VALUING ADDITIVE INVOLVEMENT IN UNIVERSITY-INDUSTRY PARTNERSHIPS: DO GOVERNMENT COLLABORATORS ENGAGE AT SCALES THAT OPTIMIZE THEIR VALUE-ADDED?

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LIST OF SYMBOLS AND ABBREVIATIONS

ACT	Agreements to Commercialize Technology
CINT	Center for Integrated Nanotechnologies
CNSE	College of Nanoscale Science and Engineering
CRADA	Cooperative Research and Development Agreement
IG	Industry-Government
IP	Intellectual Property
IRB	Institutional Review Board
JIF	Journal Impact Factor
MSA	Metropolitan Statistical Area
NIS	National Innovation System
NNI	National Nanotechnology Initiative
ORTA	Office of Research and Technology Applications
PSM	Propensity Score Matching
RIS	Regional Innovation Systems
RV	Research Value
RVRI	Research Value Responsiveness Index
SP	Semi-Perimeter
TC	Times Cited
UG	University-Government
UI	University-Industry
UIG	University-Industry-Government

V_G	Incremental Value Added by Government Collaborators
V_I	Incremental Value Added by Industry Collaborators
V_U	Incremental Value Added by University Collaborators
V_{UI}	Value of a University-Industry Partnership
V_{UIG}	Value of a University-Industry-Government Partnership
WOS	Web of Science
XPS	X-Ray Photoelectron Spectrometer

SUMMARY

Collaboration between academic and corporate entities has increased in recent years. On many occasions Government actors (e.g. federal laboratories) will participate in these collaborations, especially when advanced technologies are involved. The following inquiry considers the degree to which the federal entities add scientific value to University-Industry partnerships and how this value is spatially mediated. Quantifying degrees of the value that Government actors induce across the spectrum of University-Industry collaborative arrangements is useful for identifying scales at which intervention by federal organizations is more effective and/or justified. It is anticipated that the value-added by federal researchers in University-Industry collaboration is not spatially uniform but will be greater across specific scales of interaction. Comparing these against actual scales of interaction provides room for discussion on whether Government actors engage Universities and Industry at scales that optimize the scientific value they introduce to these partnerships.

CHAPTER 1

OVERVIEW

Introduction

The following inquiry is interested in measuring the scientific value produced by University-Industry partnerships for emerging technologies and how (scale of) Government actor involvement influences the same. The topic itself raises a number of questions that should be addressed before a more substantive discussion occurs. These include: Who are Government actors and how does their behavior differ from Universities and Industry actors? What is meant by scale of interaction and why does it matter? What is value and how can it be measured? These and similar questions are discussed in the sections that follow. The present chapter provides an overview, background and initial definitions for some of the more central concepts guiding this study. It is augmented by the literature review in the next chapter. After preliminary concepts are outlined, this study then moves to questions concerning whether Government add value to University-Industry partnerships, how this is influenced by scale of engagement and how actual scales of engagement compare against ideal scales for the same.

Preliminary Concepts

Today's economy is increasingly knowledge-based.[1] The developed world transitioned from a post-industrial mode of economic organization to a knowledge-based mode of economic organization in the late 20th century, and since that time the way in

[1] Prior work has documented the increasing knowledge content of the economy. See OECD (1996).

which regions compete has significantly changed. The ability of a region to produce and utilize knowledge with economic value is of critical and increasing importance to its competitive position. Knowledge is said to be "crucial in helping to create innovation which in turn stimulates economic growth…It also plays a more specific role in establishing and sustaining the long-term capabilities and performance of firms and organisations" (Howells, 2002). If a region can generate and take advantage of more or better knowledge than its competitors it will enjoy a competitive advantage in today's global marketplace.

A determining feature of today's knowledge-based marketplace is that not all knowledge is equal in value. This holds true for preexisting knowledge and, important for this study, that knowledge which has yet to be produced. Knowledge value, it will be argued, is influenced by scale of interaction (among and between knowledge producers). Another feature of note (to be discussed later) is that the transfer of certain types of knowledge (key to competitiveness) depends critically on scale of interaction between knowledge producers as well (i.e. not all scales of interaction are equally conducive to knowledge transfer). Scale of interaction (or engagement) between the producers of knowledge has significant implications for knowledge outcomes on a number of levels. It is to this concept, which has a significant bearing on a number of analyses conducted in this study, we now turn.

The Organisation for Economic Co-operation and Development (OECD) classifies knowledge into four types: (i) Know-what, (ii) Know-why, (iii) Know-how and (iv) Know-who. Type (ii) is defined in the following way (OECD, 1996):

> Know-why refers to scientific knowledge of the principles and laws of nature. This kind of knowledge underlies technological development and product and process advances in most industries. The production and reproduction of know-why is often organised in specialised organisations, such as research laboratories and universities. To get access to this kind of knowledge, firms have to interact with these organisations either through recruiting scientifically-trained labour or directly through contacts and joint activities.

Indeed, the interaction of firms with Government laboratories and universities to obtain this knowledge type is of special interest to this study. In the analyses that follow know-why manifests in terms of published research. Analyzing the ability of firms, Government laboratories and universities to produce work of high impact, along with the conditions and frequency for which this occurs, is a key objective of the present undertaking.

Previous studies have shown that the ability to produce high impact research is a collaborative process (Lawani, 1986) influenced by scale of interaction (Katz, 1994). The scale at which knowledge producers interact can be taken as a general reference to the degree of closeness between them. But why does this matter? If research which argues that innovative activity is more likely to occur in close proximity to a given source of knowledge production (Audretsch and Feldman, 1996) and proximate interaction facilitates the transfer of tacit knowledge (Autant-Bernard et al., 2007; Howells, 2002) is correct, the conclusion follows that proximity between collaborators is innovation-enhancing. In other words, closeness between collaborators has a salutary effect on knowledge outcomes. More recent scholarship (Frenken et al., 2010) has questioned this position, however. Just as too little proximity can be detrimental, too much proximity, it is argued, can contribute to inertia and lock-in (i.e. a lack of flexibility or openness), which can undermine innovative performance (Boschma, 2005). In this line of thinking, some proximity is a good thing, but too much is not. Irrespective of how much proximity is desirable, studies new (Frenken et al., 2010) and old (Katz, 1994) agree that research performance is spatially mediated.

In addition to the considerations of proximity, research value is also influenced by the compositional arrangement of its affiliates. Collaboration between University, Industry and Government (UIG) entities has been lauded as a highly effective knowledge production arrangement (Etzkowitz and Leydesdorff, 1996, 1998, 2000), especially for emerging technologies (Schultz, 2011). This study sets its focus on nanotechnology, one of the most promising emerging technologies of the 21st century, and notes that UIG collaborations for this domain are steadily increasing over time (see Appendix A). Given its heterogeneous and interdisciplinary and character, nanotechnology is ideally suited for UIG knowledge production and analysis. The more visible, pronounced and increasing role of Government actors in University-Industry (UI) partnerships might raise concerns[2] by those in favor of more limited government as to whether the involvement of federal agents in UI collaborations adds value to research outputs above and beyond that which would have occurred had Government collaborators not become involved, as well as whether all potential benefits of these interventions are fully realized.

The following analysis anticipates Government collaborators do, in fact, add significant value to research outputs produced by Universities and Industry—i.e. the author thinks it unlikely corporate and academic entities would continue to voluntarily collaborate with federal actors on a frequent and increasing basis if they received little or no benefit in so doing. What seems less clear, however, is whether all Government collaborator induced value is fully captured or realized (i.e. there is room to question

[2] Richard Nelson observes that, “in the United States the universities, rather than government laboratories, are seen as the appropriate sites for fundamental research” (Nelson, 1993).

whether Government collaborator value added is optimized). This raises the questions: What is meant by the term 'value' and who are 'Government collaborators'? The paragraphs below provide a preliminary overview of these and related concepts.

What is value and how should we think about it? As its recurring presence in the title suggests, the concept is integral to the inquiry that follows. Economists and philosophers have produced a number of (competing) theories of value. Two of the more prominent will be mentioned here. The labor (or Marxian) theory of value equates a given commodity's value (or worth) with the labor invested in its production. By contrast, the utilitarian theory of value equates a given commodity's value (or worth) with the satisfaction, or utility, it produces. Economic historian Robert Heilbroner elaborates on this distinction by posing the following question: "[are] prices…a reflection of the cost of production of a good, or of the final degree of satisfaction yielded by that good—were diamonds high-priced, in other words, because they were hard to find or because people enjoyed wearing them?" (Heilbroner, 1999). The latter perspective is emphasized in this analysis for reasons discussed below.

This study measures value in terms of citation impact, which can essentially be viewed as a measure of scientific value. This metric is more in line with the utilitarian theory of value (than the labor theory of value) from the perspective that citations seem to be more a reflection of how useful the scholarly community finds a given piece of research (as opposed to how much work was invested in its production). It is acknowledged that a number of alternative metrics[3] exist. It is acknowledged as well that—as is the case with any commodity—a given piece of research can be over- or undervalued. When a commodity is over- or under priced, market mechanisms can serve

[3] Liao (2011) provides a number of alternative metrics to value research.

to pull its price into alignment with its true worth, but what mechanisms exist to correct poorly valued scholarship? As will be discussed in more detail at a later juncture, it is possible to control for factors (e.g. self-citation, the Halo Effect and differential citation rates across disciplines) that can overvalue research as well as factors (e.g. insufficient citation exposure time) that might undervalue research. Suffice it to say at present that, of all available options, citation impact is seen as the best (and most common, or universal) currency with which to assign value to research.

Citation data as an indicator of research value has been used by a number of previous studies. Goodall (2009) considers the scholarly achievement (measured in terms of lifetime citations) of university presidents in relation to university performance and finds that the latter is significantly influenced by the former. Her study is parallel to the present analysis in that it not only uses a citation-based metric of research quality, but also takes a fine-grained approach in focusing on the ability of individual actors (in her case university presidents) to mold outcomes. Chang (2008) also points to citations when measuring the value of research, as well as the journal impact factor (JIF) and what he calls 'knowledge value', which consists of concepts that can be a challenge to measure on a large-N basis (like work experience, teamwork and organizational support). We note that, since JIF is calculated on the basis of citations, Chang's is predominantly a citation-based approach. It is argued that Chang's concept of knowledge value is better (or can be more accurately) applied to individual (or a small number of) groups or organizations.

Like Chang, Liao (2011) relies on citation impact and JIFs to measure research value (or what he calls 'research quality'). He also relies on research awards. As has been previous noted, JIF is calculated on the basis of citations. Hence, like Chang (2008), Liao's is a citation-based approach. In addition to citations and JIFs, Liao also makes use of data for research awards, which can be difficult and/or costly to obtain on a large-N basis. While the argument can be made that research awards are a valid indicator of research quality, it is anticipated this metric is likely to be highly correlated with the citation rate. It is worth noting as well that citations can be viewed as a research award in and of themselves.

This study posits that, like research awards, a number of non-scientific measures of value (discussed in this study's Interviews chapter) are often strongly connected and/or interrelated with the citation impact induced by Government collaborator involvement in UI partnerships. In this respect, a reference to alternative research value metrics can be, and often is, an implicit acknowledgment of the influence of citation data. Ergo, the argument is made that many so called non-citation measures of quality often translate or in some way contribute to a citation-based approach for research value. Because citations, it is argued, provide a least common denominator for a number of measures of research quality and can be seen as the most fundamental indicator for how to value research, they are advanced in this study. In addition to providing a foundational and common measure of research value, citation impact lends itself particularly well to the type of large-N analyses conducted in the present analysis. Hence, unless stated otherwise, all uses of the word 'value' in this study are made in reference to a scientific context.

To acknowledge and account for other forms of (non-scientific) value Government actors introduce to UI partnerships a number of UIG collaborators are interviewed and asked to identify all forms of Government collaborator induced value in UI partnerships—see Theme #2 in this study's Interviews chapter. A number of these responses tend to be more abstract in nature. In addition, to impart a sense of the net value introduced by federal agents UIG collaborators are also interviewed on the question of what costs Government collaborators impose on UI partnerships—see Theme #5 in this study's Interviews chapter.

Having provided an overview of how the word 'value' is used this study, a discussion of the term 'Government collaborator' is in order. Who are these entities and are they expected to exhibit behavior or capabilities different than University and Industry collaborators? Government collaborators are identified with benefit of a thesaurus, provided by Search Technology,[4] that classifies affiliation types on the basis of keywords contained in their title. The overwhelming majority of those entities identified as 'Government' by this thesaurus (which is supplemented by manual verification) are federal laboratories. Some of the entities the thesaurus labels 'Government,' however, cannot be termed laboratories proper. Hence, for purposes of this study, a Government actor/collaborator/agent is operationally defined as any entity affiliated (at least in name) with, and funded and operated by, the federal government that becomes involved in a University-Industry partnership, whose primary[5] mission is driven by government and governmental interests.

Conceptually, a Government actor can be thought of as any entity acting on behalf of the state (the federal government in the US). These symbolize any government-operated organization that promotes state objectives and as such oftentimes behave

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[4] AcadCorpGov.the is the VantagePoint thesaurus used in this study. See www.thevantagepoint.com

[5] The word 'primary' is used here to indicate that a given organization is driven, for the most part, by state interests. It is possible for an organization to be driven by multiple interests, however. For example, The United States Military Academy at West Point (more commonly known as West Point) can be potentially classified as a (1) University, or (2) Government entity. Given that the author believes the primary mission or focus of this organization to be academic in nature, it is classified in the former terms.

differently than University and Industry actors. That they will behave differently than their UI collaborators is reflected in the fact that Government actors are likely to be driven by different motivations—i.e. a key role of the these actors is to serve the public good and national interests. In their article "Government, Industry, the University, and Basic Research" Klopsteg and colleagues (Klopsteg et al., 1955) argue that "basic research is important in the national interest, and…it is a proper function of government to support such research." They cite Executive Order No. 10521, which states:

> As now or hereafter authorized or permitted by law, the [National Science] Foundation shall be increasingly responsible for providing support by the Federal Government for general-purpose basic research through contracts and grants. The conduct and support by other Federal agencies of basic research in areas which are closely related to their missions is recognized as important and desirable…

From the preceding it appears that Federal agencies (unlike Universities and Industry) are specifically tasked by the President of the United States with the mission of conducting basic research. Such a responsibility is certain to have behavioral implications in the context of UIG relations. Concern for the production of more public science (by Government collaborators) can act as a check and balance against the more applied research orientation characteristic of Industry actors. If Government collaborators have enough influence to direct research along a given trajectory (which they oftentimes do given the amount of funding, equipment and expertise they provide), it is expected to be broader in focus (i.e. more basic) than the direction favored by those whose self-interest is aligned with a more applied trajectory.

In this study Government actors represent key components of the national science and engineering infrastructure and introduce unique capabilities to University-Industry partnerships. That federal laboratories have historically possessed specialized equipment and expertise is documented by Peter Westwick (2003) when he observes that leading universities have often sent their students to study at federal laboratories (given that the universities themselves often did not possess the specialized—and customarily classified—knowledge or capabilities utilized by Government labs). Accordingly, the conceptual notion of Government actors advanced in this study are those actors, acting on behalf of the state and in support of its objectives, that possess unique funding opportunities, advanced equipment and scientific know-how. For these and similar reasons it is anticipated that, in addition to citation impact, Government actors will add the following to UI partnerships: (1) name weight (and/or reputation), (2) economic capabilities, (3) technical capabilities, (4) facilities (and/or advanced equipment), (5) scientific expertise and (6) an orientation toward more basic research. While these contributions are significant, this study maintains a specific focus on the ability of Government collaborators to influence the scientific impact of UI research.

Conclusion

In an effort to weave the above concepts into one fabric, it is the author's position that the value-added of federal intervention (in University-Industry partnerships) will not be spatially uniform but vary across the spectrum of Government collaborator engagement. It is posited that scale of interaction is nontrivial from the perspective that certain scales of engagement will prove more valuable, on average, than others. As will be discussed in greater detail, citation optimizing scales of Government collaborator engagement can differ by domain (and sub-domain). Identifying the manner by which value varies across the spectrum of engagement allows room for discussion as to whether Government collaborators have or currently engage Universities and Industry at scales that optimize the value they introduce to these partnerships.

CHAPTER 2

LITERATURE REVIEW

Introduction

The review that follows discusses literature related to tacit and explicit knowledge and knowledge transfer, proximity studies, national innovation systems, regional innovation systems, federal laboratories and University-Industry-Government collaboration. Of these sections, contributions made by the proximity and University-Industry-Government literature are emphasized (a section discussing theoretical implications for the same appears in the final chapter of this document). The analysis that follows seeks to forge a link not yet established by this research. While previous scholarship (e.g. Frenken et al., 2010) has systematically analyzed the proximate dynamics of different UIG collaborative arrangements, room exists to build on this work by quantifying proximity induced value that individual UIG actors introduce to research outputs. In particular, measuring the impact Government collaborators wield in terms of their ability to influence research value via the scale they engage Universities and Industries at is a key objective and contribution of the present undertaking. Before elaborating on this issue, however, a review of the literature germane to this question is in order.

Systems of Innovation

Employing a definition similar to that enunciated by Sylvan Katz (2006) this study views an innovation system as a set of institutions (and individuals) that interact to produce knowledge. More specifically, the present inquiry is interested in identifying how the interaction of federal actors with Universities and Industry influences innovative outcomes for advanced technologies. This interaction occurs at national, regional and local levels. Reviewing the characteristics of innovation systems at each scale is useful for better understanding how the level at which Government collaborators engage with University and Industry adds value to these partnerships.

Broadly construed, the national innovation system (NIS) "includes all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring - the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place" (Lundvall, 1992). Of more specific interest for the purposes of this study are institutions that interact to produce knowledge within a given innovation system. It is noted that this interaction occurs at national, regional and local levels. While all of these contribute to the following analyses it is anticipated that the latter two systems will be more efficient and effective in the knowledge production process. A number of studies on NIS are comparative in the respect that they seek to measure differences in innovation systems among and between nation states (e.g. Nelson, 1993; Chudnovsky et al., 2000; Owen-Smith, et al., 2002). Other studies posit that, irrespective of the nation-state under consideration, the proactive and coordinated participation of governmental, academic and corporate actors is an essential condition for a NIS to be competitive in the knowledge-based economy (e.g. Etzkowitz and Leydesdorff, 1997). This study sets its focus on innovation systems in the United States in particular and posits that, ceteris paribus, UIG collaboration within local and regional systems is more likely to generate research of high impact than UIG collaboration at the national level.

It is noted at the outset that not everyone agrees that the involvement of Government actors in UI partnerships will automatically add value to NIS (or other innovation systems). Previous research has questioned the purported benefit of additional institutional involvement on innovative performance. Prior studies (e.g. Alston et al., 1996; Borrás, 2004) posit that the inclusion of auxiliary institutions in a given collaboration may actually undermine innovative performance and that prudence dictates assessment of the role a given institution plays in terms of its ability to make positive contribution to the performance of the system it is part of. While it is anticipated that federal entities will, on average, add value to the UI partnerships they are involved in, it is also anticipated that the involvement of Government collaborators at the national scale will not be as likely to generate high impact research as similar engagements at regional and local levels (i.e. the latter are more likely, it will be argued, to optimize the value of research outputs than the former).

Regional Innovation Systems (RIS) constitute a subcomponent of NIS. While they are influenced by NIS they generally have enough freedom of movement to be considered autonomous (Atalik and Fischer, 2002). A number of efforts (e.g. Amin, and Robins, 1990; Cooke et al., 1997; Cooke, 2001) have been made to outline the boundaries of an RIS. For purposes of the present analysis a RIS and its knowledge production assets (i.e. institutions and individuals) are geographically localized and marked by frequency of interaction (i.e. institutions within a given region will generally interact more with each other than they will with institutions external to the region).

Geographic proximity and frequency of interaction, it is argued, will significantly influence the production of high impact research within the RIS. AnnaLee Saxenian points to Silicon Valley as an example of the salutary effects regional culture and cooperation can have on innovation (Saxenian, 1996). It is posited that RIS will enjoy a relative advantage over NIS in terms of interactive learning and tacit knowledge transfer that stems from, not only regional culture, but also proximate interaction among its knowledge production assets. Accordingly, a bottom-up approach is advocated for purposes of identifying an ideal scale of interaction (i.e. a movement from most to least proximate collaborative arrangements is promoted for efforts to identify citation optimizing scales of interaction). It is argued that the prominence of the roles that actors play in a given innovation system is a function of the size of the system itself. In the present analysis, Government collaborators play a leading role, and it is this role we now consider.

Federal Laboratories

Federal laboratories play a central role in this study. Measuring the value they (along with other Governmental collaborators) add to UI research is key objective of the present undertaking. Understanding their history and (evolving) mission in the NIS is beneficial for purposes of this inquiry. According to Philip Metz (1988), "the national laboratory system began [in the mid 20th century] with very narrow missions related to nuclear energy: nuclear weapons development, operation of reactors and particle accelerators, nuclear-related sciences, and so on." Since that time federal labs activities have significantly expanded. The role that federal labs *should* play in the US NIS is a matter of some debate. Before touching on this, however, we first consider a brief history of federal lab activities in the US.

After their initial debut on national scene, federal labs slowly began to expand their non-nuclear capabilities. By the late 1960s the nuclear power industry became a "commercial reality", and with no new (non-nuclear) mission in clear sight "lab staff and funding levels began to dwindle. This trend was not reversed until after the 'energy crisis' of 1973 totally reordered government energy R&D priorities, providing a new raison d'etre for the labs" (Metz, 1988). It is worth noting that crises can often serve to significantly influence the nature, focus and scope of governmental R&D. In the 1980s the focus of federal lab research changed again when the US government shifted attention back toward research that was more long-range and high risk and involved weapons (Metz, 1988). Since that time federal labs have assumed a number of additional responsibilities, such that a significant discussion has developed concerning when and how they ought become involved in the private sector. The following paragraphs provide highlights from this discussion.

The role that federal labs should play in the US NIS is a matter of ongoing debate. In his essay, "Federal labs and industry come together", Steven Ashley provides outlines a number of key points in the debate over how involved Government laboratories should be in the private sector. Ashley mentions micromanagement, red tape[6] and other impediments as issues that undermine joint research arrangements (Ashley, 1996). He also highlights the problems associated with being fair to all collaborators (in terms of achieving a win-win outcome), and acknowledges that when Government actors choose to collaborate with a given company, they do so at the expense of its competitors. Free-market and equity considerations give rise to an assessment of the value of these

[6] Those who participated in the interviews conducted in this study cite similar impediments (see Theme #5 in the Interviews chapter).

interventions in the private sector. Identifying conditions or scales under which the involvement of Government actors is relatively more justified can contribute to a resolution of (or at least progress in) these debates.

In a related article, Darmody and Bendis (2012) observe that the government spends $30 billion annually on internal R&D at federal laboratories and employ tens of thousands of scientists at the same. Like Ashley, these authors mention red tape and other inefficiencies such as: (i) long negotiation times for technology licensing, (ii) a misunderstanding of how markets work and (iii) conflict of interest rules preventing federal researchers from interacting with private sector business representatives. In summary, Darmody and Bendis argue that "the technology commercialization effort is not business-like, but government-like" (2012). For this reason, they call for the establishment of a congressionally chartered federal lab authority staffed by experts with private sector experience. In their estimation, this entity could be used by existing federal labs and their offices of technology transfer "to legally assign government-produced technologies, federal researcher's time, or access to equipment, making these resources available to the private and non-profit sectors" (Darmody and Bendis, 2012). The establishment of a federal lab authority would, in their view, make public-private partnerships more efficient and less costly. In terms of the present analysis, the establishment of such an authority could be useful for guiding UIG collaborations towards scales of interaction that optimize the value of the work they produce.

It's worth noting that federal laboratories have not only expanded their capabilities, they've also expanded their numbers. A leading text for the study of federal labs in the US is provided by Michael Crow and Barry Bozeman. In their book, *Limited* *by Design*, Crow and Bozeman draw on 14 years of experience profiling labs to provide an extensive analysis of the more than 16,000 R&D labs in the US (1998). While an exact number is unknown, Crow and Bozeman deconstruct America's national lab system as follows: "There are approximately 700 federal labs directly funded by the U.S. government…Hundreds of university labs produce everything from new Ph.D.'s in chemistry to new synthetic proteins to new rat poisons. To this mix one must add nearly 14,000 industrial laboratories" (Crow and Bozeman, 1998). According to their best estimate between 16,000 to 17,000 R&D labs exist in the US, "defining an R&D laboratory as focusing on science or engineering and employing at least 25 personnel" (Crow and Bozeman, 1998). These authors cover the histories, objectives and evolution of these labs, and provide a framework for analyzing their locations and performance. While the work of Crow and Bozeman doesn't focus on the spatial dynamics of public-private partnerships, it does contribute to the present analysis in that it highlights the large number of labs in this country, which implies that Universities and Industry have some degree of choice in decisions related to federal collaborator involvement (i.e. the decision about who to partner with does not have to be spatially constrained or predetermined for each and every UIG collaboration).

As federal laboratories capabilities and numbers have increased, so have the amount of inventions they've produced. When other parties (e.g. Universities and Industry) collaborate with federal labs, who owns the resulting invention(s)? Prior to the Bayh–Dole Act (or Patent and Trademark Law Amendments Act), ownership of inventions stemming from federally funded research went to the federal government. The Bayh–Dole Act, which was a response to the economic stagnation of the 1970s, allowed universities and small businesses to pursue ownership of an invention whose research was federally funded. This act encouraged universities and small businesses to increase their technology transfer with the federal government.

Other acts would also serve to encourage technology transfer. The Technology Innovation Act of 1980 (also known as the Stevenson-Wydler Act) was designed to augment cooperation and technology transfer between University, Industry and Government actors. This law required federal laboratories to engage in technology transfer with Universities and Industry and allocate part of their budget for the same. It implemented an Office of Research and Technology Applications (ORTAs) at major federal labs, which served to assist in technology transfer. The Federal Technology Transfer Act of 1986 would later amend the Stevenson-Wydler Act by authorizing Cooperative Research and Development Agreements (CRADAs) between federal labs and private firms. This act made technology transfer the responsibility of each scientist and engineer employed by a federal laboratory and required that technology transfer activities be made part of employee evaluations. Research (e.g. Adams et al., 2003) has shown that CRADAs have been highly successful. While the above legislation focuses on technology transfer from federal to non-federal entities, the current study calls for greater technology transfer between federal labs themselves. As will be elaborated on in the Discussion chapter, if federal laboratories engage in the transfer of technology and equipment to the point where each has comparable or near comparable capabilities, it is expected that Universities and Industry will partner more with federal entities at more ideal scales of proximate interaction.

We note from the above that technology transfer has become a key mission of federal labs. While patents provide a standard measure for this activity, it is a mistake to underestimate or ignore the role that publications also play in this process. Given that a strong and increasing linkage between basic science and the development of technology in the US can be made (Narin et al., 1997), this study argues that publication activity should be included in an understanding of the technology transfer process as well. It is also argued that the literature heretofore has not paid sufficient attention to the publication measure and seeks to call greater attention to it.

From the above it is noted that technology transfer and the role of federal labs have significantly increased over time. How much increase is desirable? As will become more apparent in the chapters which follow, it is argued that the role federal laboratories play in the NIS should be guided by ideal scales of engagement (i.e. those that optimize research value) with academic and corporate partners (when they are involved). A policy conducive to ideal scales of engagement is expected to produce research outputs of higher quality, facilitate the transfer of superior technologies and augment the benefit to all those with a stake in the results. It is also argued that an increase in technology transfer between federal labs themselves is desirable to the extent that it endows them with comparable capabilities, which is expected to facilitate interaction (between UIG partners) at more ideal scales of engagement.

Tacit v. Explicit Knowledge Production

As mentioned previously, co-location is critical for the transfer of tacit knowledge (see Autant-Bernard et al., 2007, and Howells, 2002), and the transfer of tacit knowledge, it is argued, is critical for the production of innovative research of high impact. A failure to craft policies conducive to tacit knowledge transfer is a serious misstep in today's economy. Previous scholarship (e.g. Lundvall and Johnson, 1994; Lundvall and Nielson, 2007) has shown that tacit knowledge is a critical for the success and survival of a learning economy (i.e. deprived of this knowledge form a learning region's competitive position would quickly deteriorate). The key point made about tacit knowledge in this analysis is that research collaborations significantly benefit from this form of knowledge, and this knowledge form is spatially mediated. Before elaborating on these issues, however, a more precise definition of the tacit knowledge concept is in order.

