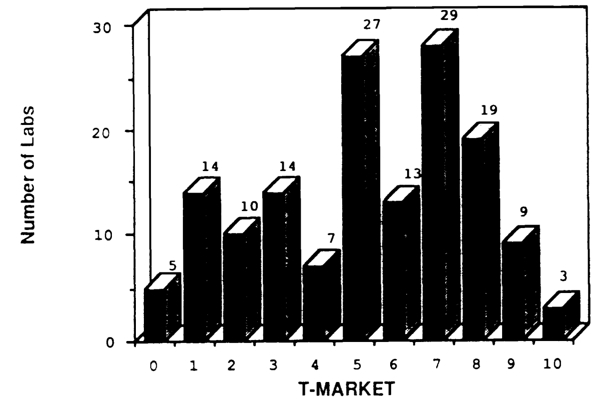


TABLE THREE
DISTRIBUTION OF GOVERNMENT LABS BY LEVEL OF COMMERCIAL IMPACT



The descriptive information suggests that there is, in the case of the self-rated measures, considerable variance in technology transfer success. The success in licensing technology is relatively modest, with few labs having more than one license for the year in question.

Turning to the questions of the determinants of technology transfer success, we consider results for a number of statistical models. In a first step, OLS regression was used to estimate the following models:

(1.1) $\text{T-LICEN} = \beta_0 + \beta_1 \text{ LOGPER } + \beta_2 \text{REDTAPE} + \beta_3 \text{MISSDIV} + \beta_4 \text{BUREAU} + \varepsilon_1$

(1.2) $\text{T-OUTDOOR} = \beta_0 + \beta_1 \text{ LOGPER } + \beta_2 \text{REDTAPE} + \beta_3 \text{MISSDIV} + \beta_4 \text{BUREAU} + \varepsilon_2$

(1.3) $\text{T-MARKET} = \beta_0 + \beta_1 \text{ LOGPER } + \beta_2 \text{REDTAPE} + \beta_3 \text{MISSDIV} + \beta_4 \text{BUREAU} + \varepsilon_3$

Tables 4.0, 4.1, and 4.2 present the results for the three regression models. As Table 4.0 shows, the results for T-LICEN are based chiefly on the strength of a single variable, LOGPER. Number of licenses is extremely sensitive to the number of personnel for the laboratory (and, correlational analysis shows, other size measures such as number of scientists and technicians and size of total budget), but is not well predicted by other variables in the model.

Table 4.0: Regression Results for Technology Licenses, Core Model

n=117 mean= 1.5 R-Square: 0.144

Source	DF	Sum of Squares	F Value	Pr > F
Model	4	121.201	4.72	0.0015

Source	Type I SS	F Value	Pr > F
LOGPER	105.862	16.50	0.0001
REDTAPE	14.766	2.30	0.1321
MISSDIV	0.000	0.00	0.9994
BBUREAU	0.572	0.09	0.76582

Table 4.1 indicates that T-DOOR is reasonably well predicted by the simple four variable model. The R-square for the model is a respectable .182 and three of the four variables are significantly associated and in the expected direction. Only the size measure seems to have no relation to out-the-door technology transfer success.

Table 4.1: Regression Results for T-DOOR, Core Model

n=123 mean = 6.0 R-Square =0.182

Source	DF	Sum of Squares	F Value	Pr > F
Model	4	113.713	6.80	.0001
Error	122	510.285		
Corrected Total	126	624.000		

Source	Type I SS	F Value	Pr > F
LOGPER	6.578	1.57	0.2122
REDTAPE	23.862	5.71	0.0184
MISSDIV	26.066	6.23	0.0139
BUREAU	57.205	13.68	0.0003

By contrast, the commercial impact of technology transfer is poorly predicted by the basic model, as depicted in Table 4.2. The R-square of only 0.109 is certainly modest, though two variables, REDTAPE and MISSDIV are highly significant in the equations.

Table 4.2: Regression Results for T-MARKET, Core Model

n=113 mean= 5.1 R-Square: 0.109

Source	DF	Sum of Squares	F Value	Pr > F
Model	4	95.623	3.74	0.0066
Error	122	778.835		
Corrected Total	126	874.456		

Source	Type I SS	F Value	Pr > F
LOGPER	0.013	0.00	0.9628
REDTAPE	31.566	4.94	0.0280
MISSDIV	63.457	9.94	0.0020
BUREAU	0.582	0.09	0.7631

A next step involves expanding the models to take into consideration the commercial orientation of the laboratory. Again, the expectation is that doing so will have substantial effects for the T-MARKET and some effect on T-LICEN. The equations for this step in the analysis are represented below:

