Technology Transfer Research and Evaluation: Implications for Federal Laboratory Practice

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1.0 Introduction

On October 28, 2011, the White House released a Presidential Memorandum (White House, 2011) entitled “Accelerating Technology Transfer and Commercialization of Federal Research in Support of High Growth Businesses.” The memorandum noted that one of the goals of the Administration’s “Startup America” initiative is “to foster innovation by increasing the rate of technology transfer and the economic and societal impact from Federal research and development (R&D) investments.” The Presidential Memorandum (hereafter President’s memo) goes on to note that as part of this effort executive departments and agencies are mandated to improve their technology transfer and commercialization activities. In pursuit of these improvements, departments and agencies are required to “establish performance goals, metrics, and evaluation methods” and to track progress toward these goals. While the President’s memo applies to all federal departments and agencies, it gives particular attention to federal agencies with federal laboratories, exhorting them to increase technology transfer activities “in partnership with non-federal entities, including private firms, research organizations, and nonprofit entities.” The President’s memo provides a special task for the Federal government’s Interagency Workgroup on Technology Transfer to make recommendations about current programs and practices in Federal laboratory technology transfer; new or creative approaches that could serve as models;
assessments of cooperative R&D; and, most pertinent to the present paper, “criteria to assess the effectiveness and impact on the Nation’s economy of planned or future technology transfer efforts.”

The President’s memo encourages a wide variety of activities, some of which could possibly benefit from extant research on technology transfer and commercialization. The current analysis provides a critical review of research, a review aimed at providing support for decisions and activities responding to the President’s memo and seeking to improve U.S. Federal government technology transfer and commercialization policies, programs and activities. The study provides preliminary assessments of various approaches to developing and applying criteria and measures for technology transfer and commercialization and concludes with recommendations about strategies for developing measures and metrics. The study suggests no specific measures or metrics.

2.0. Boundaries for the Review of the Literature

A first boundary for the current study is a time demarcation. In 2000, the author of this monograph published a comprehensive state-of-the-art review of the domestic\(^3\) technology transfer literature (Bozeman, 2000). That study included nearly every published research study available in Web of Science, as well as a few

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\(^3\) There is an extensive technology transfer literature that focuses on international technology transfer, chiefly from more developed to less developed nations. That literature was not covered in the earlier review (Bozeman, 2000) and is not addressed here. The aims of the international literature tend to be quite different than any domestic literature (that is, not only US but other nations) and the policy drivers are very different ones.
then unpublished, un-cited papers. While it is not the case that the pre-2000 literature is ignored here- for continuity’s sake it cannot be- the emphasis here is on literature from 2001 to the present.

Given that this monograph aims to contribute to deliberations about approaches to improving U.S. federal laboratory technology transfer, the major emphasis of this review is the literature pertaining directly to U.S. federal laboratories. Unfortunately, the published literature on U.S. federal laboratories remains quite modest. Examining the literature directly pertaining to federal technology transfer, one finds the preponderance of studies were published in the 1990’s, influenced perhaps by new legislation initiatives such as the Federal Technology Transfer Act and the Cooperative Research and Development Act. Moreover, much of the post-2000 literature on federal government technology transfer falls in one of these categories: exhortations for more or better technology transfer at federal labs, conceptual models of transfer processes, or extremely narrow-gauged descriptions of technology transfer activities. One finds very few published studies based on any empirical data (systematic case studies, surveys, economic performance data) about technology transfer at federal laboratories. While some of these studies are, as we shall see below, quite instructive, they are also rare.

Though the published literature on federal laboratory technology transfer has not grown much since 2000, the broader technology transfer literature has been expanding rapidly, especially in the domain of university-based technology transfer.
Similarly, there have been many studies of government laboratory and research center technology transfer published, but government laboratories of other nations, especially European nations. A key issue, then, for the current analysis is this: “To what extent are those studies of technology transfer, studies set not in federal laboratories but in other settings, relevant to federal laboratory practice or assessment?” While reasonable persons could reasonably disagree with respect to this question, the view here is that a great many of these studies are potentially relevant- and a great many are not relevant at all. Thus, one of the contributions of this paper is a codex for assessing the relevance for federal laboratories of studies that are not about federal laboratories. Were any additional motivation needed to include information from the broader technology transfer literature we can consider this: the Presidential Memorandum (2011) focuses explicitly on encouraging partnerships with universities, business and non-profit entities and, thereby, gives relevance to literature focused on those putative federal laboratory partners.

3.0. Organizing Model for the Review: The Revised Contingent Effectiveness Model of Technology Transfer

3.1 Revisiting the Contingent Effectiveness Model

In organizing and assessing the literature on federal technology transfer (and technology transfer studies relevant to federal technology transfer) the current study employs a modestly revised version of the model employed in the author’s earlier paper (Bozeman, 2000). This model, originally entitled the “Contingent
The Contingent Effectiveness model has been used in application or as a conceptual framework in a wide variety of articles, ranging from industrial ecology to higher education innovations to transfer of vaccines (see for example Ramakrishnan, 2004; Albors, Hervas, and Hidalgo, 2006; 2009; Mohammed, et al., 2010; Kitagawa and Lightower, 2012; Hendriks, 2012).
The revised model is nearly identical to the original Contingent Effectiveness Model. Both the original and revised models identify five categories of technology transfer effectiveness determinants or contingencies, including: (1) characteristics of the transfer agent, (2) characteristics of the transfer media, (3) characteristics of the transfer object, (4) demand environment, and (5) characteristics of the transfer recipient. These dimensions are not entirely exhaustive but are broad enough to include most of the variables examined in studies of government technology transfer activities. The arrows in the model indicate relations among the dimensions (broken lines indicate weaker links). In a nutshell, both models maintain that the impacts of technology transfer can be understood in terms of who is doing the transfer, how they are doing it, what is being transferred and to whom.
The term “contingent” is key in both the original and revised model because of the assumption that technology transfer by definition includes multiple parties and these parties generally have multiple goals and, ergo multiple effectiveness criteria. Effectiveness is considered in terms of multiple criteria including (1) out-the-door (was anything transferred?), (2) market impact, (3) economic development, (4) political advantage, (5) development of scientific and technical human capital, and (6) opportunity costs considerations. The revised model adds an additional effectiveness criterion: *public value*. Described in full below, let it suffice at this point to say that the Public Value criterion takes into account the fact that economic impacts are sometimes not the best measure of well-being. For example, if economic impacts are in aggregate favorable to exacerbate inequalities then such an outcome may not in some circumstances be desired.
The table below describes the public value criterion along with other effectiveness criteria developed previously. The table also briefly reviews the advantages and disadvantages of each effectiveness criterion (developed further elsewhere in this monograph).

**Table 1. Technology Transfer Effectiveness Criteria**

<table>
<thead>
<tr>
<th>Effectiveness Criterion</th>
<th>Key Question</th>
<th>Theory Base</th>
<th>Major Advantage and Disadvantage</th>
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</table>
| "Out-the-Door"                | Was technology transferred?                                                   | A theoretical or classical organization theory             | Advantage: Does not hold transfer agent accountable for factors that may be beyond control.  
Disadvantage: Encourages cynicism and focuses on activity rather than outcome. |
| Market Impact                 | Did the transferred technology have an impact on the firm's sales or profitability? | Microeconomics of the firm                                  | Advantage: Focuses on a key feature of technology transfer.                                    
Disadvantage: Ignores important public sector and nonprofit transfer; must accommodate market failure issues. |
| Economic Development          | Did technology transfer efforts lead to regional economic development?        | Regional science and public finance theory.                | Advantage: Appropriate to public sponsorship, focuses on results to taxpayer.                  
Disadvantage: Evaluation almost always requires unrealistic assumptions. |
| Political                     | Did the technology agent or recipient benefit politically from participation in technology transfer? | Political exchange theory, bureaucratic politics models   | Advantage: Realistic.  
Disadvantage: Does not yield to systematic evaluation. |
| Opportunity Cost              | What was the impact of technology transfer on alternative uses of the resources? | Political economy, cost-benefit analysis, public choice   | Advantage: Takes into account foregone opportunities, especially alternative uses for scientific and technical resources.  
Disadvantage: Difficult to measure, entails dealing with the "counterfactual" |
| Scientific and Technical Human Capital | Did technology transfer activity lead to an increment in capacity to perform and use research? | Social capital theory (sociology, political science), human capital theory (economics) | Advantage: Treats technology transfer and technical activity as an overhead investment. |
| Public Value | Did technology transfer enhance collective good and broad, societally shared values? | Public interest theory, public value theory | Advantage: Excellent and easily sanctioned criteria for public policy. Disadvantage: Extremely difficult to measure systematically |

### 3.3 An Interpretive Codex for Understanding the Relevance of Findings

In the technology transfer article review article (Bozeman, 2000) preceding this one, as well as in reviews produced before (Zhao and Reisman, 1992) and after (Agrawal, 2003; Tran and Kocaoglu, 2009) that article, relatively few of the studies reviewed focused specifically on U.S. federal laboratories. Indeed, a comprehensive review of the post-2000 literature on federal laboratory technology transfer would perforce be quite limited. However, that portion of the technology transfer literature dealing with foci other than US federal laboratories has grown significantly. If one agrees that lessons from other nations, from university transfer, or from state government laboratories are possibly relevant then the question remains “how does one determine which findings are relevant and which are not?” In this section we identify a few criteria relevant to the comparison of research from different geographic, conceptual or institutional domains.

1. **Social connectedness of behaviors and outcomes.** We can consider technology transfer activities, and indeed all human activities, in terms of the extent to which the individual has autonomy to produce outcomes. To give an example, that individual may exercise considerable autonomy over the choice of a research topic. True, there are instances where individuals have researched topics dictated or
where they have shared determinants whereby a variety of features, including individual choice, determine research topics. But at least in some cases, individuals’ ability to choose research topics comes about as close as one can come to individual freedom of choice. By contrast, the publication of a research paper is, except in the case of vanity publications, not only socially constrained but constrained by a wide variety of people, playing different roles, acting distinctive norms, and usually behaving in unpredictable ways. Thus, in the case of the choice of a research topic there is a limited degree of connectedness, whereas in the publication of the research topic there is a considerable degree of social connectedness. Of course, in the case of technology transfer there is usually even more social connectedness than one would expect in the publication of a research article. However, if we consider technology transfer as a broad social process then there are some aspects of activity that are much more dependent than others on social connectedness. Thus, one criterion for examining disparate technology transfer research results is the degree to which they focus on aspects of technology transfer that are less connected rather than aspects that are more dependent on connections.

2. Similarity of public policies and institutional settings. Technology transfer research has become a popular topic among many nations’ scholarly communities. Generally speaking, scholars tend to focus on the technology transfer activities of organizations and institutions within their own nation. How can we determine if a study that focuses on the government laboratories of, say Italy, are in any way relevant to federal laboratories in the United States? One answer is to apply the criterion discussed above. If the activities are less dependent on social connectivity
and more on individual actions then it may make less difference whether the actor is an Italian or an American. However another answer is that, all else equal, it is more useful to compare the US with countries that have similar public policies and traditions of governance. This turns out to be somewhat easier than might be expected and as much as policies that have been developed in the United States have often been a basis for policies employed in other nations. For example, US public policies related to the creation of interdisciplinary and multi-organizational university research centers have been directly imported to several other nations. By contrast, when a nation’s technology transfer policies and institutions, as well as the nation’s economic framework, are very different from those of the US, research comparisons are much more difficult.

3. Adoptability. One of the best reasons to examine technology transfer practices in settings far removed from US federal laboratories is to identify innovative and effective approaches used by others. In such cases, it is perhaps advisable to relax comparability requirements. If an approach or policy is truly innovative then, almost by definition, it is has a distinctive context and history (Downs and Mohr, 1976; Meyer and Goes, 1988). This does not imply, of course, that innovations can be separated from their national or institutional context, only that one must recognize the value of others’ innovations before dismissing them on the basis of “not-invented-here” (Katz and Allen, 2007).

4.0 Conceptual Issues in Analysis of Technology Transfer

As noted previously (Bozeman, 2000; Crow and Bozeman, 1998), one of the hazards in the actual use and application of technology transfer literature is that
studies of technology transfer often are hampered by the fact that so much ambiguity surrounds the term. In this section, some of these conceptual issues are reviewed. However, since the conceptual problems examined are not remarkably different from those identified earlier (meaning that few have been remedied) the section is a succinct summary of issues explored earlier as well as a more intensive analysis of a new conceptual issue that has arisen in the past few years of technology transfer study.

Bozeman (2000) identified three major conceptual problems in technology transfer research: (1) defining technology and technology transfer; (2) demarcating the focal technology, (3) assessing the stability and “transformation rules” of the focal technology. Each of these is briefly examined here. Perhaps more important, this section considers broadly how the conceptualization of technology transfer research has in recent years evolved such that technology transfer often is conceived as part of broader knowledge diffusion foci on networks, “learning organizations” and open innovation, topics not commonly addressed at the turn of the decade.

4.1. Defining “Technology” and “Technology Transfer”

Given that the purpose of this paper is to provide useful information to its sponsor, the National Institute of Standards and Technology [NIST], and to the
Interagency Workgroup on Technology Transfer in their effort to respond to the
President’s Memorandum, it is appropriate to being with a stipulative definition of
technology transfer articulated by NIST (2011, p. 7):

*Technology transfer is the overall process by which NIST knowledge, facilities,
or capabilities in measurement science, standards and technology promote U.S.
innovation and industrial competitiveness in order to enhance economic
security and improve quality of life.*

 Appropriately, the NIST definition is tailored to the NIST mission (e.g. capabilities in
measurement science) and, thus, it is useful to examine others’ definitions of technology
transfer even while keeping the NIST definition at the forefront for the present paper.

Surprisingly few studies of technology transfer provide an explicit definition and the
definitions provided have changed substantially over time (Seeley, 2003). The few who
offer a definition of technology transfer (e.g. Autio and Laamanen, 1995; Teece, 1977;
Reisman and Zhao, 1991; Kremic, 2003) typically leave the reader to infer the meaning of
“technology.” In many studies technology is simply defined as “a tool” but with little if any
discussion of just what type of tool or its range of application. Some studies include social
tools, while others focus exclusively on physical implements.