Michael Polanyi (1962, 1966a, 1966b) divides knowledge into two fundamental categories: (i) explicit and (ii) tacit. While the former can be transcribed, codified and formalized, the latter cannot. The transfer of tacit knowledge depends critically on personal interaction and learning by doing. Howells (2002) elaborates on this distinction in the following way:

> Explicit or codified knowledge involves know-how that is transmittable in formal, systematic language and does not require direct experience of the knowledge that is being acquired and it can be transferred in such formats as a blueprint or operating manual. By contrast, tacit knowledge cannot be communicated in any direct or codified way. Tacit knowledge concerns direct experience that is not codifiable via artefacts. Thus, it represents disembodied know-how that is acquired via the informal take-up of learned behaviour and procedures. Indeed, some tacit knowing is associated with learning without awareness—a process termed as 'subception' by Polanyi (1966). Tacit knowledge can also be associated with scientific intuition (see, for example, Ziman, 1978, p. 103) and the development of craft knowledge within scientific disciplines (Delamont and Atkinson, 2001).

For purposes of the present inquiry the key point in the above discussion is that tacit knowledge does not travel well across space or via codified mediums—its transmission depends critically on proximate interaction.[7] Ergo, proximity between individuals and organizations is expected to increase the likelihood of their interacting, networking and

[7] Kevin Morgan (2004), among others, also asserts this.

establishing norms based on best practices. Research quality, it is argued, is significantly and positively influenced by geographical proximity.[8]

Michael Polanyi's knowledge dichotomy is nontrivial for today's global marketplace. While Polanyi is a renowned philosopher, his concept of tacit knowledge is not simply an abstract philosophical theory. It is increasingly recognized that tacit knowledge plays a highly useful role in the performance of economies and firms (see Howells, 1996). A number of researchers have acknowledged that tacit knowledge "forms the foundation for building sustainable competitive advantage" (Cavusgil et al., 2003). The work of Cavusgil and colleagues finds that the transfer of this knowledge "makes a significant contribution for firms to develop greater innovation capability", and "[f]irms with greater collaborative experience can benefit more from…tacit knowledge transfer" (Cavusgil et al., 2003). Ikujiro Nonaka (1994) posits that "organizational knowledge is created through a continuous dialogue between tacit and explicit knowledge". As tacit knowledge has assumed an increasingly important role for the performance of Industry actors, Howells (1996) argues that "firms need to accept and incorporate it more into their learning regime so as to enhance and maintain their competitive advantage".

The degree of tacitness contained within a given body of knowledge is not uniform but will vary, and the less amenable to codification tacit know-how is, the more difficult it will be for individuals and organizations to absorb, especially over distance (see Howells, 1996, 2008). Cavusgil and colleagues (2003) reaffirm this principle when they posit that the existence of absolute tacit or explicit knowledge is a rarity. The implications for the present inquiry are that, within a given institution or region, tacit and

[8] See Katz (1994) for further discussion.

explicit knowledge forms are often difficult to distinguish and often times intimately connected in a way not readily apparently but important to the way an institution or region evolves and competes. It has been observed (Johnson et al., 2002) that attempting to disentangle and isolate the two knowledge forms can be problematic. In addition, interaction between these two forms of knowledge is imperative for the creation of new knowledge (see Lam, 2000), which is a critical activity in today's economy. For these and similar reasons both forms of knowledge should be taken into account in the knowledge economy innovation process.

Based on the preceding it is emphasized that tacit knowledge is of critical importance to the production of high impact research, innovation and economic competitiveness, and the transfer of more tacit knowledge forms is accomplished most efficiently via proximate interaction. Given that the natural human tendency is to quantify, and the process of codification lies at the heart of scientific progress (Johnson et al., 2002), tacit knowledge can seem a nebulous and fuzzy concept. The old adage: stick-to-what-you're-familiar-with harkens to mind in situations where the unknown is uncodifiable. The fact remains, however, that tacit knowledge plays a significant role in collaborative outcomes in a learning economy, and this role is spatially mediated. Ignoring or forcing the influence of tacit know-how into an error-term doesn't do justice to a form of knowledge that meaningfully influences the evolution and competitive position of firms and regions. Identifying scales of interaction that more efficiently facilitate the transfer of this knowledge form is a key objective of the present undertaking.

University-Industry-Government Collaboration

UIG collaboration represents a unique partnership with special capabilities. This form of knowledge production has assumed an increasingly important role in a number of S&T capacities (see Miao et al., 2002). Henry Etzkowitz and Loet Leydesdorff suggest that academic, corporate and governmental entities are increasingly interdependent and cannot be completely understood in isolation (1996, 1998, 2000). They argue that a knowledge infrastructure arises in spaces where these three spheres intersect. In their analysis, the co-location of these entities is an essential condition for the development of successful industrial clusters in today's economy. In a similar vein, Frenken and colleagues (2005) posit that:

> [o]ne of the factors explaining the importance of geographically localised networks of knowledge production is said to be the institutional hybridisation of knowledge production. Since collaborations in university–industry–government networks are only partially formalised in contractual arrangements, these are to be supplemented by frequent face-to-face, informal contacts, and the exchange of personnel. The formation and stability of these networks is to an important extent facilitated by geographical proximity…

In other words, it is argued that UIG knowledge production reinforces the importance of spatial proximity.

The present inquiry is interested in assessing whether the involvement of Government actors in UI research collaborations adds value (in terms of citation impact). Previous research has addressed the question of whether a larger number of organizations contributing to a paper increases its citation impact (Frenken et al., 2005). In particular, Koen Frenken, Werner Holzl and Friso de Vor (2005) test the hypothesis that the benefits of inter-organizational collaboration are higher than the benefits of intra-organizational collaboration, and find that number of organizations contributes "positively and significantly to the number of citations a paper receive[s]". The same authors hypothesize that academic-only collaborations are more likely, on average, to produce basic research (which has a large variety of potential application), whereas collaborations involving Industry and/or Government actors are more likely, on average to produce research that is more applied in nature. Accordingly, they test the hypothesis that collaboration within academia will increase a paper's citation impact relatively more than collaboration involving non-academic organizations, and find that this hypothesis cannot be accepted (i.e. the inclusion of non-academic organizations added citation value) (Frenken et al., 2005). It is likewise hypothesized by the present inquiry that the inclusion of federal researchers (in UI partnerships) will add citation value, and that this value will be spatially mediated.

Of interest to this inquiry as well is why UIG partnerships occur to begin with. Motivations for this collaboration type are expected to vary across time and domain. This study sets its focus on nanotechnology in particular (for the years 1990 to 2011) and seeks to highlight factors leading to the formation of UIG collaborations in this research area.

An initial motivation for UIG collaboration involves nanotechnology's interdisciplinary character, which can act to promote inter-institutional collaboration. Gaston Heimeriks (2013) describes how interdisciplinary research attracts collaborators of diverse backgrounds:

> Efforts to understand the emerging knowledge economy have paid particular attention to the shifting boundary between academic and commercial research, especially in the life sciences. Empirical studies suggest that interaction between university and commercial science has increased, blurring the boundary between them and generating a new knowledge regime (Van Rijnsoever and Hessels 2011; Heimeriks et al. 2008). Consequently, at this level, interdisciplinartiy relates to the intensity of knowledge use in society and the importance and variety of non-academic collaborators.

Heimeriks notes that UIG collaborations for nanotechnology have increased dramatically since 2003 and observes that this is concurrent with an increase in funding priority during this time.

Funding considerations provide another reason why University, Industry and Government actors collaborate. From its inception nanotechnology research has required the use of expensive equipment. Nicolas Battard (2012) emphasizes the role costs play in this domain:

> …to perform research at the nanoscale, specific equipments such as atomic force microscopes, scanning electron microscopes, etc. are necessary. Although this type of equipment is available on the market and thus available to all laboratories, they remain expensive. So, laboratories have to resort to external funding in order to buy nano-related equipments.

Government (and other) actors are often sought out to participate in UIG collaborations for this reason—i.e. to provide the requisite funding and/or access to expensive equipment.

Another motivation for UIG collaboration within the nano domain involves public opinion formation. In his article "A Hyperlink and Semantic Network Analysis of the Triple Helix (University-Government-Industry): The Interorganizational Communication Structure of Nanotechnology" Jang Kim (2012) uses “the triple helix model to understand the structure and influence of interorganizational communication of the three helices” and finds that “the university, government, and industry sectors are becoming increasingly interdependent and flexible through communication and that such a process has promoted nanotechnology development”. Hence, we make room for the possibility that nanotechnology can be more effectively marketed with the backing of University, Industry and Government actors, and that this can result in enhanced collaboration between the same.

The interviews conducted in this study (which appear in Appendix G) shed additional light on various motivations for UIG partnerships. Interview questions 3 and 4 prompt respondents (who all participated in UIG partnerships) to share their thoughts on what motivated their UIG collaboration to come about. Motivations for collaboration surfaced in responses to other questions as well. Respondents cited the following factors as prompting their UIG partnership to take place: unique capabilities provided by their collaborators, the need for funding, networking, relationship maintenance, publication quality and collaborator expertise. Comparative advantages and specializations among UIG actors can also play a role in promoting collaboration. Interview #12 responds to question six by noting: "[c]ollaborators make up for deficits among the other collaborators. Each person brings something to the table that the rest of the group needs."

In addition to the preceding, it is posited that UIG collaborations are motivated by knowledge creation and sharing (Lu and Etzkowitz, 2008), resource access (Ruuska and Teigland, 2009; Teigland and Lindqvist, 2007, as cited in Ruuska and Teigland, 2009), goodwill (Ruuska and Teigland, 2009; Teigland and Lindqvist, 2007, as cited in Ruuska and Teigland, 2009), reputation (Ruuska and Teigland, 2009; Teigland and Lindqvist, 2007, as cited in Ruuska and Teigland, 2009) and legitimacy (Ruuska and Teigland, 2009; Teigland and Lindqvist, 2007, as cited in Ruuska and Teigland, 2009). A number of these are expected to positively interact or be mutually reinforcing—e.g. obtaining access to resources of one type (e.g. advanced equipment) is expected to be positively correlated with obtaining access to resources of other types (e.g. human resources or expertise). While the preceding factors are probably not exhaustive, they are offered as representative of the major rationales for the collaboration type analyzed in this study. It is noted as well that this study focuses on scholarship for nanotechnology and the values associated with UIG collaboration for co-authored publications. Co-authored UIG scholarship can be taken as a general proxy for knowledge sharing, networking activity, legitimacy and reputation building. They do not, however, represent all collaboration benefits (e.g. informal knowledge flows).

The Role of Proximity

The impact of proximity (be it geographic, organizational, institutional, etc.) on collaboration and knowledge production has been emphasized by a number of scholars (e.g. Amin and Wilkinson, 1999; Katz, 1994; Ponds et al., 2007). Traditional thinking holds that innovation is facilitated via proximate interaction (Katz, 1994 provides a leading work on this). The work of Audretsch and Feldman finds that innovative activity is more likely to occur within close geographic proximity to the knowledge source it is based on, and that knowledge spillovers tend to be geographically localized (1996). In the more traditional line of thinking (which will later be contested), more proximity is almost always a good thing.

Co-location provides a number of benefits. Benefits manifest in terms of "cost advantages in search costs for partners and new personnel, sharing of infrastructure, and the availability of supporting services. Furthermore, the cost of collaboration is lower as travel costs increase with physical distance" (Frenken et al., 2009). Proximate interaction is also said to facilitate the transfer of tacit knowledge (see Autant-Bernard et al., 2007; Howells, 2002). Moreover, it is argued that coordination problems (i.e. lack of standardization) are best resolved within the dimensions of proximity (Boschma, 2005).

In addition, proximate interaction normally involves shared language and culture, which facilitates interactive learning (see Frenken et al., 2010).

The role of proximity on collaboration in science-based industry, like nanotechnology, has been addressed by previous scholarship. Scott Cunningham and Claudia Werker, for example, consider the influence of proximity on collaboration for nanotechnology in Europe. In their study, "Proximity and Collaboration in European Nanotechnology", they find that geographic proximity "influences collaboration intensity in two ways: first, collaborations benefit from geographical closeness in terms of pure physical distance. And second, collaborations benefit from geographical proximity in functional terms, that is, belonging to the same unit of administration such as NUTS regions" (Cunningham and Werker, 2012). The present study is also interested in looking at proximity on a regional level, but within the context of UIG relations. We note that collaboration involving at least three affiliation types provides an additive dimension of proximate engagement.

The relative importance of proximate interaction can depend on the types of institutions involved in a given collaboration. In their paper, "The geographical and institutional proximity of research collaboration" Roderik Ponds, Frank van Oort and Koen Frenken (2007) find that distance, manifested in terms of travel time, decreases collaboration frequency, but more so for UIG collaborations than for university-university collaborations given that institutional proximity is lacking in the former arrangement. They conclude that "geographical proximity is more relevant for collaboration between academic and non-academic organisations than for purely academic collaboration. This suggests that geographical proximity is indeed a way of overcoming the institutional differences between organisations, which is necessary for successful collaboration" (Ponds et al., 2007). These authors posit that the regional scale is not the ideal scale for all collaboration types and that the role of geographic proximity assumes a greater importance when institutional differences exist[9].

In "The citation impact of research collaboration in science-based industries: a spatial-institutional analysis", these same authors proceed to analyze the citation impact of research collaboration in eight science-based industries: (1) Information technology, (2) Optics, (3) Semiconductors, (4) Telecommunications, (5) Agriculture & food chemistry, (6) Biotechnology, (7) Organic fine chemistry and (8) Analysis, measurement & control technology. They classify industries (1) thru (4) as belonging to the Physical sciences, (5) thru (7) as belonging to the Life sciences and do not classify industry (8). Their geographic units of analysis cover three scales: (1) regional (which they define as publications involving at least two collaborating organizations located in the same NUTS 3 region), (2) national (which they define as publications involving at least two organizations located in the Netherlands) and (3) international (which they define as collaboration between at least one Dutch and one foreign affiliation). Out of the eight science-based industries they analyze, these authors find that UIG collaboration benefits from organization at the regional scale only in the cases of Biotechnology and Organic fine chemistry. Given that collaborations in physical sciences had no additional citation impact, they conclude that "the specific importance of regional University-Industry-Government collaboration may be limited to life sciences only" (Frenken et al., 2010).

[9] As will be later discussed, the present study concurs that proximity assumes a more prominent role when institutional differences exist, but finds that proximity's impact can assume a relatively more important role for some institutional differences (i.e. Government collaborators and Industry) than for others (i.e. Government collaborators and Universities). See the discussion related to Tables 7A and 7B for a more thorough treatment of this.

Frenken and colleagues conclude with a warning to policymakers not to overemphasize regional collaboration given that collaboration at larger scales may be more beneficial, at least for certain domains (e.g. those affiliated with the Physical sciences) (2010). The results of this study indicate that more proximity is desirable only in certain technological contexts.

Frenken and colleagues are not the only scholars who argue that more proximity is desirable only in certain circumstances. In his article, "Proximity and Innovation: A Critical Assessment", Ron Boschma (2005) takes a critical view of the role of proximity in the innovation process. While traditional thinking equates more proximity with more learning and innovation, Boschma argues that more proximity (beyond a certain point) can actually have a negative impact on innovation and seeks to demarcate between the positive and negative aspects of proximity. Boschma classifies proximity into five dimensions: cognitive, organizational, social, institutional and geographical, and highlights the adverse consequences associated with too much or too little proximity in each dimension. Boschma's classification scheme can be contrasted with the French School of Proximity Dynamics, which distinguishes between geographic and organizational proximity, and occasionally adds the third dimension of institutional proximity (Boschma, 2005). Boschma calls on future research to identify the ways in which various dimensions of proximity are related and concludes that:

> On the one hand, one might expect that too much proximity (in the meaning of inertia and lock-in) is harmful when a radical innovation requires completely new knowledge and skills, new organizational arrangements, and new institutions. On the other hand, problems of coordination (e.g. due to a lack of standardization) must be solved by the various dimensions of proximity.

Boschma offers a conclusion similar to that proffered by Frenken et al. (2010) in the respect that he argues that more proximity does not always result in better performance.

He also suggests that the negative aspects of proximity (e.g. inertia and lock-in) may not immediately manifest, but develop over time (2005). The work of Boschma (2005) lends credence to the notion that more-proximity-is-better holds true up to a point, and the work of Frenken et al. (2010) lends credence to the notion that the location of that point is different for different technological domains.

Controversies in the Literature

It is noted that the major bodies of literature referenced in this study are not without controversy. A number of scholars have questioned the theoretical underpinnings that guide much of the current undertaking. While this inquiry touches on a number of subject areas, the three which form the cornerstone for the present analysis are: (1) Proximity Studies, (2) UIG Relations and (3) Research Valuation (via citation impact). Controversies involving these areas are discussed below.

Debate exists within the literature on proximity as to whether its effect is as pronounced as has been traditionally thought[10] and whether its effect is diminishing over time. Advances in information and telecommunication technologies have led some to declare victory over the 'tyranny of distance' (Castells, 1996; Cairncross, 1997, as cited in Hoekman et al., 2010). In this line of thinking, technological advances, over time, are expected to mitigate the effect distance has on collaboration. In her book, "The Death of Distance: How the Communications Revolution will Change Our Lives", Frances Cairncross (1997) "starts from the assumption that technology, driving economics, has the power to change the social and physical world". She expresses particular interest in how communications technology will revolutionize the world we live in and writes: "[o]ne thing…is certain. The death of distance and the communications revolution will be

[10] Traditional thinking on proximity is associated with Katz (1994).

among the most important forces shaping economics and society in the next fifty years or so." In her estimation, "[w]ireless-the other communications revolution – is simultaneously killing location, putting the world in our pockets." In this line of thinking the advent of communications technologies is expected to (eventually) diminish and/or negate the effect of distance.

In their article, "Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe" Hoekman and colleagues (2010) test the hypothesis that distance "impedes research collaboration in Europe yet its effect is decreasing over time". They write:

> In the event that travelling and communication at a distance would not require time and resources…research partners would be matched based on a 'fit' between their research questions, irrespective of their geographical location. In the most extreme case we would observe a completely random spatial pattern of research collaboration that is solely guided by differences in the amount and focus of research inputs. In this study, such a system would be regarded a perfectly integrated system.

Results indicate that distance does, in fact, impede research collaboration, but these authors do not find evidence that its effect is decreasing over time, at least not for the years analyzed in their study (2000 – 2007). In discussing the advantages of face-to-face interaction over technology-facilitated collaboration at distance Hoekman et al. (2010) write the following:

> …as with all human activities, physical co-presence remains important in carrying out the complex tasks associated with scientific research (Collins, 2001). Face-to-face interaction offers the possibility of having intense and complex forms of interaction in which not only language is involved but the entire behavioural complex. Contrary to modern communication media (e.g. e-mail, video conferencing) this enables the unique establishment of common reference frames through amongst others rapid feedback, pointing and referring to objects in real space, subtle communication, informal interaction and a shared local context (Olsen and Olsen, 2000). All these factors facilitate the creation of a common language, shared meaning within a research team and the passing on of knowledge that cannot easily be expressed in words or visualizations (Collins, 2001; Urry, 2002).

Hoekman and colleagues (2010) also note that spatially dispersed collaboration "more often experience conflict, free-riding, lack of monitoring and diverging interests (Hinds and Bailey, 2003)". In addition to considering the effect of distance over time, Hoekman et al. (2010) consider the effect regional, national and linguistic borders have on research collaboration and find that borders impede research collaboration, but their effect is declining over time. In conclusion, Hoekman and colleagues find that research collaboration significantly benefits from physical proximity as well as regional, national and linguistic commonalities. While the influence of the latter was shown to diminish over time, the influence of the former was not.

Hoekman and colleagues (2010) cite advances in information and telecommunication technologies as potential alleviators of the effect distance has on collaboration. In a similar study, Frenken and colleagues (2005) cite "the widespread use of the Internet, the emergence of English as standard language in most disciplines, and the rapid fall in the costs of long-distance travel" as potential alleviators of the effect distance has on collaboration. As was the case with Hoekman et al., however, Frenken and colleagues do not conclude that these variables negate the effect of proximity. They write:

> These processes…should not be taken to imply that one should speak of 'the death of distance' in science, and that location would no longer matter in scientific knowledge production…Research at the subnational level suggests that geographical proximity affects the probability of collaboration. Katz's (1994) study on collaboration in the UK showed that scientific collaboration decreases exponentially with the distance separating partners. A study by Liang and Zhu (2002) on China also found that geographical proximity is one of the important factors determining the pattern of inter-regional collaboration…In all, geographical proximity thus provides a good predictor for the frequency of collaboration between research institutes.

While a number of developments (e.g. advances in information and telecommunication technologies, the growth of the Internet, the use of English in most disciplines, decline in the cost of long-distance travel) have been thought to potentially undermine or eradicate the effect of proximity on research collaboration, previously mentioned studies (e.g. Liang and Zhu, 2002 as cited in Frenken et al., 2005; Frenken et al., 2005; Hoekman et al., 2010) find that this is not the case. Moreover, Kevin Morgan (2004) responds to claims that globalization and digitalization signal the "death of geography" by arguing that certain forms of knowledge exchange depend critically on proximity and charting the growth of territorial innovation systems over time.

In addition to controversy within the literature on proximity, the literature on UIG can be characterized as an area of ongoing debate as well. While UIG collaboration is argued to be an important form of organization for high impact research, its more common name (i.e. the Triple Helix) is not without detractors. In his article, "The Triple Helix and New Production of Knowledge: Prepackaged Thinking on Science and Technology", Terry Shinn (2002) argues that the (citation) impact of the Triple Helix on the Social Science Citation Index or the Internet is not large for the period 1995 to 2000. In addition, Juha Tuunainen (2002) argues that the Triple Helix model:

> …may run the risk of glossing over some vital conceptual insights. The first instance where more focused attention should be given is the analytic distinction between theoretical, methodological and applied dimensions of a local research program. By appreciating it, a central source of dynamic that formed the ground for the commercialization of the group's research results is preserved. The second deficiency is that neither the Mode 2 nor the Triple Helix pays close enough attention to the problems and contradictions that come into the world as university research results are commercialized.

Moreover, some scholars have suggested that the name Triple Helix may be a misnomer given that other actors (i.e. the media- and culture-based public) can and/or should be thought of as a fourth helix (Carayannis and Campbell, 2009). Other scholars have advocated including a fourth helix that involves civic and community engagement (Chatterton and Goddard, 2000). Given the controversy surrounding this model, the designation ‘University-Industry-Government relations’ is used in lieu of ‘Triple Helix’. Despite the above and related controversies, however, the present study maintains the position that this mode of knowledge production retains very significant value for the production of high impact research, especially for emerging technologies like nanotechnology (see Schultz, 2011 for a more thorough treatment of this).

The use of citation impact as a proxy for research value is also seen as controversial by a number of scholars. Gingras and Wallace (2010) observe that well known authors (e.g. Nobel laureates) tend to receive higher citations than would have been the case had they not come into the academic spotlight. Otherwise known as the “Halo Effect”, the fact that Nobel Prize winners tend to attract more citations after their receipt of this award than they did prior to their rise to stardom—or than they would have without receiving the award—can be taken as evidence that the citation rate is less than a perfect proxy for research quality (i.e. evidence of a citation bias towards popular authors exists). Not only do citations tend to gravitate toward popular authors, they also tend to gravitate towards popular subject areas. Carley and Porter (2012) demonstrate that citations are not uniformly distributed across all subject areas, but certain disciplines naturally receive more citations than others. Furthermore, Carley et al. (2013) argue that the practice of self-citation can bias citation results. Despite these and similar shortcomings the use of citation impact is still advanced as a valid measure of research quality. It is argued that no measure of research value is perfect, but certain measures qualify as satisfactory for certain purposes. It is also argued that of all available measures of quality, citation intensity lends itself well to large-N analysis and many of its shortcomings (e.g. the Halo Effect and different citation rates across disciplines) can be controlled for in regression models and other quantitative analyses.

Shortcomings in the Literature

The previously cited research lays an indispensible foundation for the analyses that follow. The author is truly indebted to the above scholars for providing the guidance and direction they do. Indeed, there is room to question whether the current line of research would have even been pursued without benefit of the groundwork already laid. As helpful as the preceding has been, the current state of the literature related to this study is nonetheless described as incomplete. The remainder of this chapter highlights shortcomings in the literature, as well as proposed remedies.

Generally speaking, the literature on proximity stands to benefit from devoting more attention to UIG interaction, as this unique form of knowledge production has proved highly effective for the development of advanced technologies (Schultz, 2011). It is argued that UIG proximity dynamics differ in nontrivial ways from non-UIG proximity dynamics, which make more traditional proximity theories less than completely relevant to the specifics of UIG interaction. Flushing out the specific features related to this mode of interaction will serve to better cater to, and inform, policies that govern UIG proximity dynamics and resultant knowledge outcomes. It is the position of this study that the current body is literature related to UIG proximity dynamics cannot to be termed large or fully developed and future research is encouraged to devote more attention to this area. Specific examples of how this can be remedied follow.

Previous scholarship on UIG proximity dynamics focuses on the total scale of interaction between UIG actors (as opposed to the impact of individual actors on knowledge outcomes). For example, in their 2010 study Frenken and colleagues examine

UIG proximity dynamics for eight science-based industries in Europe using three scales of interaction: regional, national and international. They designate the regional scale as a publication involving any two collaborating institutions co-located in the same NUTS 3 region and the national scale as a publication involving at any two institutions co-located in the Netherlands. While the author found their analysis to be both insightful and an important contribution to the literature (and one which lays critical groundwork for the current undertaking), he also argues there is room for more specificity and/or precision. For example, three scales of interaction is not seen as a large number—additional and more specific scales are available. Furthermore, instead of analyzing the co-location of any two UIG actors (within a given region) analyzing the position of specific (University, Industry or Government) actors within the UIG framework is expected to more fully inform both the literature and policy. By holding the distance between two given UIG institutions (e.g. University and Industry) constant, and letting the position of the third actor (e.g. Government) vary (across a large N of cases), more precise results—at the individual actor level—can be obtained. Such an approach is useful for identifying the responsiveness of citation impact to movements by individual UIG actors. For example: is citation impact more responsive when Government collaborators move from scale A to scale B (holding the position of University and Industry actors constant), or is it more responsive when Industry collaborators move from scale A to scale B (holding the position of University and Government actors constant)? An approach that focuses on the position a specific UIG actor allows us to address these and similar questions.

Continuing with the argument that more attention to the specifics of UIG interaction is in order, it is posited that the attention given thus far to proximity's influence on institutional differences (within the UIG framework) is not fully developed. Ponds et al. (2007) note, for example, that the role of proximity assumes a relatively greater role when institutional differences exist. Within the UIG framework, however, multiple institutional differences exist (e.g. University-Government, University-Industry, Industry-Government). It is important for policy purposes to determine, for instance, whether proximity's influence is the same when Government actors are close to Universities as when Government actors are close to Industry (e.g. if a Government actor can narrow the proximity gap between one institution or the other, but not both, which institution would be preferable to draw near to?). A more thorough and systematic examination of proximity's influence across the spectrum of all possible institutional differences (within the UIG framework) would serve benefit both the literature and policy.

It is argued as well that the literature heretofore has not paid sufficient attention to regional federal lab activity. Indeed, this can almost be viewed as a contradiction in terms given that the terms 'federal labs' and 'national labs' are used almost interchangeably (conveying the sense that the entire country is the geographic unit of analysis for federal lab studies). A subfield within the literature on federal labs, devoted specifically to their regional influence and capabilities, would serve to better inform federal lab and proximity policy.

In closing this section, it is observed that studies (e.g. Frenken et al., 2005; Hoekman et al., 2010) which argue that advances in information and telecommunication technologies have not undermined proximity's influence were published at a fixed point in time. As these and related technologies are produced and adopted (on a widespread and increasing basis), and as the time-span between the last of these studies and the present increases, a heightened need exists to update these assessments. Accordingly, the argument is made that the literate on proximity stands to benefit from more routine updates on the status of proximity's influence, especially after the introduction of more transformative technologies.

CHAPTER 3

RESEARCH QUESTIONS AND HYPOTHESES

A principal shortcoming in the literature is a paucity of attention to proximity dynamics for UIG interaction in general and the position of individual (UIG) actors in particular. Accordingly, this study sets its focus on Government actors and how their position (within the UIG framework) influences knowledge outcomes. While Q2 focuses on if/how the *position* of Government collaborators (within the UIG framework) influences knowledge outcomes, Q1 begins with a more basic focus on if/how the *presence* of Government collaborators (within UI partnerships) influences the same. The first research question made in this study can be articulated as follows:

> **Q1:** *Does the involvement of Government collaborators in University-Industry partnerships add value above and beyond that which would have occurred had they not become involved?*

As mentioned at the outset, this study operationalizes value in terms of citation impact,[11] while acknowledging that alternative metrics[12] exist. How can these be thought of with respect to UI research and Government collaborator value-added? Citations can be generally seen as a measure for attention by the scholarly community. They convey a sense of how influential, important or useful a given piece of work is to others. It's worth noting that, ceteris paribus, a paper with more citations is more likely to attract greater future attention. In this respect, citations positively contribute to the (future) marketability of published research—they contribute to the future promise and potential

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[11] Hence, another way of posing the Q1 is to ask whether the involvement of federal agents in UI partnerships significantly influences the citation intensity of the work they produce.
[12] Liao (2011) discusses a number of alternative research value metrics.

of scholarship today. It's worth noting that not all quality work is (immediately or adequately) cited, however. A key challenge, then, is the "conversion of non-citers to citers" (Small, 2010). Government collaborators actors can play an important role in this regard—i.e. they can potentially attract citations for quality UI research that would otherwise not have occurred. The question posed in this section is: does this occur?