(2.1) T-LICEN = $\beta_{0} + \beta 1$ LOGPER + β_2 REDTAPE + β_3 MISSDIV + β_4 BUREAU + β_5 RDIND + β_6 COMMPROJ + ε_1

(2.2) T-DOOR = $\beta_{0} + \beta 1$ LOGPER + β_2 REDTAPE + β_3 MISSDIV+ β_4 BUREAU + β_5 RDIND + β_6 COMMPROJ + ε_2

(2.3) T-MARKET = $\beta_{0} + \beta 1$ LOGPER + β_2 REDTAPE + β_3 MISSDIV+ β_4 BUREAU + β_5 RDIND + β_6 COMMPROJ + ε_3

Tables 5.0, 5.1 and 5.2 show the results for the OLS estimation of these equations. Tables 5.0 and 5.1 indicate that the improvement provided by these new equations is relatively modest, with neither of the two additional variables proving significant even at the .05 level (though the R-square for T-DOOR goes to .205). The equation for T-MARKET is more impressive, however. The amount of variance accounted for nearly doubles with the two commerce-related variables and four of the six variables in the equation are significantly associated with signs in the expected direction.

Table 5.0. Regression Results for T-LICEN, Expanded Model

n=113 mean=1.5 R-Square: 0.151

SOURCE	DF	Sum of Squares	F Value	Pr > F
Model	6	124.381	3.15	0.0069
Error	106	696.583		
Corrected Total	112	820.964		

Source	Type I SS	F Value	Pr > F
LOGPER	98.255	14.95	0.0002
REDTAPE	16.269	2.48	0.1186
MISSDIV	0.094	0.01	0.9045
BUREAU	1.705	0.26	0.6115
RDIND	7.447	1.13	0.2895
COMMPROJ	0.607	0.09	0.7616

Table 5.1. Regression Results for T-DOOR, Expanded Model

n=123 mean= 5.99 R-Square: 0.205

Source	DF	Sum of Squares	F Value	Pr > F
Model	6	122.435	5.01	0.0001
Error	116	472.556		
Corrected Total	122	594.991		

Source	Type I SS	F Value	Pr > F
LOGPER	6.318	1.55	02.2155
REDTAPE	26.134	6.42	0.0126
MISSDIV	27.234	6.69	0.0110
BUREAU	52.547	12.90	0.0005
RDIND	0.879	0.22	0.6431
COMMPROJ	9.322	2.29	0.1331

Table 5.2 Regression Results for T-MARKET, Expanded Model

n=123 mean=5.09 R-Square: 0.184

Source	DF	Sum of Squares	F Value	Pr > F
Model	6	155.855	4.37	0.0005
Error	116	688.973		
Corrected Total	122	844.829		

Source	Type I SS	F Value	Pr > F
LOGPER	0.072	0.01	0.9126
REDTAPE	32.236	5.43	0.0216
MISSDIV	61.059	10.28	0.0017
BUREAU	1.361	0.23	0.6330
RDIND	27.714	4.67	0.0328
COMMPROJ	33.413	5.63	0.0193

In sum, the three indicators of technology transfer effectiveness appear to respond to different forces. Number of technologies licenses is, for all intents and purposes, purely a function of size and once size is controlled, none of the other explanations account for much additional variance. The Out-the-Door model, as operationalized by T-DOOR, is a function of mission diversity and the two measures of bureaucratization, but is little influenced by the commercial orientation of the laboratory. The Market Impact model, as operationalized by T-Market, is accounted for, as hypothesized, by the commercial orientation variables, mission diversity, and the more "tangible" measure of bureaucratization (with the perceptual measure showing no significant relationship).

7. CONCLUSIONS

Overall, the results seem to suggest that multi-faceted, multi-mission laboratories are likely to enjoy the most success in technology transfer, especially if they have relatively low levels of bureaucratization and either ties to industry (particularly direct financial ties) or a commercial orientation in the selection of projects. The results also indicate that while "getting the technology out the door" and commercial impact are obviously related to one another, the more stringent effectiveness criterion is sensitive to somewhat different factors. Commercial ties may not be a prerequisite for technology transfer, but may be for commercial impact.