Sahal (1981; 1982) is one of the few theorists who have written about alternative
concepts of technology and the confusion owing to poorly specified concepts (see also
Dolfsma and Leydesdorff, 2009 and Wahab, Rose and Osman, 2012). Sahal conceives of
technology as “configurations,” noting that the transfer object, the “technology,” must rely
on a subjectively determined but specifiable set of processes and products. According to
Sahal, it is limiting to simply focus on the product in the study of technology transfer and
diffusion because what is transferred is not only a discrete, tangible product but also a knowledge base embodied in the technology and that may include, for example, knowledge about use, application and range of applications. The Sahal approach resolves a major analytical problem: the difference between technology and knowledge transfer. In Sahal’s conceptualization the two are the same; it is not possible to transfer technology without transferring knowledge because technology is a form of knowledge. Indeed, absent the knowledge base of the physical (or social) technology it would have no meaning or applicability.

For present purposes, let us consider a slightly revised version of Sahal’s meaning of technology, a revision provided elsewhere (Bozeman and Rogers, 2002). According to the “churn model” of innovation, an approach similar in many ways to Sahal’s conception of knowledge and technology:

Knowledge (information-transformed-in-use) gives rise to new information encoded in inscriptions (e.g. presentations, papers, procedures, techniques, blueprints, skills, and so on). This new information has no value until (unless) it is, in its turn, put into use. Information may lie fallow and valueless... As the information is used (producing new knowledge), it takes its place in a cycle of unpredictable periodicity, a cycle which may or may not lead to new uses and, thus, further information and perhaps, in another cycle of use, new knowledge (p. 773).

Thus, a “churn” process of knowledge creation and its use comprising the fundamental element of knowledge flows includes the particular type of knowledge we call technology (Corley, 2007). Using this general model of knowledge creation and flows we can consider a definition of technology. However, it is useful to anchor that definition by, at the same time, providing a definition of two intimately related concepts, information and knowledge (adapted from Bozeman and Rogers, 2002).
Thus,

*Information*: Descriptors (e.g. coded observations) and statements (e.g. language-based synthetic propositions) concerning empirically derived observations about conditions and states of affairs in the physical world and the realm of human behavior.

*Knowledge*: Information put to use in furtherance of understanding (i.e. empirically-based, generalizable explanation of states of affairs and behavior) or in the creation, construction, or reshaping of technological devices and processes.

*Technology*: An embodiment of knowledge, technology may be either physical or conceptual in form but defines itself in the applications and active uses of the knowledge it portrays.

By this view technology is an active, usable tool and a manifestation of the knowledge that has gone into its creation and its use. Thus, knowledge is a precursor and even a prerequisite for technology, but there is no implication that the knowledge embodied in technology need necessarily be derived from formal scientific research or theory. Indeed, the history of technology shows that a great many important technologies have resulted from the work of individuals who had only passing acquaintance with science (Schiffer, 1993; Hård, 1994; Zala, 2008; Bijker, 2010). Moreover, technology pre-dates formal science by many thousands of years (Borchardt, 2002; Killick, 2004).

As technology is discussed throughout this study the definitions provided above shall obtain unless, of course, the definition seems at odds with the usage of an author whose work is discussed. In such cases, definitional differences will be noted, at least if the author has explicitly provided a quite different definition.

Having a working definition of technology makes the job of defining technology transfer easier. As suggested above, there is no stable meaning of
technology transfer and, indeed, many definitions have been provided. In many
cases definitions are provided in isolation and do not take into account others’
usages. One simple and useful definition has been provided by David Roessner, a
long-time student of technology transfer and commercialization. According to
Roessner (as quoted in Bozeman, 2000, p. 629), technology transfer is ““the
movement of know-how, technical knowledge, or technology from one
organizational setting to another.” Since the definition uses the term ‘technology’
in its definiendum it would be problematic had we not offered above a definition of
technology.

As Zhao and Reisman (1992) note in an earlier review of the technology transfer
literature, technology transfer definitions and concepts differ according to discipline.
Economists (e.g. Arrow, 1969; Dosi, 1988; Siegel, Veugelers and Wright, 2007) tend to
define technology on the basis of the properties of generic knowledge, many focusing
particularly on variables that relate to production and design (Cooke, 2005; Hammami,
Frein and Hadj-Alouane, 2008). By contrast, sociologists (Rogers, 1962; Rogers and
Shoemaker, 1971; Foos, Schum and Rothenberg, 2006; Winter, 2008) tend to link
technology transfer to innovation and to view technology broadly, including social
technology.

By far the greatest volume of technology transfer studies has been in fields related
to management. According to Zhao and Reisman (1992), those from the business
disciplines tend to focus on stages of technology transfer (e.g. Teese, 1976; Lake, 1979) and
on the relation of technology transfer to strategy (Laamanen and Autio, 1996; Lambe and
Spekman, 1997). The strategic focus has led management scholars (Mowery, Oxley and
Silverman, 1996; Niosi and Bergeron, 1992; Niosi, 1994; Hagedoorn, 1990; 1995; Kingsley and Klein, 1998) to give greater attention to alliances among firms and how alliances pertain to the development and transfer of technology.

Standard usage may or may not be desirable, but there is no likelihood that a consensual definition of technology transfer will emerge any time in the near future. Let us focus then on one simple definition of technology transfer, one used in several empirical research studies of technology transfer (Coursey and Bozeman, 1992; Bozeman, 1994; Spann, Adams and Souder, 1995; Saavedra and Bozeman, 2004): technology transfer the “transfer of physical devices, technological processes, or ‘know-how’ from your organizations to another.” This definition does have the advantage that it has been used in research instruments and seems to have communicated sufficiently with persons engaged in technology transfer. It will serve us as a core definition of technology transfer for the remainder of this study but, again, when others’ usages are very much at odds with this definition it will be noted.

4.2 Demarcating the Focal Technology

It is surprisingly difficult, to demarcate a transfer object (either technology or knowledge) from aspects of its environment, including the persons using and producing it (Clarke, 2005; Sawyer and Huang, 2007). This is especially the case for technologies that exist in great variety and embody highly varied bases of knowledge (Lam, 1997; Arthur and Polak, 2006). Some questions to ask:

- Which specific components and which specific characteristics of its use does one consider when specifying the transfer object?
• Which specific characteristics demarcate the technology from all others?
• What factors trigger the mutation of the technology and its range of applications?

Sometimes these questions are easily answered, sometimes not. For technologies that are highly standardized and delivered in a standard socio-technical package, demarcation is usually straightforward. However, few technologies are transferred in invariant form and any failure to be clear about the specifics of the transfer object can lead to confusion, especially among researchers seeking to understand the phenomena of technology transfer.

4.3 Stability and Transformation Rules

Most technologies of any consequent are by nature highly changeable. As technologies develop a widespread user base, the users find deficits, improvements, or new applications and either the users themselves change the technology or provide feedback to producers who change technology (Orikowski, et al, 1995; Hopkins et al., 2011). The conceptual question of concern here is “what are the functional requirements, the diagnostic criteria, that permit one to say that a technology has been transferred?” The key to this question is the simple article “a.” In many instances the transfer object has mutated, either by conscious design or not, such that it is not always possible to say when a technology has been transferred as opposed to a new technology having been invented or, more commonly, an existing technology having evolved (Adomavicius et al., 2008).

Why is this issue important? For most concerns it is not. If the objective is an effective use of a transfer object then the typing and characterizing of the transfer object is important only to the extent that such stable understanding is required for the transfer. But if the objective is to provide an explanation of technology and a theoretical grasp of the
interactions among the knowledge embodied in technology, the expression of the knowledge in a particular device, and the range of applications for the device, then this seemingly esoteric concern becomes more important. In a commercial context, an understanding of the technological trajectory and evolution of a product can be vital to such issues as knowing when to develop a planned modification or determining when a product life cycle is near its end (Chen, Huang and Chen, 2012). As we see in the literature reviewed below, an inadequate understanding of the transformation and mutations of technology muddle some studies of technology.

4.4. Conceptual Problem: Is Technology Transfer Even the Right Concept?

As mentioned at the beginning of this section, there are significant trends in the technology policy and management literature that might lead one to question whether technology transfer is a particularly compelling analytical focus in an era of open innovation, knowledge and innovation, networks, learning organizations, and technology-based meta-strategy.

The fact that this monograph has been undertaken suggests that some feel that technology transfer remains a useful concept. However, it is worth giving greater consideration to the institutional and environmental embeddedness of technology transfer. Technology transfer is a social process but it is not a discrete, separable one. True, technology transfer and innovation theorists and researchers have long recognized the interdependence of technology transfer with others social and economic processes (see for example Tushman, 1977; Marcus, 1981; Mowery and Oxley, 1995).

One reason to consider theories and frameworks adjacent to technology transfer conceptualizations is that some of these include technology transfer or diffusion as a
component. The most long-standing of these close connections is the innovation literature. Many studies of national innovation systems feature the role of technology transfer in innovation and growth (e.g. Krugman, 1979; Gee, 1981; Mowery and Oxley, 1995). More relevant to the present study are the many publications focusing on technology transfer in either innovation networks (Simme, 2003; Von Hippel, 2007; Schilling and Phelps, 2007) or organizational alliances (Contractor and Ra, 2002; Chen, 2004; Hagedoorn, 2006; Ernst, Lichtenthaler and Vogt, 2011).

In earlier (pre-2000) studies of technology transfer, researchers focused largely on a firm or organizational set of activities. The key question, whether or not stated explicitly, was “how best to transfer technology from one organization to another?” or sometimes to a defined user set. Beyond early transfer, subsequent activity was largely the province of the literature on innovation diffusion (e.g. Mahajan and Muller, 1979; Jensen, 1982). In today’s literature technology transfer is often viewed as an outcome of multiple, interacting organizations, some of them loosely-coupled, such as innovation networks, but some more closely-coupled such as members in inter-sector consortia (Lin and Bozeman, 2006; Lin, et al., 2009; Ryu and Pak, 2010; Allarakha and Walsh, 2011).

The Conclusions section of this paper considers further the implications of these newer conceptualizations of technology transfer not as less a discrete activity by discrete organizations but as an embedded activity of multiple organizations. However, the literature examined below focuses chiefly on relevant technology transfer literature, venturing into adjacent literature when it is possible to do so without losing the main focus of the study.

5.0. Technology Transfer: Findings on Determinants of Effectiveness
Having addressed at least of few of the thorny conceptual issues in technology transfer and having revisited and expanded the contingency model of technology transfer effectiveness, let us turn to a review of the relevant literature’s findings pertaining to effectiveness. The review presented below is broad in sweep but is dictated by relevance to issues pertaining to technology transfer from federal laboratories and federal programs and, thus, any studies focusing directly on these issues receive much more attention than studies only indirectly related.

While the technology transfer literature includes a great many conceptual papers and single case study papers, the current analysis focuses chiefly on empirical research, including qualitative research. The robust literature on international and cross-national literature, likewise, receives little attention because the concerns of that literature tend to be quite different, focusing on donor and recipient nations or developing nations and trade policies. A good review of the international technology transfer literature is provided by Reddy and Zhao (1990) and, more recently, by Wahab, Rose and Osman (2012).

As before (Bozeman, 2000), the Contingent Effectiveness Model provides the organizing basis for the review. Using the same structure should facilitate comparison of the pre- and post-2000 literature on technology transfer. Table Two, adapted from Bozeman (2000) provides a summary of the dimensions of the Contingent Effectiveness Model.
Table 2. Dimensions of the Contingent Effectiveness Model

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Focus</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Agent</td>
<td>The institution or organization seeking to transfer the technology.</td>
<td>Government agency, university, private firm, characteristics of the setting, its culture, organization, personnel.</td>
</tr>
<tr>
<td>Transfer Medium</td>
<td>The vehicle, formal or informal by which the technology is transferred.</td>
<td>License, copyright, CRADA, person-to-person, formal literature.</td>
</tr>
<tr>
<td>Transfer Object</td>
<td>The content and form of what is transferred, the transfer entity.</td>
<td>Scientific knowledge, technological device, process, know-how, and specific characteristics of each.</td>
</tr>
<tr>
<td>Transfer Recipient</td>
<td>The organization or institution receiving the transfer object</td>
<td>Firm, agency, organization, consumer, informal group, institution and associated characteristics.</td>
</tr>
<tr>
<td>Demand Environment</td>
<td>Factors (market and non-market) pertaining to the need for the transferred object</td>
<td>Price for technology, substitutability, relation to technologies now used, subsidy, market shelters.</td>
</tr>
</tbody>
</table>

The chief focus here is on technology transfer in federal laboratories, but the vast majority of the post-2000 technology transfer literature focuses on transfer from university settings or from multi-organizational research centers or consortia (many of which are anchored by or housed entirely in universities). Thus, the review begins with a discussion of setting or, as it is referred to in the Contingent Effectiveness Model, characteristics of the transfer agent.
5.1 Characteristics of the Transfer Agent

In present terms, the dimension “transfer agent” refers to the organization or institution transferring the knowledge or technology. In many instances this will also be the creator and developer of the technology but not in every instance. Understanding of the transfer agent requires not only knowledge of the particular activities associated with transfer but also the nature of the institution, its history and culture. Much of the research on technology transfer deals in one manner or another with this question: “How does the institutional culture of the university (or the government laboratory) affect its ability to conduct technology transfer?”

We can, at the broadest level, consider thee major transfer institutions, government (including government laboratories), universities and “hybrids.” While the term “hybrid” now has many meanings, in the current context this is the term used for institutions that integrate organizations from diverse sectors. Thus, for example, many university research centers would qualify as hybrids because they sometimes include formal partners from either government labs or industry. However, multi-university research centers would not by this definition qualify as hybrids because they are composed of organizations from a single sector.