An additional consideration for the citation-based approach used in this study makes room for the possibility that citations are not likely to offer the same utility for all audiences or recipients. For instance, University actors (and those with a more basic research orientation in general) may find this currency more valuable or practically useful (see response to Question 17 of Interview #10 and response to Question 17 of Interview #16). At the same time, however, we note that some Industry personnel admit to being "obsessed" with this metric (see response to Question 8 of Interview #11). Hence, while its utility may not be uniform (across or within all institutions), citation impact is recognized as a valid indicator by a very large number of audiences and it is likely to be the most commonly agreed upon measure of research value.[13] Accordingly, it is advanced as a valid indicator of UI research value and contribution of Government collaborators to the same.

The second question posed in this study considers not only the *presence*, but also the *position* of Government collaborators in UI partnerships. As will become more evident Q2 provides key guidance for, and is intimately connected with, Q1:

[13] We note that when UI researchers indicate an interest in other forms of research value—like journal quality or a more basic research orientation—they many times implicitly acknowledge the importance of citation impact (as Journal Impact Factors are based on citation data and a more basic research orientation is highly correlated with the citation rate).

Q2: *How is the value that Government collaborators introduce to University-Industry partnerships (if any) influenced by the scale at which they engage?*

Another way to pose this question is to ask whether the value added of Government researchers is spatially uniform or is influenced by scale of interaction. Previous scholarship (e.g. Boschma, 2005; Frenken et al., 2010) posits that, for a given collaboration, scale of engagement significantly influences research outputs. A gap heretofore unaddressed by proximity studies, however, is whether the position of individual actors can significantly influence research value (via proximate interaction) within the UIG framework. Evidence of the introduction of proximity induced value by individual actors (i.e. Government researchers) to UI collaborations is a meaningful contribution to the literature. Moreover, if the value introduced by Government actors does not vary across space, this also adds to the proximity debate from the perspective that it lends credence to the notion that some actors may be relatively more immune to proximity dynamics than others. To test the hypothesis that certain actors are more resilient to proximity dynamics than are others a comparable study is suggested (in the Discussion chapter) that assesses the spatially mediated impact of University (V_U) and Industry (V_I) involvement in UIG collaborations.

Q3: *How do actual scales of Government collaborator engagement (in University-Industry partnerships) compare against idea scales for the same (i.e. scales at which Government collaborator value-added is optimized)?*

After identifying scales that optimize the value added of federal agent involvement (in UI partnerships), the present analysis proceeds by identifying the scales at which Government actors actually engage with Universities and Industry. Comparing these provides room for discussion as to whether Government collaborators have or are currently engaging Universities and Industry at scales that optimize the value they introduce to these partnerships. A misalignment between actual and ideal scales of engagement begs for more efficient policy.

In response to the preceding questions and shortcomings in the literature the following hypotheses are advanced:

H_1: *The involvement of Government collaborators in University-Industry collaboration will, on average, add (scientific) value.*

As Table 8 indicates, the number of UIG collaborations in nanotechnology is steadily increasing over time. H_1 is expected given that the author thinks it unlikely that Universities and Industry would continue to voluntarily, repeatedly and frequently collaborate with federal entities if they repeatedly received little or nothing in return. From the perspective of game theory a player can get away with making little to no contribution in a single-play game, but not in a game of repeated play. The protection of intellectual property and other knowledge assets make corporations disinclined to share knowledge in a collaborative manner if there is no value accrued in so doing (Teece, 2000).

It is acknowledged that not everyone agrees that the inclusion of additional institutions in a given collaboration type is appropriate or likely to add value. While some scholars argue that the inclusion of Government collaborators in UI partnerships is desirable (Etzkowitz and Leydesdorff, 1996, 1998, 2000), others (e.g. Alston et al., 1996; Borrás, 2004) question the alleged benefit of additional institutional involvement in a given UI collaboration. Other scholars still raise questions about the involvement of

Government collaborators in particular in certain types of research. As has been previously noted Richard Nelson opines that: “in the United States the universities, rather than government laboratories, are seen as the appropriate sites for fundamental research” (1993). One of the individuals interviewed in this study voiced concerns about the ethical issues involved when Government collaborators decide to collaborate with one company at the expense of not collaborating with others (i.e. picking winners).[14]

The above concerns are noted, but setting normative discussion on whether Government actors should or should not become involved in UI partnerships aside, it is anticipated that their actual involvement in these partnerships is likely to add (scientific) value, on average. The author takes this position for reasons previously discussed, as well as noting that the considerable resources Government actors possess are expected to augment—on average—the resources and capabilities currently available to UI collaborators. When working with a technology as advanced as nanotechnology additional (technical, economic and human) resources are expected to result in research outputs of higher quality. Previous scholarship (e.g. Schultz, 2011) argues that UIG collaboration has proven a particularly effective collaboration type for the development of nanotechnology, and this is expected to result in research outputs of superior quality, ceteris paribus. While citation intensity is not the only form of value Government entities can contribute to UI collaborations, it is recognized as a major form (Liao, 2011), and one expected to manifest within the context of the current study. H_1, if confirmed, can be seen as a validation of research (e.g. Etzkowitz and Leydesdorff, 1996, 1998, 2000; Schultz, 2011) that advances UIG as a particularly effective collaboration type for advanced technologies.

[14] See response to Question #18 of Interview #16 in Appendix G.

The second hypothesis advanced in this study can be expressed as follows:

H_2: *The value-added of Government collaborators in University-Industry collaboration will vary across different scales of UIG interaction.*

The effect of proximity on research outcomes has been documented by a number of studies. While Katz (1994) argues that more proximity translates into research of higher quality, more recent scholars (e.g. Boschma, 2005) posit that some proximity is good but too much is not. Scholars from both schools of thought agree that research value is spatially mediated. It is anticipated this will hold true within the context of the current study as well (i.e. the spatial mediation of research value is expected to be validated herein).

Previous scholarship has analyzed UIG proximity dynamics using methods and approaches different from those used in the present study. Frenken and colleagues (2010), for example, analyze UIG proximity dynamics for eight science-based industries in Europe, on the basis of the total scale of interaction between UIG actors. While their analysis, which lays important groundwork for the current undertaking, considers the co-location of any two UIG actors (within a given region), the current study seeks to analyze the ability of specific and individual actors within UIG relations (i.e. the Government actor) to influence research outcomes via proximity dynamics. A confirmation of H_2 would demonstrate that research value is amenable to the position of specific and individual actors within the UIG framework.

Given that previous research (e.g. Frenken et al., 2010) has shown that research value is spatially mediated within UIG relations (for the total scale of interaction), if H_2 is not confirmed in the current study this would indicate that individual UIG actors (i.e. the

Government actor) are limited in their ability to influence research value via spatial relations. If H_2 is confirmed, however, this raises a few additional research questions: is research value amenable to the position of (individual) University or Industry actors as well? Which UIG actors possesses the most substantial ability to influence research value (via proximity dynamics) and for what domains or scales of engagement? A section providing guidance for future research (Chapter 7.6) elaborates on this discussion.

The third hypothesis advanced in this study is articulated as follows:

> **H_3:** *The scale that optimizes Government collaborator involvement in University-Industry partnerships will vary across sub-domains within the nanotechnology framework.*

After analyzing the citation impact of research collaboration in eight science-based industries across three geographic scales Frenken and colleagues find that proximity's impact differs by domain and in not every domain is more proximate interaction desirable (2010). In view of this finding they caution against a policy of making all collaboration as proximate as possible. In light of their study the present analysis anticipates that scales that optimize the value-added of federal agent involvement (in UI partnerships) are likely to vary across sub-domains within the nanotechnology framework.

H_3 can be tested both quantitatively and qualitatively. That is, in addition to running quantitative analyses at the domain level (and comparing results across the same), interviews can be used to help assess whether proximity 'matters more' for certain research areas. It is interesting to then assess whether quantitative and qualitative results both indicate that proximity's impact differs by domain. It is also interesting to assess whether quantitative and qualitative results are consistent across different domains and/or research areas.

The confirmation of H_3 can be seen as a validation of previous research (e.g. Frenken et al., 2010) arguing ideal proximity is a function of the research area under consideration. The confirmation of this hypothesis reinforces the message that proximity policy should be made domain specific. We make room for the possibility as well that for certain domains Government collaborator proximity to University actors may be more consequential (for purposes of research quality) and for other domains Government collaborator proximity to Industry actors may be more consequential.

The fourth hypothesis advanced in this study can be expressed in the following way:

> **H_4:** *Proximity's influence will produce different research values for different institutional differences within the UIG framework. When Government collaborators narrow the proximity gap with Universities it will result in outcomes different than when they do the same with Industry.*

Earlier it was argued that the (lack of) attention given thus far to proximity's influence on institutional differences (within the UIG framework) represents a deficiency in the literature. This study purposes to explore these differences in greater detail and posits that differences across institutional differences are nontrivial. In particular, it is anticipated that research value will not change at the same rate (or in the same manner) when Government collaborators become increasingly proximate to Universities as it does when Government collaborators become increasingly proximate to Industry.

Groundwork has already been laid to the effect that institutional differences can meaningfully impact the impact of spatial proximity. In particular, Ponds and colleagues argue that the role of spatial proximity assumes greater importance when institutional differences exist. These authors write: "geographical proximity is more relevant for collaboration between academic and non-academic organisations than for purely academic collaboration" (Ponds et al., 2007). Hence, the argument can be made that institutional proximity acts as a substitute for geographic proximity. Stated in other words, when institutional differences exist research value is expected to be more sensitive or responsive to geographic proximity.

Building on the notion that as alternative proximity types (e.g. institutional proximity) are removed the impact of spatial proximity becomes more pronounced, it is further posited that geographic proximity will wield different impacts across different institutional differences. Stated differently, the impact of geographic proximity is expected to be different for the Industry-Government actor institutional difference than it is for the University-Government actor institutional difference. It is noted that Universities and Industry are different institutions with different objectives and different research orientations. The manner in which research value changes (with respect to an increasing Government collaborator proximity) is expected to differ across these different institutional differences. It is interesting to assess both (i) the mean final value of research when Government actors co-locate at the closest scale with Industry and when Government actors co-locate at the closest scale with Universities, and (ii) the rate of change of research value when Government actors become increasingly close to Industry and when Government actors become increasingly close to Universities. A confirmation of H_4 is expected to both validate and elaborate or expand on previous research (e.g. Ponds et al., 2007).

The fifth and final hypothesis is expressed as follows:

H_5: *Proximities within the UIG framework are interconnected: optimal (or citation optimizing) scales of Government collaborator engagement are a function of proximity between University and Industry.*

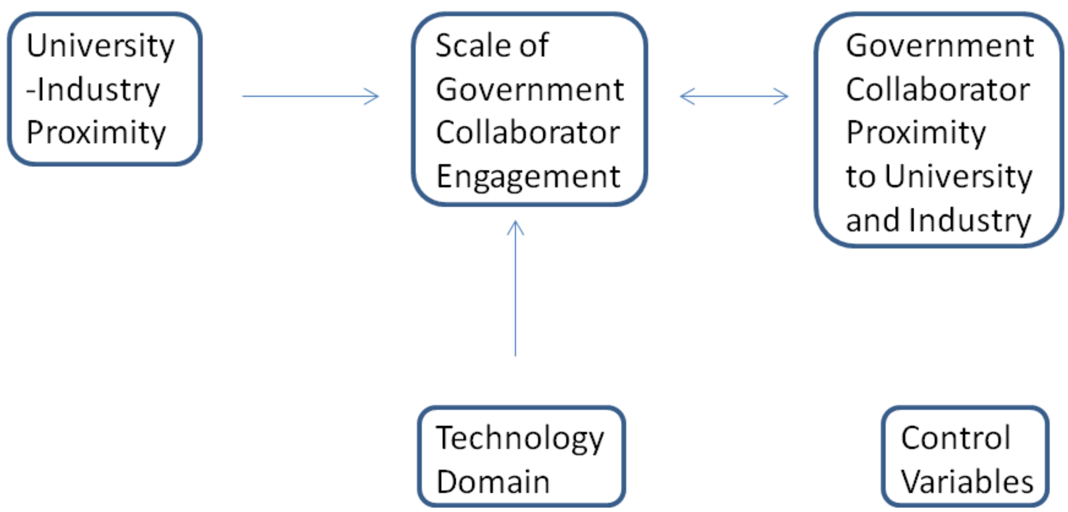
While this study seeks to isolate, focus on and assess ideal proximities for Government actors in particular, it is posited that proximities within the UIG framework are interconnected. Within UIG relations proximity dynamics governing the University-Industry institutional difference are expected to influence ideal (or citation optimizing) scales of Government collaborator engagement. For example, when University and Industry actors are distant, it may be relatively more important (for purposes of optimizing research value) that Government collaborators engage at more proximate scales and vice versa.

As mentioned previously, Etzkowitz and Leydesdorff argue that University, Industry and Government actors are interdependent and cannot be fully understood in isolation (1996, 1998, 2000). In an analogous fashion it is hypothesized that the proximities between these actors are interdependent (within the context of UIG relations) and cannot be properly understood in isolation. Within the total scale of interaction one proximity (i.e. the proximity between two given collaborators) is expected to influence other proximities, and vice versa. The implications for policy of this hypothesis being confirmed are that an ideal Government actor proximity should take into account the proximity between University and Industry actors.

Mathematically this hypothesis can be described as follows: the indicator advanced in this study—UIG triangle area—is calculated on the basis of the length of a given UIG triangle's three sides. From a quantitative viewpoint triangle area cannot be assessed on the basis of just one or two of its sides—i.e. all three must be taken into account. If the length of the side connecting the University and Industry actor is relatively short it is relatively less important that the Government actor be close (to one or both of these actors) to produce a triangle area relatively small in size. By contrast, if the length of the side connecting the University and Industry actor is relatively long it becomes relatively more important that the Government actor be close (to one or both of these actors) to produce a triangle area relatively small in size. The wording of this quantitative illustration can also be expressed in the language of spatial scientometrics: if the University and Industry actor are proximate it is relatively less important that the Government actor also be proximate (to one or both of these actors) to produce a triangle area relatively small in size. By contrast, if the University and Industry actor are not proximate it is relatively it becomes relatively more important that the Government actor be proximate (to one or both of these actors) to produce a triangle area relatively small in size. A confirmation of H_5 is not expected to validate or refute any existing research but show that UIG proximity dynamics represents a specialized sub-domain with unique properties within the larger field of spatial scientometrics.

A sixth hypothesis—that Government collaborators do not, on average, engage at citation optimizing scales with Universities and Industry—was considered. The reasoning behind this is based on the premise that federal laboratories tend to cluster in certain areas (e.g. Washington, DC), while Universities and Industry tend to be more geographically diffuse. In their work on federal laboratories Crow and Bozeman (1998) note, however, that a sizeable number of labs exist in the US NIS (they estimate c.a. 700 federal labs are directly funded by the U.S. government). Their findings makes it difficult to conclude that the majority of federal laboratories cluster in the Washington, DC area and geography is a (pre)determining factor influencing the spatial arrangements of UIG partnerships. Accordingly, judgment is suspended on the question of whether Government collaborators engage at citation optimizing scales with Universities and Industry (Q3).

In summary, the relationships hypothesized above can be visually depicted as follows:



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: research value

Figure 1: Determinants of University-Industry Research Value

In the above figure UI research value is influenced by: University-Industry proximity, scale of Government collaborator engagement, technology domain, Government collaborator to University and Industry and control variables (outlined in the next chapter). In this figure (which is similar to a hub-and-spoke configuration) scale of Government collaborator engagement acts as a primary or central determinant of UI research value. Ideal scales for the same are, at least partially, influenced by each of the variables pointing to it, all of which are elaborated on in the chapter that follows.

CHAPTER 4

METHODOLOGY AND DATA

Dataset

The following inquiry proceeds by identifying all US-based UIG nanopublications in Georgia Tech's global nanotechnology dataset, which was built using a modularized Boolean approach for identifying nanotechnology research (Porter et al., 2008). The designation 'US-based' is used to refer to those UIG nanopublications whose authors are co-located in the continental United States (the analyses conducted in this study do not lend themselves well to regions covering oceans or large bodies of water). The definition of nanotechnology used herein is parallel to the designation used by the US National Nanotechnology Initiative (NNI), which defines this technology as: "encompassing the science, engineering, and technology related to the understanding and control of matter at the length scale of approximately 1–100 nanometers" (PCAST, 2005, as cited in Porter et al., 2008).

Nanotechnology is selected as the disciplinary unit of analysis in this study for a number of reasons. As indicated at the outset, this inquiry is interested in the effect Government collaborator involvement in UI partnerships has for emerging technologies, and nanotechnology presents an emerging technology of considerable interest and appeal, especially for UIG collaborative purposes. In her paper, "Nanotechnology's triple helix: a case study of the University at Albany's College of Nanoscale Science and Engineering", Laura Schultz analyzes the University at Albany's College of Nanoscale Science and Engineering (CNSE). After comparing the outputs and economic impact of CNSE with other university-based nanotechnology research centers Schultz concludes that "the CNSE is more successful at generating nanoknowledge as measured by publications and patents", and that its UIG collaborative structure plays a key role in this outcome (2011).

Given that nanotechnology has attracted no small amount of attention from University, Industry and Government actors it provides an ideal case study. Given as well that the federal government has invested massive amounts of money into the NNI, the argument can be made that if key relationships (related to this study's questions) are to be found at all, they will be found in this burgeoning domain.[15] Nanotechnology covers a considerable number of research areas—the insights gleaned from its study are expected to be representative of, and applicable to, a number of emerging technologies.

In light of the fact that nanotechnology covers a number of research areas, several scholars (e.g. Wong et al., 2007; Schultz and Joutz, 2010) have argued that this field consists not of one, but several technologies. Given that the nanotechnology framework can be divided into a number of sub-disciplines, and given that Frenken and colleagues find that performance enhancing scales of interaction vary across different technologies (2010), it is not unreasonable to posit that the relationship between proximity and research value is likely to differ based on the particularities of the technology under consideration. Hence, the questions can (and should) be addressed across sub-domains within the nanotechnology framework.[16]

[15] Key relationships are (related to this study's questions) are also expected to appear in the nanotechnology domain because this technology lends itself to testing by the kind of advanced instrumentation found in federal laboratories.

[16] We make room for the possibility that answers to the questions posed in this study can change, not only across technology domain, but also across time. Consequently, results are presented from 1990 to 2011 inclusive, using individual years as units of analysis.

A number of approaches have been made to deconstruct nanotechnology into constituent domains. In their paper, "Internationalization and evolution of application areas of an emerging technology: The case of nanotechnology" Wong and colleagues use a combination of keyword searches and manual classification to divide the nanotechnology framework into four broad based application areas: (1) Instrumentation, tools, metrology, standards, (2) Chemical Processes & Materials, (3) Medical & Biotechnology, and (4) Nanoelectronics and perform a number of analyses on these areas (2007). In addition, Laura Schultz and Frederick Joutz employ a co-citation network analysis to deconstruct the nanotechnology framework into seven technology clusters: (1) Crossbar memory devices and related nanotechnologies, (2) Carbon nanotube production, (3) Scanning probe for nanopatterning, (4) Electrophoretic displays, (5) Medical diagnostic nanotechnologies, (6) Nanolithography, and (7) Copper deposition for integrated circuits (2010). Furthermore, Alan Porter (Georgia Tech) has devised a thesaurus[17] that categorizes all scientific publications indexed on WOS into four Meta Disciplines: (1) Biomedical Sciences, (2) Physical Sciences, (3) Social Sciences and (4) Environmental Sciences, as well as six Meta Disciplines: (1) Biology and Medicine, (2) Physical S&T, (3) Environmental S&T, (4) Psychology and Social Sciences, (5) Computer Science and Engineering, and (6) Social Sciences. Of the above classification schemes the latter approach lends itself particularly well to the dataset used in this study. Using this scheme it is possible to assess whether answers to the questions posed herein are specific to sub-domains within nanotechnology or hold constant across the entire

[17] Appearing in Appendix H.

nanotechnology framework.[18] If it can be shown that the manner in which research value is spatially mediated differs by nanotechnology sub-discipline, the case can be made that resulting policy implications should be domain-specific.

UIG nanopublications are identified on the basis of a thesaurus,[19] provided by Search Technology,[20] that classifies affiliations into Academic, Government and Industry categories. Results are supplemented by a manual verification process. If a given nanopublication simultaneously contains an independent Academic, Corporate and Government affiliation (each of which is co-located in the continental United States) it is identified as a UIG record for present purposes.[21] Appendix A provides record counts for these collaborations, along with counts for UI, University-Government (UG) and Industry-Government (IG) collaborations.

Variable Measurement

When Government collaborators become involved in a given UI partnership two variables are influenced: (i) total scale of interaction, and (ii) total value of research produced. Change in the latter with respect to change in the former is of interest to this analysis. The present study measures the first variable in terms of UIG triangle area (in both squared and unsquared terms) and the second in terms of citation impact. These variables, along with techniques for their measurement, are discussed in greater detail below.

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[18] Given that Carley and Porter (2012) show that citation impact varies by discipline (i.e. some disciplines receive more citations than others), it is not unreasonable to posit that the citation intensity of disciplines within nanotechnology may differ (for reasons unrelated to the effects of proximity). Accordingly, results are made domain-specific.

[19] The thesaurus AcadCorpGov.the is a component of the VantagePoint textmining software.

[20] See www.thevantagepoint.com

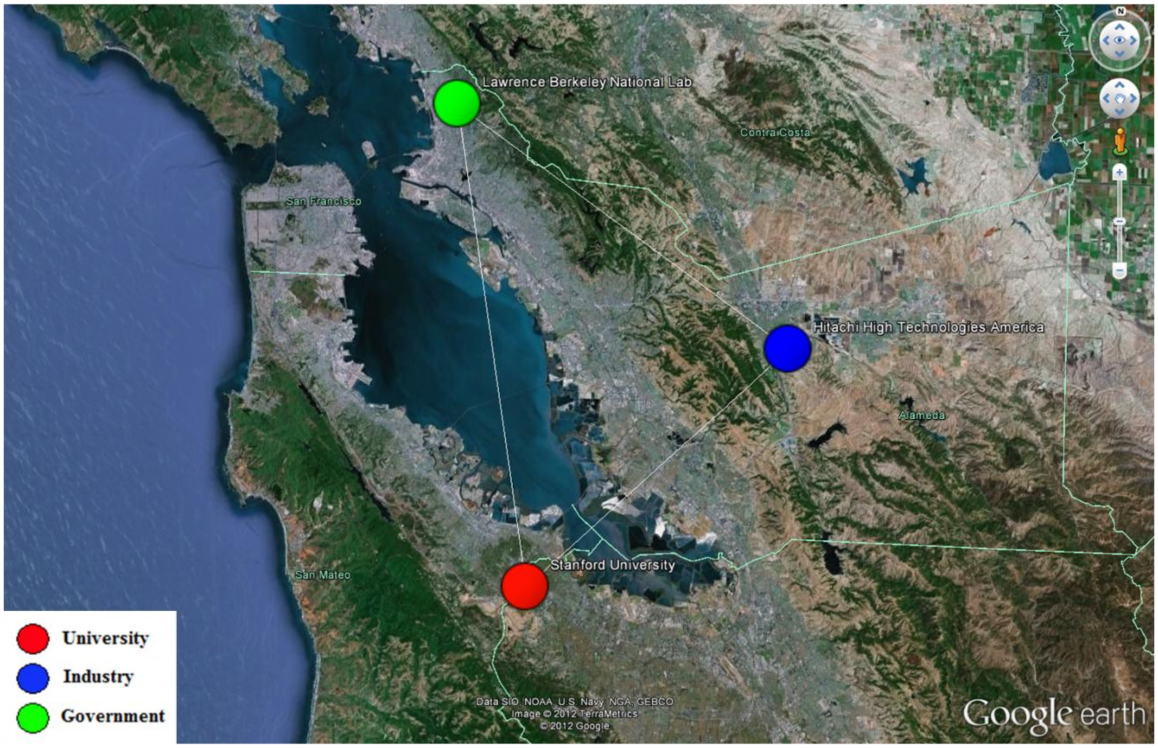
[21] A nanopublication with two authors, one of which was affiliated with Academic and Corporate entities, and the other of which was affiliated with a Government entity, would not be classified as a UIG record for purposes of this study because not all three entities are independently represented by three individual authors.

As concerns the first variable affected by the involvement of Government collaborators in UI partnerships (scale of interaction): proximity data for each UIG collaboration is calculated with benefit of a macro, written by the author, that identifies and maps coordinates[22] for University, Industry and Government collaborators listed on individual nanopublications, on a large-N basis. Displaying a given UIG collaboration on a Mercator projection will produce a triangle whose vertices represent the geographic coordinates of each co-author. It is then possible to draw on Heron's Formula[23] to calculate UIG triangle area. Drawing on this identity, a triangle (with sides X, Y and Z) has a semi-perimeter (SP) of (X+Y+Z)/2. After a SP is determined for a given UIG triangle its area is calculated as follows:

$$\text{Triangle Area} = \sqrt{SP(SP - X)(SP - Y)(SP - Z)}$$

The author developed a macro based on the above formula to calculate triangle area on a large-N basis (i.e. for any number of UIG Unique Article Identifiers). Figure 2, which was generated with benefit of Google Earth,[24] provides an example:

[22] Coordinate data is compiled with benefit of www.gpsvisualizer.com.
[23] See Klain (2004) for a more thorough treatment of this identity.
[24] See http://www.google.com/earth



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 1; Timespan = 2008; Unit of Analysis: UIG triangle area of an individual nanopublication

Figure 2: University-Industry-Government Nano-Triangle for ISI 000252117000012

The UIG nano-triangle in the above figure is produced using Web of Science (WOS)[25] Unique Article Identifier 000252117000012. As can be seen from the figure, this record contains a University (red icon), Industry (blue icon) and Government (green icon) affiliation.[26] The nanopublication this triangle is based on has been cited 755 times and has a Diffusion score[27] of 0.403. The distance between the red and blue icons is 22.96 miles, between the blue and green icons is 26.14 miles, and between the green and

[25] See www.isiknowledge.com
[26] Unless stated otherwise, the same color scheme will be used for all academic, corporate and government affiliations analyzed in this study.
[27] A Diffusion score (Carley and Porter, 2012) can be viewed as the corollary to Porter's Integration score (Porter et al., 2007) in that it measures variety, balance and diversity among citing (as opposed to cited) article cohorts.

red icons is 31.5 miles.[28] Using Heron's Formula we calculate a semi-perimeter of (22.96+26.14+31.5)/2, or 40.3 miles, and an area of $\sqrt{40.3(40.3 - 22.96)(40.3 - 26.14)(40.3 - 31.5)}$, or 295.01 square miles.

It is acknowledged that the effect of using a squared distance function to estimate research value has the potential to skew results, especially when working with triangles that cover large areas. Accordingly, this study provides both triangle area and the square root of the same as proxies for proximity. In particular, Appendix E provides the (square root) corollary to Figure 11 (below).

It is acknowledged as well that a mathematical purist might argue that the earth's surface is curved, and its shape spherical, making the use of planar triangles dubious. It is possible such an individual would advocate instead the use of spherical triangles and their area as a proxy for proximity. The author would respond those favoring an approach based on spherical trigonometry by initially observing that relative orders of proximity are not affected by this difference. If UIG triangle area A is larger than UIG triangle area B in planer terms, the same will also hold true in spherical terms (i.e. if UIG collaboration B is found to be more proximate than UIG collaboration A by one triangle area measure, the same result will necessarily occur using the other as well). The area of a spherical triangle (also known as Euler's triangle) can be denoted:

$$\text{Spherical Triangle Area} = R^2(A+B+C-\pi)$$

where A, B and C represent the angles of the triangle and R represent the radius of the sphere upon which it rests.[29] A defining feature of spherical triangles is that the sum of

[28] The distance between pairs of latitude and longitude coordinates for cities is calculated using a macro written by the author, which measures distance between coordinates for any number of pairs of latitude and longitude coordinates. The macro is based on Vincenty's formulae (Vincenty, 1975) for calculating the distance between a given set of latitude and longitude coordinates.

their angles (A+B+C) is always larger than the 180 degree sum obtained for the angles of every planar triangle. Given that one of the committee members of this dissertation has posited that the use of (planar) triangle area can bias results in favor of larger UIG triangles we note this concern becomes even more pronounced in the case of spherical triangles. Hence, the argument can be made that the use of planar in lieu of spherical triangle areas is one technique for reigning in the effect more distant collaborations have in terms of skewing results. It is observed as well that the shape of the earth is not a true sphere. Ergo, the use of spherical triangles to measure proximity is itself an approximation. No triangle area (spherical, planar or otherwise) will provide a flawless measure for each of the proximities considered in this study. It is argued, however, that the indicator advanced herein is adequate for present purposes.