The results indicate that many of the thrusts of national policies are headed in the right direction. Recent policies are aimed at ensuring that the government laboratories will take a more commercial orientation in their work and, from a technology transfer standpoint, this seems to be beneficial. However, an important model of technology transfer effectiveness was not considered here. The "Opportunity Cost Model"[7] considers not only the beneficial impact of technology transfer but the likely benefits had the resources used for technology transfer been used elsewhere. From the standpoint of measurement, it is not possible to test empirically the Opportunity Cost Model using questionnaire data. But from a conceptual standpoint it is wise to keep in mind the fact that resources used for technology transfer often are diverted from other laboratory activities. More generally, the whole idea of increasing the commercial consciousness of the government laboratories must be treated with some caution as there is a potential that the new enterprising, entrepreneurial laboratories may lose their edge in basic research or pre-commercial applied research. But these questions are beyond current concerns. The data examined here suggest that the "commercialization" of U.S. R&D laboratories is coming to pass and that technology transfer missions may well be enhanced by this change.

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9. REFERENCES

1. J. D. Bagur and A. S. Guissinger, "Technology Transfer Legislation: An Overview," Journal of Technology Transfer, vol. 12, no. 1, pp. 51-63, 1987.

2. J. Baron, "The Pilot Technology Access Program: A Federal Experiment in Technology Transfer," Journal of Technology Transfer, vol. 15, no. 4, pp. 25-30, 1990.

3. B. Bozeman and M. Crow, "Technology Transfer From U.S. Government and University R&D Laboratories," Technovation, forthcoming.

4. B. Bozeman and M. Crow, "The Environments of U.S. R&D Laboratories: Political and Market Influences," Policy Sciences, vol. 23, pp. 25-56, 1990.

5. B. Bozeman and M. Crow, "U.S. R&D Laboratories and their Environments: Public and Market Influence," Report prepared for the National Science Foundation, Syracuse, NY: Technology and Information Policy Program, March, 1988.

6. B. Bozeman and M. Crow, "R&D Laboratories Environmental Contexts: Are the Government Lab-Industrial Lab Stereotypes Still Valid?" Research Policy, vol. 16, no. 5, pp. 229-258, 1987.

7. B. Bozeman and M. Fellows, "Technology Transfer at the U.S. National Laboratories: A Framework for Evaluation," Evaluation and Program Planning, vol. 11, pp. 65-75, Dec. 1987.

8. M. A. Brown, L. G. Berry, and R. Goel, "Guidelines for Successfully Transferring Government-Sponsored Innovations," Research Policy, vol. 20, no. 2, pp. 121-143, 1991.

9. M. A. Brown and H. C. Major, "Technology-Transfer Strategies of DOE's Conservation Programs," Journal of Technology Transfer, vol. 15, no. 1 &2, pp. 33-40, 1990.

10. M. Brown, J. Morell, S. Snell, E. J. Soderstrom and W. Friggle, Evaluation of the Energy-Related Inventions Program: An Empirical Analysis of 204 Inventions, ORNL/CON-225. Oak Ridge, Tennessee: Oak Ridge National Laboratory, March, 1987.

11. R. L. Chapman, "Implementing the 1986 Act: Signs of Progress," Journal of Technology Transfer, vol. 14, no. 1, pp. 5-13, 1989.

12. M. Crow and B. Bozeman, "R&D Laboratories in the United States: Structure, Capacity and Context," Science and Public Policy, forthcoming.

13. D. M. De la Barre, "Federal technology transfer act of 1985: PL99-502 at a Glance," The Journal of Technology Transfer, vol. 2, no. 1, 1985.

14. R. C. Dorf and K. K. F. Worthington, "Models for Commercialization of Technology from Universities and Research Laboratories," Journal of Technology Transfer, vol. 12, no. 1, pp. 1-7, 1987.

15. Executive Order 12591, Facilitating Access to Science and Technology, April 10, 1987.

16. Federal Technology Transfer Act of 1986, PL 99-502, enacted October 20, 1986.

17. I. Farkas, "Human Aspects of Information Management for Technology Transfer," Information Management Review. vol. 4, pp. 47-56, 1988.

18. D. L. Feldman, "Transferring Superconductivity Technology at a National-Laboratory User Center," Journal of Technology Transfer, vol. 15, no. 4, pp. 25-30, 1990.

19. G. C. Gillespie, "Federal Laboratories: Economic Development and Intellectual Property Constraints," Journal of Technology Transfer, vol. 13, no. 1, pp. 20-26, 1988.

20. L. Godkin, "Problems and Practicalities of Technology Transfer: A Survey of the Literature," International Journal of Technology Management, vol. 3, no. 5, 1988.

21. D. Kearns, "Federal Labs Teem with R&D Opportunities," Chemical Engineering, vol. 97, no. 4, pp. 131-137, 1990.

22. J. Morone & R. Ivins, "Problems and Opportunities in Technology Transfer from the National Laboratories to Industry." Research Management. pp.35-44, 1982.