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5 Private sector technology transfer is not considered here, neither firm to firm nor inter firm transfers. The reasons for this exclusion include: (1) the primary focus here is on federal laboratories; (2) private firms work in an institutional setting that has relatively little in common with federal laboratories, especially because (3) whereas firms generally wish to make a profit on technology transfer, federal laboratories, even after Stevenson-Wydder, usually do not have profit as the major motivation. Most important, with the exception of formal research partnerships (Hagedoorn, Link and Vorortas, 2000) firm-to-firm technology transfer is relatively rare (see Davies, 1977). Among private sector firms, knowledge and technology more often flow through sales, including relations between vendors and customers, and through mergers and acquisitions (De Man and Duysters, 2005).
5.1.1 Federal Laboratories as Transfer Agents

The primary concern here is with government and especially federal laboratories as a transfer agent and, according to this dimension, the focus is on the ways in which the distinctive characteristics of federal laboratories, their history, culture, organizational structure and personnel affect technology transfer effectiveness. An especially useful resource for understanding the history of federal laboratories in technology transfer is provided by Reisman and Cytraus (2004). The Reisman and Cytraus study provides more breadth than depth but examines various influences on technology transfer beginning with legislation from the 19th century and continuing until 2004. They focus on the activities of particular agencies, especially NIST and its now defunct ATP program as well as various agencies in the Departments of Agriculture and Energy. The study also deals with university and state government technology transfer activities and with the role of the Federal Laboratory Consortium but only addresses to a limited degree the activities of specific federal laboratories.

A number of transfer agent-focused studies examine the distinctive aspects of the federal laboratory as either an initiator or partner in technology transfer. Many of these studies focusing on culture and history are very broad, even ruminative (e.g. Franza and Grant 2006;) and after such reflection offer uncorroborated “lessons” for improving technology transfer (Erlich and Gutterman, 2003). Sometimes these studies include interview data, but employed unsystematically to derive ideas about barriers to transfer or about best practices (e.g. Greiner and Franza, 2003). For example Franza and Grant underscore the need for a “transfer culture” and provide some anecdotes indicating just what that might mean.
Rogers, Takegami and Yin (2001) provide a useful “lessons learned” study from intensive examination of the technology transfer history and activities of Sandia National Laboratories, Los Alamos National Laboratory and the geographically proximate University of New Mexico. They note that the relationship among these actors is greatly abetted by the “entrepreneur-friendly” economic environment of New Mexico and this, combined with the technology-rich resources of the three cooperating institutions, provides the basis for effective technology transfer and high-technology spin-offs. Nonetheless, even with obvious resource advantages, technology transfer partners have had to hone their communications practices and develop management structures and incentives to promote technology transfer.

Research by Bozeman and Wittmer (2001) examines not only the relationship of characteristics of US federal laboratories to technology transfer success but also the mix of federal laboratory technical roles when partnering with industry. Their findings are examined in some detail as it is especially relevant to the objectives of the present study, focusing as it does on federal laboratories’ technology partnerships with industry. Their study asks two questions, both strategic in nature and neither of which has received much attention in the technology transfer research: “Are some combinations of technical roles (e.g. basic research, applied) and performer (e.g. federal laboratory, company, or both) more effective than others?” The second question: “Regardless of the particular technical roles, does the number of technical roles relate to effectiveness?”

Drawing from questionnaire-based data of 229 U.S. federal laboratory-industry joint R&D projects, most of them based on CRADAs, the research focuses on the composition of the technical interaction by character of the R&D performed by each of the respective
parties to technology transfer. In addition to the particular technical roles, their number and diversity are examined, giving particular attention to the subset of projects in which the company played no technical role. Bozeman and Wittmer find that increased technical range on the part of industry (not the federal laboratories) is associated with both increased product development and net economic benefit. The highest marginal benefit (as estimated by the company officials responding) occurred when the company's technical role involved pre-commercial research (but not development) and the federal laboratories involved basic research. In such partnerships the net benefit was estimated to be $1,390,466 on average. The least fruitful combination was in cases where both the federal laboratory and the firm viewed pre-commercial research as its primary contribution (-$296,840 net disbenefit on average). For each combination of partner roles, there was less success when the partners were performing the same roles (e.g. basic and basic, applied and applied, development and development).

Relatively few companies (only 10% in the authors' data) are technically passive with respect to their partnerships with federal laboratories. Nevertheless, a passive role can, surprisingly, have positive results in terms of product development and improvement, especially in the case of larger firms. Bozeman and Wittmer (2001) find that among the 22 passive companies examined 41% were likely to have developed marketable products from their federal laboratory partnerships as opposed to 21% of all firms. However, these findings must be treated with care not only because of the small number of passive cases but also because the active partners are much less likely (40%) than the passive ones (86%) to give “product development” as their primary objective in the partnership and
because the passive partners tend to be much smaller in size (both employees and financial resources) than the active ones.

In a related follow-up study Saavedra and Bozeman (2004) investigate a “gradient effect” in technology transfer from federal laboratories to industrial partners. Using the same data set of 229 CRADA-based partnerships and the strategy of examining respective technical roles (e.g. basic research, applied research, development), they examine effectiveness in terms of company participants’ estimates of economic cost-benefit ratios, whether technology was transferred and whether or not products were developed. They find that effectiveness is enhanced when there is a gradient to the roles, specifically when the participating company plays a role that is only a step away from the federal laboratory in the basic research, pre-commercial research, applied research, development spectrum. Effectiveness diminishes when the federal laboratory and the company play the same technical roles or when there is a “gap” between their roles on the research spectrum. The results seems to have implications for public policy partnerships, suggesting that although partnership effectiveness requires distinctive roles, partner roles should not be so different as to undermine possibilities for coordination and integration.

Greiner and Franza (2003), in an experiential study, note that one of the problems in technology transfer from federal laboratories is that many lab scientists remain unaware of the commercial potential of their inventions. In addition to the Greiner and Franza prescription to develop a “transfer culture,” the lack of scientists’ knowledge of commercial potential can also be remedied by increased interaction with industry (Gupta, et al., 2000) and establishing a “new business model” that involves not only increasing collaboration with industry but also a business assessment of the commercial potential of technologies.
Jain and Martyniuk (2000) note that many culture problems can be resolved with more attention to the human resources deployed in technology transfer. They suggest that very different skills are needed in such roles as understanding user needs, assessing newly created knowledge and becoming an advocate of particular technologies for transfer and, just as important, that these are skills that can be developed through training programs. The difficulty with focusing on training and skill development, of course, is that in some cases the deficit lies with the scientists, human resources typically more interested in doing research than developing skills to commercialize it.

In another human resources-focused study, Mom, Oshri and Volberda (2012) focus on technology transfer professionals’ skills base. Using both interviews and survey data the study finds that technology transfer is enhanced when transfer agents have skills in human relations, management of intellectual property and a knowledge of the technology and the particular characteristics of the industry to which it is potentially being transferred.

Markman and colleagues (2005) focus specifically on technology transfer officers and their role as “technology intermediaries.” The study is based on 128 (university) technology transfer officers asking especially about their licensing strategies and how these affect new venture formation and about the relationship of the structure of their offices to the licensing strategies. They find that for-profit technology transfer structures are more common when there are business incubators present. Licensing-for-equity strategies are more likely to lead to new venture formation and spin-offs, but sponsored research licensing is actually negatively related. In this setting they find that licensing-for-case is generally not an effective means of spurring new ventures. In the authors’ judgment the
technology transfer offices overemphasized royalty income and underemphasized entrepreneurship. It is not, of course, clear that these findings for university technology transfer offices are directly relevant to federal laboratory or federal agency technology transfer operations since the governing policies are somewhat different.

One of the more comprehensive studies of the relationship of transfer agent characteristics and technology transfer outcomes is a National Academy of Public Administration study (Toregas, et al., 2004). The study focuses intensely on the NASA context, including points not especially amenable to generalization. However, the study also provides ideas about effectiveness measures and these are examined in a later section of this paper.

Another relevant single agency-focused study is Keller and Block's (2012) analysis of the Small Business Innovation Research (SBIR) program's role in technology transfer, commercialization and development. They view their study as an illustration of the ways in which government programs can spur innovation even with relatively small resources at their disposal. They examine SBIR program data, data on venture capital and federal procurement data to show the role of SBIR as a broker contributing to the growth of innovative technology firms. They use the term “social resonance” to describe how small government programs can have a large impact on institutional change if those programs are targeted at the key levers to change.

More closely attuned to the “social resonance” of the federal laboratory context is a consulting report by Riggins and London (2009). Based on a small number of interviews, they examine process-related problems in federal agencies’ technology transfer activities. Riggins and London focus particularly on some of the legal and administrative barriers
businesses face when they work with more than one agency. They note that there is little standardization to the legal documents used by various agencies and that the transfer recipient is simply expected to be familiar with all of them in their sundry varieties. This can be a particular burden on nonprofit organizations and small businesses. This same problem inhibits participation in joint research projects involving a multitude of government agencies and government labs.

A phenomenon somewhat similar to that described by Riggins and London (2009) is examined empirically by Kathoefer and Leker (2012) under the heading “not-invented-here” syndrome. However, Kathoefer and Leker are more concerned with exchange of knowledge among academics than with technology transfer. Their examination of 166 engineering and physics researchers indicates that while neither research discipline nor nature of the scientific output per se have any strong relation to the not-invented-here syndrome, researchers’ attitudes toward basic science and their level of project experience are important in mitigating the syndrome.

Katz and Allen (2007) discuss a quite similar problem encountered in industrial R&D. Taken together, these findings suggest that the not-invented-here problem is one not confined to government or to technology transfer but rather is endemic to a variety of knowledge and technology creation and diffusion efforts (Hussinger and Wastyn, 2012).

5.1.2 Universities as Transfer Agents

During the past decade or so, the work on technology transfer from universities has grown at a rapid pace, far outstripping published research on federal laboratory technology transfer. However, inasmuch as the present study is particularly aimed at federal government technology transfer there is no specific attention to the contextual
determinants pertaining to university technology transfer. Rather the interest is in findings that transcend context. In other sections, university-based literature is examined when there is some likelihood that the findings may be generalizable to a federal laboratory setting. For those more interested in the distinctive nature of university-based technology transfer a number of excellent literature reviews already exist (Rothaermel, Agung, and Jiang, 2007; Geuna and Muscio, 2009; Grimaldi, et al., 2011). There is also a recent special issue of IEEE Transactions on Engineering Management ([Link, Rothaermel and Siegel, 2008]) that brings together a number of papers focused specifically on the university context in technology transfer.

There is some considerable attention here to one particular contextual element of universities or, to be more exact, one particular institutional context involving universities: hybrid research organizations. As discussed below, hybrid research organizations are in many respects much closer to the model of a federal laboratory than is the case with conventional university departments or single-discipline laboratories.

5.1.3 Hybrids as Transfer Agents

In the present context, hybrid institutions involve multiple sectors (public, private, nonprofit, universities) and multiple organizational partners. A familiar example of a hybrid is SEMATECH, a consortium established in 1987 with the objective of spurring the U.S. semiconductor industry and enhancing U.S. economic competitiveness. Partner firms included more than 85 percent of the resources of the U.S. semiconductor industry. From 1987-1997, both the private sector and the federal government funded SEMATECH.

Carayannis and Gover (2002) provide a detailed case study of SEMATECH, focusing on the partnership relation of the consortium with Sandia National Laboratories. The case
study describes early SEMATECH strategies including workshops on various technical topics and approaches to needs assessment. This “road-mapping” process identified a variety of priorities including work in lithography, thermal processes, and chip packaging. Sandia representatives participated in several such workshops, developed proposals and submitted them to SEMATECH. In 1989, a SEMATECH-focused research program was established at Sandia, a “work-for-others” project initially fully funded by SEMATECH and later, with the development of a CRADA, supplemented by the Department of Energy. The case studies shows the complementary interests as Sandia developed work for SEMATECH but, at the same time, SEMATECH provided benefits to Sandia’s work on defense-related microelectronics.

During the past decade or so, the genus of hybrid research organization that has received the most attention from researchers is the university research center (URC). A recent taxonomic analysis of URC’s (Bozeman and Boardman, in press) showed that there is a great variety of center types including (1) small university-owned centers dominated by one or a few disciplines (Boardman and Gray, 2010), (2) centers developed by state governments, often as part of a centers of excellence program (Mowery and Sampat, 2005; Geiger and Sa, 2005; Clark, 2010), (3) federally-sponsored centers, some of which are problem- or discipline-focused, such as, for example, the Earthquake Engineering Center (Ponomariov, Welch and Melkers, 2009), (4) others of which include many disciplines and many partners outside the focal university (Min and Bozeman, 2006; and (5) industry-university centers where government plays a small role or none at all (Santoro and Chakrabarti, 2001; Bercovitz and Feldman, 2007).
The most complex and fully articulated of the many varieties of university-based research centers is the Multipurpose Multidiscipline University Research Center (MMURC). These centers lie outside the usual academic core of university departments, and they bring several fields of science and technology together, in some cases even helping create new fields (e.g. Murray, 2002; Jones, Wuchty and Uzzi, 2008).

The MMURCs often play pivotal roles in new partnerships with industry and government. Many of these MMURCs are distributed networks for attacking national science and technology agendas in new ways and, in many cases, without the trappings of traditional university administration. Today's research universities and MMURCs often play leading roles in national science and technology programs critical to the national interest - programs ranging from new smart phone technology (Styhre and Lind, 2010) to the National Nanotechnology Initiative (e.g. Rocco, 2004; Woolley and Rottner, 2008; Thursby and Thursby, 2011).

Arguably, some of the largest university-based research hybrids, particularly the hybrids referred to as MMURCs, are competitors encroaching on the historical role of the largest federal laboratories and especially the so-called national laboratories, the Department of Energy's multi-program “national laboratories.” Historically, the national laboratories have been the place policy-makers look to for largest scale science directed at major national missions. The utmost national mission, winning World War II, was, of course the origin of the national laboratory system but these labs have retained a “mission critical” focus with national security and weapons development, later with large scale environmental and energy tasks and, in the 1980's (and most relevant for present
purposes), national economic competitiveness, chiefly through technology development and transfer.