The second variable (total value of research produced) influenced by Government collaborator involvement in a given UI partnership is ideally estimated via propensity score matching (PSM) – an advanced quantitative technique for calculating unbiased estimation of treatment effects on a given population (Rosenbaum and Rubin, 1983). The treatment effect of Government actor involvement in UI partnerships is of particular interest to the present inquiry. For this technique to work reasonably well one needs (1) to have access to a large dataset and (2) be able to make reasonable matches between the treatment (UIG partnerships) and control (UI partnerships) groups. While the dataset used in this study is sufficiently large, obtaining good match criteria (for treatment and control groups) is problematic. When and if reasonable match criteria can be obtained future research is encouraged to apply this technique within the context of the present (or a similar) study. In lieu of PSM other quantitative techniques are available. In particular, it

[29] See http://planetmath.org/areaofasphericaltriangle for a proof of this identity

is possible to use regression models to determine whether the involvement of Government collaborators (in UI partnerships) significantly adds to the collaboration's (scientific) value. Such a model would use citation impact as the dependent variable. Independent variables in this model would be: a dummy variable indicating Government collaborator involvement (in a UI partnership) as well as control variables (to account for other factors that influence UIG research value).

An alternative regression model regresses citation impact on multiple dummy variables—one for each scale (e.g. City/MSA/State) of Government collaborator engagement (with Universities and Industry). Definitions for Cities, States and Metropolitan Statistical Areas are provided by the US Census Bureau[30]. Using standardized measures, like beta weights, it is possible to objectively rank order the strength of impact each of the above independent variables (on UIG research quality). Control variables to incorporate in this regression model include:

(i) **Number of authors for a given UIG collaboration**: The positive effect of authors per paper on citation intensity is documented by previous research (e.g. Katz and Martin, 1997, as cited in Frenken et al., 2005; Frenken et al., 2005). Generally speaking, more authors contributes to research of higher impact.

(ii) **Number of affiliations for a given UIG collaboration**: Like co-authorship counts, more affiliations will generally translate into research of higher impact. The positive effect of affiliations per paper on citation intensity is documented by Frenken and colleagues (2005).

[30] See www.census.gov

(iii) **How basic or applied UIG research is**: In their 1997 study Narin and colleagues demonstrate a strong and increasing linkage between basic science and the development of technology in the US. In the context of the current study more basic research is expected to attract more citations given that it generally has more room for potential application.

(iv) **If a star scientist's name appears on a UIG nanopublication**: When a scholar enjoys academic success and fame he or she is likely to receive citations above and beyond that which would have otherwise occurred. This is often referred to as the Halo Effect.[31] In a 2012 study Youtie and colleagues identify star scentists, or what they call "creative researchers", within the nanotechology domain. Their definition of creativity "refers to social recognition by other researchers rather than research productivity as measured by publication" (Youtie et al., 2012). Youtie and colleagues (2012) were kind enough to share their dataset of creative researchers, which is used to identify star scientists in the dataset used in this study. In light of the Halo Effect and similar dynamics it is expected that UIG publications containing the name of a star scientist are likely to attract more citations, ceteris paribus, than that which would have otherwise occurred.

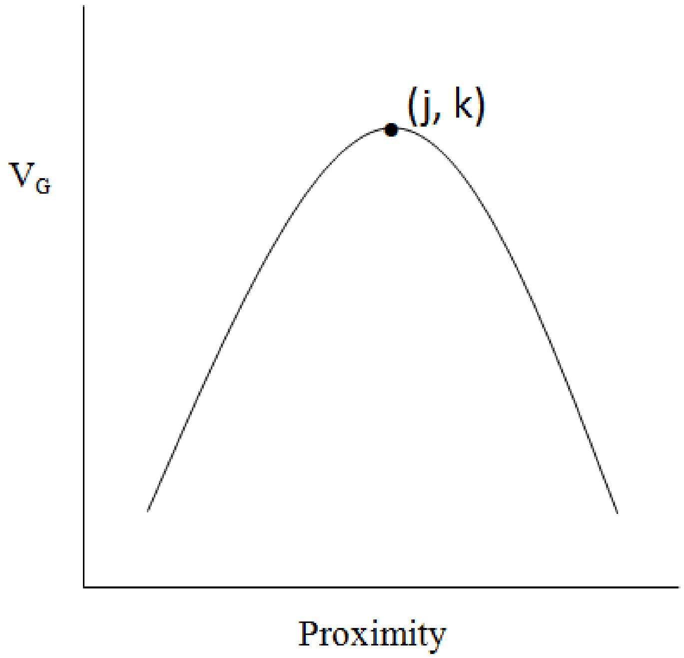
The present undertaking seeks to isolate the value introduced by Government collaborators to UI partnerships and assess how this changes across different scales of engagement. To do this, it is helpful to identify the difference in value of UIG research

[31] See Gingras and Wallace (2010) for a more thorough treatment of this phenomenon.

pre- (V_{UI}) and post- (V_{UIG}) involvement by a Government actor. V_{UIG} in Figure 2 is 755. V_{UI} represents a counterfactual: it is what the value of UIG research would have been had Government collaborators not become involved. The difference between these values (V_{UIG} – V_{UI}) represents the incremental value introduced by the engagement of Government actors with Universities and Industry (V_G). While previous scholarship (e.g. Boschma, 2005; Frenken et al., 2010) has posited that V_{UIG} is spatially mediated, the literature heretofore has yet to consider the spatially mediated value introduced by individual UIG actors. The present study purposes to fill this gap by advancing an indicator of proximate interaction among UIG actors which accounts for the position of individual actors and how this influences knowledge outcomes.

Collecting data for Government collaborator scale of engagement and changes in the research value of the work produced by UI partnerships they engage with for all US[32] UIG nano-triangles (in Georgia Tech's global nanopublication dataset) allows for at least two analyses for assessing the degree to which the value of Government actor involvement in UI partnerships is spatially mediated, as well as whether Government collaborators have or currently engage at scales that optimize their value added. The first is based on an interval scale of interaction. If Ron Boschma's (2005) argument that both too little and too much proximity undermines performance is validated in this study, we would expect the relationship between proximity and the contribution of Government actors to assume a curvilinear shape similar to that which appears in Figure 3:

[32] The continental United States is the selected geographical unit of analysis in light of the fact that international collaborations are likely to bias and/or skew triangle area results.



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: parabola

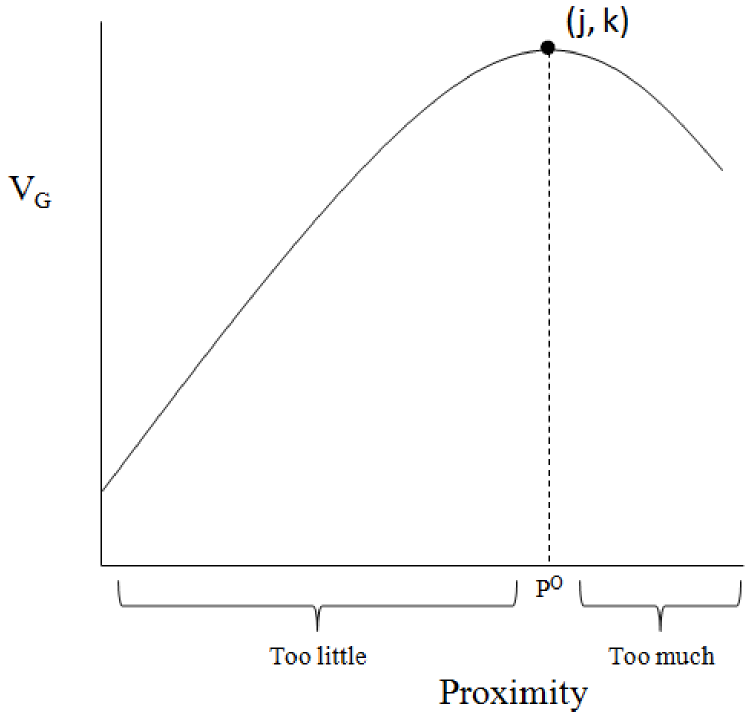
Figure 3: Downward Opening Parabola

The equation for the quadratic in Figure 3 can be written:

(1) $\mathbf{y = a(x - j)^2 + k}$

where *y* is the independent variable, *x* is the dependent variable, and (*j*, *k*) is the vertex of the parabola. Variables *a*, *j* and *k* are constants. Given that the variable *a* determines the direction of the parabola, *a* will have a negative value in the above figure (i.e. the parabola opens downward).

The shape in Figure 3 is a general depiction of a downward opening parabola. Tailoring this figure to the specifics of the results expected for this study yields the following:



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: parabola

Figure 4: A Scale of Interaction that Optimizes the Value-Added of Federal Agents

In Figure 4 P^O represents scale of interaction that optimizes the value that federal agents introduce to a given UI partnership. P^O can be determined using calculus: by setting the derivative of equation (1) equal to 0 and solving for *x*, we have:

$$\mathbf{2a(x - j) = 0}$$

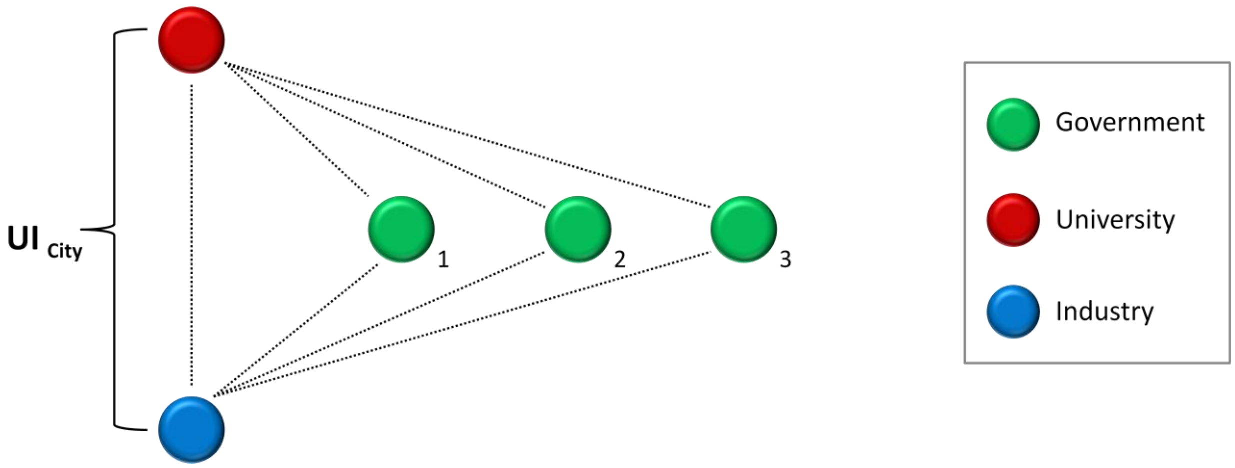
$$\mathbf{x = j = P^O}$$

We note that P^O is not centered on the x-axis, but falls closer to the maximum value of x (i.e. Figure 4 exhibits negative skew). This is a reflection of the hypothesis that more proximity is generally preferred to less. Given that too much proximity is expected to undermine performance, P^O falls short of the maximum point on the horizontal axis.

Plotting triangle size and V_G scores on an X-Y graph (similar to what is seen in Figure 4) allows for the identification of a scale of UIG interaction that optimizes the value that federal agents introduce to UI partnerships.

The first analysis, which is based on interval data, considers the ideal scale of interaction for all nanopublications across the entire spectrum of all possible proximities. We make room for the possibility, however, that ideal scales of Government collaborator involvement can change based on the proximity between academic and corporate actors in a given UIG collaboration. The approach that follows considers movements in V_G when the distance between UI entities is held constant (across different scales of interaction) but the location of the Government actor is variable.

A second analysis accounts for proximity between University and Industry actors. By holding the distance between University and Industry actors fixed and allowing the position of Government collaborators to vary it is possible to determine a UIG triangle size that optimizes citation impact (for a given UI proximity). By way of illustration: assume there are three instances (i.e. nanopublications) where Government actors become involved in a UI collaboration in which the University and Industry collaborators are co-located in the same city. Such a scenario can be visualized as follows:



Source: Own analysis
Notes: N = 3; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 5: Three Instances of Federal Agent Involvement in a University-Industry$_{City}$ Co-Location Category

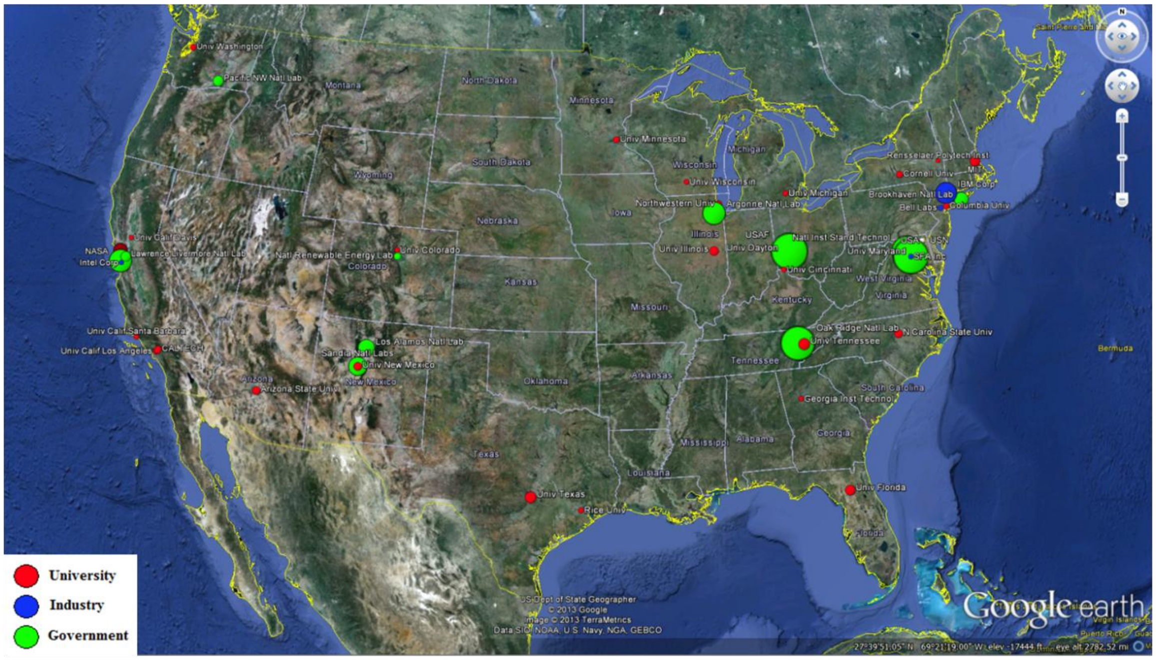
Identifying which of the three UIG triangles in Figure 5 produces the maximum value added score for Government collaborator involvement (V_G), as well as the maximum value of the research produced by all three collaborators (V_{UIG}), is of special interest to this study. The UIG triangle size associated with the latter value can be seen as an optimal scale of engagement (for this particular co-location category).

Equipped with ideal scales of Government collaborator engagement (across fixed UI distances) the present analysis proceeds by assigning each UIG nanopublication: (i) an actual scale of Government collaborator engagement, (ii) an ideal scale of engagement for the Government collaborator (i.e. one that optimizes citation impact for a given proximity between University and Industry collaborators) and (iii) the difference, if any, between ideal and actual scales of involvement for the Government collaborator. If (iii) is reasonably small, the intervention by the Government actor can be termed 'a hit'. If (iii) is large, however, the intervention by the Government actor is termed 'a miss.' After collecting all hits and misses in the dataset used in this study a batting average is calculated for engagement by Government collaborators across the spectrum of all UI proximities to address the question of whether Government agents engage Universities and Industry at scales that optimize the value they introduce to these partnerships.

UIG Leadership

Within the 1,418 UIG nanopublications analyzed in this study (see Table 8) a number of trends emerge. The following pages provide an overview of these trends by leading affiliations and authors. They are expected to impart the reader with a general sense of who the more prominent participants are within the UIG landscape (in the US), where they're located, how proximate they are to one another and what their relative strengths are. Toward this end, the 'Author Affiliations (Organization Only)' field[33] is cleaned twice, reducing it from 1,695 list items to 1,537. The author then applies his Acronym Identifier script (which combines all acronym abbreviations with their full word form) to this field, further reducing it from 1,537 items to 1,513 (e.g. the list item 'NIST' is absorbed into 'Natl Inst Stand Technol'). He then applies his Geomacro script (which maps list items from VantagePoint to Google Earth) to the top 50 items (i.e. those with the most records) in this field, assigning all Government collaborator icons a green color, all Industry icons a blue color and all University icons a red color. Icon sizes are set proportional to record counts, with the largest icon (USAF)[34] being assigned a size of 3.0.

[33] In the UIG dataset used in this study
[34] USAF = United States Air Force

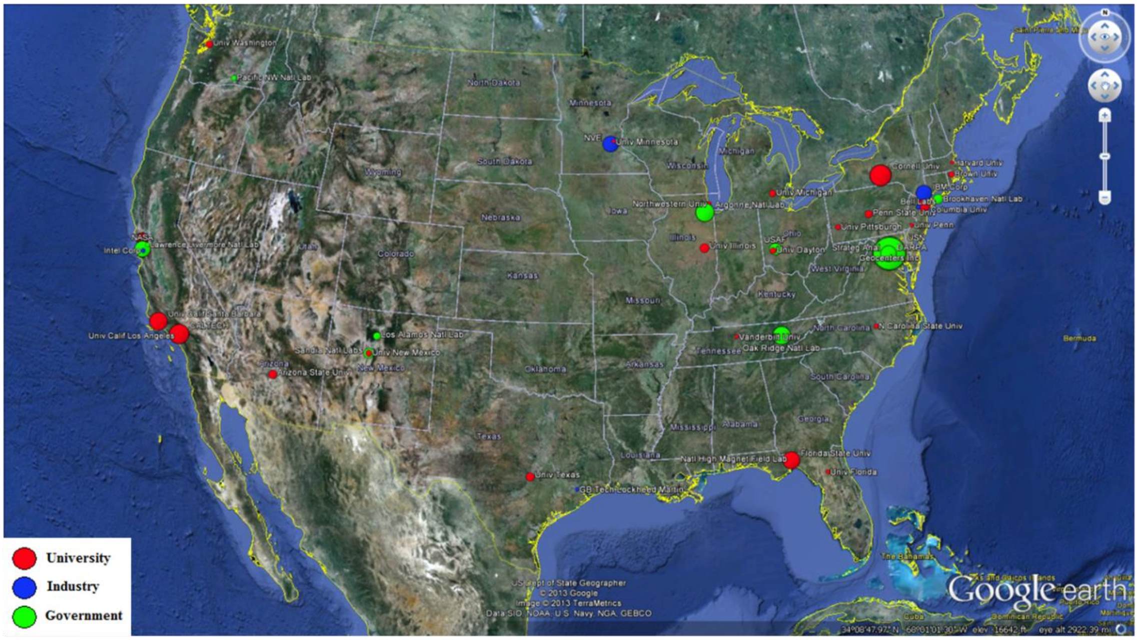


Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 50; Timespan = 1990-2011; Unit of Analysis: UIG affiliations

Figure 6: Top 50 University-Industry-Government Affiliations, by Record Count

In the above figure 29 Universities are mapped (58%), 7 Corporations are mapped (14%) and 14 Government collaborators are mapped (28%). The average University icon size is 0.67, the average Industry icon size is 0.70 and the average Government collaborator icon size is 1.77. The average size for all icons on this map is 0.96. We observe that the northeast appears busier in this figure—i.e. UIG activity seems to cluster in that part of the country. We observe as well that Universities are more spatially disperse and Government collaborator icon sizes are much larger (i.e. the same Government actors appear to repeatedly collaborate with different University and Industry partners).

While Figure 6 considers top UIG affiliation by record counts (i.e. a measure for quantity), Figure 7 considers top UIG affiliation by citation counts (i.e. a measure for quality). The figure below lists the top 50 UIG affiliations by cumulative citation count (using the same field used in Figure 6 of 1,513 affiliations):



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 50; Timespan = 1990-2011; Unit of Analysis: UIG affiliations

Figure 7: Top 50 University-Industry-Government Affiliations, by Cumulative Citations

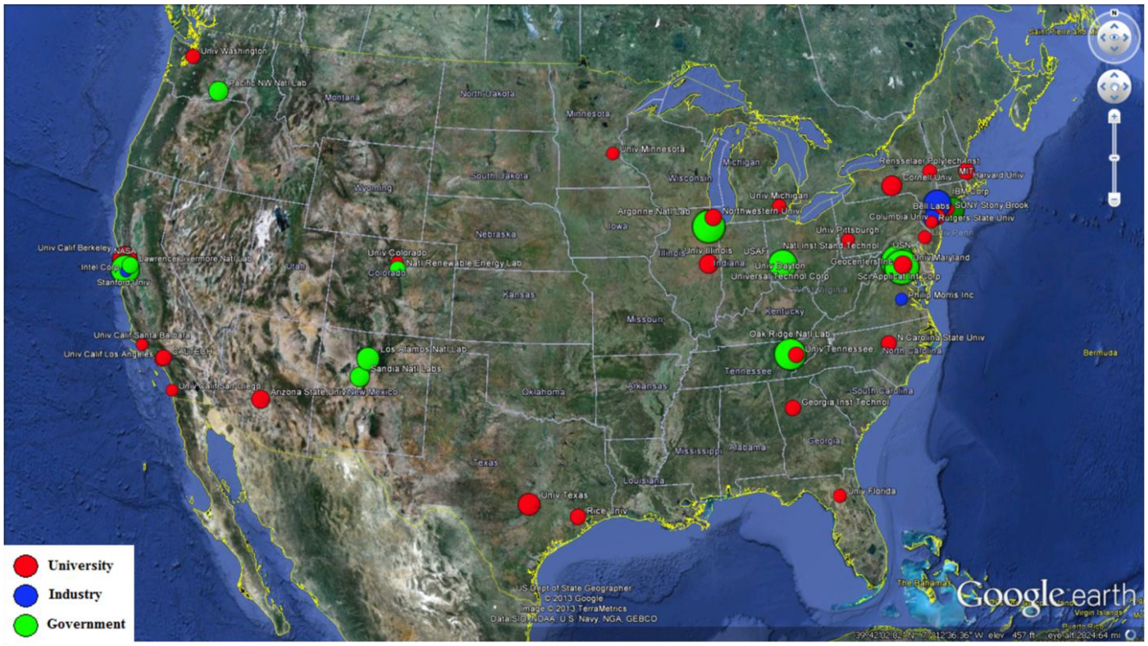
In the above figure icon sizes are set proportional to cumulative citation counts, with the largest icon (USN)[35] being assigned a size of 3.0. In total: 28 Universities were mapped (56%), 9 Corporations were mapped (18%) and 13 Government collaborators were mapped (26%). The average University icon size is 0.76, the average Industry icon size is 0.73 and the average Government collaborator icon size is 1.22. The average size of all icons in this figure is 0.87.

[35] USN = United States Navy (aka Naval Research Laboratory)

A number of observations can be made about the figure above. To begin with, we note that differences in mean icon size (across UIG affiliations) are much smaller in Figure 7 than they are in Figure 6 (i.e. Government collaborators seem to have less of a monopolistic hold on mean icon size in this figure). Secondly, we note that some institutions which do not appear at all in Figure 6 make a relatively significant showing in Figure 7. For example, Florida State University has a total of ten records, one of which has been cited 4,662 times. For this reason, it is present in the second but not the first map. Thirdly, there appears to be only one large (or relatively larger) green icon in this picture—USN (in Washington, DC). This icon appears to be located in a relatively close radius to the blue and red icons on this figure (lending support to the proximity-enhances-research-value argument). This third observation is to be taken with a grain of salt, however, given that Figure 7 displays only 50 (out of 1,513) UIG affiliations.

While Figure 6 considers top UIG affiliation by record counts (i.e. a measure for quantity) and Figure 7 considers top UIG affiliation by citation counts (i.e. a measure for quality), Figure 8 considers top UIG affiliation by Hirsch Index scores (i.e. a measure for both quantity and quality). It is generated by applying a Hirsch Index script[36] (written by the author) to the same field (of 1,513 affiliations) used in the two preceding figures and then mapping results into Google Earth.

[36] This script calculates Hirsch Index scores on the basis of the Times Cited field in a given VantagePoint file. Given that UIG publications often represent a subset of total publications for a given author or affiliation, the Hirsch Index scores presented in this study are likely to increase if we were to calculate them using additional (non-UIG) publications.



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 50; Timespan = 1990-2011; Unit of Analysis: UIG affiliations

Figure 8: Top 50 University-Industry-Government Affiliations, by Hirsch Index Scores

In the figure above icon sizes are set proportional to Hirsch Index scores, with the largest icon (USN) being assigned a size of 3.0. In total: 30 Universities were mapped (60%), 7 Corporations were mapped (14%) and 13 Government collaborators were mapped (26%). The average University icon size is 1.37, the average Industry icon size is 1.38 and the average Government collaborator icon size is 2.21. The average size of all icons on Figure 8 is 1.59.

In Figure 8 (which measure both quantity and quality) mean University icon size is noticeably larger than it is in the figures which precede it (there are also more University icons in this figure than in its predecessors). While Government collaborators still maintain a lead in mean icon size, Universities extend their lead in total number of institutions a top 50 category to 60% and exhibit a much more uniform spatial distribution in this and preceding figures as well.

While the preceding figures offer a bird's eye view of the top 50 UIG institutions (in terms of record counts, citation counts and Hirsch Index scores) analyzed in this study, the following tables focus specifically on the top 10 Government laboratories (by the same indicators) in this study's UIG dataset:

Table 1: Top 10 Government Collaborators, by Record Count

Government Collaborator	University-Industry-Government Nanopublication Count
USAF	159
USN	158
Oak Ridge Natl Lab	148
Natl Inst Stand & Technol	136
NASA	106
Argonne Natl Lab	99
Sandia Natl Labs	81
Los Alamos Natl Lab	73
Brookhaven Natl Lab	66
Lawrence Berkeley Natl Lab	64

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 10 most prolific Government collaborators; Timespan = 1990-2011; Unit of Analysis: individual Government collaborators

We note from the above table that the top producers of UIG research among all Government collaborators come from the military. This outcome is in keeping with Ruttan's (2006) study on military procurement and the development of technology: results appear to suggest that the military continues to act as a major driver for the development and dissemination of advanced and general purpose technologies. While raw record counts essentially focus on quantity, the following table provides a sense of which Government collaborators produce work of superior quality:

Table 2: Top 10 Government Collaborators, by Cumulative Citations

Government Collaborator	Cumulative Citation Count
USN	10,069
Argonne Natl Lab	5,429
Oak Ridge Natl Lab	5,331
NASA	5,032
DARPA	4,798
Natl Inst Stand & Technol	4,455
USAF	3,510
Lawrence Berkeley Natl Lab	3,101
Sandia Natl Labs	3,001
Brookhaven Natl Lab	2,963

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 10 most highly cited Government collaborators; Timespan = 1990-2011 (for cited articles); Unit of Analysis: individual Government collaborators

From the table above we note that while competition on the basis of total record counts can be seen as a close race between Government collaborators, competition on the basis of cumulative citation counts cannot. USN holds the a sizeable lion's share of cumulative citations, and some labs that emerged as leaders in terms of record counts (e.g. USAF) witness a relative loss in position in the category of cumulative citation counts. The following table provides a list of leading Government collaborators using an indicator for both quantity and quality:

Table 3: Top 10 Government Collaborators, by Hirsch Index

Government Collaborator	Hirsch Index
Natl Inst Stand & Technol	36
USN	36
Argonne Natl Lab	33
Oak Ridge Natl Lab	32
NASA	31
USAF	29
Brookhaven Natl Lab	26
Lawrence Berkeley Natl Lab	23
Los Alamos Natl Lab	23
Pacific NW Natl Lab	21

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 10 Government collaborators with highest Hirsch Index Scores; Timespan = 1990-2011; Unit of Analysis: individual Government collaborators

From the preceding three tables we note that rankings appear to be most similar in the latter two (cumulative citations and Hirsch Index scores). We note as well that these tables incorporate measures of quality, while record counts can be essentially viewed as a measure of quantity.