23. National Competitiveness Technology Transfer Act of 1989, PL 101-189, enacted November 29, 1989.

24. National Superconductivity and Competitiveness Act of 1988, PL 100-697, enacted November 19, 1988.

25. T. G. O'Keefe, "Evaluating Technology Transfer: Some Problems and Solutions," Journal of Technology Transfer. vol 6, no. 2., pp. 53, 1982.

26. Omnibus Trade and Competitiveness Act of 1988, PL 100-418, enacted August 23, 1988.

27. Patent and Trademark Laws Amendment (Bayh-Dole Act), PL 96-517, enacted December 12, 1980.

28. D. Rahm; B. Bozeman; and M. Crow, "U.S. Competitiveness and Technology Transfer," Public Administration Review, vol. 48, no. 6, pp. 969-978 Nov/Dec 1988.

29. J. D. Roessner and A. S. Bean, "Industry Interactions With Federal Laboratories," Journal of Technology Transfer, vol. 15, no. 4, pp. 5-14, 1990.

30. S. A. Rood, "Legislative-Policy Initiatives as a Problem-Solving Process: The Case of Technology Transfer," Journal of Technology Transfer, vol. 14, no. 1, pp. 14-25, 1989.

31. A. Rubin, "Proponents of Technology R&D Emphasize Competitiveness," Congressional Quarterly, March 2, 1991.

32. L. C. Schmid, A Report to the Congress and the Federal Agencies: Activities and accomplishments of the Federal Laboratory Consortium for Technology Transfer Pursuant to the Federal Technology Transfer Act of 1986. A report by Federal Laboratory Consortium for Technology Transfer, 1989.

33. A. Schriesheim, "Toward a Golden Age for Technology Transfer," Issues in Science and Technology, vol. VII, no. 3, pp. 52-58. 1990-91.

34. R. W. Smilor and D. V. Gibson, "Accelerating Technology Transfer in R&D Consortia," Research-Technology Management, vol. 34, no.1, pp. 44-49, 1991.

35. Stevenson-Wydler Technology Innovation Act of 1980, PL 96-480, enacted October 21, 1980.

36. Technology and Information Policy Program, Technology and Knowledge Transfer: A Case Study of Brookhaven National Laboratory, Working Paper No. 85-023, Technology and Information Policy Program, Syracuse University, Syracuse, New York, 1985.

37. A. Thayer, "Industry, Federal Laboratory Technology Transfer on Rise," Chemical and Engineering News, vol. 68, no. 1, p. 13, Jan. 1, 1990.

38. The Small Business Administration Reauthorization and Amendments Act of 1990, PL 101-574, enacted November 15, 1990.

39. The Small Business Innovation Development Act of 1982, PL 97-219, enacted July 22, 1982.

40. Trademarks-State Justice Institute-Semiconductor Chips-Courts-Patents Act, PL 98-620, enacted November 11, 1984.

41. U.S. Congress, House of Representatives, Domestic Technology Transfer: Issues and Options, Testimony before the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, U.S. House of Representatives, 95th Congress. GPO, Washington, D.C., November, 1978.

42. U.S. Congress, House of Representatives, Implementation of P.L. 96-480 Stevenson-Wydler Technology Innovation Act of 1980: Hearings Before the Subcommittee on Science, Research, and Technology of the Committee on Science and Technology, U.S. House of Representatives, 97th Cong., 1st sess., July 14, 15, 16, 1981, GPO, Washington, D.C.: G.P.O., 1982.

43. U.S. Congress, House of Representatives, An Agenda for a Study of Government Science Policy. Report prepared by the Task Force on Science Policy Transmitted to the Committee on Science and Technology, 98th Congress, 2nd session, December 1984, GPO, Washington, D.C., 1985.

44. U.S. Congress, House of Representatives, Technology Transfer and Patent Policy: DOE and Other Perspectives: Hearing Before the Subcommittee on Science, Research, and Technology of the Committee on Science and Technology, U.S. House of Representatives, 99th Cong., 1st Sess., July 15, 1985, GPO, Washington, D.C., 1985.

45. U.S. Congress, House of Representatives, Technology Transfer: Hearings Before the Subcommittee on Science, Research, and Technology of the Committee on Science and Technology, U.S. House of Representatives, 99th Cong., 1st Sess. May 21, 22, 1985, GPO, Washington, D.C., 1985.

46. United States General Accounting Office, Technology Transfer: Implementation Status of the Federal Technology Transfer Act of 1986, 1989.

47. White House Science Council, Report of the Federal Laboratory Review Panel. GPO, Washington, D.C., 1983.

48. D. U. Wilde and N.R. Cooper, "Federal Laboratories and American Industry: Fueling Innovation," Journal of Technology Transfer, vol. 15, no. 1 & 2, pp. 47-52, 1990.