Since at least the 1970’s, universities, historically viewed as the home of principal-investigator-led “small science” have begun to answer the call for large-scale, multidisciplinary science and technology. With the creation of the Engineering Research Program and, later, Science and Technology Program, initiatives for multi-organizational university-based research institutions, historical roles are evolving rapidly (Bozeman and Boardman, 2004). Are the MMURCs the “new national laboratories?” Are they supplements, complements or substitutes for the traditional national laboratories? Most relevant for present purposes, what do MMURCs’ and federal laboratories’ technology transfer missions have in common and what can they learn from one another?

One point of difference is clear. It remains the case that universities, no matter the extent of focus on large-scale multidisciplinary science and technology cannot bring the level of focus and specialization found in some federal laboratories. Many of the largest MMURCs are based on NSF cooperative research agreements that require university researchers to be teaching faculty and to have an academic departmental home. This has many advantages with respect to mentoring and with brokering student involvement with industry but, at the same time, necessarily requires researchers to engage in disparate boundary-spanning activities (Boardman and Ponomariov, 2009; Boardman, 2012), with different reporting lines (Boardman, 2009) and, sometimes considerable role conflict (Boardman and Bozeman (2004).

5.2 Characteristics of the Transfer Media
The nature of the transfer medium is especially important in the case of federal laboratories because they operate with a specific medium developed to enhance technology transfer from federally owned installations, cooperative research and development agreements (CRADAs). As a result of the Federal Technology Transfer Act, the U.S. multi-program, national laboratories, among others, have been permitted to develop cooperative research agreements and to negotiate licenses. In 1989, the National Competitiveness Technology Transfer Act extended that authority to the weapons laboratories. In the years following this enabling legislation tens of thousands of CRADAs have been developed and implemented.

Since the inception of CRADA’s, a good deal of scholarly attention has been devoted to analyzing impacts of CRADAs (e.g. Roessner, 1993; Roessner and Bean, 1994; Gibson, et al., 1995; Bozeman, Papadkis and Coker, 1995; Bozeman, 1997). Since pre-2000 studies are reviewed elsewhere (Bozeman, 2000), let us suffice to discuss one early study (Ham and Mowery, 1998) here, one that is particularly relevant to the conceptual approach employed. After this example, discussion will focus on post-2000 studies focused on transfer media (including but not confined to CRADAs).

Ham and Mowery (1998) examined CRADAs issued from Lawrence Livermore National Laboratory. In assessing the success of the cases, according to market impact criteria, Ham and Mowery focused on five CRADA cases based on diverse technologies, including, for example, improving the recording density of disk drive heads and commercializing high-precision amplifiers. The projects had considerable range in size (less than $250 thousand to more than $20 million) and varied from 14 to 48 months in duration. In assessing the success (Market Impact Criteria) of the CRADA projects, Ham
and Mowery found several transfer agent characteristics fundamental to success including degree of budgetary and managerial flexibility of the projects, quality of relations among collaborating parties, the laboratory researchers’ knowledge of the firms’ needs and requirements. They also found that the firm’s ability to absorb and apply the results of the collaboration played a major role in the success of projects.

A particularly valuable post-2000 study analyzing CRADAs is provided by Adams, Chiang and Jenson (2003). The authors examine industrial research labs working with federal agencies using CRADAs but also other types of relationships and transfer media. They developed data for a set of 220 industrial laws owned by 115 firms in a variety of industries, including machinery, electrical equipment, chemicals and motor vehicles. They employed a qualitative indicator of effectiveness, importance of the projects to the firm’s R&D managers. They find that CRADAs not only are the most common medium of technology transfer from federal laboratories to firms but that they now have a near monopoly on transfer activities. According to the authors, having CRADAs is associated with the industrial laboratories spending more on their own R&D as well as devoting a larger share to their federal laboratory partnerships and, especially important, with developing more patents. For those industries working with federal laboratories but not having a CRADA, the level of patenting is largely unchanged as is the company investment in either its own R&D or the federal laboratory partnership.

Without this influence, patenting stays about the same, and only federally funded R&D increases, mostly because of government support. The authors conclude that CRADAs may be especially beneficial in interactions with federal laboratories because they usually lead to a higher level of effort from both parties.
The Adams, Chiang and Jensen study certainly suggests that CRADAs play an important role in improved technology transfer outcomes, but the impact is not direct nor is the causal mechanism clear cut. Conceivably, having a CRADA is a proxy for a more intense and serious relationship and it is possible that there is nothing in particular about the legal instrumentality that produces desired effects. Related, it could simply be that the higher level of formalism garners attention from both parties. It would be useful to know what explains the different levels of effectiveness among CRADAs.

A quite different CRADA focus is provided by Hemphill (2006) who focuses on NIH technology transfer and CRADAs, especially legal and licensing issues. His is a case study of one instance of technology transfer, Taxol, a cancer treatment drug which was commercialized by Bristol-Myers Squibb and quickly became a best-selling drug, one of the best-selling in the history of the industry. However, various legal and financial troubles nonetheless emerged with a report from the General Accounting Office (now Government Accountability Office) criticizing NIH’s alleged undue concern for financial gain as it negotiated the CRADA. The author provides several policy recommendations designed to forestall such criticisms including: (1) recognizing the importance of reasonable pricing in “good corporate citizenship,” (2) encouraging multiple-partner CRADA applications, (3) requiring lowest federal fee schedule for all government purchases and (4) calculating a royalty payback fee that covers NIH investment. The Hemphill paper is especially relevant to the idea of introducing a Public Value Effectiveness Criterion, indicating that it is not always sufficient to have a strong market or economic development benefit, it sometimes makes a difference as to who benefits and who bears the cost for innovation.
A different agency-focused study is provided by Heisey and colleagues (2006) who examine patenting and licensing at the Agricultural Research Service (ARS). Their basic point is that after the decision has been made to patent and license any given technology much of the success or failure of the transfer is owing to the particular structure of the licensing agreement. Thus, revisions can be extremely important as a sort of adaptive learning as licensing partners and the agency become more and more familiar with the market conditions affecting the technology. It is important to understand that incentives change with markets and levels of technology development and licensing terms are best revisited. In a related study, Rubenstein (2003), again focusing on the ARS, reviews patents and licensing and suggests that ARS technology transfer works best when it is not strongly revenue driven and works poorly when research agendas are changed directly in response to articulated program needs and technology targets.

Various scholars have argued that federal agencies should take a “portfolio management” approach to their research and attendant intellectual property. Munson and Spivey (2006) analyze 124 federal agency-industry partnerships and develop a taxonomy based on the type of agreement (constellation, exchange, process) and the stage of the technology life cycle (pre- versus post-dominant design). They conclude that the partnership should help the CRADA recipient reinforce its strategic approach and its basis of competition (e.g. technology, service, value). They note that CRADAs have most impact when they affect continued innovation and add value to the entire network of industrial actors, including competitors, vendors and customers.

Bozeman and Rogers (2001) and Rogers (2001), likewise make an argument for a portfolio management approach in federal labs, but their focus is earlier in the processes, in
the knowledge and technology creation stages. Their case studies of more than 40 projects (in both universities and federal laboratories) sponsored by the Department of Energy's Office of Basic Energy Sciences suggest that labs are more successful in technology transfer when they develop systematic strategies taking into account the inter-relationships among multiple projects.

5.3 Characteristics of the Transfer Object

To reiterate, with the “transfer object” the focus is on the impact of the object and its properties on the nature of the transfer, where the object may include, for example, such different content as scientific knowledge, psychical technological devices, process knowledge, or know-how. Many scholars find it particularly useful to distinguish between knowledge transfer and technology transfer (e.g. Gopalakrishnan and Santoro, 2004). Gilsing and colleagues (2011) provide one study that swims against the tide. Noting that in science-based regimes and technology development-based regimes transfer processes have a great deal in common, including the fact that they often confront the same transfer barriers. But most studies have noted that the actors, norms and drivers of success, and even the meaning of success, is quite different in knowledge transfer compared to technology transfer. One study in partial agreement with Gilsing and colleagues (2011) is Ciccotello and colleagues (2004) who examined 582 CRADAs, all related to Air Force agencies, and concluded that the key transfer object issue is not whether it is knowledge-based or technology-based but the degree of novelty involved in the transfer object.

Among the many categories of transfer object, older studies (Roessner, 1993; Geisler and Clements, 1995, Ham and Mowery, 1998) and the more recent studies reviewed
here give greatest attention to physical technologies that have potential to develop into commercial products. For example, in their study of 219 federal laboratory-industry technical interactions, Bozeman, Papadakis and Coker (1995) found that about 22% resulted in a product brought to market. It is not clear that this more “tangible” focus is superior inasmuch as some studies have focused on indirect benefits of technology partnerships (Ham and Mowery 1998; Roessner and Bean 1994).

Some studies focus on the interaction of the transfer object with assessment and measurement. For example, Heslop, McGregor and Griffith (2001) note that technology transfer success is very much dependent on knowledge of the candidates for technology transfer, i.e. the particular attributes of the transfer object. They present a tool (the “cloverleaf model,” so named because of the interaction of four assessment factors) to help make such assessments. Mowery (2003) has devised an array of measures to help make such determinations in the management and assessment of CRADAs.

Martyniuk, Jain and Stone (2003) present a series of case studies aimed at identifying success factors and barriers to technology transfer, focusing specifically on environmental technologies developed in federal laboratories. They focus closely on the characteristics of the technologies themselves, noting that “a mix of factors extrinsic and intrinsic to the technology itself” are the most important in determining the commercial success of the transfer. Unfortunately, this focus gives rise to consideration of a large number of idiosyncratic factors that provide limited help in developing systematic technology transfer strategies.

The transfer of tacit knowledge has received a perhaps surprising amount of attention. Recently, Karnani (in press) examined universities tacit knowledge and the ways
in which tacit knowledge becomes central to technology transfer to university spin-off firms. The role of tacit knowledge implies that technology transfer requires more interaction between the donor and recipient than is typical because the tacit knowledge can in most instances be transferred only face-to-face.

5.4. Characteristics of the Transfer Recipient

While the characteristics of the transfer recipient have an obvious importance, there are not as many empirical studies of industry partners to technology transfer as one might expect, probably because it is generally more difficult to study private firms on topics related to their proprietary work. Many of the studies of transfer recipients’ roles in technology transfer are more conceptual or speculative (e.g. Franza and Grant, 2006). For example, Lundquist (2003) provides a conceptual model based on value-chain management that is offered as a tool for possible use by transfer recipients (though no test for the tool is provided in the paper).

Another approach, also passive but useful, is represented by Jones and Jain (2002) in their analysis of the particular problems small and medium enterprises (SMEs) face in the technology transfer process. They note that SMEs have limited resources and, thus, limited ability to absorb the costs and risks of in-house technology development and, thus, can find technology transfer especially rewarding. However, that same lack of resources inhibits participation in technology transfer and reduces the SME’s ability to absorb technology. The authors present strategies SMEs might adopt to overcome resource barriers in technology transfer.

Interestingly, few recent studies seem to use the straightforward approach of simply interviewing (or using questionnaires) to determine firms’ values for technology transfer.
or the characteristics of firms who partner with technology transfer donors. Several older studies took this straightforward approach. Typical is Roessner and Wise (1994) who interviewed companies’ research directors and chief technical officers about sources of external technical knowledge and found that universities fared considerably better than federal laboratories or other firms, ranking first among companies with R&D budgets in excess of $500 million. In related studies, Roessner and Bean (1991; 1994) found that the companies most likely to work with federal laboratories are larger in both budgets and personnel, motivated by access to unique technical resources available at the laboratory and they are, in general, more active than otherwise comparable firms in acquiring external technical information from a wide variety of sources.

At least a few empirical studies of firm characteristics in technology transfer have been undertaken since 2000, but typically they are not so direct in approach and they tend not to be conducted in the U.S. Mohen and Hoareau (2003) present one of the few data-based papers on transfer recipients, seeking to determine the characteristics of firms that develop partnerships with universities and government laboratories. Their models indicate that R&D intensive firms and highly innovative firms tend to use sources of knowledge from universities and government labs but do not often partner with them. Very large firms, but ones that are not highly R&D intensive, are much more likely to partner directly. The findings must be treated with caution since they are from a very different context, firms operating in France, Germany, Ireland and Spain.

5. Characteristics of the Demand Environment

The effectiveness determinant “characteristics of the demand environment” includes both market and non-market factors related to the need for the transfer objects.
proffered. Such factors include, for example, the ability of a technology to solve a perceived pressing social problem, the price of the technology compared to substitutes, the subsidization of the technology’s development or adoption and so forth. Thus, such factors as market-push and market-pull are relevant but not exhaustive of this category.

In some cases, there are specific characteristics of organizational sets or users that shape the demand for technology or the lack of it. Bauer (2003) presents a study of a set of organizations whose distinctive needs affect technology transfer- those working with assistive technologies aimed at end users with disabilities. Complications arise not owing only to differences in sector but the interaction of the technology environment, the user group and the technology producers. Bauer’s case study focused on the U.S. Department of Education’s Rehabilitation Engineering Research Centers aimed at producing, promoting and transferring a wide array of technologies such as, for example, accessible ATM machines and voting booths for persons who have sensory loss, talking signs for sight impaired pedestrians, or hand-held hearing screening devices for hearing tests in infants (see U.S. Department of Education, 2012).

Bauer’s (2003) study found that many of the markets for assistive technology are small and fragmented. While some of the needs of disabled persons are quite general and public in nature, many more are related to specific impairments of persons with specific needs and many of these require highly sophisticated but also highly specialized technologies. Often the end users are persons with limited incomes who rely on third party reimbursement. As a result, technology transfer efforts have often been thwarted. However, the innovative Department of Education program Demand-Pull Project on
Wheeled Mobility is examined by the author in the case study and shows ways to promote technology transfer even when the markets are highly specialized niche markets.