We next consider the same statistics for the authors analyzed in this study. To do this, the 'Authors' field (in this study's UIG dataset) was first cleaned twice (reducing it from 8,209 list items to 7,687). Total records, cumulative citations and Hirsch Index scores (based on the UIG dataset used in this study) are then tallied for each of the UIG authors analyzed in this study. Authors are assigned a primary affiliation on the basis of record counts (e.g. if the same author is affiliated with both a University and Government entity, but is more published with the former, he or she is assigned to that affiliation). Results appear below:

Table 4: Top 10 University-Industry-Government Authors, by Record Count

Author	Primary Affiliation	University-Industry-Government Nanopublication Count
Marquez, Manuel	Industry	27
Bunning, Timothy J	Government	16
Arepalli, Sivaram	Government	14
Donley, MS	University	11
Vaia, RA	Government	11
Balbyshev, VN	Industry	10
Jonker, BT	Government	10
Li, XZ	Government	10
Pfeiffer, LN	Industry	10
Venkatesan, Thirumalai	University	10

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 10 UIG authors with most nanopublications; Timespan = 1990-2011; Unit of Analysis: individual UIG authors

As might be expected, the table above indicates that (the same) Government collaborators tend to produce the highest total number of UIG nanopublications. University and Industry authors, by contrast, seem to produce a smaller total number of publications per author (but contribute to a larger share of total institution counts).

Table 5: Top 10 University-Industry-Government Authors, by Cumulative Citations

Author	Primary Affiliation	Cumulative Times Cited
Wolf, SA	Government	4,727
Von Molnar, Stephan	University	4,703
Authors of ISI 000172240500038[37]	University	4,662
Zhu, Jiang	University	1,983
Kim, P	University	1,932
Arepalli, Sivaram	Government	1,831
Stormer, H L	University	1,610
Pharr, GM	Government	1,587
Di Ventra, Massimiliano	Government	1,320
Oliver, WC	Government	1,283

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 10 most highly cited UIG authors (from this study's Nanotechnology dataset); Timespan = 1990-2011 (for cited articles); Unit of Analysis: individual UIG authors

The above table indicates University authors enjoy relatively higher percentage of cumulative citations, among leading cited authors, which is to be expected. We note as well that a number of the above authors have coauthored, resulting in similar cumulative citation counts (see footnote associated with 'Authors of ISI 000172240500038').

[37] Six of the (co)authors for ISI Unique Article Identifier 000172240500038 share a cumulative citation count of 4,662 (Awschalom, DD; Buhrman, RA; Chtchelkanova, AY; Daughton, JM; Roukes, ML; Treger, DM).

Table 6: Top 10 University-Industry-Government Authors, by Hirsch Index

Author	Primary Affiliation	Hirsch Index
Marquez, Manuel	Industry	15
Bunning, Timothy J	Government	11
Arepalli, Sivaram	Government	9
Vaia, RA	Government	9
Morris, RV	Government	8
Auciello, O	Government	8
Rafailovich, Miriam	University	8
Donley, MS	University	8
Balbyshev, VN	Industry	8
Pharr, GM	Government	7

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 10 UIG authors (from this study's Nanotechnology dataset) with highest Hirsch Index Scores; Timespan = 1990-2011; Unit of Analysis: individual UIG authors

The table above paints a different picture than its predecessor. While University authors enjoyed a comparative advantage in terms of cumulative citations (a measure for quality), Government collaborator authors enjoy a comparative advantage in terms of Hirsch Index Scores (a measure for quantity and quality). We note that top Government collaborator authors demonstrate a unique ability to consistently produce a sizeable quantity of high impact research.

Table 7: Descriptive Statistics for all University-Industry-Government Authors

	University Authors	**Industry Authors**	**Government Authors**
Number of Records	1,650	3,588	2,058
Mean Record Count	1.54	1.27	1.59
Mean Cumulative Citation Count	90	42	69
Mean Hirsch Index Score	1.37	1.14	1.40

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 7,296 UIG authors (from this study's Nanotechnology dataset); Timespan = 1990-2011; Unit of Analysis: individual UIG authors

The table above produces descriptive statistics for all UIG authors analyzed in this study. As might be expected, Government collaborator authors produce the highest mean number of publications per author. They also produce the highest mean Hirsch Index Score per author. As might also be expected, University authors command the highest mean cumulative citation counts per capita.

Interview Data

To complement and illuminate quantitative analyses a number of qualitative interviews[38] are conducted to assist in addressing the research questions posed in this study, as well as to provide a better understanding of quantitative results (as results themselves can raise their own questions). Drawing on the UIG dataset used in this study—which is taken from Georgia Tech's global nanopublication dataset—(all available) email addresses are identified for individuals who have participated in a UIG collaboration. These are then classified as either (1) University – if the email ends in a

[38] approved by the Institutional Review Board (IRB)

‘.edu’, (2) Industry - if the email ends in a ‘.com’, ‘.org’ or ‘.net’, or (3) Government – if the email ends in a ‘.gov’ or ‘.mil’. Emails are also assigned a most-recent-publication-date based on when the author affiliated with them was most recently published in the UIG dataset used in this study.

After sorting UIG email addresses in reverse chronological order (based on their most-recent-publication-date) more recently published UIG coauthors were contacted (via email) in a series of waves (i.e. approximately 100 UIG coauthors were contacted every 10 days). The recruitment email included an identification of this study’s author, an overview of this study, the purpose and outline of the interview and a request for participation. A total of 16 interviews were conducted (interviews ceased when the same themes began to repeatedly emerge and new themes began to generally cease). Of those interviewed four UIG coauthors are University-affiliated, seven UIG coauthors are Industry-affiliated and five UIG coauthors are affiliated with Government laboratories.

The (20) questions asked of each interviewee focus primarily on Government collaborator value added and how this is influenced by the scale at which they engage. Interview results are primarily used in two ways: (1) to shed light on quantitative analyses a number of ‘Qualitative Insights’ sections appear in the Results chapter (these directly touch on and/or explain the quantitative results which precede them), and (2) to provide a thematic overview of major and recurring themes that emerged from all interviews (found in the Interviews chapter). The interviews themselves can be found in Appendix G.

CHAPTER 5

RESULTS

Introduction

This chapter presents results for the three questions posed in this study. The author had initially considered devoting an individual chapter to results for each of this study's three research questions, but given the interconnected nature of the questions and their answers opted instead for a single chapter (divided into three sections). As will become increasingly apparent the following questions, responses, datasets and analyses significantly build on, and interrelate with, one other.

Question 1 Results

The first and primary question driving this study is:

> ***Q1: Does the involvement of Government collaborators in University-Industry partnerships add value above and beyond that which would have otherwise occurred?***

Given that the present analysis operationalizes research value in terms of citation intensity, another way of posing Q1 is to ask whether the involvement of Government agents in UI partnerships significantly influences their citation impact (i.e. scientific value).

Dataset

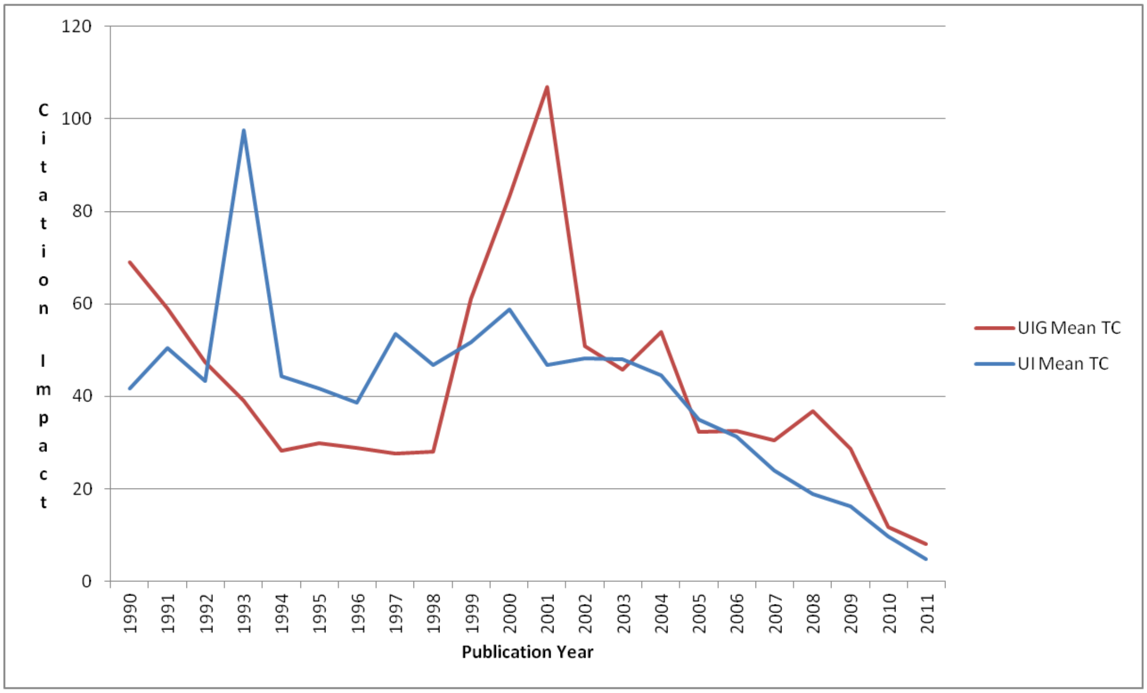
An initial response to the above question can be made by considering annual citation data for all UI and UIG partnerships, co-located in the continental US, in EI2's Nanopublication dataset. We note that these datasets are mutually exclusive (i.e. there is no overlap between them—see Appendix A). Our unit of analysis is individual nanopublications. Considering record counts and mean Times Cited (TC) values between these over time we have the following:

Table 8: Mean Annual Citation Values for University-Industry and University-Industry-Government Nano-Partnerships Co-Located in the Continental United States, 1990-2011

Publication Year	University-Industry Record Count	University-Industry-Government Record Count	University-Industry Mean Citations	University-Industry-Government Mean Citations
1990	49	3	41.61	69.00
1991	150	14	50.41	59.00
1992	162	16	43.37	47.31
1993	169	19	97.63	39.00
1994	171	17	44.26	28.18
1995	199	15	41.76	29.80
1996	210	23	38.61	28.91
1997	233	29	53.55	27.62
1998	374	40	46.79	27.98
1999	394	54	51.73	61.02
2000	417	48	58.82	83.21
2001	418	80	46.83	106.83
2002	381	57	48.12	50.93
2003	565	96	47.97	45.70
2004	596	96	44.52	53.82
2005	652	112	35.00	32.35
2006	753	148	31.20	32.59
2007	858	131	24.03	30.43
2008	867	129	18.77	36.77
2009	666	100	16.17	28.62
2010	645	110	9.77	11.80
2011	383	81	4.86	8.06
Total	9,312	1,418	34.98	39.72

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = Mean citations, by year, for 1,418 UIG and 9,312 UI records; Timespan = 1990-2011 (cited records); Unit of Analysis: nanopublications (cited records); publications indexed on WOS (citing records)

Depicting the citation data in Table 8 visually we have:



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = Mean citations, by year, for 1,418 UIG and 9,312 UI records; Timespan = 1990-2011 (cited records); Unit of Analysis: nanopublications (cited records); publications indexed on WOS (citing records)

Figure 9: Mean Annual Citation Values for University-Industry and University-Industry-Government Nano-Partnerships Co-Located in the Continental United States, 1990-2011

As can be seen from the above figure, the citation impact of UIG nanopublications appears to be generally larger than those produced by UI partnerships for years prior to 1993 and following 1998. While the distance between the red and blue lines in Figure 9 appears to be narrowing in more recent years, it is noted that the most recent five years of citation data have generally not had a significant amount of exposure time (to reach their full citation potential), making it difficult to draw hard conclusions for the 2007-2012 publication year time period (Rogers, 2010). We observe from Table 8 that the mean TC for all years is larger for UIG (39.72) than it is for UI (34.98) partnerships.

Comparing Mean Citation Values

Given that citation data, as a rule, is not normally distributed, a difference of means test (aka t test) does not help us interpret whether the presence of Government collaborators generally adds significant scientific value to UI partnerships. Additional techniques are available, however, for comparing two samples of independent observations that are non-normally distributed. In particular, the Mann–Whitney–Wilcoxon test provides a non-parametric hypothesis test for determining whether one of two samples has significantly larger values than the other. This test does not produce significant results for all years combined. As noted previously, however, it is problematic to draw hard conclusions about citation data for scholarship published in (approximately) the last five years (Rogers, 2010). Accordingly, the mean TC from 1990 to 2006, for both UI and UIG partnerships is presented below:

Table 9: Mean Citation Values for University-Industry and University-Industry-Government Nanotechnology-Partnerships Co-Located in the Continental United States, All Years (1990-2006)

	Number of Records	**Mean Citations**
University-Industry	5,893	45.80
University-Industry-Government	867	49.34

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = Mean citations for 867 UIG and 5,893 UI records; Timespan = 1990-2006; Unit of Analysis: nanopublications (cited records); publications indexed on WOS (citing records)

Applying the Mann–Whitney–Wilcoxon test to the data in Table 9 also fails to produce significant results. Applying this test to annual UI and UIG citation data yields significant results for the years 2007 (at the 0.05 level) and 2009 (at the 0.1 level). These results provide some—but not much—evidence that a significant relationship exists between Government agent involvement in UI partnerships and the value of the research they produce[39]. Given that 2007 and 2009 fall within the most recent five years of citation data hard conclusions are not drawn from these results.

Regression Analysis

Regression analysis provides an additional tool for addressing Q1. In particular, the following model can impart insight into this analysis:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \varepsilon$$

In this model:

Y = Citation impact

X_1 = A dummy variable indicating if a Government actor became involved in a UI partnership

X_2 = A dummy variable indicating if a star scientist is listed as a coauthor (control variable)

X_3 = A variable, ranging from 1 to 4, indicating how basic or applied a given nanopublication is (control variable)

X_4 = Number of authors (control variable)

X_5 = Number of affiliations (control variable)

ε = Error term

[39] As a corollary to Figure 9 Figure 23 (Appendix B) charts median annual citation values for UI and UIG Nano-Partnerships. Values in Figure 23 are more closely aligned than they are in Figure 9, making it difficult to conclude that Government collaborators add value to UI partnerships (in the aggregate).

The dataset for the above model is taken from all UI and UIG partnerships analyzed in this study (see Appendix A). In the above model X_1 is code 1 for UIG partnerships and 0 for UI partnerships. Control variables in the above model include: (i) number of authors participating in a given UIG collaboration,[40] (iii) number of affiliations listed on a given UIG publication,[41] (iv) how basic or applied a given nanopublication is[42] and (v) whether the name of a star scientist appears on the UIG nanopublication.[43] In addition to these controls, Carley and Porter (2012) demonstrate that citations are not uniformly distributed across all disciplines, but some subject areas will naturally receive more citations than others. To control for the influence of discipline on the citation rate the dataset used in this analysis is divided, using a thesaurus[44] provided by Alan Porter (Georgia Tech), into four Meta Disciplines: (1) Biomedical Sciences, (2) Physical Sciences, (3) Social Sciences and (4) Environmental Sciences.[45] Regression results are presented for all nanopublications affiliated with each of these classifications:

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[40] The positive effect of authors per paper on citation intensity is documented by previous research (e.g. Katz and Martin, 1997, as cited in Frenken et al., 2005; Frenken et al., 2005).

[41] The positive effect of affiliations per paper on citation intensity is documented by Frenken and colleagues (2005).

[42] More basic research is expected to attract more citations, on average. The National Science Foundation, along with CHI Research, provides a thesaurus to evaluate how basic or applied a given journal indexed by the Science Citation Index is. The thesaurus used in this analysis rates journals from 1 to 4 (i.e. 1 = very applied, 4 = very basic).

[43] Star scientists are expected to attract more citations, ceteris paribus, than researchers whose names are not well known. Youtie and colleagues (2012) provide a dataset of star nano-scientists.

[44] The thesaurus used in this analysis classifies all scientific publications indexed on WOS into Meta Disciplines on the basis of their Web of Science Category (WC) assignments.

[45] All analyses involving Meta Disciplines in this study are applied specifically to the nanotechnology dataset used herein and can be taken as representative of subdivisions within this domain.

Table 10: Regression Results, by Meta Discipline, for the Influence of Government Agent Involvement in University-Industry Partnerships on Research Value (1990-2011)

Citation Impact	**Biology and Medicine**	**Environmental S&T**	**Physical Science and Engineering**	**Psychology and Social Sciences**
Government Involvement	17.54 (17.39)	5.94 (22.72)	0.03 (4.55)	-150.47 (127.72)
Star Scientist	336.74 (33.86)***	(dropped)	51.52 (9.24)***	(dropped)
Basic v Applied	34.48 (5.59)***	16.57 (12.06)	8.05 (1.98)***	96.95 (50.55)*
Number of Authors	0.59 (1.43)	-2.64 (4.23)	0.96 (0.57)*	-23.68 (21.17)
Number of Affiliations	6.38 (3.07)**	4.72 (8.29)	0.15 (1.49)	23.40 (33.38)
Constant	-72.64 (20.66)***	-4.04 (29.49)	0.48 (7.03)	9.01 (99.86)
N	1,346	203	8,729	35
R squared	0.11	0.01	0.01	0.14

***significant at the 0.01 level
**significant at the 0.05 level
*significant at the 0.1 level

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 1,346 Biology and Medicine records, 203 Environmental S&T records, 8,729 Physical Science and Engineering records, 35 Psychology and Social Sciences records; Timespan = 1990-2011; Unit of Analysis: nanopublications

As can be seen from the above table, none of the coefficients for Government agent involvement in UI partnerships is statistically significant (most control variables do, however, appear to be significant). It can be argued, however, that publications generally need at least five years exposure time to reasonably approximate their citation potential (Rogers, 2010). Dropping the most recent five years of data from Table 10 and rerunning the above analysis results in the following:

Table 11: Regression Results, by Meta Discipline, for the Influence of Government Agent Involvement in University-Industry Partnerships on Research Value (1990-2006)

Citation Impact	Biology and Medicine	Environmental S&T	Physical Science and Engineering	Psychology and Social Sciences
Government Involvement	44.57 (32.74)	13.30 (55.08)	-3.72 (6.99)	-993.69 (79.10)*
Star Scientist	405.76 (51.44)***	(dropped)	66.48 (13.74)***	(dropped)
Basic v Applied	40.47 (11.08)***	23.28 (23.91)	10.79 (3.21)***	586.38 (24.87)**
Number of Authors	2.18 (3.05)	-3.21 (9.41)	1.40 (0.89)	-64.47 (43.97)
Number of Affiliations	9.69 (5.67)*	3.64 (19.94)	2.09 (2.52)	-39.16 (77.92)
Constant	-89.32 (41.90)**	9.77 (60.65)	-7.75 (11.68)	333.67 (80.41)
N	716	91	5,751	6
R squared	0.12	0.02	0.01	1

***significant at the 0.01 level
**significant at the 0.05 level
*significant at the 0.1 level

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 716 Biology and Medicine records, 91 Environmental S&T records, 5,751 Physical Science and Engineering records, 6 Psychology and Social Sciences records; Timespan = 1990-2006; Unit of Analysis: nanopublications

We note from the above that the coefficient on Government agent involvement in UI partnerships is statistically significant (at the 0.1 level) only in the case of Psychology and Social Sciences. We note also that the number of cases (6) for this regression is quite small, especially in light of the size (10,730) of the combined UI/UIG dataset this data came from. Hence, like its predecessor, the above table does not provide conclusive evidence that Government agent involvement in UI partnerships meaningfully enhances resulting research value.

Qualitative Insights

The interviews conducted in connection with this study provide qualitative insights into the preceding results. In particular, interviewees were asked whether increasing citation rate and/or journal quality was a consideration in including Government collaborators in a UI partnership. A number of those interviewed provided an affirmative response. Interviewees were also asked if Government collaborators introduce non-citation value to UI partnerships and what form this takes. Virtually every respondent provided an affirmative response. Common examples of non-citation value included facilities, funding and expertise. For a more developed list of the benefits Government collaborators introduce to UI partnerships see Theme #2 of this study's Interviews chapter.

Question 1 Conclusion

While a modicum of evidence exists that Government actors add (scientific) value to UI partnerships in the aggregate (i.e. Table 8, Figure 9 and Table 9), it is seen as less than convincing. It is not viewed as sufficient to provide an affirmative and unqualified response to Q1. In short, more evidence is needed to provide a response that is both affirmative and compelling to this study's first research question. Toward this end a number of UIG collaborators are interviewed specifically on the point of whether Government actors add scientific value to UI partnerships and if/how this is spatially mediated. Before discussing interview results, however, a more specific and precise response to Q1 is provided in findings for Q2. As will become apparent in the next section, the answer to the question of whether Government actors add (scientific) value to

UI partnerships is significantly influenced by the scale at which they engage. It is to Q2 that we now turn—whose answer provides key guidance not only for Q1, but also for Q3.

Question 2 Results

The second question driving this analysis is:

> ***Q2: How is the value Government collaborators introduce to University-Industry partnerships influenced by the scale at which they engage?***

Another way of posing Q2 is to ask whether the scale at which Government actors engage Universities and Industry significant influences the scientific value they introduce to these partnerships. Still another way of posing the same question is to ask whether the value added of Government researchers is spatially mediated.

Dataset

Q2 analyses cover all years during the period 1990 to 2006 (inclusive). Records from 2007 to the present are dropped to allow citation values reasonable exposure time (Rogers, 2010), reducing the UIG nanopublication dataset from 1,418 records to 867. UIG collaborations with more than three affiliations (i.e. triangle vertices) are also dropped (further reducing the UIG nanopublication dataset from 867 to 450). Unless stated otherwise this constitutes the dataset used for all analyses addressing Q2. Appendix C discusses techniques for analyzing triangles with more than three affiliations, but it is the author's position that analyses involving UIG triangle area will be more straightforward (and results less subject to controversy) by focusing specifically on UIG triangles with exactly three (UIG) affiliations. Analyses pertaining to geographic distance and/or UIG triangle area present units in miles (for the former) or square miles (for the latter). As will be discussed below, a citation optimizing scale of Government collaborator engagement depends on how proximate University and Industry are to each other. Accordingly, University and Industry partners are divided into 50 Distance Groups of equal size[46], which provide the anchor column for the table below:

Table 12: Descriptive Statistics for Question 2 Dataset

University-Industry Distance Group	Number of Records	Number of Publication Years	Mean Citations
1	9	5	29.89
2	9	5	141.33
3	9	6	82.78
4	9	5	21.11
5	9	4	18.33
6	9	6	38.67
7	9	8	40.89
8	9	7	16.78
9	9	7	39.78
10	9	7	130.89
11	9	5	32
12	9	6	45.44
13	9	7	12.67
14	9	8	52.67
15	9	7	13.89
16	9	7	42.44
17	9	8	29.11
18	9	7	64.56
19	9	7	18.22
20	9	7	53.67
21	9	5	16.78
22	9	8	24.56
23	9	7	20
24	9	8	24.56
25	9	5	37.33

[46] Distance Groups are equal in size in that they have the same number of records. They differ, however, in that as Distance Group number increases, so does the distance between University and Industry collaborators. These groups were generated by sorting UI distances in ascending order and then grouping results into consecutive increments of nine records (which resulted in exactly 50 groups).

Table 12 (continued)

26	9	6	10.89
27	9	7	27
28	9	6	30.44
29	9	5	37.11
30	9	6	153.11
31	9	5	29.11
32	9	7	152.56
33	9	7	69.11
34	9	6	88.22
35	9	7	154
36	9	6	33.78
37	9	6	20.11
38	9	5	18.44
39	9	8	12.44
40	9	5	24.56
41	9	7	28.56
42	9	7	33.67
43	9	5	12.56
44	9	6	26.33
45	9	8	32.89
46	9	7	85.56
47	9	6	43
48	9	6	32.89
49	9	5	70.56
50	9	7	37.44

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 450 records partitioned into 50 UI distance groups; Timespan = 1990-2006; Unit of Analysis: UI distance groups

Regression Analyses

Three levels of engagement can be initially used for the geography covered by the dataset used in this study (the continental US): (1) City, (2) Metropolitan Statistical Area (MSA) and (3) State. We begin by analyzing results when Government actors co-locate in the same City/MSA/State with University actors (for all UIG records in our dataset published between 1990 and 2006). The following regression model is used to provide an initial answer to this question:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \varepsilon$$

In this model:

Y = Citation impact

X_1 = A dummy variable indicating if a Government actor engaged with a University actor at the City level

X_2 = A dummy variable indicating if a Government actor engaged with a University actor at the MSA level

X_3 = A dummy variable indicating if a Government actor engaged with a University actor at the State level

X_4 = A dummy variable indicating if a Star Scientist is listed as a coauthor (control variable)

X_5 = A variable, ranging from 1 to 4, indicating how basic or applied a given nanopublication is (control variable)

X_6 = Number of authors (control variable)

X_7 = Number of affiliations[47] (control variable)

ε = Error term

Results are initially presented across Porter's four Meta Disciplines:

[47] Note: Because the dataset used to address Q2 analyzes only UIG nanopublications with exactly three affiliations, this variable is controlled for (and dropped) in the models that follow.

Table 13: Regressions (for University and Industry Engagements) for the Biology and Medicine 4-Classification Meta Discipline Scheme (1990-2006)

Citation Impact	Biology and Medicine		Citation Impact	Biology and Medicine
G engages with U at City Level	140.62 (133.59)		G engages with I at City Level	251.16 (85.04)***
G engages with U at MSA Level	5.53 (131.11)		G engages with I at MSA Level	4.01 (68.96)
G engages with U at State Level	-73.14 (171.62)		G engages with I at State Level	-39.67 (67.83)
Star Scientist	dropped		Star Scientist	dropped
Basic v Applied	62.15 (59.60)		Basic v Applied	40.81 (50.57)
Number of Authors	-7.28 (9.11)		Number of Authors	-2.25 (7.86)
Number of Affiliations	dropped		Number of Affiliations	dropped
Constant	-66.64 (205.49)		Constant	-40.15 (164.82)
N	27		N	27
R squared	0.1203		R squared	0.3664

***significant at the 0.01 level
**significant at the 0.05 level
*significant at the 0.1 level

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 27 Biology and Medicine records (for Government collaborator engagement of Universities) and 27 Biology and Medicine records (for Government collaborator engagement of Industry); Timespan = 1990-2006; Unit of Analysis: nanopublications

The table above provides results for two regressions—one for the engagement of Universities by Government collaborators and one for the engagement of Industry by Government collaborators. The only scale of Government actor involvement that is statistically significant for this Meta Discipline is when Government actors engage Industry at the City level. We note that this result is highly statistically significant (i.e. at the 0.01 level).

Table 14: Regressions (for University and Industry Engagements) for the Environmental S&T 4-Classification Meta Discipline Scheme (1990-2006)

Citation Impact	Environmental S&T		Citation Impact	Environmental S&T
G engages with U at City Level	Dropped		G engages with I at City Level	-117.06 (133.55)
G engages with U at MSA Level	40.43 (133.91)		G engages with I at MSA Level	49.57 (172.56)
G engages with U at State Level	45.88 (117.91)		G engages with I at State Level	-108.85 (161.11)
Star Scientist	Dropped		Star Scientist	dropped
Basic v Applied	-12.02 (49.28)		Basic v Applied	19.03 (66.77)
Number of Authors	0.85 (38.71)		Number of Authors	-43.06 (50.48)
Number of Affiliations	Dropped		Number of Affiliations	dropped
Constant	79.91 (209.53)		Constant	307.99 (253.32)
N	9		N	9
R squared	0.2168		R squared	0.4247

***significant at the 0.01 level
**significant at the 0.05 level
*significant at the 0.1 level

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 9 Environmental S&T records (for Government collaborator engagement of Universities) and 9 Environmental S&T records (for Government collaborator engagement of Industry); Timespan = 1990-2006; Unit of Analysis: nanopublications

The table above provides results for two regressions—one for the engagement of Universities by Government collaborators and one for the engagement of Industry by Government collaborators. No scales of Government actor involvement are statistically significant for this Meta Discipline. This is likely the result of a low number of cases (9). The correlation matrices which follow indicate, however, which levels of engagements are most correlated with citations for Environmental S&T.