The Bauer (2003) article gives general lessons about means by which government agencies, technology producers, vendors and user groups can cooperate to make the serving of niche markets worthwhile. A related but more recent paper (Bauer and Flagg, 2010) gives more detailed prescriptions for such strategies. An earlier study by Lane (2003) presents a review of research on transfer of assistive technology.

Several studies of the demand environment focus on the geography of innovation and technology transfer. (e.g. Clark, 2010; Coccia and Rolfo (2002). Many of these, such as Feldman (2001) give emphasis to the role of social capital and entrepreneurial support as well as availability of venture capital.

Maiik (in press) provides an especially broad focus on the demand environment in a cross-national study. He provides an empirical analysis of six “institutional dimensions” where the transfer recipient is a nation and the focus is on the ability to engage in cross-national university-to-industry transfer. He finds that while the political distance among nations has little or no effect, industrial distance has a negative effect and educational distance a positive effect.

6.0. Conclusions: Technology Transfer Effectiveness Models and Criteria

While previous sections focused on the conceptualization of technology transfer and reviewed findings from research articles on technology transfer, the current section returns to the task at hand, namely distilling the implications of these findings for the challenges set forth in President Obama's technology transfer memorandum. Revisiting the
technology transfer effectiveness criteria identified in the contingent effectiveness model (table above), literature directly relevant to the criteria are considered. There is no attempt to examine all the literature on technology transfer considered above since much of that literature is conceptual or theoretical in nature and provides neither measures nor ideas about measures.

It is at this juncture of the monograph that we also consider the work activities of professionals who are currently developing technology transfer measures or metrics. Most of this work, not heretofore reviewed, is found in the gray literature or government documents. Specifically, we examine agency reports and briefings responsive to the White House memorandum. Cross walking the formal literature and the work provided by technology transfer experts and professionals in government should help reveal some of the current gaps in work and thinking about technology transfer indicators and criteria. This approach should also prove helpful in the ensuing section of the monograph, in which the focus is on recommendations.

To enable the analysis according to the elements of the Contingent Effectiveness model, a table was developed focusing on findings and recommendations from the scholarly literature. Since the table is quite large we include it as an appendix (Appendix One) to this paper but we draw from the table below.

We began with the overview of effectiveness criteria. Since this model overlaps considerably with the earlier Bozeman (2000) monograph the explanations are relatively brief and the focus is more on practical implications and measurement. The table below provides a summary of effectiveness criteria, key questions, and the theory basis for these.
6.1 “Out-the-Door” Criterion for Technology Transfer Effectiveness

Disproportionate attention is given to what is referred to as the “Out-the-Door” technology transfer effectiveness criterion. The reason is simple: this is the one most often used by both scholars and practitioners and, in many cases, the only one used. For this reason, if no other, it warrants special attention. But, as we see below, it also has the merit of practical utility and convenience of measurement.

The primary assumption of the Out-the-Door criterion for technology transfer effectiveness is that the technology transfer agent (e.g. the federal laboratory) has succeeded once the technology has been converted into a transfer mechanism, either formal or informal, and another party has acquired the technology. The organization acquiring the technology may or may not have put it to use. Thus, the organization receiving the intellectual property (IP) may do so reflexively or because there is a directive to do so, with an intent to use the IP or not, or even with an intent to quash the technology so that it is not available for rivals. Neither the motive nor the uses of the IP are considered in the Out-the-Door criterion. As suggested by the label, the goal is getting the IP out the door.

Within this general concept of the Out-the-Door model we can distinguish three sets of significantly different results revealed by three different sets of indicators. In the first place we have the case of the "Pure Out-the-Door" in which there is no indication that anything has occurred with research to the IP except for its transfer. Second, there is “Out-the-Door with Transfer Agent Impacts.” In some cases it is clear that transferring organization has benefited from the activity even if no one else ever does. Thus, if a federal laboratory obtains licensing revenue, that is a sort of impact. That type of impact might not
be related to the primary goals of the Stevensen-Wydler Act or the Technology Transfer Act, but it is an impact and one than provides benefit. Third, there is “Out-the-Door with Transfer Partner Impacts.” In most cases public policy focuses not on enriching technology transfer partners but rather on broader social and economic impacts. Nonetheless, if partners benefit then certainly that qualifies as an external benefit, though usually a relatively narrow gauge one.

Among the surprisingly few academic studies examining and data pertaining to technology transfer success, in either a federal laboratory or a university setting, the vast majority employ Out-the-Door measures (see for example, Thursby, et al. 2001; Siegel, et al., 2003; Park, et al., 2010; Heisey and Adelman, 2011). A typical approach is Jaffe and Lerner’s (2001). The authors examine patenting results for 23 Department of Energy FFRDC’s seeking to determine factors related to the volume of patenting, with no analysis of the impacts of the patents. Adams, Chiang, and Jensen (2003) provide another study focusing on federal laboratories and CRADA’s. They employ survey data for two years (1996 and 1998). The sample for the survey is based on federal laboratory CRADA partners. They find that CRADAs stimulate both industrial patents and industrial R&D and do so to a greater extent than other technology transfer mechanisms. Thus, the Adams, Chiang and Jensen study (2003), focusing as it does on impacts internal to the firm, is viewed as Out-the-Door with Transfer Partner Impacts.

Most published technology transfer studies focus on university technology transfer and IP activity, perhaps because of the availability of data compiled by the Association of University Technology Managers (AUTM). Thus, for example, Powers (2003) analyzes 108 universities and finds that the number of licenses produced relates to the technology
transfer offices’ year of origin and to higher levels of R&D funding. Powers also examines revenues from licenses and finds that the sizes of technology transfer offices predict license revenue (and, thus, the study falls in the Out-the-Door with Transfer Agent Impacts category). While license revenue does not necessarily provide evidence of impacts outside the transferring institution (for example, companies could pay for a license to suppress activity) it is likely that licenses revenue is usually an indication of external impacts. Whether the impacts are in the Economic Development category is a question unanswered here.

Despite obvious disadvantages to the Out-the-Door criterion, the model has a certain compelling logic. Depending upon whom one views as the transfer agent, care must be taken to give some account of the agents’ domain of control. To put it another way, a technology transfer agent such as an ORTA officer typically has a domain of influence but a limited one. For example, the ORTA office may have some capability of strategic choice among technology options, may be able to induce work on selected technologies, and may be able to develop good administrative and business practices such that technology transfer can be facilitated. However there are many other factors over which the technology transfer agent may have no control, particularly the ability of firms to effectively develop and market technology or the ability of firms to manage products once they have been brought to market.

To be sure, some might argue that technology transfer agent lab is at least partly culpable if it transfers technologies to companies who have inadequate capital, manufacturing ability, or market savvy to make a good technology into a good, profitable product. However, since the transfer agent certainly does not control the transfer partner
(or in many instances even have much influence on the partner) and since federal laboratory technology transfer agents often have limited or no background market forecasting (Piper and Naghshpour, 1996; Franza and Srivastava, 2009) it does not seem reasonable to hold the federal lab and its technology transfer professionals responsible for the actions or inactions of partnering firms.

The expansion beyond the Pure Out-the-Door category to consider impacts on, respectively, transfer agents and transfer partners suggests that the Out-the-Door models has some reach and viability. Likewise, the obvious fact that technology transfer agents have clearly limited domains of control over the actions of transfer partners means that the criterion has some common sense appeal. Nevertheless, we must consider this: if one uses only Out-the-Door criteria one will likely never have direct knowledge that the technology transfer activities have achieved the goals of having economic and social impacts beyond those accruing to the technology transfer partnership. Conceivably, despite the inferences one might wish to make, it is possible that in many instances simply getting technology out the door achieves little beneficial impact and, absent more intensive analysis, may actually do harm. For example, in one case study (Kingsley and Farmer, 1997) of state government transfer of a transportation technology, it was determined that the technology had been successfully transferred to a firm and for years the transfer was viewed as a major success. Only later was it learned that the technology was in short order sold by the acquiring company to a foreign firm who used it to develop a strong competitive edge against U.S.-based firms, arguably driving some out of business. For many years (the technology is now being used in the U.S.) the transfer had significant negative economic effect on U.S. firms.
Was the technology transferred? Yes. Was it beneficial? Only if one provides an expanded geography of benefit.

Despite its critical limitations, the Out-the-Door model is, arguably, the most commonly used criterion and the basis for most metrics employed for technology transfer. In interviews conducted during the decade or so of the initial “CRADA push” (e.g. Crow and Bozeman, 1987; Bozeman and Crow, 1998; Crow, 1988; Bozeman and Fellows, 1988), the answer to the question “what motivates your technology transfer activity” quite often was “we were told to.” That same response often explained much about increases in CRADA signings. While the policy environment has surely changed in important ways since the early period of federal laboratory technology transfer (i.e. the mid-1980’s to the early 1990’s), doubtless much early activity resulted from formal mandates, not from strategic business plans or from significant bottom-up initiatives (Bozeman, Papadakis and Coker, 1995). The Stevenson-Wydler Act required establishing technology transfer offices and the setting aside of .05% of research budgets for technology transfer. Many laboratories did not quickly comply (U.S. GAO, 1989), but later studies (e.g. Franz, Grand and Spivey, 2012) found widespread compliance, albeit with mixed success.

The Out-the-Door model’s popularity seeming goes hand-in-hand with the desire for objective measures or metrics to evaluate or track technology transfer. If we consider federal agencies’ responses to the White House memorandum (2011) on technology transfer measurement and metrics, most responses are based on Out-the-Door measures. Consider the table below based on responses from NASA to the President’s memo (Adapted from NASA, 2012).
### Table Three. NASA Technology Transfer Measures

<table>
<thead>
<tr>
<th>Metric</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Invention Disclosure</td>
<td>Categorized by filing date: NTRs are counted once they are assigned a case number by the NASA Technology Transfer System.</td>
</tr>
<tr>
<td>New Patent Applications Filed</td>
<td>Categorized by application filing date: Patents filed by NASA. Includes joint inventions with Small Business, Large entities, Universities and Non-Profits that are filed by NASA.</td>
</tr>
<tr>
<td>Technology Licenses Executed</td>
<td>New technology licenses, counted by date effective. Includes sublicenses, U.S. and international partnerships, and both royalty-bearing and non-royalty bearing.</td>
</tr>
</tbody>
</table>
| Software Agreements         | 1. Software Usage Agreements: All releases except for Beta.  
2. Software copyright licenses.                                                                                                     |

Similarly, the U.S. Department of Transportation (Department of Transportation, 2012) response to the requirements of the President’s memo includes:

- Number of executed T2 agreements with government partners.
- Number of executed T2 agreements with nongovernment partners.
- Number of teleconferences attended and presentations made.
- Number of policies revised and implemented.
- Number of process changes identified.
- Reduce the time required to establish CRADAs.
- Total revenue generated by USDOT licensees.

In every case the measures and metrics focus on Out-the-Door criteria. In only one instance (revenue generated by USDOT licensees) does an indicator not fit easily into the Pure Out-the-Door criterion. Moreover, some indicators are not output indicators at all but rather process indicators (e.g. reduce time required to establish CRADAs).

To be sure, data developed from indicators such as those listed above could prove extremely useful. They are certainly good indicators of levels of technology transfer activity. But as stated they do not provide information about downstream impacts and outcomes.
While most technology transfer participants well understand that just getting technology or IP out the door certainly does not imply that there will be any beneficial effect from the transfer, they are equally aware of the difficulty of measuring technology transfer by any other means. Moreover, many technology transfer officers feel that their activities, even when quite valuable may not have early, measureable returns. As the U.S. GAO noted more than a decade ago:

Experts in research measurement have tried for years to develop indicators that would provide a measure of results of R&D. However the very nature of the innovation process makes measuring the performance of science-related projects difficult. For example, a wide range of factors determine if and when a particular R&D project will result in commercial or other benefits. It can also take many years for a research project to achieve results.

Nevertheless, the demand for accountability and effectiveness measures is unlikely to be deterred by the challenge of developing timely, valid measures. Nor should it be. Federal laboratories and others in the technology transfer chain are not likely to receive a “pass” just because their results typically require more time to gestate and fully develop. Witness the recent White House memo (2011). However, one reaction to the need to develop metrics for near term results is that metrics are developed to measure activity not impacts.


The "Market Impact/Economic Development” criterion focuses on (1) the commercial success of the transferred technology including (2) impacts on regional and or national economic growth. Hereafter, the simpler term Market Impact criterion will be used to signify either. Generally, market impact pertains to commercial results obtained by a single firm or a few firms. However, much of the technology transfer activities
undertaken by government agencies, as well as by universities, is rationalized by broader economic multipliers assumed to flow from technology transfer. While much of the language of the recent White House memo on technology transfer (Office of the Press Secretary, 2011) is actually quite broad, so much so that it seems to encompass nearly all the effectiveness criteria presented here, the more specific terminology focuses on economic impacts. Thus, the memo articulates the quite general goal “to foster innovation by increasing the rate of technology transfer and the economic and societal impact from Federal R&D investments” (Office of the Press Secretary, 2011, p. 1), but when attention is turned to measures and metrics those identified as examples are ones chiefly relating to or supporting economic and marketplace impacts:

These goals, metrics, and evaluation methods may vary by agency as appropriate to that agency’s mission and types of research activities, and may include the number and quality of, among other things, invention disclosures, licenses issued on existing patents, Cooperative Research and Development Agreements (CRADAs), industry partnerships, new products, and successful self sustaining spinoff companies created for such products (Office of the Press Secretary, 2011, p. 1-2).

To a large extent the Market Impact criterion is the ‘gold standard’ for technology transfer effectiveness evaluation. Much federal policy reflects quite comfortably the idea that economic impact is de facto social impact and that economic growth accruing from science and technology policy investments in inherently good. Not all agree (see for example European Commission, 2012), but the Obama administration, like virtually every Presidential administration before it, is on record articulating that science and technology runs the “engine for economic growth” in the U.S. and economic growth is the cardinal value for a great many federal programs. As noted in President Obama’s speech on November 23, 2009, announcing the “Educate to Innovate” policy initiative: “Reaffirming
and strengthening America’s role as the world’s engine of scientific discovery and technological innovation is essential to meeting the challenges of this century.”