Table 15: Regressions (for University and Industry Engagements) for the Physical Science and Engineering 4-Classification Meta Discipline Scheme (1990-2006)

Citation Impact	**Physical Science and Engineering**		**Citation Impact**	**Physical Science and Engineering**
G engages with U at City Level	38.84 (22.71)*		G engages with I at City Level	19.21 (26.44)
G engages with U at MSA Level	-0.02 (19.34)		G engages with I at MSA Level	-2.96 (15.49)
G engages with U at State Level	6.96 (17.55)		G engages with I at State Level	-5.46 (15.61)
Star Scientist	-22.50 (51.13)		Star Scientist	-9.62 (52.09)
Basic v Applied	17.99 (8.22)**		Basic v Applied	17.99 (8.29)**
Number of Authors	-2.55 (2.38)		Number of Authors	-3.31 (2.39)
Number of Affiliations	dropped		Number of Affiliations	dropped
Constant	-1.41 (29.15)		Constant	10.20 (29.35)
N	401		N	401
R squared	0.0303		R squared	0.0176

***significant at the 0.01 level
**significant at the 0.05 level
*significant at the 0.1 level

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 401 Physical Science and Engineering records (for Government collaborator engagement of Universities) and 401 Physical Science and Engineering records (for Government collaborator engagement of Industry); Timespan = 1990-2006; Unit of Analysis: nanopublications

The table above again provides results for two regressions—one for the engagement of Universities by Government collaborators and one for the engagement of Industry by Government collaborators. The only scale of Government actor involvement that is statistically significant for this Meta Discipline is when Government actors engage Universities at the City level.

Regression results could not be produced for the fourth and final Meta Discipline (Psychology and Social Sciences) due to too a lack of observations. In addition to a 4 Meta Discipline classification scheme, Porter also provides a more refined 6 Meta

Discipline classification scheme[48]. Appendix F applies the previous analyses to this scheme. Results are similar to what appear above—i.e. the only significant scale of Government collaborator engagement is the City level. Hence, in both the 4 and 6 Meta Discipline regressions the City level of engagement is the only scale of Government actor engagement found to be statistically significant. This occurs for Government actor engagement of Universities (in the case of 'Physical Science and Engineering') and Industry (in the case of 'Biology and Medicine') for the 4 Meta Discipline scheme and Government actor engagement of Universities (in the case of 'Physical S&T') and Industry (in the case of 'Biology and Medicine') for the 6 Meta Discipline scheme. The City scale of engagement represents the tipping effect of proximity in this study—i.e. this represents boundary at which proximate interaction makes a considerable difference. For nanotechnology in the US, closer is better (at least for research associated with the above disciplines).

Correlation Analyses

To better contextualize the above regressions, the following tables provide correlation coefficients between citation impact and a given scale of Government collaborator engagement for the four Meta Disciplines. The first table does this for University partners, and the second for Industry.

[48] This appears in Appendix I.

Table 16: Correlation Coefficients for when Government Actors Engage University Actors at the City, Metropolitan and State Level (1990 to 2006)

Citation Impact	Biology and Medicine	Environmental S&T	Physical Science and Engineering	Psychology and Social Sciences
G engages U at City Level	0.2064	no correlation	0.1258	no correlation
G engages U at MSA Level	0.0669	0.4394	0.0819	no correlation
G engages U at State Level	0.0814	0.2621	0.0827	no correlation

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 28 Biology and Medicine records, 10 Environmental S&T records, 422 Physical Science and Engineering records, 2 Psychology and Social Sciences records; Timespan = 1990-2006; Unit of Analysis: nanopublications

Table 17: Correlation Coefficients for when Government Actors Engage Industry Actors at the City, Metropolitan and State Level (1990 to 2006)

Citation Impact	Biology and Medicine	Environmental S&T	Physical Science and Engineering	Psychology and Social Sciences
G engages I at City Level	0.5792	-0.422	0.0352	no correlation
G engages I at MSA Level	0.2766	-0.3021	0.0066	no correlation
G engages I at State Level	0.1618	-0.4544	-0.0042	no correlation

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 28 Biology and Medicine records, 10 Environmental S&T records, 422 Physical Science and Engineering records, 2 Psychology and Social Sciences records; Timespan = 1990-2006; Unit of Analysis: nanopublications

As can be seen from the above tables, the correlation coefficient for the closest scale of engagement (i.e. the City level) is always the largest. In only one instance (i.e. 'Environmental S&T') is this coefficient negative. It is noted, however, that the number of cases (10) producing this (negative) instance is low. It is noted as well that the largest of these correlation coefficients (0.5792) occurs in the case of 'Biology and Medicine'. The regression coefficient for this scale of engagement (between Government collaborators and Industry) is significant at the 0.01 level (see Table 13).

Qualitative Insights

The interviews conducted in connection with this study provide qualitative insights into the preceding results. In particular, interviewees were asked whether certain research areas benefited from proximate collaboration more than others and whether the nature of research conducted at close proximity differed from the nature of research conducted at distance. Respondents cited:

- research that involves testing of devices in development
- research involving a large amount of visual data
- research that requires continuous meetings and/or mass participation
- research involving complex equipment (and/or more complex research in general)
- research requiring iteration (and/or multiple experiments)
- research involving interaction with the human anatomy
- research requiring frequent access to a (Government) facility, and
- research involving biological applications

as examples of research areas that stand to benefit relatively more from more proximity. These responses seem to confirm the above finding that the Meta Disciplines 'Biology and Medicine' and 'Physical Science and Engineering' particularly benefit from proximate interaction. For more on this see responses to Interview Questions 13 and 14.

Closer is Better, but Whither To?

Preceding analyses provide evidence that closer scales of Government collaborator engagement benefit nanotechnology research value (at least for nanotechnology's more prominent Meta Disciplines). This section considers whether closer scales of Government collaborator engagement benefit research value differently for Universities and Industry. In other words: does research value appreciate at the same rate when Government collaborators become increasingly proximate to Universities as it does when Government collaborators become increasingly proximate to Industry (within the context of UIG relations)? Two statistics of interest in the following analysis are: (1) the rate of research value appreciation as Government collaborators become increasingly proximate to Universities/Industry, and (2) the absolute (scientific) value of research at Government collaborators' most profitable scale of interaction with Universities/Industry.

The following tables consider mean citation values for all US-based UIG nanopublications published between 1990 and 2006, by engagement type. By way of illustration: Table 18 indicates that the mean citation impact when Government collaborators engaged in the same cities as Universities (between 1990 and 2006) is 69.32. This figure represents a 36.79% increase from the Mean TC value (50.68) at the previous scale (MSA) of Government collaborator engagement with Universities.

Table 18: Mean Citation Values, and Percent Increases, Across Scales of Government Collaborator Engagement with Universities

Engagement	Mean Citations	% Mean Citation Increase from Previous Scale
G engages U at City Level	69.32	36.79%
G engages U at MSA Level	50.68	-5.40%
G engages U at State Level	53.57	NA

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 450 Total records and 50 UI distance groups; Timespan = 1990-2006; Unit of Analysis: nanopublications

Table 19: Mean Citation Values, and Percent Increases, Across Scales of Government Collaborator Engagement with Industry

Engagement	Mean Citations	% Mean Citation Increase from Previous Scale
G engages I at City Level	138.60	109.15%
G engages I at MSA Level	66.27	2.74%
G engages I at State Level	64.50	NA

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 450 Total records and 50 UI distance groups; Timespan = 1990-2006; Unit of Analysis: nanopublications

The above tables are similar in that mean citation impact is optimized at the City level of engagement. These tables differ, however, in two key respects:

(1) Mean citation values (second column in the above tables) are larger, in absolute terms, when Government collaborators engage with Industry than they are when Government collaborators engage with Universities at the same scales of engagement, and

(2) The rates of (Mean TC) increase moving from larger to smaller scales of Government collaborator engagement is noticeably larger for Industry than it is for Universities—i.e. moving from the MSA to the City level results in a 36.79% Mean TC increase for Universities while the same movement results in a 109.15% Mean TC increase for Industry.

It is concluded that research value does not appreciate at the same rate when Government collaborators become increasingly proximate to Universities as it does when Government collaborators become increasingly proximate to Industry. If a given Government collaborator's objective is to maximize research value, and it has the option of engaging at a close scale with either University or Industry (but not both), it would be best served engaging at closer quarters with its corporate partner.

Qualitative Insights

The interviews conducted in connection with this study provide qualitative insights into the preceding results. In particular, after being made aware of the finding that research value appreciates relatively more quickly when Government collaborators engage at increasingly close scales with Industry than when Government collaborators engage at increasingly close scales with Universities, interviewees were asked to comment on this outcome. The following responses shed light on this finding:

Table 20: Interviewee Thoughts on the Finding that Government Collaborator Proximity with Industry is Particularly Effective

Interview #	Question #	Interviewee Response
3	16	I'm not a business person. I'm totally an academic. I think that maybe, even more so in the business environment, it's important that everyone sits down and looks everyone in the eye to establish trust. Any venture involves risk – and you need to establish trust, and maybe that's more important to business people than to academics, I think.
13	16	It doesn't surprise me. Funding is under the management of government – if you have one or the other close to the government you have more face to face talks. You get more results. When industry has face to face talks it counts for more than when universities have face to face talks.
4	16	It doesn't surprise me that much. I've worked in both environments. At the university we're educating trainees. The people doing the research are learning as they go (a lot of time they don't know what they're doing). So, when government and industry work together it's two groups of highly competent professionals that are doing work. When government and industry collaborate a lot of times its high value research. But we're training people here at the university, so we don't have the same kind of firepower that industry and the government does.

Source: Interviews conducted by the author of UIG collaborators
Notes: N = 3; Timespan = 2013; Unit of Analysis: Interviewee responses to individual interview questions

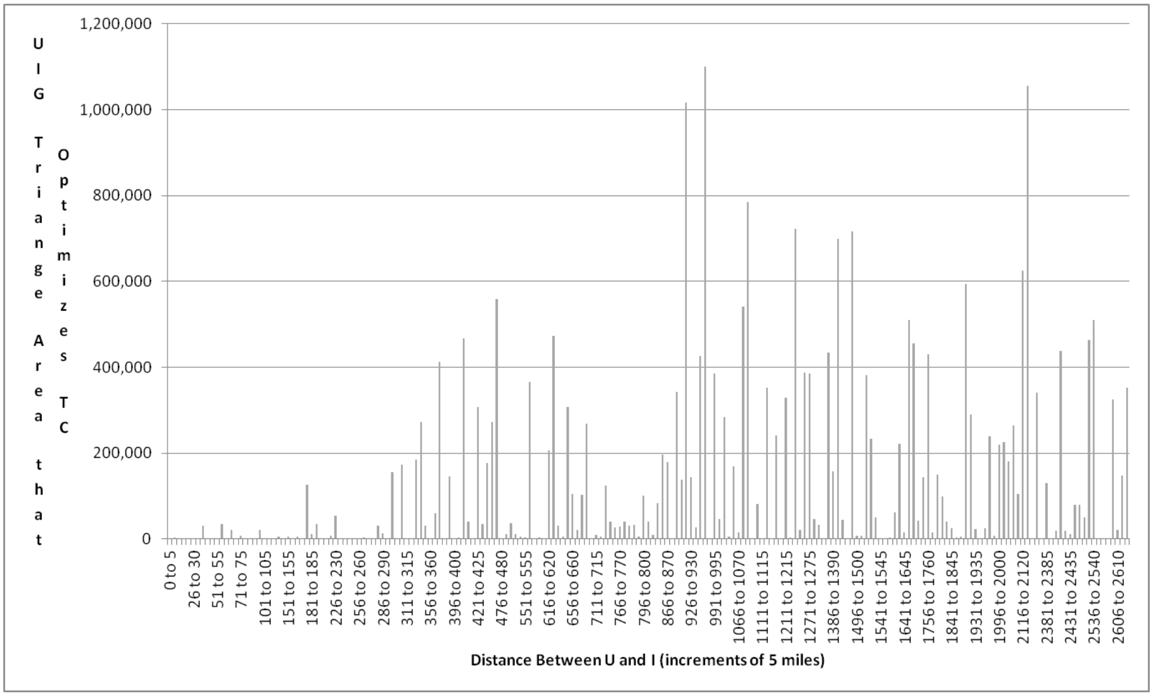
Interview numbers 3 and 13 in the above table seem to lend weight to the notion that individuals in the corporate world negotiate for a living and negotiation and its results are augmented by more proximity. Interview number 4 seems to lend weight to the notion that Industry and Government personnel are more skilled, on average, than University personnel, at engaging in advanced research (for technologies like nanotechnology). Particular emphasis is placed on the latter response given that the respondent was one of the few interviewed with both University and Industry experience and has participated in multiple UIG collaborations. For more on this see responses to Interview Question 16.

The Effect of University-Industry Proximity

Analyses up to this point have sought to identify optimal scales of federal agent engagement for all UI partnerships in this study's dataset. It is acknowledged, however, that Universities and Industry can engage each other at near and far proximities (within a given UIG collaboration). This raises the question of whether an optimal scale of federal agent engagement is in any way a function of the distance between University and Industry actors (for a given UIG collaboration). In other words: if the distance between U and I is near is it relatively more important that Government actors engage at a closer scale than when the distance between U and I is far? The present analysis seeks to address this question by holding the distance between U and I constant, letting Government actor scale of engagement vary and then, among all proximate variations of Government actor engagement (for a fixed distance between U and I) identifying the scale of Government actor engagement that optimizes citation impact (i.e. that produces the largest TC value). Scale of engagement is measured in terms of UIG triangle size[49].

We start by grouping the distance between UI actors into increments of five miles—i.e. all UIG nanopublications with a UI distance between zero and five miles are assigned to a first group, all UIG nanopublications with a UI distance between six and 10 miles are assigned to a second group, etc. Appendix D provides an overview of record counts, mean and max TC figures and optimizing triangle areas for the UI Distance Groups created by this schema. The scale of federal actor engagement that optimizes citation impact for each UI Distance Group (see Appendix D for a summary of these) can be visualized as follows:

[49] Mapping a given UIG collaboration on a Mercator projection will produce a triangle whose vertices represent the geographic coordinates of each collaborator. Triangle size (area) is then calculated via Heron's Formula.

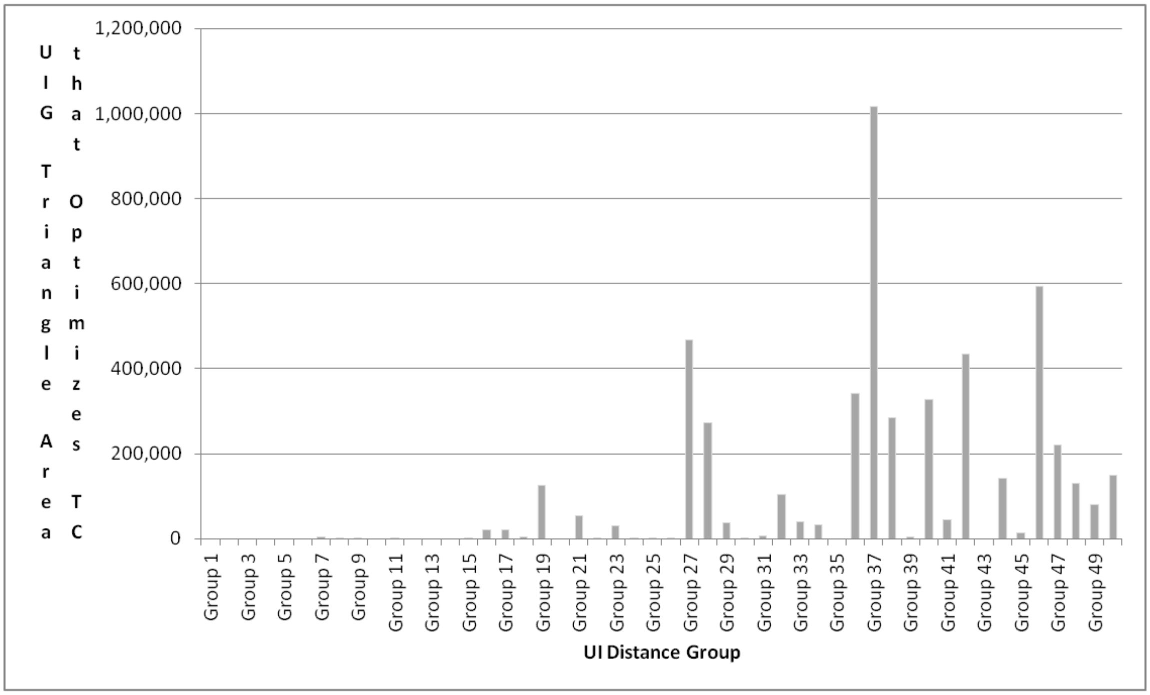


Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 450 UIG records partitioned into 201 UI distance groups; Timespan = 1990-2006; Unit of Analysis: UI distance groups

Figure 10: Optimal University-Industry-Government Triangle Sizes by Five-Mile UI Distance Groups (1990 to 2006)

From Figure 10 we observe that an optimal scale of Government actor engagement (i.e. one that maximizes TC) varies across the spectrum of UI Distance Groups (which is significant for the analyses that follow). The larger data points in this figure seem to cluster in middle of the x-axis, in a bell-shaped fashion, indicating that when Universities and Industry are very proximate or very distant it is relatively more important that the Government collaborator be proximate, and when Universities and Industry are neither proximate nor distant it is relatively more important that the Government collaborator be distant (in general). The point of the above figure is not to identify a hard and fast rule (or curvature) for what constitutes an ideal proximate interaction by Government collaborators across all UI Distance Groups, but to highlight the fact that citation optimizing scales of Government collaborator engagement differ across the spectrum of University-Industry proximities. Hence, when seeking to identify an ideal scale of Government collaborator interaction it is essential to take into consideration how proximate UI actors are.

Given the large number of UI Distance Groups in Figure 10 (201) several of these contain a low N of cases (see column 2 of Appendix D). To remedy this, Figure 11 plots exactly 50 UI distances groups (using the same data from Figure 10), each containing the same number of records (9). As group number increases, so does the distance between University and Industry—i.e. rightward movement along the horizontal axis in Figure 11 is associated with larger UI distances (see first footnote in this section for a description of how these were generated).



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 450 UIG records partitioned into 50 UI distance groups; Timespan = 1990-2006; Unit of Analysis: UI distance groups

Figure 11: Optimal University-Industry-Government Triangle Sizes by 50 University-Industry Distance Groups of the Same Record Count (1990 to 2006)

As with its predecessor, Figure 11 seems to generally conform to a bell-shaped curve (from Group 16 onward), highlighting the facts that (1) ideal scales of Government collaborator engagement are not uniform across all UI proximities, and (2) a closer scale of Government agent interaction is generally desirable for small and large UI distances, while a more distant scale of Government agent interaction is generally desirable when UI are neither proximate nor distant. It is noted, however, that most of the UI Distance Groups in Figure 11 seem to favor a closer scale of Government actor interaction (i.e. closer scales are more likely to optimize citation impact). This is especially true for Distance Groups 1 through 15 (which cover all UI distances between 0 and 60 miles). We note as well that the apex of the bell-shape in Figure 11 is moved farther to the right than was the case with its predecessor (i.e. Figure 11 exhibits negative skew).

One of the committee members of this dissertation has suggested that using triangle area as a proxy for proximity can potentially bias results given that a squared measure of distance can lend disproportionate weight to collaborations covering more space. To accommodate this concern the analysis performed in Figure 11 is replicated in Appendix E—but instead of using UIG triangle area as the vertical axis unit of measurement the square root of the same is employed. As is the case in preceding figures, the figure in Appendix E conforms to a bell-shaped curve (with smaller Distance Groups favoring as much Government collaborator proximity as possible). The point is again emphasized, however, that the curvature produced by Figures 10, 11 and Appendix E is secondary in importance to the finding that citation optimizing scales of Government collaborator engagement are not uniform across the spectrum of UI proximities.

Question 2 Conclusion

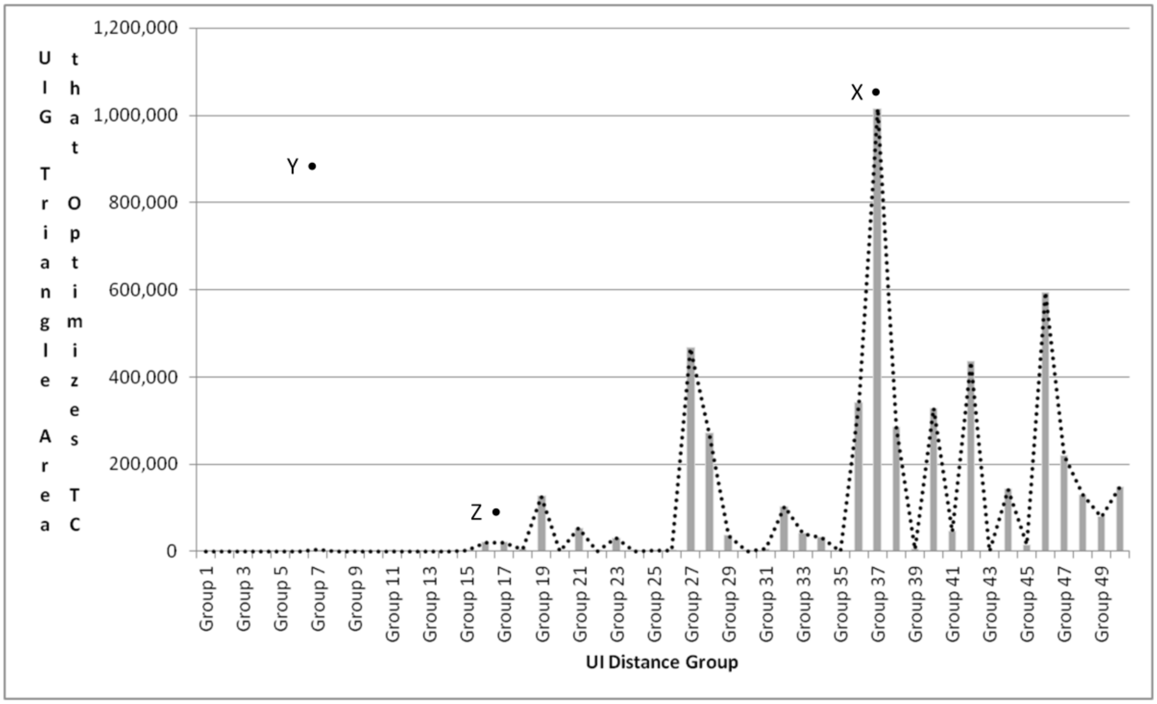
The preceding lends support to the conclusion that UIG citation impact is influenced by the scale at which Government collaborators engage with University and Industry. Citation impact is optimized when Government actors are at closer scales (i.e. the City level), for both University and Industry, but when Government actors are close with Industry this increases citation impact considerably more than when Government actors are close with Universities (i.e. being close with Industry seems to 'count for more'). Figures 10, 11 and Appendix E lend support to the notion that the scale of federal agent engagement that optimizes citation impact of UI partnerships is not uniform across all UI Distance Groups (i.e. large and small UI distances generally favor a closer scale of federal agent engagement for purposes of optimizing citation impact). Q1 focuses on whether the presence of Government collaborators adds value to UI partnerships. Q2 results demonstrate that the answer to Q1 depends on the position of Government collaborators (within a given UIG collaboration). Findings for both questions contribute to a better response to the third question posed in this study.

Question 3 Results

The third and final question driving this study is:

> ***Q3: How do actual scales of Government collaborator engagement in University-Industry partnerships compare against ideal scales for the same (i.e. scales at which the value added of Government agents is optimized)?***

To address this question it is useful to know: (1) actual scales of Government collaborator engagement, (2) ideal scales of Government collaborator engagement (i.e. scales that optimize their value-added), and (3) whether the distance between (1) and (2) is sufficiently close to be termed reasonably ideal. Identifying how close is close enough can involve somewhat of a judgment call. By way of illustration, if we linearly connect the columns in Figure 11 the new figure looks like a mountain range who's tallest peaks centrally cluster on the right side of the x-axis (at Distance Group 37):



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 450 UIG records partitioned into 50 UI distance groups; Timespan = 1990-2006; Unit of Analysis: UI distance groups

Figure 12: A Linear Connection of the Columns in Figure 11

The dotted lines in the above figure represent (approximate) optimal scales of Government collaborator engagement across the spectrum of UI Distance Groups. Points X, Y and Z represent three individual (Government collaborator) engagements. Which of these is close enough to the blue line to be considered ideal? X seems to be reasonably close, Y seems not close at all, but what about point Z? What criteria can be used to decide if this constitutes a hit or a miss?

Dataset

The dataset used to respond to Q3 is the same as the dataset used for Q2 (see Table 12).

Identifying Optimal Engagements from Categorical Scales

An initial technique for determining how many Government collaborator engagements can be termed optimal finds its basis not in UIG triangle areas, but rather in whether a given engagement occurs at any City/MSA/State level that optimizes citation impact (for a given UI Distance Group). By way of illustration, assume that a given UI Distance Group consists of 9 engagements (consistent with Figure 11):

Table 21: Government Collaborator Engagement in a Given University-Industry Distance Group

Government Collaborator Engagement #	Citation Impact	Scale of Government Collaborator Engagement with University	Scale of Government Collaborator Engagement with Industry
1	10	MSA Level	State Level
2	20	City Level	City Level
3	33	State Level	State Level
4	40	City Level	MSA Level
5	45	MSA Level	State Level
6	50	MSA Level	City Level
7	60	City Level	City Level
8	65	City Level	City Level
9	70	MSA Level	City Level

Source: Own analysis
Notes: N = 9; Timespan = NA; Unit of Analysis: Government collaborator engagements with University and Industry actors

The scale of Government collaborator involvement with Universities that optimizes citation impact in this table is the MSA level. The scale of Government collaborator involvement with Industry that optimizes citation impact in this table is the City level. In the above table, Government collaborators engage with Universities at an optimal scale 4 out of 9 times, or 44% of the time for this particular UI Distance Group. In the same table, Government collaborators engage with Industry at an optimal scale 5 out of 9 times, or 56% of the time for this particular UI Distance Group. Applying this rule to the data in Figure 11, Government collaborators engaged with Universities at an optimal scale in 85 instances, or 19% of the time (for all UI Distance Groups). Using the same rule, Government collaborators engaged with Industry at an optimal scale in 99 instances, or 22% of the time (for all UI Distance Groups).

The following table caters to those who would argue that looking at a top percentile of citation values is a more holistic approach. Table 22 considers all citation values that fall in the 90th percentile of citation impact (for a given UI Distance Group).

Table 22: Government Collaborator Engagement for a Given University-Industry Distance Group

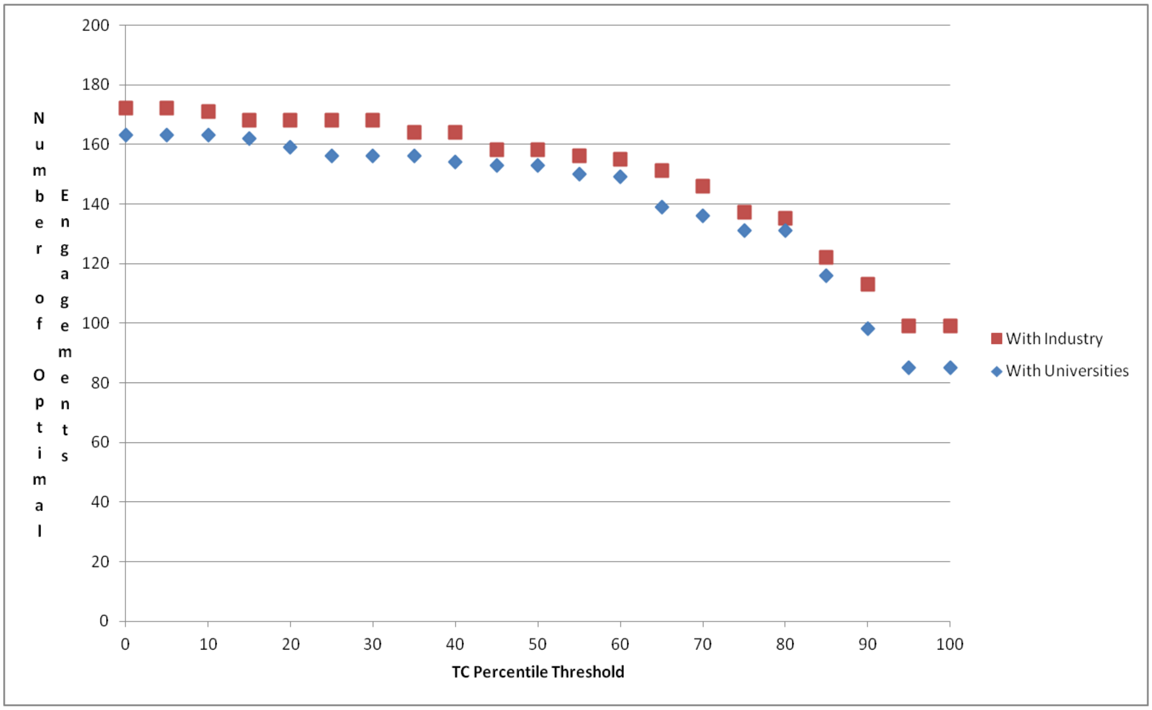
Government Collaborator Engagement #	Citation Impact	Citation Impact in 90th Percentile	Scale of Government Collaborator Engagement with University	Scale of Government Collaborator Engagement with Industry
1	10	no	State Level	State Level
2	20	no	City Level	City Level
3	33	no	State Level	State Level
4	40	no	City Level	MSA Level
5	45	no	MSA Level	State Level
6	50	no	State Level	MSA Level
7	55	no	State Level	State Level
8	60	yes	MSA Level	City Level
9	60	yes	City Level	City Level

Source: Own analysis
Notes: N = 9; Timespan = NA; Unit of Analysis: Government collaborator engagements with University and Industry actors

In Table 22 engagement numbers 7 and 8 fall in the 90th percentile of citation impact. The citation optimizing scale of Government collaborator involvement with Universities for these engagements is the City and MSA levels. The citation optimizing scale of Government collaborator involvement with Industry for these engagements is the City level. Using this (90% citation threshold) rule, Government collaborators engaged with Universities at a citation optimizing scale 5[*] out of 9 times, or 56% of the time for this particular UI Distance Group. Using the same (90% citation threshold) rule, Government collaborators engaged with Industry at a citation optimizing scale 3 out of 9 times, or 33% of the time for this particular UI Distance Group.