When we consider below another effectiveness criterion, Public Value, we see that economic effectiveness criteria should perhaps not pre-empt all others. Nevertheless, it is clearly the case that most technology transfer policy is to a large extent rationalized by its economic impacts. Nor is this at all unreasonable. The use of science and technology policy and, specifically, technology transfer to spur economic development has sound basis in many public laws and policy documents and strong support from the general public (Seely, 2003).

Even if the Market Impact model is the gold standard for effectiveness it can in some instances prove to be fool’s gold. An important problem with the Market Impact criterion is misattribution of success and poor understanding failure. If a particular instance of transfer is not commercially successful, is it because the product or process transferred is of limited value? Perhaps. But the failure may be owing to such factors as the recipient organization’s problems in development, manufacture, marketing, or strategy. Thus, if a new drill bit project enables deeper drilling, opening up North Sea oil exploration (Link, 1995), how much does one credit the project versus prior science? If a firm that has been working for years on

automobile battery technology and finally, with the help of a federal laboratory CRADA-based partnership, works with a university consortium to produce a better battery and then brings it to market, how does one sort out the various contributions (Sperling, 2001; Sperling and Gordon, 2008)? How quickly would the technology have developed if not for the project? Most important, if a U.S.-developed technology provides great benefits abroad, what does that do to the accounting? Analytical precision and close accountings are nearly impossible.

A number of studies employ the Market Impact model in assessing federal laboratory technology transfer effectiveness. However, the studies are not recent ones. Among the older studies, Bozeman and colleagues (Bozeman, Papadakis and Coker, 1995; Crow and Bozeman, 1998; Bozeman, 1994; Bozeman, 1997; Bozeman et al., 1999) and Roessner and his colleagues (Feller and Roessner, 1995; Roessner and Bean 1991) provide consistent evidence from different data sources that federal laboratory partnerships yield a great deal of economic value in the transfer of knowledge. Some studies (e.g. Bozeman, Papadakis, and Coker, 1995; Link and Scott, 2001; Meyers, et al., 2003) go so far as to offer cost-benefit estimates. Typical among these earlier studies is Bozeman, Papadakis and Coker’s (1995) study of 219 federal laboratory partnerships, most of them based on CRADAs. They find that the mean value for company managers’ estimates of net economic benefits to the firm is approximately $1.5 million per project, whereas the median estimate is zero. This implies that such partnerships yield a few “big winners” and quite a lot of “no impact” projects.
During the past decade or so, several technology transfer evaluation studies have been produced using the Market Impact model and based on economic impact measures. However, almost all of these studies have focused on university technology transfer rather than federal laboratory transfer. Many of the university studies employ the AUTM database. Roessner and colleagues (2013) use the AUTM annual surveys from 1996 to 2010 and economic input-output models to find that the impact of university licensing to the U.S. economy during that period is in excess of $162.1 billion and that jobs created over the same period range from 7,000 to 23,000 per year. Using those same AUTM surveys, Cardozo, Ardichvili and Strauss (2011) examine aggregate university activity and find that growth in revenues seems to have crested as technology transfer processes have become more costly and less efficient. In one of the few recent publications using Economic Impact criteria and focusing on federal agencies, Rowe and Temple (2011) conduct a smaller-scale study focused on 11 firms from the semiconductor industry partnering with NIST. Their interviews and cost-benefit analysis show that the NIST projects had benefits well in excess of the full cost of the projects.

In responding to the President’s memo (Office of the Press Secretary, 2011), it is perhaps not surprising that relatively few agencies have included measures and metrics aimed at direct economic impacts or economic development. While it seems clear that the Economic Impact model is valued among policy makers, developing valid measures is a much different proposition and, moreover, most agencies either do not have the requisite in-house evaluation expertise or, if they do, have these
personnel fully deployed in other tasks. But the Economic Impact model is not completely abandoned on federal agency measures and metrics. For example, the Department of Energy (2011, p. 9), while focusing chiefly on process indicators and Out-the-Door activity indicators (e.g. number of active patents; ratio of invention disclosures to research expenditures by facility), also includes this metric:

*Economic Contribution of Commercialized Technologies.* The dollar value of the commercialized technology sold or in commercial use in a Year (derived from royalty and other reporting by licensees).

Likewise, among its many process and activity indicators, the EPA (2011) includes a “new metric of the number of startups” created from EPA technology transfer activities. While new business startups are not necessarily strong indicators of economic impact (the impact depending on the size, scope and duration of the startup and the specific contribution of the transfer agent to it), it at least provides a preliminary, potentially useful indicator of economic impact outside the transferring agency.

### 6.3 Political Reward Criterion for Technology Transfer Effectiveness

The Political Reward criterion receives relatively little attention here but is worth mentioning. The President’s technology transfer memo (Office of the Press Secretary, 2011) requires no calculation of political benefit and, of course, no federal agency sets out to measure its political reward, at least not directly and explicitly. However, the criterion at least bears some mention in the name of reality.
Parties to technology transfer think in terms of possible political rewards accruing from compliance or from ‘good citizen’ activities. During various on-site interviews (Crow and Bozeman, 1998), university and federal laboratory officials have on many occasions made direct or, more frequently, indirect reference to the political pay-offs expected from technology transfer activities. Technology transfer activities are often seen as a way to curry favor or enhance political support rather than as a means providing significant economic and social benefit. In this sense it is a means not an end (Rogers, Takegami and Yin, 2001; Guston, 2007).

As noted previously (Bozeman, 2000), there are at least three possible avenues to political reward. In the least likely of scenarios, the lab is rewarded because the technology it has transferred has considerable national or regional socio-economic impact and the lab’s role in developing and transferring the technology is recognized by policy superiors and, in turn, the lab is rewarded with increased funding or other resources. This scenario is not unprecedented but does not commonly occur. In the first place, few technologies have such an impact. But even when there are huge impacts from technology transfer, funding processes usually do not respond to even documented ‘big successes.’

Another way in which the Political Reward criterion may yield resource results for the federal laboratory is through the transfer recipient. Under this scenario, the organization or industry benefiting from the technology transfer, communicates to policymakers the value of its interaction with the laboratory technology transfer partner. The policymaker then, in turn, rewards the lab for being a “good industrial partner.” There is evidence of such political reward but, understandably, it is based on rumors and anecdotes.
Probably the most common and realistic rationale under the Political Reward criterion is for the lab to be rewarded for the appearance of active and aggressive pursuit of technology transfer and commercial success. In this case, the Political Reward criterion turns out to be much the same as Out-the-Door: activity is its own reward. Much bureaucratic behavior seems to support this view. Often federal laboratories are as active in publicizing their technology transfer and economic development activities as in actually doing the transfer work. In examining the many metrics provided in agencies’ responses to the President’s technology transfer memorandum, a great many simply document (presumably good faith) effort. It is not, of course, unreasonable for any federal agency to wish to seem responsive to a President’s dictates, either in hope of reward or to minimize likelihood of negative funding repercussions.

### 6.4 Opportunity Cost Criterion for Technology Transfer Effectiveness

When considering technology transfer activities of federal laboratories it is well worth recognizing that technology transfer is one of many missions of federal labs and usually not the ones viewed as the most important, at least not in the view of labs’ scientists and technical personnel. In hundreds of interviews with federal laboratory scientists Crow and Bozeman (1998) found a wide range of perspective on technology transfer, ranging from enthusiasm and avid participation to outright hostility and cynicism. Even as technology transfer activity is enhanced and nurtured, it remains important to understand that technology transfer takes its place, and often a secondary place, to missions such as advancing advance of basic research and scientific theory, providing equipment and infrastructure for the growth of scientific knowledge, training scientists and
engineers, and ensuring the nation can perform its defense, national security, public health and energy missions.

While it is easy enough to understand the fact of opportunity costs in technology transfer it is not so easy to draw practical lessons about technology transfer measures and metrics. Thus it is perhaps unsurprising that none of the agency responses to the President’s memo on technology transfer reflect the thinking implicit in the Opportunity Cost model. The literature on university technology transfer gives much greater attention to this criterion, especially possible impacts on individual researchers’ research agendas (Bercovitz and Feldman, 2008) and teaching (Mendoza, 2007) responsibilities and, more generally, impacts of organizational culture (Lee, 1996; 1998; Lee and Gaertner, 1994; Slaughter and Rhoades, 2004).

Few recent studies focus directly on opportunity costs and technology transfer. However, Saavedra and Bozeman’s (2004) study of federal laboratories and Woerter’s studies of university-industry activity do employ contingency-oriented models and show that certain “portfolios” of technical activity are more productive than others. That is, while some federal laboratories are, because of their technical focus, able to engage in technology transfer activities with win-win results (for both the technology transfer and for their other technical missions), other labs suffer declines in effectiveness in some of their technical missions with an increase in technology transfer.

6.5 Scientific and Technical Human Capital Criterion for Technology Transfer

Effectiveness

A premise of the Scientific and Technical Human Capital model is that one of the most critical objectives in almost all aspects of science and technology policy is
building human and institutional capabilities, even aside from particular accomplishments reflected in discrete knowledge and technology outputs (Bozeman, Dietz and Gaughan, 2001). The focus of Scientific and Technical Human Capital (hereafter STHC) is on long-term capacity building. Indeed, a deep understanding the value of scientific and technical knowledge requires a view of the role of scientific and technical human capital in the capacity for producing productive scientific work of scientific work (Audretsch and Stephan, 1999; Corolleur, Carrere and Mangematin, 2004) and an understanding that all such work is produced in networks (Casper and Murray, 2005).

The formal and informal networks of scientists, engineers and knowledge users depend upon the conjoining of equipment, material resources, organizational and institutional arrangements for work, and the unique human capital embodied in individuals (Dietz and Bozeman, 2005; Rigby and Elder, 2005; Ponomariov and Boardman, 2010). At any level, from the individual scientist to organizational actor, network, or entire fields, knowledge value is capacity—capacity to create new knowledge and technology (Bozeman, Dietz and Gaughan, 2001).

Capacity is revealed through the changing patterns of the scientific and technical human capital footprints individuals leave behind throughout their careers. Bozeman, Dietz and Gaughan (2000) define STHC as the sum total of personal skills, knowledge, and the social resources scientists and engineers bring to, and develop from, their work. Thus, STHC includes not only the individual human capital endowments traditionally included in labor models (e.g. Becker,
1964; Shultz, 1963), but also the individual scientist’s tacit knowledge (Polanyi, 1969; Senker, 1997), craft knowledge, and know-how (Bidault and Fischer, 1994). STHC further includes the social capital (Coleman, 1988) that scientists inevitably draw upon in framing research and technological questions, creating knowledge, and developing social and economic certifications for knowledge (Fountain, 1998; Landry, Amara and Lamari, 2002).

As mentioned, much of scientific and technical human capital is embedded in social and professional networks or technological communities (Liyanage, 1995; Murray, 2002). These networks integrate and shape scientific careers. They provide knowledge of scientists’ and engineers’ work activities, serve as resources for job opportunities and job mobility, and reveal possible applications for scientific and technical work products. Increasing STHC generally enhances individuals’ capacities while simultaneously increasing the capacity of networks of knowledge and technology producers.

Some technology transfer professionals, especially those in government agencies (Bozeman and Rogers, 2001; Rogers and Bozeman, 2001) take the view that technology transfer, even if it does not have immediate effects from discrete projects, helps build capacity within either a geographic area, a scientific and technical field or an institution (Fritsch and Kauffeld-Monz, 2010; Florida, Mellander and Stolarick, 2010). For these reasons, among others, Autio and Laamanen (1995) and Sala, Landoni and Verganti (2011) argue that evaluation of technology transfer is most appropriately directed to impacts on networks of interconnected scientific and commercial actors.
While there are no technology transfer assessments based exclusively on an STHC model, there are a few studies in which STHC plays a significant role. One study of Italian research centers (Coccia and Rolfo, 2002) focuses on the complimentary roles of research, education, and training and documents interdependent impacts. Focusing on university researchers affiliated with interdisciplinary centers, Lin and Bozeman (2006) employ an STHC model to identify the impacts of industrial interaction on university researchers’ careers and their productivity. In another study employing an STHC model, but not for technology transfer assessment, Bozeman and Corley (2004) examine the impacts of university researchers’ collaborations on their accumulated STHC. Perhaps the only full scale STHC research assessments are those produced by Youtie and colleagues (2006) and by Gaughan and Ponomariov (2008), both focusing on knowledge impacts from NIH research centers. Youtie and colleagues employ qualitative methodologies to trace the growth of collaborations and network activity resulting from research sponsored by the NICHD NIH’s National Institute of Child Health and Human Development. Gaughan and Ponomariov provide a quantitative, time-series analysis (hazard models) of university faculty curricula vita to show the impacts of research center affiliation on the accumulation of STHC.

To this point, most federal agencies’ responses to the requirements of the President’s technology transfer memo have not included STHC criteria. An exception is the Department of Commerce/NIST response (Department of Commerce, 2012). Specifically, NIST will “(d)evelop a complete, NIST-wide accounting of current and recent postdoctoral researchers” and will expand current systems for tracking where postdoctoral researchers are employed after leaving
NIST.” Such approaches are part and parcel of STHC assumptions about the role of technology and knowledge transfer activities in developing long-term capacity. NIST’s plans, similar to other agencies’ plans, to track start-up companies could also be viewed as relevant to an STHC evaluation model.

6.6 Public Value Criterion for Technology Transfer Effectiveness

Perhaps the most difficult and elusive evaluation criterion is Public Value. The term “public value” has many meanings and implications (Bozeman, 2001; Bozeman, 2007; Benington and Moore, 2010). Some use the term as equivalent to the collective good, others in connection with the public interest, and still others as a sort of residual category for commodities not encompassed in either private value or markets (Jørgensen and Bozeman, 2007).

At the broadest level, we can begin with, and the then build upon, a public values definition I provided elsewhere (Bozeman, 2007, p. 37):

“A society’s “public values” are those providing normative consensus about (1) the rights, benefits, and prerogatives to which citizens should (and should not) be entitled; (2) the obligations of citizens to society, the state and one another; (3) and the principles on which governments and policies should be based.”

While this definition has some merit for present purposes— it shows that public values may be the most fundamental criterion upon which to evaluate nearly any public policy, its practical use as a criterion for technology transfer is quite limited. However, there have been efforts to move from the realm of broad values discourse to application (Bozeman and Sarewitz, 2004; Slade, 2011; Valdivia, 2011). Bozeman and Sarewitz (2011) suggest that concerns about economic productivity have been
dominant in science and technology policies and their assessment and that there is a need for greater infusion of public values in science and technology policy. There are three reasons to give greater attention to public values and thinking about S&T policy. First, public values are more likely to encompass outcomes that are ultimately important to most people. For example, despite its pervasiveness as an instrumental concern, few people care about economic growth for its own sake. Instead, they care about better health, more or better leisure, safety, educational opportunity, or increased likelihood of obtaining a satisfying job. Economic growth is prized because it is seen as enabling these first order values. Second, public science and technology are supported by tax dollars, under tax systems that include in most nations progressive elements and promotion of equity. Thus, a rationale for infusing public values in science, technology and innovation policy is that those values are by definition broader values and, by implication, ones more likely to affect all or most citizens.

A third reason for systematic inclusion of public values in science, technology and innovation policy is that without direct attention they are easily set aside or ignored. We can say that science, technology and innovation policy values, and indeed all values expressed in major policies, are both dynamic and “stage dependent.” That is to say, public policies evolve in stages (Rose, 1993; John, 1998), though not necessarily in fixed sequence. In most instances, these stages include (1) agenda-setting, (2) policy design(s), (3) policy choice, (4) policy implementation and (usually but not always), (5) policy assessment or even systematic evaluation. Particularly in science and technology policy (Burgess, et al., 2007; Bozeman and
Sarewitz, 2005), values are important at every stage, but they are changeable and not always in predictable ways. Values change as a result of learning, in other cases they fall aside for lack of advocacy, and in still others they fall under the weight of new values injected by other self-interested parties in political processes (Beierle and Konisky, 2000).

How would public value possibly be subverted in the case of technology transfer? A couple of examples will perhaps suffice. In the case of university-industry technology transfer, a cornerstone of so-called “academic capitalism,” some critics (Kleinman, 2003; Slaughter and Rhoades, 2004; Henkel, 2005) have alleged that the increased commercialization of universities has undermined the core educational mission of universities. In reflecting on possible impacts of universities’ technology development and transfer roles, former Harvard University president Derek Bok (2003, p. 106) warns: “Even the appearance of hiring professors for commercial reasons will lower the morale of the faculty and diminish the reputations of the university[].” The limited number of studies providing Systematic empirical evidence (Stephan, 2001; Ponomariov, 2009; Bozeman and Boardman, in press) on the impact of university technology commercialization and transfer activities on university educational missions shows that impacts are diverse, sometimes undermining education but in other cases augmenting the mission. But the criticism remains worth noting: leaders must be vigilant that the primary public value of universities, education, not be undermined by the secondary economic value of technology commercialization and transfer.
The missions of federal laboratories are, of course, quite different from those of universities. While education is an important part of many federal laboratories’ activities, none lists education as its primary mission. The chief lesson from university criticism of technology commercialization and transfer is not one about education but, more generally, the possibility of secondary purposes undermining primary purposes. This thwarting of public values can happen in federal laboratories as well. For example, if technology transfer activities undermine national security then there has been a supplanting of public values (Mowery, 1988; Aronowitz, 1999; Jaffe and Lerner, 2001; Kassicieh, et al., 2002; Evans and Valdivia, 2012). Likewise, if the private entrepreneurship enabled under the Stevenson-Wydler Act were to diminish the core research capabilities of federal laboratories’ corporate research mission, here, too, would be a thwarting of public values (see Coursey and Bozeman, 1992; Butler and Birley, 1998). Overall, the “public values” criterion can be thought of as the “keep-your-eye-on-the-prize” criterion in the sense that it focuses on provision of beneficial public outcomes as opposed to the lesser value of organizational goal achievement.

Since the idea of Public Value evaluation of technology transfer activities is relatively new it is not surprising that most agencies’ responses to the President’s memo pay little heed to (non-economic) indicators of public value. The emphasis of many agencies on education and outreach impacts are to a certain extent related to Public Value criteria. Moreover, the measurement challenges of Public Value criteria for evaluation are exceedingly difficult ones (e.g. Gupta, 2002; Bozeman and Sarewitz, 2011), though one attempt to develop to employ the Public Value model in
connection with university technology transfer shows some promise (Valdavia, 2011).

7.0 Recommendations for Developing Systems of Measurement and Metrics in Response to the President’s Memo

In this concluding section a number of recommendations are provided on the basis of implications of the literature reviewed here. While these recommendations should be considered in connection with federal agencies’ efforts to comply effectively with White House requirements for enhanced technology transfer, they do not focus on particular metrics but, rather, on general issues in assessing technology transfer effectiveness.

1. Making the most of Out-the-Door. While the Out-the-Door model of effectiveness is not ideal, it is realistic and useful (Geisler, 1994; Lepori, 2006). For agencies able to develop large scale, contract-out, resource-intensive technology transfer assessment regimes, Out-the-Door criteria can be improved upon. But for agencies facing personnel scarcity, limited in-house evaluation personnel, and no budget increment for external evaluation contracting, it seems likely that the Out-the-Door model will continue to be the primary basis of any measurement activity (Geisler, 1994). Certainly, agencies’ initial responses to the President’s memo reflect approaches relying almost entirely on an Out-the-Door evaluation model. Given these realities, the recommendation is for Out-the-Door done right. Ways to do this include the following:

   a. In recognition of the fact that some technology transfer outcomes are going to occur in streams of benefits and costs realized over time, there is no more vital
Out-the-Door activity than providing good periodic benchmarks. If measures of activity are going to dominate metrics, then those measures need to be as precise as possible and need to be tracked over time. A good number of the agencies’ responses recognize the importance of quality, valid benchmark measures.

For example, in the Department of Energy’s plans (U.S. Department of Energy, 2012) for technology transfer metrics, one of the criteria is “patenting effectiveness.” But rather than simply reporting the number of patents, they plan to report the ratio of patents in a given year to patent applications filed for a three year base period, using a rolling three-year average as new metrics are reported.

b. Surprisingly few sets of Out-the-Door measures and metrics developed thus far by agencies give any consideration to the resources agencies and their facilities bring to technology transfer activities. It is not useful, and may even be counterproductive, to show that the number of licenses has declined over a given time period when, in fact, that decline may be owing to a sharp reduction of the technology transfer personnel available. For any valid inference about effectiveness, activity measures must relate to resource measures.

c. Perhaps it is time to move away from what are referred to here as Pure Out-the-Door measures. While it is sometimes exceedingly difficult to document particular causes and effects, it is possible and useful to at least develop measures of Out-the-Door Transfer Agent Impacts and Out-the-Door Transfer Recipient Impacts. These types of measures can likely be gathered and recorded even absent a large cadre of evaluation specialists available to that purpose. For example, in the case of Transfer Recipient Impacts there may be desirable changes that do not immediately
and directly translate into market impacts. Thus, in working with a particular company the federal lab may have a strong impact on training firms’ personnel, benefits that will never show up directly and obviously in market indicators but that nonetheless have the potential to provide major advantages. Similarly, technology transfer recipients often benefit enormously from using state-of-the-art or even unique scientific equipment and instruments made available to them by the laboratory. Such benefits are out-the-door impacts, not (direct) market impacts and are well worth capturing. (For a discussion of the indirect impacts of federal laboratories on industry partners see Adams, Chiang and Jensen, 2003).

2. Identification of expected ranges of impact. A common problem for most evaluation efforts, including attempts to evaluate technology transfer impacts, is the failure to understand the domain of influence of the “intervention” (Midgley, 2006; Shalock and Bonham, 2003). If at the beginning of a technology transfer effort there is at least some attention to providing a rationale for the expected domain of influence of the transfer then there is a guidepost to help one understand the diffusion of impacts. Absent such guideposts, it is altogether natural to claim impacts of great breadth when, in fact, the technology transfer activity is one significant event in a multi-causal chain of events. Equally important, having a pre-established hypothesis about domain of influence leads to subsequent cues for obtaining evidence of influence. An impact theory is a useful precursor to any attempt to measure impact. In developing impact measures, the analyst does well to ask questions such as: (1) “What set of causal assumptions need be true for impacts to occur?” (2) “What is the likely chronology of impact, when should benefits begin
to occur and why then?” (3) “What are the alternative causes that could result in this impact that seems to be caused by our technology transfer efforts”? (i.e. alternative plausible hypotheses). Indeed, it may be worthwhile to routinely pose or even require answers to these and similar questions as part of any effort to measure out-the-door technology impacts or market impacts.

3. Further development of scientific and technical human capital indicators. It is encouraging that at least some of the agencies’ responses to the President’s memo include indicators of enhanced scientific and technical human capital. Research evaluators and program managers have known for some time that it is often at least as valuable to enhance the capacities of organizations or knowledge producing communities as to provide beneficial direct outputs. If a small company develops the capacity to use computer aided machine tools, that capacity may provide a stream of benefits stretching out for many years.

Some R&D managers assume that if knowledge producers’ capacity is fully developed then good things happen with the level of production and the quality of outputs and, indeed, there is at least some evidence for this capacity focus (e.g. Ponomariov and Boardman, 2010). Furthermore, it is sometimes easier to develop valid measures of scientific and technical human capital than valid measures of economic impact in over-determined systems of interrelated economic producers and consumers. Thus, for example, one could trace the career trajectories of researchers who have interacted with a federal laboratory, comparing those researchers to a group similar in every other respect except that they have not
interacted with a federal laboratory. Using the laboratory interaction as an inflection point in time, it is possible to compare differences in one set of researchers (those interacting with the labs) with the other (who have not). With a sufficient sample size for valid “treatment” and “comparison” groups, any difference between the two sets’ career accomplishments could be owing to the resources and activities of their interactions with the federal laboratories. Previous studies have used curricula vitae as a convenient means of examining the impacts of such events on researchers’ careers (for examples of such applications see Bozeman and Gaughan, 2007; Cañibano, Otamendi & Andújar, 2008; Lepori and Probst, 2009).

4. Correlate process reforms and activity measures. Many of the agency responses to the President’s memo include process changes or reforms as well as activity measures. In fact if we take these two categories (process and activity) of indicators together they comprise at least 90% of the anticipated performance metrics. The problem is that the two are not, under most plans, brought together. While everyone recognizes that correlation is not causation, it is at least of heuristic value to track activity measures against implemented changes in technology transfer processes and managerial approaches.

5. Make greater use of logic models and mapping techniques. Systems of indicators are more valuable than lone, discrete indicators. Systems of indicators brought together in logic models or mapping systems are more valuable yet (Cooksy, Gill and Kelly, 2001; Shalock and Bonham, 2003). Each indicator employed in agency metrics can be thought of as having an underlying rationale. In most cases the rationale remains implicit and can be teased out without much difficulty.
However, in some cases developing a simple logic model can show that the presumed rationale for specific metrics may be less than compelling and, related, such a model can help the analyst determine the need for additional metrics and the prospects for eliminating redundant ones. None of the agency responses to date take much care in providing a decision logic attendant to the metrics provided. This point relates to point 2 above, namely, the need for explicit causal thinking and for explicit assumptions. Logic models require attention to explicit assumptions, requiring the analyst not simply to list but to show the presumed causal connections among inputs (e.g. federal laboratory technology), activities (e.g. marketing technologies), outputs (e.g. licenses), and impacts (e.g. new products developed by participating companies). Many textbooks on logic models include frameworks with specific templates that assure that temporally-relevant questions are asked and that causal assumptions are explicates and inter-related (see Frechtling, 2007, p. 65-78).