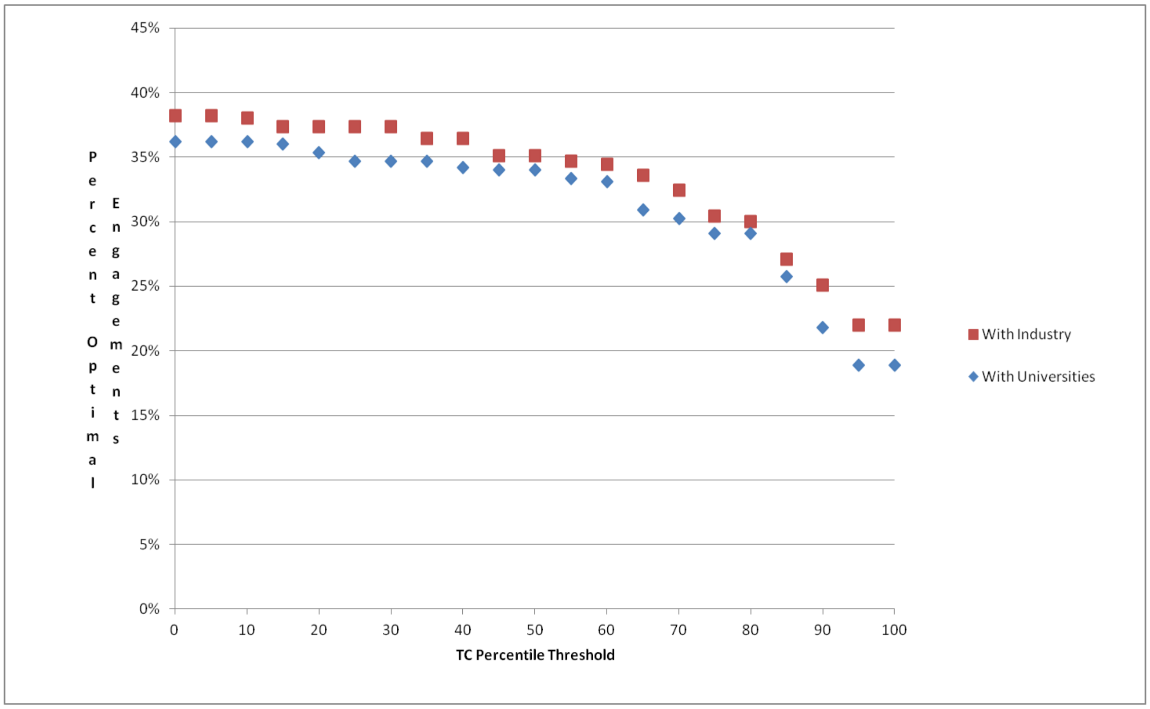
Applying the 90% citation threshold rule to all 50 UI Distance Groups reveals that Government collaborators engaged at optimal scales in 98 instances (or 22% of the time) with Universities and 113 instances (or 25% of the time) with Industry. As mentioned previously, however, notions of what constitute an 'ideal' engagement can involve somewhat of a subjective judgment call, delving into the realm of normative (as opposed to positive) policy analysis. While the argument can be made that the 90% citation threshold is a reasonable benchmark, Figures 13 and 14 cater to those who might prefer different benchmarks. These figures provide the number and percentage of optimal engagements for the following TC Percentile Thresholds: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95 and 100.

[*] i.e. five of the values in the fourth column of Table 11 are labeled either 'City Level' or 'MSA Level'



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2006; Unit of Analysis: number of optimal Government collaborator engagements

Figure 13: Number of Optimal Government Engagements for 20 Citation Percentile Thresholds (1990-2006)



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2006; Unit of Analysis: percentage of optimal Government collaborator engagements

Figure 14: Percentage of Optimal Government Engagements for 20 Citation Percentile Thresholds (1990-2006)

From the above two figures we note that Government collaborators consistently engage at more optimal scales with Industry than with Universities. We note as well that the percentage (and number) of optimal engagements seems to steadily decline up until the 70th percentile threshold, after which the decline (in optimal engagements) becomes more pronounced. In the language of economics, the number (and percentage) of optimal engagements seems to be relatively inelastic (or resistant to changes in TC Percentile Thresholds) up until the 70% citation threshold, after which it becomes more responsive. Of the above thresholds it is suggested a realistic benchmark not fall below 80 percent. Applying a no-less-than-80%-threshold to the data in Figure 14 reveals that Government collaborators engage at citation optimizing scales between 19 and 29% of the time with Universities and between 22 and 30% of the time with Industry.

Identifying Optimal Engagements from UIG Triangles

An alternative approach to determining whether an actual engagement is close enough to a citation optimizing scale to be termed reasonably ideal finds its basis in UIG triangle areas. From this perspective an engagement is said to be optimal if its UIG triangle area falls within a percentile range of a UIG triangle that area optimizes citation impact (for a given UI Distance Group). We begin with a percentile range of ±5%. By way of illustration, assume that a given UI Distance Group consists of 9 engagements (consistent with Figure 11):

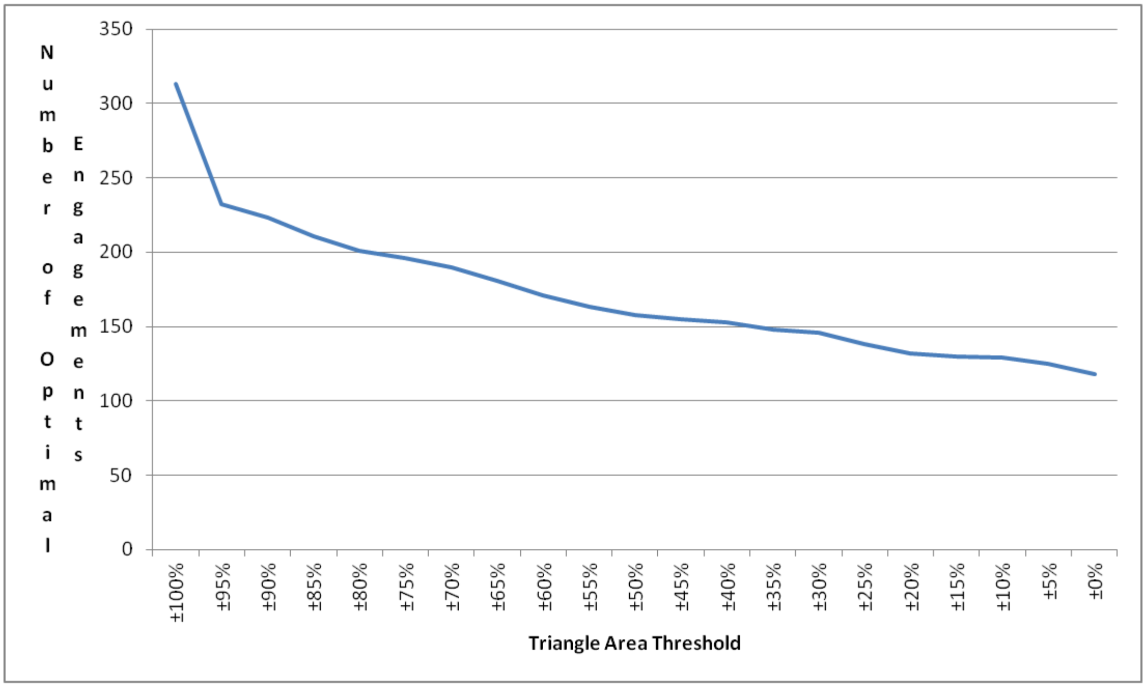
Table 23: Government Collaborator Engagement in a Given University-Industry Distance Group

Government Collaborator Engagement #	Citation Impact	University-Industry-Government Triangle Area	University-Industry-Government Triangle Area in ±5 Percentile
1	10	50	no
2	20	15	no
3	35	30	no
4	40	200	no
5	45	50	no
6	50	105	yes
7	55	30	no
8	60	95	yes
9	80	100	yes

Source: Own analysis
Notes: N = 9; Timespan = NA; Unit of Analysis: Government collaborator engagements with University and Industry actors

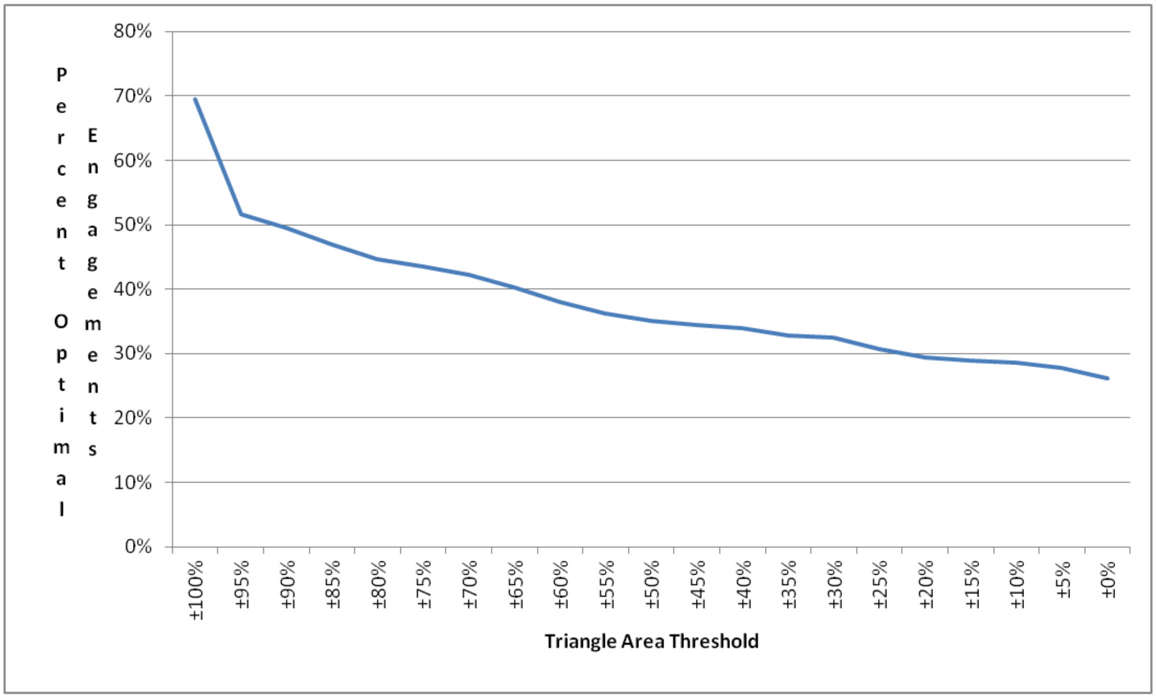
The UIG triangle area that optimizes citation impact in the above table is 100. Triangle areas for three of the above nine engagements fall within a ±5 percent of this area (i.e. Engagement #s 6, 8 and 9). Ergo, using a ±5 percent threshold Government collaborators engaged at optimal scales in 3 out of 9 engagements, or 33% of the time for this particular UI Distance Group.

Applying the ±5 percentage threshold rule to all 50 UI Distance Groups reveals that Government collaborators engage at optimal scales in 125 instances (or 28% of the time). As mentioned previously, however, notions of what constitute an 'ideal' engagement can involve somewhat of a subject judgment call, crossing into the realm of normative policy analysis. For those who might prefer different benchmark(s) the figures below provide the number and percentage of optimal engagements at the following triangle area (percentage) thresholds: ±5, ±10, ±15, ±20, ±25, ±30, ±35, ±40, ±45, ±50, ±55, ±60, ±65, ±70, ±75, ±80, ±85, ±90, ±95 and ±100.



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2006; Unit of Analysis: number of optimal Government collaborator engagements

Figure 15: Number of Optimal Government Engagements for 20 Triangle Area Thresholds (1990-2006)



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2006; Unit of Analysis: percentage of optimal Government collaborator engagements

Figure 16: Percentage of Optimal Government Engagements for 20 Triangle Area Thresholds (1990-2006)

We observe from the above figures that as the percentage triangle area thresholds increase, the number (and percent) of citation optimizing engagements by Government collaborators decreases. A realistic benchmark threshold of not more than ±20 is suggested (i.e. if the area of a given UIG triangle is larger or smaller than 20% of the area of a triangle in the same Distance Group that optimizes citation impact, it probably should not be considered an ideal scale of engagement). Applying a no-more-than-20%-threshold to the data in Figure 16 reveals that Government collaborators engage at citation optimizing scales between 26 and 29% of the time. We note that these results are comparable to those appearing in Figure 14.

Question 3 Conclusion

Q3 can be addressed via (at least) two approaches: (1) identifying citation optimizing scales using City/MSA/State levels of engagement, and (2) identifying citation optimizing scales using UIG triangle areas. The former approach indicates that Government collaborators engage at citation optimizing scales between 22 and 30% of the time for Industry and between 19 and 29% of the time for Universities. The latter approach indicates that Government collaborators engage at citation optimizing scales between 26 and 29% of the time (for Universities and Industry). Hence, these two approaches produce comparable, but not identical, results. Irrespective of the approach used, one can conclude from the preceding that Government collaborators engage at citation optimizing scales no more than 30% of the time. Results indicate there is room for improvement.

CHAPTER 6

INTERVIEWS

Introduction

This chapter provides a thematic overview of all interviews conducted in connection with this study. While preceding analyses can describe relationships in quantitative terms, they do not provide an explanation for why a given relationship is so. For example, numeric data can tell us that when Government collaborators engage with Industry at the City level research value appreciates more than when Government collaborators engage with Universities at the same level, but it doesn't tell us the reason why this is so. To get at the why behind the numbers this chapter provides results for a number of UIG interviews. These are expected to not only illuminate and clarify quantitative analyses, but also impart insights into the questions raised in this study not found in numeric data. It is noted that the previous chapter provides a number of qualitative insight sections (that emerge from this study's interviews) to accompany and shed light on quantitative analyses. When this occurs these insights are not repeated—i.e. they do not appear in the main text of the present chapter—but the more prominent are made reference to in the footnotes.

Methodology and Descriptive Statistics

Interviewees were selected from Georgia Tech's global nanopublication dataset. Recent nanopublications were given preference. In total, 16 interviews were conducted. Interviews were discontinued after: (i) the same themes began to remerge time and again, and (ii) new themes began to generally cease. Of those interviewed, four were University-affiliated, seven were Industry-affiliated and five were affiliated with

Government laboratories. The average time each interviewee has been associated with their present affiliation is 14 years (with five interviewees having worked more than 20 years at their present affiliation) and at least six interviewees report having collaborated in approximately five or more UIG collaborations (with four indicating participation in 10 or more UIG collaborations). Each respondent was asked 20 questions[50], most of which focused on the value that Government collaborators introduce to UI partnerships and how this is influenced by scale of engagement. The interviews themselves appear in Appendix G. Major themes that emerge from responses to interview questions appear below:

Theme #1: Proximity Matters, or at Least has the Potential to Matter

Virtually all of those interviewed in this study indicated that either (i) proximity made a positive difference in the case of their research, or (ii) has the potential to make a positive difference (i.e. if not for their particular research or working conditions then for someone else's). Responses differed in terms of how much of a difference proximity makes and under what circumstances or research areas[51] it makes the most difference. Responses to questions on whether proximity matters varied from an enthusiastic and unconditional endorsement of proximity's benefits to a mild acknowledgement of its potential to make a positive impact. Support for proximity's benefits seemed to depend, in large part, on the type of research the respondent engaged in. The response to Question 10 found in Interview number 14 is indicative of this point:

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[50] After a list of questions was assembled Professor Alan Porter (Georgia Tech) and Professor Jan Youtie (Georgia Tech) provided feedback on the question list and general guidance for conducting the interviews that appear in Appendix G of this study.

[51] See the Qualitative Insights section following Table 11 for a list of research areas and conditions which interviewees identified as deriving particular benefit from proximate interaction.

> I work on large datasets and numbers – we don't produce a product. We don't work in a lab. We don't analyze samples. We work on numbers. And so, when you work on numbers, whether you're close or not, it really doesn't matter. Of course being close makes a difference in other areas that require interaction.

By way of comparison, a more enthusiastic endorsement of proximity's benefits, based on personal experience of the interviewee, can be seen in the response to Question five of Interview number four:

> Yes. Absolutely. I found that, a lot of the time, when you're close to your collaborator there's more opportunity to exchange samples and discuss outcomes and plans. When your collaboration is far away you've always got to mail them your samples and that always adds more time to the process, and you can never really see their setup unless you go there, and that can raise barriers to understanding, especially when you're using a new technique.

Hence, virtually all of those interviewed indicated that proximity either makes a positive difference, or has the potential for the same, within the context of UIG collaboration for nanotechnology.

Theme #2: Government Collaborators Add Value

While the present study sets its focus on the scientific value Government collaborators introduce to UI partnerships, it is acknowledged that their contribution goes beyond this. Interviewees were asked what value Government collaborators provide in general. A list of Government collaborator value added items cited by respondents appears below:

- A broader perspective (and/or vision)
- Direction for research
- A basic research orientation
- Citation impact
- Funding
- Expertise

• Analytical techniques

• The ability to create a demand [for an end product]

• Facilities

• Equipment

• Leadership

• Intellectual interaction

• The ability to expand research capabilities

Hence, it is acknowledged that the contribution Government collaborators make to UI partnerships goes beyond citation impact. Government actors can make a number of additional contributions (some of which are difficult to quantify) to UI partnerships. Given its widespread usage and quantifiable nature, however, scientific (aka citation) impact remains the focus of this study. It is noted that some of the non-citation benefits listed above have the potential to translate or in some way contribute to the citation impact of UIG research.

Theme #3: Government Collaborators Provide Life-Sustaining Support

Question nine of the survey conducted in this study asks respondents if the outcome of their UIG collaboration would have been any different had a Government collaborator not become involved. While one interviewee replied: “Probably not”, virtually every other respondent provided an affirmative response. The most common explanation for how a given UIG partnership would be different had the Government collaborator not become involved was: “without their help this research wouldn’t have happened.” In these instances the Government collaborator often provided funding or expensive equipment upon which a given research project critically depended. In many instances the application of this expensive equipment to a given research project depended critically on Government personnel with the expertise to operate it. Hence, Government collaborator funding, equipment and expertise (which all appear in this chapter's second theme) often proved to be necessary ingredients to make a given research project take place.

It is observed that the above assets (i.e. funding, equipment and expertise) can be used as leverage when discussion related to optimal proximity arrangements occurs. For example, if a Government collaborator (in possession of expensive equipment and funding capabilities) enters into proximity discussions with an Industry partner it repeatedly collaborates with, and it is decided that more proximate interaction would significantly benefit the work they produce, the Government collaborator is in a relatively stronger position to request that the Industry partner narrow the proximity gap. Conversely, if an Industry or University collaborator is in possession of unique capabilities or expertise their relative bargaining position in proximity debates is enhanced. An interesting scenario arises when all three collaborators bring something unique to the table. Indeed, this is often a key reason why UIG partners collaborate. We note that Interview #12 responds to question six by observing: "[c]ollaborators make up for deficits among the other collaborators. Each person brings something to the table that the rest of the group needs." In these situations, if it's possible to specify the unique capabilities each actor brings to the table (and compare the same), and involve a mediator, it might then become more apparent which actor is in a relatively stronger position to request that other collaborators narrow the proximity gap.

Theme #4: Face to Face Meetings are Different than Skype

Question 12 of the survey conducted in this study asks respondents if they met their (UIG) collaborators face to face and, if so, why they did that instead of talking on the phone or using Skype. The responses that follow are emphasized for their insight. The first comes from Interview #3:

> …we definitely met face to face. Those were typically times we had group meetings and wanted to go over data together. We could have done webinars, but I hate those – it's hard to hear and you can't see people's reactions and where they're at. It's helpful to have everyone being access to all the information (and it's hard to do that over the phone). And it was only 15 minutes to get there.

The above respondent indicates that the ability to observe "people's reactions" and identify "where they're at" is an important component of interactive learning, and one which significantly benefits from proximate interaction. While information and telecommunication technologies (like Webinars) were at the disposal of the researchers involved in this collaboration, the respondent indicated they were not as effective as meeting in person. A second response of interest comes from Interview #14:

> Yes, we met face to face, usually in the occasion of meetings. The face to face interaction is usually more effective than any other type of interaction. You accomplish a lot more. Nonverbal communication and the ability to write on paper, work on team, observe facial expressions and body language can only be done face to face. Not even video conference allows for this.

As was the case with Interview #3, this respondent seems to indicate that personal interaction facilitates the transfer of certain types of knowledge that otherwise would not occur (i.e. this respondent indicates that video conferencing is not as effective as meeting in person). A final response (to survey Question 12) that will be highlighted here comes from Interview number five:

> Maybe it's a generational thing, but in face to face meeting you get far more information, and far more happens, than in an electronic meeting (where someone is often distracted and multi-tasking). Much more information exchange and much more happens. Face to face is often necessary to fully push something through.

The above responses underscore the importance of nonverbal communication, body language, attentiveness and enhanced information exchange as positive results of proximity, and harken back to the earlier discussion (in this study's Literature Review), by Hoekman and colleagues (2010), on the advantages of face-to-face interaction:

> …as with all human activities, physical co-presence remains important in carrying out the complex tasks associated with scientific research (Collins, 2001). Face-to-face interaction offers the possibility of having intense and complex forms of interaction in which not only language is involved but the entire behavioural complex. Contrary to modern communication media (e.g. e-mail, video conferencing) this enables the unique establishment of common reference frames through amongst others rapid feedback, pointing and referring to objects in real space, subtle communication, informal interaction and a shared local context (Olsen and Olsen, 2000). All these factors facilitate the creation of a common language, shared meaning within a research team and the passing on of knowledge that cannot easily be expressed in words or visualizations (Collins, 2001; Urry, 2002).

See question 12 responses of interviews 1, 7, 10, 11, 15 and 16 for thoughts similar to those that appear above.

The author contributes to the above discussion as well by noting that as the world becomes increasingly globalized a number of UIG partnerships will involve scholars who do not share the same native language. On such occasions it is suggested that effective communication will be significantly increased, and the potential for misunderstanding significantly decreased, if collaborators interact in person instead of through electronic media. While this observation is relevant for collaborators who share the same native tongue, it is emphasized as even more relevant for those who do not.

As has been previously noted, proximate interaction facilitates the transfer of tacit knowledge (Autant-Bernard et al., 2007; Howells, 2002). While tacit knowledge is, by definition, uncodifiable (and therefore difficult to fully capture or measure), the above quotes lend support to the notion that this type of information exchange is significantly benefited by proximate collaboration. It is again noted that Interview number five observes that face to face meetings differ from other forms of interaction in that "[m]uch more information exchange [occurs] and much more happens." While this respondent did not explicitly reference tacit knowledge as being included in the enhanced knowledge transfer (that comes with in-person interaction), the author was left with the sense that this represented a key component of the information exchange being referred to.

Theme #5: Involving Government Collaborators is not without Costs

While preceding analyses and interview results suggest that Government collaborators add significant benefit to UI partnerships, they also have the ability to impose costs. Identifying these can serve to impart a sense of the net value that Government collaborators bring to UI partnerships. Interviewees were asked to identify the major challenges or costs that came with involving Government collaborators in a given UI partnership. Downsides of collaborating with Government actors include:

- Onerous reporting requirements (e.g. keeping close tabs on spending, paperwork, etc.)
- Disagreements over intellectual property rights (and ownership rights in general)
- Difficulty gaining access to equipment and facilities
- Long wait times for obtaining access to experts, equipment or funding
- High overhead (i.e. it's very expensive doing business with Government collaborators)
- Government collaborators will sometimes ask for full cost recovery

Other than the red tape which typically accompanies working with a large bureaucracy, most respondents indicated an overall positive experience with the Government collaborator that became involved in their UI partnership. The author thinks it safe to conclude that, on a cost-benefit analysis, including Government collaborators resulted in a net benefit for the majority of UIG partnerships.

Conclusion

The interviews conducted in this study provide a number of insights that quantitative analyses, by themselves, cannot. In particular, it is revealed that Government collaborators introduce a number of benefits other than citation impact to UI partnerships. It is also revealed that UIG research oftentimes depends critically on some of the benefits (e.g. funding and equipment) provided by Government collaborators (i.e. many times UIG research could not occur without these benefits). It is suggested that the most important insights provided by this study's interviews are: (1) face to face meetings are different than Skype in that a number of respondents indicate they involve a greater exchange of information, and (2) the fact that research value appreciates relatively more quickly when Government collaborators engage at increasingly close scales with Industry than when Government collaborators engage at increasingly close scales with Universities is likely a result of the pairing of two groups of highly competent professionals (i.e. Industry and Government collaborators).[52]

The interviews conducted in this study also reveal that, while Government collaborators can introduce a number of positive benefits to UI partnerships, they also impose costs. In particular, Universities and Industry report that Government collaborators often impose onerous reporting requirements, make arduous demands (vis a vis intellectual property rights), can make access to their facilities and equipment difficult to obtain, can impose long wait times (for access to resources), and can impose high overhead. These costs notwithstanding, most respondents indicate an overall positive experience in including Government collaborators in a given UI partnership.

[52] See Table 8 in the previous chapter.

CHAPTER 7

DISCUSSION

Overview

This study advances an indicator for proximate interaction within UIG partnerships that contributes to knowledge production and proximity debates. In so doing, it seeks to document and incentivize performance enhancing spatial arrangements for a method of knowledge production important to the development of emergent technologies. Using this indicator the present analysis demonstrates that, within the UIG framework, value introduced by individual collaborators is spatially mediated. In particular, this study shows that Government collaborators do, in fact, add value to UI partnerships when they engage at ideal scales. (Scientific) value is generally optimized when Government collaborators engage at closer scales (when Universities and Industry are also close) and when Government collaborators engage at closer scales with Industry. This study also finds that the distance between University and Industry influences citation optimizing scales of Government collaborator engagement. In this respect, evidence exists that ideal scales of proximate engagement are interconnected (within UIG partnerships). Analyses conducted in this study indicate that Government collaborators engage at citation optimizing scales not more than 30% of the time. Results indicate room for improvement exists.

Building on the above indicator this study also advances an indicator of how responsive research value is to the engagement of UIG actors by individual members within a UIG partnership. This indicator appears in the Guidance for Future Research section (below), instead of Methodology and Data, because it is not actually applied in the present inquiry, but provided as a tool for future research. The questions it addresses go beyond the scope of the current undertaking (which focuses specifically on the engagement of UI partnerships by Government collaborators).

A Review of the Hypotheses Made in this Study

A number of hypotheses were advanced at the outset of this study. The first of these (H_1) is not confirmed. This hypothesis anticipated that Government collaborators would, on average, add significant (scientific) value to UI partnerships. It was thought unlikely Universities and Industry would continue to voluntarily and frequently collaborate with Government actors if the latter brought little or nothing to the table. While results indicate Government collaborators add significant (scientific) value to UI partnerships at certain scales of engagement, the same cannot be said for their engagement of UI partnerships in the aggregate. While it is anticipated Government collaborators probably add non-scientific value to UI partnerships in the aggregate, the measurement of such falls outside the scope of this study.