6. Develop peer review of metrics. There is a natural skepticism of performance measures that are developed by interested parties, data collected by interested parties, and then interpreted by those same interested parties. While in-house evaluation is a widespread practice in both government and business, it is also the case that evaluations that are submitted to independent peer review generally inspire greater confidence (Georghiou, 1998; Georghiou and Roessner, 2000). Perhaps even more important, it is almost always the case that good ideas come from independent peer reviews and such regular reviews can provide for constant learning and improvement. Some of the social structures needed for independent
peer reviews of agency metrics are already in place and it should prove possible to develop such capabilities with very limited funding or perhaps no additional funding whatsoever. If nothing else, such peer review can save interested parties from making embarrassingly lavish claims. For example, this analyst, working as a peer reviewer, once saved a state agency from claiming a net benefit in excess of that state’s entire gross state product. More important, it is quite likely that assessments submitted to peer review would have the consequence of improving the quality of technology transfer effectiveness evaluation.
Appendix One: Technology Transfer Literature Organized by Contingent Effectiveness Model’s Categories

<table>
<thead>
<tr>
<th>Effectiveness Criteria</th>
<th>In-text Citation</th>
<th>Relevant Findings</th>
<th>Data and Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out-the-Door</td>
<td>Rogers et. al (1998)</td>
<td>Firms are critical of the amount of time and complexity necessary to form a CRADA.</td>
<td>Data: Surveys mailed to lab and firm CRADA participants at Los Alamos National Lab in 1994 (59 private firm respondents and 63 lab respondents). Also, conducted 3 case studies at LANL.</td>
</tr>
<tr>
<td>Out-the-Door</td>
<td>Bercovitz et. al (2001)</td>
<td>Differences in organizational structure and capacity result in differences in technology transfer activities in terms of patenting, leveraging, and the likelihood that customer firms overlap across university units.</td>
<td>Data: 21 interviews with personnel from 3 research intensive universities; data were also gathered about the top 30 firms active in licensing at each of the three universities during the 1993-1998 period. Also data on annual patents, disclosures, and licenses at each university were collected for this period. Differences of means tests were used to compare patent, disclosure, and license yields.</td>
</tr>
<tr>
<td>Out-the-Door</td>
<td>Jaffe and Lerner (2001)</td>
<td>Federal technology transfer legislation and initiatives since the 1980s have had a significant effect on the number of patents produced by DOE labs without a commensurate decrease in patent quality.</td>
<td>Data: Sample of 23 DOE FFRDC's active between 1977 and 1997. Methods: Fixed effects regression analysis on the panel for the years 1981-1993 to estimate the effects of policies and control variables on patenting.</td>
</tr>
<tr>
<td>Out-the-Door</td>
<td>Thursby et. al (2001)</td>
<td>For patents and sponsored research size of the technology transfer office is positively associated with higher levels. For licenses number of disclosures, size of the technology transfer office, and whether the university has a medical school are statistically significant. Also, the stage of technology development, size of the tech transfer office, and quality of the researchers are associated with greater royalty values.</td>
<td>Data: AUTM annual survey data Linear Regression</td>
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<tr>
<td>Out-the-Door</td>
<td>Thursby and Kemp (2002)</td>
<td>Licensing has increased for reasons other than overall increases in university resources.</td>
<td>Data: AUTM annual licensing survey 1991-1996 (112 respondents) Statistical methods: DEA to create an efficiency score (dependent variable) and logit regression</td>
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<tr>
<td>Out-The-Door</td>
<td>Adams, Chiang, and Jensen (2003)</td>
<td>CRADAs stimulate industrial patents and industrial R&amp;D, and do so to a much greater extent than other tech transfer mechanisms.</td>
<td>Primary data: Two surveys (1996 and 1998). The first is of firms in the chemicals, machinery, electrical equipment and transportation equipment industries (115 responding firms representing 220 labs) and the second is of CFOs of non-DOD government labs. Supplemental data: Compustat data measuring R&amp;D expenditures and net sales of parent firms. Models: Two equation maximum likelihood estimates of patents and CRADAS. OLS and Tobit models estimating</td>
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7 The author is grateful to Heather Rimes, University of Georgia doctoral student and research associate, for her work in compiling this table.
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Summary</th>
<th>Data/Methods</th>
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<tr>
<td>Friedman and Silberman (2003)</td>
<td>Incentives for researchers, university location within a region with a concentration of high technology firms, a clear technology transfer mission, and previous technology transfer experience are positively associated with technology transfer performance.</td>
<td>Data: AUTM annual licensing survey (1997-1999) Two equation recursive system</td>
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<tr>
<td>Siegel, Waldman and Link (2003)</td>
<td>Invention disclosures are positively associated with both number of licenses and license revenue. The size of the technology transfer office staff results in more licenses but not more revenue. Spending on external lawyers reduces the number of agreements but increases license revenue.</td>
<td>Data: AUTM survey (1991-1996) 113 U.S. universities. Statistical methods: OLS regression and Stochastic Frontier Estimation in which average annual number of licensing agreements and annual licensing revenues are dependent variables</td>
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<tr>
<td>Chapple et. al (2005)</td>
<td>University technology transfer offices in the U.K. are found to have low levels of efficiency and decreasing returns to scale.</td>
<td>Data: March 2002 survey of U.K. universities (50 respondents) Data Envelopment Analysis and Stochastic Frontier Estimation; dependent variable is number of licenses/license income</td>
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<tr>
<td>Link and Siegel (2005)</td>
<td>When licensing activities are the dependent variable, organizational incentives (financial incentives) impact technology transfer performance.</td>
<td>Data: Structured in-person interviews of directors of university offices of technology transfer and other university technology administrators, as well as entrepreneurs, managers, and academic scientists. Also, AUTM survey (113 respondents) Statistical Methods: Stochastic Frontier Estimation</td>
<td></td>
</tr>
<tr>
<td>Anderson, Daim, and Lavoie (2007)</td>
<td>There are both efficient and inefficient universities in terms of comparing research expenditures and technology transfer outputs. Universities with medical schools tend to be less efficient than those without medical schools.</td>
<td>Data: Information was gathered about 54 universities ranked by AUTM in 2004 as having the highest levels of licensing income. Data Envelopment Analysis is used to assign each university an efficiency score. Linear regression is then employed with the DEA score as the dependent variable.</td>
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<tr>
<td>Study Title</td>
<td>Authors</td>
<td>Summary</td>
<td>Data/Methods</td>
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<tr>
<td>Out-the-Door</td>
<td>Fukugawa (2009)</td>
<td>Determinants of licensing activity vary based on the phase of technology transfer. Budget size and previous technology transfer experience does not affect licensing. Employing high quality scientists promotes licensing of granted patents. Organizational efforts aimed at encouraging scientists to understand the needs of small businesses increases royalty revenues.</td>
<td>Data: Licensing activities of Japanese public technology centers. Tobit model used for estimation.</td>
</tr>
<tr>
<td>Out-the-Door</td>
<td>Swamidass and Vulasa (2009)</td>
<td>Lack of resources in terms of staff and budget result in universities focusing on filing patent applications rather than licensing technologies.</td>
<td>Data: Surveys of University Offices of Technology Transfer (26 respondents). Descriptive statistics and correlations are reported and regression models are estimated.</td>
</tr>
<tr>
<td>Out-the-Door</td>
<td>Park, Ryu, and Gibson (2010)</td>
<td>Membership in research consortia can increase the technology transfer performance (in terms of invention disclosures, patents, licenses executed, and royalties) of participating public sector research institutions.</td>
<td>Data: Interviews with managers of regional technology transfer consortia were conducted and information from them was used to build a survey and a technology transfer performance index. Quantitative performance indicator data were collected from government ministry offices. A random sample of consortia members (34) and non-members (31) were selected. Additionally, surveys were sent to staff and managers in each group (61 responses received). Descriptive statistics for data are compared along with difference of means tests (one-tailed).</td>
</tr>
<tr>
<td>Out-the-Door and Market Impact</td>
<td>Bozeman and Crow (1991)</td>
<td>Labs involved in tech transfer do not have higher levels of red tape than other labs. Out the door measures of tech transfer success are associated with low levels of perceived red tape, and measures of market impact are associated with low levels of actual red tape in obtaining project funding and low-cost equipment.</td>
<td>Data: Surveys of federal and state government labs. Correlations between bureaucratic red tape measures and technology transfer activities. Series of multiple regression equations examining each of the significant correlations with added controls.</td>
</tr>
<tr>
<td>Out-the-Door and Market Impact</td>
<td>Bozeman (1994)</td>
<td>There is wide variation in labs in regards to out the door and market impact measures of effectiveness with some</td>
<td>Data: National Comparative Research and Development Project Phase III--surveys of directors of government R&amp;D labs.</td>
</tr>
<tr>
<td>Market Impact</td>
<td>Out-the-Door, Market Impact, and Economic Development</td>
<td>Rogers et al (2001)</td>
<td>Articles in scientific journals are not an effective technology transfer mechanism. Spin-offs are an effective technology transfer mechanism. Organizations that provide assistance with technology transfer, coupled with favorable entrepreneurial leave policies at federal labs, facilitate the growth of spin-offs.</td>
</tr>
<tr>
<td>Market Impact</td>
<td>Out-the-Door and Economic Development</td>
<td>Carlsson and Fridh (2002)</td>
<td>Organizational structure variables have an impact on technology transfer measures of licenses, patents, and start-ups. However, based on their findings, the authors argue for technology transfer success to be considered in a broader context such as overall goals of the organization.</td>
</tr>
<tr>
<td>Market Impact</td>
<td></td>
<td>Cohen, Nelson and Walsh (2002)</td>
<td>In general, public research plays an important role in private sector manufacturing R&amp;D. This impact flows through a variety of formal and informal channels and tends to be greater for applied research rather than basic research. There are some differences in impacts across industries as well, but few, if any, systematic differences between high-tech industries and other industries.</td>
</tr>
<tr>
<td>Market Impact</td>
<td>Hertzfeld (2002)</td>
<td>For companies that developed spin-off products from NASA investments, the largest benefits accrued to large companies. Many small companies reported profitable products and benefits as well, but lacked the resources to expand to large-scale production.</td>
<td>Data: Survey of companies that developed spin-off products from NASA investments (15 respondents). The study reports benefits identified by companies both financial and non-financial as well as downstream benefits.</td>
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<tr>
<td>Market Impact</td>
<td>Roessner et. al (2013)</td>
<td>Summing over a 15-year period, the authors estimate that the</td>
<td>Data: AUTM annual surveys (1996-2010) Methods: BEA I-O model</td>
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</table>
The impact of university licensing on the U.S. economy is at least $162.1 billion. Estimates for jobs created per year over the period range from 7,000 to 23,000. Models estimated with different substitution rates still yield large effects on GDP.

<table>
<thead>
<tr>
<th>Economic Development</th>
<th>Impact</th>
<th>Methodology</th>
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<tr>
<td>Market Impact and</td>
<td>Hartmann and Masten (2000)</td>
<td>Small manufacturers tend to have faster growth rates in states that focus technology transfer assistance on small firms.</td>
</tr>
<tr>
<td>Market Impact and</td>
<td>Lindelöf and Löfsten (2004)</td>
<td>New technology based firms located in university science parks exhibit a competitive advantage over firms not located in science parks in terms of product development.</td>
</tr>
<tr>
<td>Scientific and</td>
<td>Coccia and Rolfo (2002)</td>
<td>Lab rankings change depending on which measure of technology transfer effectiveness is employed. Technological labs (applied science) perform better in terms of market-oriented tech transfer and non-technological labs (economics and natural sciences) perform better in terms of education-oriented tech transfer.</td>
</tr>
<tr>
<td>Opportunity Cost</td>
<td>Rowe and Temple (2011)</td>
<td>Economic impact estimates suggest that the transfer of superfilling knowledge generated by NIST to industry were an efficient use of public resources.</td>
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<tr>
<td>Development</td>
<td>Markusen and Oden (1996)</td>
<td>Barriers to business incubation and start-up at federal labs are identified and suggestions for improvement are offered.</td>
</tr>
<tr>
<td>Development</td>
<td>Phillips (2002)</td>
<td>Technology business incubators have widely varying rates of technology transfer, but overall levels are not as high as expected.</td>
</tr>
<tr>
<td>Development</td>
<td>Shane and Stuart (2002)</td>
<td>Founder’s social capital is key to the outcome for the new venture; firms with founders that have direct and indirect relationships with venture investors are more likely to receive funding and less likely to fail.</td>
</tr>
<tr>
<td>Development</td>
<td>O'Shea et. al (2005)</td>
<td>Previous spinoff development, the presence of leading researchers, the magnitude and</td>
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<tr>
<td>Area</td>
<td>Author/Year</td>
<td>Summary</td>
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<tr>
<td>Economic Development</td>
<td>Golob (2006)</td>
<td>Universities that view their technology transfer functions as revenue generators produce fewer start-ups than universities that have economic development as an objective. Also, entrepreneurs make location decisions based on a variety of factors including existing relationships with the licensing entity.</td>
</tr>
<tr>
<td>Economic Development</td>
<td>Gulbranson and Audstretch (2008)</td>
<td>The authors discuss the utility of proof of concept centers to facilitating transfer of university innovations.</td>
</tr>
<tr>
<td>Economic Development</td>
<td>Festel (2012)</td>
<td>Start-ups, spin-offs, and spin-outs are legitimate mechanisms for technology transfer.</td>
</tr>
<tr>
<td>Economic Development and Scientific and Technical Human Capital</td>
<td>Brown (1998)</td>
<td>Sandia’s science park presents a model of technology transfer that requires different evaluation metrics than technology transfer under a CRADA.</td>
</tr>
<tr>
<td>Market Impact/Opportunity Cost</td>
<td>Saavedra and Bozeman (2004)</td>
<td>Technology transfer effectiveness is increased when the lab and firm play different but not far removed roles on the basic-applied-development spectrum.</td>
</tr>
<tr>
<td>Opportunity Cost</td>
<td>Woerter (2012)</td>
<td>Technology proximity (work in the same patent class) fosters technology transfer intensity between firms and universities. This is the case especially for smaller firms. Also, if technology proximity is low, but expertise at a university is high then technology transfer intensity is increased.</td>
</tr>
<tr>
<td>Public Value</td>
<td>Rubenstein (2003)</td>
<td>USDA's patent licensing is not revenue driven, and it does not appear to have altered the agency's research priorities. Licenses vary in terms of four social benefits: food safety, human nutrition, human health, and environmental/natural resource protection. No evidence is found of concentration of licenses in only a few firms. Research of interest</td>
</tr>
</tbody>
</table>
to the private sector makes up a larger part of the Agricultural Research Service’s licensing program than of its research program as a whole. It appears that offering complete exclusivity is not necessary to attract technology developers.

<table>
<thead>
<tr>
<th>Public Value</th>
<th>Costa-Font and Mossialos (2007)</th>
<th>The knowledge and beliefs of individuals as well as information channels affect attitudes towards new applications of biotechnology in the UK.</th>
<th>Data: 1999 Eurobarometer 52.1 survey on science and technology (1,295 respondents). Probit models are estimated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public Value</td>
<td>Sorensen and Chambers (2008)</td>
<td>The authors suggest metrics that could be used to evaluate technology transfer performance in terms of increased access to knowledge.</td>
<td>Conceptual</td>
</tr>
<tr>
<td>Public Value</td>
<td>Bozeman and Sarewitz (2011)</td>
<td>Suggested framework for including public values in science policy evaluation.</td>
<td>Theoretical</td>
</tr>
<tr>
<td>Political</td>
<td>Bozeman and Crow (1991)</td>
<td>Influence from political authority is a major determinant of technology transfer activity, specifically whether the technology is transferred to government or industry.</td>
<td>T-tests. OLS and logit models estimating the effects of goal orientation, resource dependence, boundary spanning, and structural variables on whether technology is transferred to government or industry.</td>
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</table>
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