This study's second hypothesis (H_2) is supported by results. In particular, Tables 13 through 15 and Appendix F lend support to the notion that the value Government agents introduce to UI partnerships is not spatially uniform, but varies across different scales of engagement. In this study, closer scales of engagement are shown to be generally more profitable (in terms of citation impact). More specifically, if this study were to demarcate a tipping effect of proximity (i.e. boundary at which proximate interaction makes a considerable difference) it would be at the City level. The discussion related to Tables 13 through 15, Tables 18 and 19 and Appendix F elaborates on this point.

The study's third hypothesis (H_3) is also supported by results. Benefiting from guidance by previous research (e.g. Frenken et al., 2010) it was anticipated that results would vary by discipline. In particular, 'Physical Science and Engineering' and 'Biology and Medicine' were shown to produce more robust results (than other Meta Disciplines) for the 4-Classification Meta Discipline scheme, and 'Physical S&T' and 'Biology and Medicine' were shown to produce more robust results (than other Meta Disciplines) for the 6-Classification Meta Discipline scheme. Results generally comport with interview responses in the respect that interviewees cited research involving biological applications, interaction with the human anatomy and interaction with complex equipment as especially benefiting from proximate interaction.

The fourth hypothesis (H_4) advanced herein is also supported by results. As Government collaborators become increasingly proximate to Universities research value appreciates at a different rate than when Government collaborators become increasingly proximate to Industry. As Tables 18 and 19 indicate, not only are mean citations values larger in absolute terms for a given scale of Government engagement with Industry (as opposed to University), but the rate of research value appreciation for when Government collaborators become increasingly proximate to Industry is much higher than the same for when Government collaborators become increasingly proximate to Universities. If a Government collaborator has the option of closing the proximity gap with either University or Industry (but not both), it would be best served engaging at closer scales with the latter.

The fifth hypothesis (H_5) advanced in this study finds confirmation as well. Proximity dynamics governing the University-Industry institutional difference have a direct bearing on ideal or citation optimizing scales of Government collaborator engagement. The relationship between UI proximity and ideal scales of Government collaborator engagement generally conforms to curvilinear shape. Figures 10 and 11 and surrounding discussion elaborate on this point.

Relevance and Contribution to the Literature

A number of previous works on proximity are touched on in this study. It is noted that scholarship which argues that more proximity has a beneficial effect on research outputs (e.g. Katz, 1994) has partial relevance to this study. In particular, when Universities and Industry are proximate, (scientific) research value is optimized when Government collaborators are also proximate (see Distance Groups 1 through 15 in Figure 11). Scholarship which argues that too much proximity can undermine performance (e.g. Boschma, 2005) also has partial relevance this study. In particular, when Universities and Industry are not proximate, (scientific) research value will depreciate if Government collaborators become overly proximate (see Distance Groups with larger y-axis values in Figure 11). Hence, two distinct schools of thought, which seem to be saying different things, both see at least partial confirmation in this study.

The above scholarship on proximity is partially (and not fully) relevant to this analysis because the partnerships examined herein do not cleanly lend themselves to more traditional theories. While previous scholars (e.g. Boschma) argue for the development of additional classification schemes to account for new forms of proximity (e.g. cognitive and social proximity), the present analysis does not argue for new classification schemes as much as it does a recognition of an important sub-domain within proximity studies—one that exhibits unique and interrelated properties. UIG proximity dynamics are unique in that the amount of Government collaborator proximity that optimizes research value critically depends on the proximity between its University and Industry partners (hence, one proximity depends on—and is interrelated to—another).

UIG proximity dynamics are also unique in that proximity between the three UIG actors is not equally desirable or profitable. Ponds et al. (2007) posit that the role of proximity assumes greater importance when institutional differences exist. Present analyses concur with this position, but also find that proximity's impact assumes a relatively more important role for some institutional differences (i.e. Government collaborators and Industry) than for others (i.e. Government collaborators and Universities). Not only are mean citation values larger (in absolute terms) when Government collaborators engage with Industry than they are when Government collaborators engage with Universities across the same scales of engagement, but they appreciate at a faster rate moving from one scale to another. The proximate pairing of Industry and Government collaborators makes for results of exceptional quality in this study.

In the above and similar respects results of this study are applicable specifically to the UIG framework and the author cautions against generalizing these to other forms of knowledge production. UIG proximity dynamics present a unique and specialized case study within the larger proximity framework. While the indicator advanced herein could theoretically be applied to other (non-UIG) collaborations involving triple affiliations (e.g. three Universities), results and strategy are expected to significantly differ—i.e. the institutional heterogeneity within UIG collaborations makes resulting research value more responsive to spatial dynamics (Ponds et al., 2007) and this study has shown that within the UIG framework Government actors are better served closing the proximity gap with Industry than they are with their University partners (at least for nanotechnology). More traditional theories (e.g. Katz, 1994 and Boschma, 2005) are partially—but not fully—confirmed in the present analysis because the unique nature of UIG proximity dynamics necessitates theories that cater to the idiosyncrasies of this particular mode of knowledge production.

Validation is not partial for every theory discussed in this study. It is noted that previous scholarship which argues that the manner in which research value is spatially mediated differs by discipline (e.g. Frenken et al., 2010) is corroborated in this analysis (see Tables 13 through 15 and Tables 31 through 33). A number of those interviewed in this study also validate this finding when they indicate that proximity plays a more prominent role for certain subject areas and disciplines (see responses to Interview Question 13 for more on this).[53] The point is made, however, that previous scholarship (e.g. Frenken et al., 2010) which argues that the manner in which research value is spatially mediated differs by discipline focuses on total proximity among all collaborators (for a given collaboration). This study focuses, however, on how individual actors (e.g. Government collaborators), within a larger collaboration, influence research quality differs across disciplines (see Tables 13 through 15). The discussion related to Figures 20 through 22 focuses on the ability of individual UIG actors to influence research value

[53] It is noted, however, that the vast majority of nanopublications analyzed in this study are affiliated with Meta Disciplines whose research value is lends itself to spatial mediation. Hence, the preceding is generally relevant to most, but not all, disciplines within the nanotechnology framework.

across various disciplines (e.g. within the UIG framework Industry might demonstrate a superior ability to influence research value via proximity dynamics for 'Biology and Medicine' while Universities might demonstrate a superior ability to influence research value via proximity dynamics for 'Physical Science and Engineering'). Hence, the present study takes a more refined and specific approach than previous research in accounting for differences in research quality across different disciplines (i.e. it looks at the impact of individual UIG actors and uses a more precise measure of proximate interaction).

The present analysis also contributes to the literature in that it offers an updated assessment of proximity's influence. Previous studies (e.g. Frenken et al., 2005; Hoekman et al., 2010) have tested whether proximity has retained its ability to influence research outputs in the face of factors like the rise of the Internet and widespread use of English as a common language and find that proximity still significantly impacts research. This analysis, conducted many years after the work of Frenken et al. (2005) and Hoekman et al. (2010), finds that a significant relationship between proximity and research outputs still exists. It contributes to previous work on proximity's influence as well in that it provides results for a series of interviews, asking UIG collaborators whether proximity still matters and if telecommunications technologies (like Skype) have undermined its influence. The vast majority of those interviewed in this study indicate that proximity does, in fact, still matter, and meeting in person is generally more effective than other modes of interaction (like Skype). Theme #4 in Interviews chapter elaborates on this point.

This study advances an indicator for proximity among UIG collaborators that contributes to knowledge production and proximity debates. In so doing it demonstrates that, at the time of this writing, proximity still matters. It takes a more fine-grained approach than previous studies in demonstrating that individual actors within the UIG framework can significantly influence research value. In particular, it shows that the scale at which Government actors engage Universities and Industry meaningfully influences the quality of research outputs. It is also shows that room exists to improve efficiency (i.e. results indicate that Government collaborators engage at citation optimizing scales no more than 30% of the time). The present analysis builds on previous UIG proximity research in that it applies a more refined and precise measure for proximate interaction and does so at the individual actor level.

Theoretical Implications

A number of theoretical implications emerge from the preceding. This study calls attention to the advantages of efficient spatial arrangements for UIG partnerships in particular and highlights the ways ideal engagements for these can be seen as more consequential, and carries the potential for relatively greater profit, than alternative collaboration types. It is hoped that the identification of this potential will call greater attention to the importance of proximity policy and theory for this form of collaboration.

The first theoretical observation to be made considers additive profit potential for UIG partnerships. When firms are co-located they are able to combine and harness synergies more easily and efficiently than when they are distant. In their study on spatial proximity and innovation in the Dutch software sector Anet Weterings and Ron Boschma (2009) note:

> …most innovations occur when various firm-specific competences are combined (Nooteboom, 1999)…The basic motivation for a firm to approach other organizsations to obtain knowledge is to bring together complementary skills without having to make the high investments that would have been necessary if the firm had developed it internally (Tether, 2002).

In this line of thinking the more separate (in terms of competences) and specialized firms are, the greater the potential payoff when they partner (i.e. two firms who are virtually identical in capabilities do not stand to benefit from partnering as much as two firms who are more distant in skill sets). While this holds true for partnerships in the private sector, it is expected to hold truer still for UIG partnerships involving both private and public participants. In the study above Weterings and Boschma consider organizations within industry, but if, in addition to industry, we also consider what academia and government organizations bring to the table, a much broader range of competencies, capabilities and skill sets emerges—one that has the potential to yield, on average, larger pay-offs per partnership (making optimal spatial arrangements all the more important). UIG partnerships involve the pairing of separate organizations with separate competences, capabilities and skill sets. This pairing has the ability to produce results of considerable return—theoretically more so than industry-only partnerships. Accordingly, it is argued that efficient spatial arrangements for this collaboration type are relatively more important than, and should take precedence over, alternative proximate arrangements.

The second theoretical advantage of UIG partnerships over other collaboration types involves knowledge processing and decision-making. In their 2009 study of industry-only partnerships Weterings and Boschma posit: “[f]ollowing Nelson and Winter (1982), firms are subject to bounded rationality and, consequently, are unable to gather and interpret all necessary information for optimal decision-making. They rely on routine behavior to deal with this uncertainty.” While it is not argued UIG partnerships are immune to bounded rationality, it is suggested they are less encumbered by it than industry- or university-only partnerships. In his article on energy-efficient investments Stephen DeCanio argues that Government actors can help firms overcome bounded rationality obstacles. DeCanio (1993) writes:

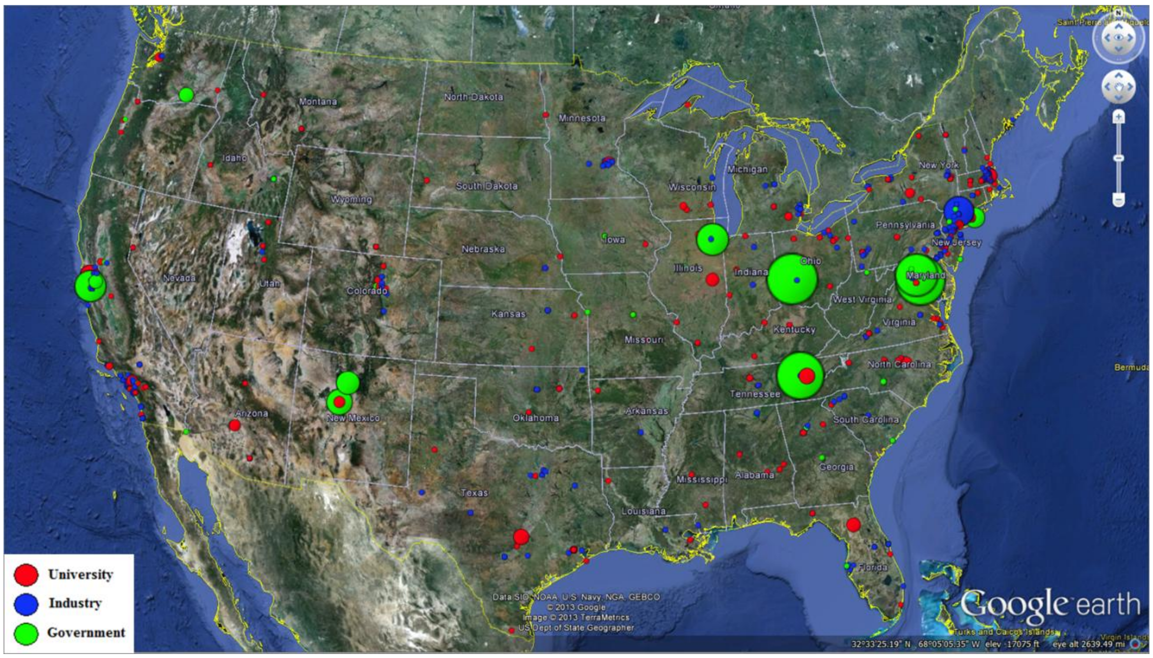
> Because of its central position and data gathering mandates, government is ideally situated to serve as a repository and distribution point for information on energy technologies. Private-sector firms often find it difficult to acquire knowledge about the set of technological options open to them, and to evaluate the characteristics of the technologies that do exist. Government agencies such as the EPA and the Department of Energy can efficiently collect, maintain, and disseminate information about energy saving possibilities.

Given their considerable resources the case can be made that Government actors are relatively less constrained by bounded rationality encumbrances than individuals and individual firms. Ergo, UIG partnerships theoretically have the ability to "see farther" and engage at more optimal scales more often than alternative collaboration types. For this reason we might hold UIG collaborations to a higher standard (when evaluating the efficiency of their engagements) and target this collaboration type for analysis and experimentation when researching ideal spatial arrangements and crafting policy for the same.

An additional advantage stems from the role of alternate proximity types, or lack thereof, in UIG collaboration. As has been previously noted, leading theorists—like those at the French School of Proximity Dynamics—have argued that, in addition to geographic proximity, other proximity types exist. In particular, scholars from the French School point to institutional and organizational proximity. Room for discussion exists as to how these types are related (Boschma, 2005). Ponds et al. posit that spatial proximity assumes a role of greater importance when institutional differences exist—these authors write: "geographical proximity is more relevant for collaboration between academic and non-academic organisations than for purely academic collaboration" (2007). Ergo, as alternative proximity types (e.g. institutional proximity) are removed, the role of spatial proximity becomes more pronounced. The implications for UIG collaboration—where multiple institutional differences, by definition, exist—are that spatial proximity dynamics are all the more consequential. This theoretical observation points, once again, to the importance and primacy of efficient UIG spatial arrangements, for the argument can be made that these arrangements are theoretically of relatively greater import, and have the potential for greater return, than alternate collaboration types.

Management and Policy Implications

A number of management and policy implications emerge from the preceding. Before outlining these, the point is again made that not every scale of interaction is equally justified. Results of this study demonstrate that certain scales of federal agent involvement are more profitable than others. Accordingly, the case can be made that intervention by Government actors at these scales is more desirable, ceteris paribus, than intervention at alternate scales. The case can also be made that differences between actual and ideal (i.e. citation optimizing) scales of engagement by federal agents in UI collaborations are also deserving of attention. If federal laboratories (and other Government entities that engage with UI partnerships) cluster in certain areas of the country (e.g. Washington, DC), and these clusters prevent Government collaborator value added from reaching its potential, policymakers ought to consider the strategic positioning of new labs (and/or relocation or existing labs) in locations that make performance optimizing scales of UIG interaction more likely (as well as incentivizing interaction at these scales for laboratories already situated in performance enhancing locales). The figure below plots the distribution of University (red icons), Industry (blue icons) and Government (green icons) collaborators onto a map generated with benefit of Google Earth,[54] for the dataset (1990 to 2011) analyzed in this study[55]:



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 1,161; Timespan = 1990-2011; Unit of Analysis: individual UIG actors

Figure 17: Map of all University, Corporate and Government Actors Analyzed in this Study

In the above figure, icon size is proportional to record counts. The green icons (i.e. Government collaborators) in this figure are noticeably larger than the blue and red icons because the same Government actors repeatedly collaborate (with different University and Industry partners). From the figure above it appears that University and Corporate

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[54] See http://www.google.com/earth

[55] Note: It is difficult to map each and every UIG affiliation analyzed in this study given that affiliations co-located in the same city will overlap—if one of these icons is larger than the other Google Earth can map the smaller on top of the larger, but if they are the same size it is difficult to render both.

actors are more geographically diffuse than their Government collaborators (i.e. it seems the spatial distribution of federal laboratories is not in sync with the geography of Universities and Industry in the United States). From the misalignment between Government collaborator and non-Government collaborator icons in the above map it shouldn't come as a surprise that preceding analyses indicate Government collaborators engage at citation optimizing scales not more than 30% of the time. Results suggest that if federal laboratories were less concentrated (i.e. more diffuse) UIG research value would stand to significantly benefit.

In light of the preceding the following proposals are made:

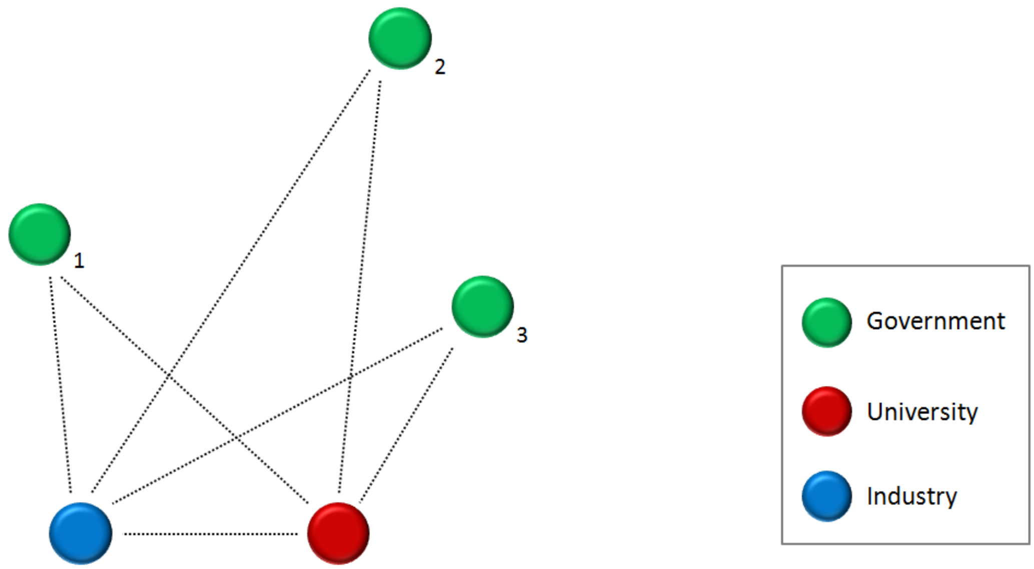
1. When building new federal laboratories policymakers and regional planners ought to consider their strategic placement in locations that make performance optimizing scales of UIG interaction more likely. Proximity to Universities is important and proximity to Industry is very important. We note, for example, from Figure 17 that in the state of Texas no major federal lab activity occurs, but a sizeable presence of corporate and academic entities exists. To identify strategic locations for new labs it is recommended policymakers draw on Figure 17 to identify all regions that do not already house a federal lab but contain sizeable concentrations of academic and corporate entities.
2. If a given federal laboratory is not performing on par with other federal laboratories, policymakers ought to consider relocating this laboratory within a radius of Universities and Industry that would optimize the value of the research it produces. Given that relocation is expected to be impracticable in most situations (at least for larger labs), an alternative is to establish satellite offices for a sub-

performing federal lab located in ideal proximity to its major collaborators (discussed in greater detail below). Another alternative is to have the lab and its facilities/equipment/personnel absorbed into a better performing lab, but one which does not rank in a Top 10 category—increasing the abilities of the absorbing lab and making it more competitive with the leading labs in this study (see Table 1). By making less competitive laboratories more equal in ability with Top 10 laboratories the decision (made by UI partners) of which laboratory to collaborate with does not have to be driven by unique capabilities, but can be guided instead by identifying the scale at which ideal collaboration occurs.

3. Federal funds are limited, especially in times of budget cuts. During times of fiscal restraint more profitable research should be given (funding) priority. When deciding which of two or more potential UIG partnerships ought to be funded, if these are similar in every respect with the exception that the one occurs at a scale of interaction likely to optimize its research value, while the others do not, preference should be given to the former. By way of illustration, in the figure below a given UI partnership has the option of engaging with three federal labs with comparable facilities (or, from the perspective of Government collaborators: three federal labs with comparable facilities have the option of engaging with a given UI partnership). While the location of each federal lab in this figure is fixed,[56] the decision on which of these should engage with the UI partnership in this figure is not. Let us assume that collaboration between this UI partnership and federal lab #1 represents the scale at which the value of resulting research is

[56] An alternative perspective is to view this scenario as characterized by one federal laboratory that can assume three positions (instead of three that can assume one position). From this point of view federal lab location is not fixed per se.

optimized for this particular UI Distance Group. The argument is made that that engagement at this scale should be prioritized and/or incentivized.



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 18: Three Potential Engagements by Government Collaborators

4. As a corollary to the previous proposal—in times of prosperity, when federal funding is available for copious UIG partnerships, funding can be pro-rated based on proximities between collaborators. For example, a UIG partnership could receive a gold package (i.e. a significant amount of funding) if all three collaborators engage at an ideal proximity, a silver package (i.e. a moderate amount of funding) if two of the three collaborators engage at an ideal proximity and a bronze package (i.e. a modest amount of funding) if none of the collaborators engage at an ideal proximity.

5. While the location of federal labs is somewhat fixed, the location of (yet to be built) satellite offices is not. The construction of satellite facilities in regions housing institutions of frequent collaborators can serve to significantly narrow the proximity gap. For example, a given institution (outside of the DC area) that frequently collaborates with an institution in the DC area ought to consider establishing a DC branch office that would facilitate more proximate interaction. This proposal is especially relevant for collaborators with greater ability to be mobile, or to collaborators who are relatively more dependent on the services provided by their partners. Unique assets can be used as leverage in negotiations related to ideal proximity arrangements. For example, if a given UIG actor (in possession of unique equipment and expertise) repeatedly collaborates with a given partner at distance, and it is decided that more proximate interaction will significantly benefit the work they produce, the former will be in a stronger position to use its assets to lobby the latter to establish a satellite office in the former's vicinity (instead of vice versa). As a management practice it is recommended that University, Industry and Government collaborators rotate their personnel in and out satellite offices they establish (to facilitate proximity). This practice is expected to enhance the experience and networks of personnel rotated through these offices. It is also expected to help the rotating affiliation better identify which of its researchers benefit most from proximate interaction, and contribute most to the same. It was earlier suggested that collaborating scholars who do not share the same native language might benefit relatively more from proximate interaction than collaborating scholars who do share the same native

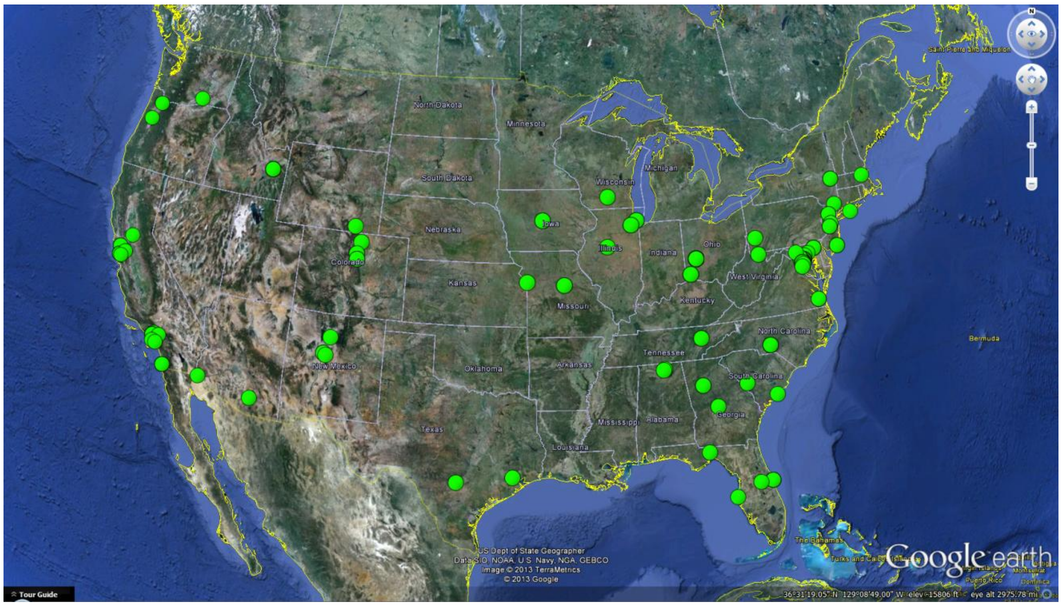
language. This hypothesis can be tested in the context of various satellite office rotation schemes. Other hypotheses (vis a vis which researchers perform best under more proximate conditions) can be tested in the same context as well.

6. Building on the previous proposal it is suggested that policies which encourage Government collaborators to take sabbaticals with major and longstanding UI collaborators would serve to significantly benefit proximate interaction. Such sabbaticals could be taken in satellite branch offices or collaborator facilities designed for this purpose. Such sabbaticals could also be taken in federal laboratories housed in regions marked by a high degree of (UIG) collaboration. Rotating personnel through the various federal labs is expected not only to foster proximate interaction and develop personal network ties, but also cross-train personnel on laboratory equipment and enhance the expertise and capabilities of such individuals. By making laboratory personnel (and federal labs themselves) more equal in terms of capabilities and expertise decisions by UI partners on which labs to collaborate with could be guided more by optimal scales of engagement and less by unique lab capabilities (discussed below). Sabbatical duration can vary depending on the length of a given project or time needed to develop expertise, significant network ties or foster long-term interaction (as well as on the nature of the research involved). Management is expected to benefit by debriefing those recently finishing sabbaticals and use their feedback to develop best practices and prepare those about to embark on a sabbatical. A management practice encouraged for testing the efficacy of various configurations of this proposal is to rate the performance of labs engaging in this behavior and labs that

do not and compare results—i.e. lab performance could be regressed on a number of explanatory variables, one of which is a binary variable indicating whether a given lab adopted this practice or not. The performance of individual personnel within a given lab could be rated in a similar manner—i.e. individual performance could be regressed on a number of explanatory variables, one of which indicates whether the individual had taken a sabbatical or not (and/or how long for). Such performance evaluations are expected to assist management in efforts to fine-tune sabbatical frequency and length, which are anticipated to vary in effect across different research areas and lab types.

7. Enhanced technology transfer (along with the transfer of other assets) between federal labs themselves is advocated to the degree that it makes them comparable in terms of capabilities. We note that some UI partners decide to collaborate with federal labs located at great distance (or non-optimal scales of engagement) because of the lab's unique capabilities or assets. If technology transfer were to occur between federal labs to the point where they were comparable and/or competitive the decision of which labs UI partners collaborate with would not have to be spatially constrained or (pre)determined. The map of Government collaborators in Figure 17 does not paint a competitive picture in terms of federal lab activity—i.e. a small number of Government collaborators produce a large volume of UIG nanotechnology research, while a large number of Government collaborators produce a small volume of the same. If all Government

collaborators in Figure 17 produced the same volume of UIG nanotechnology research their icon sizes would look like this[57]:



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 158; Timespan = 1990-2011; Unit of Analysis: individual Government actors

Figure 19: Map of all Government Actors Analyzed in this Study (Equal Icon Size)

It is suggested that the discrepancy in (green) icon size between Figures 17 and 19 can be—at least partially—seen as the result of an unequal distribution of resources and capabilities among Government actors. A more uniform distribution of these assets would allow UIG partnerships to occur at more optimal scales of engagement. We observe from these figures that a number of major labs (e.g. Pacific NW, Los Alamos, Sandia) are situated in locations with low population

[57] Note: Some cities house more than one federal entity—i.e. a number of cities in Figure 19 are assigned multiple icons, but it's not apparent from this map given that all icons are the same size.

densities and/or little University and Industry presence. The transfer of technologies (and other assets) from these labs to (less competitive) labs situated in more populous regions with greater University and Industry presence would serve to benefit US UIG research in the aggregate.

The proposals above involve a number of stakeholders. The following table seeks to provide actor specific guidance (pre- and actual collaboration) for the major stakeholders involved:

Table 24: Actor Specific Policy Guidance

Actor	Pre-Collaboration	Actual Collaboration
University Actor	Based on distance from Industry partner identify an ideal scale of engagement with a Government collaborator and identify all viable collaboration options at this scale.	If the (UIG) partnership occurs at a sub-optimal scale, see if this can be remedied via satellite branch offices, short-term trips, sabbaticals, etc. Consider lobbying for the same if these are not immediately available.
Industry Actor	Based on distance from University partner identify an ideal scale of engagement with a Government collaborator and identify all viable collaboration options at this scale.	If the (UIG) partnership occurs at a sub-optimal scale, see if this can be remedied via satellite branch offices, short-term trips, sabbaticals, etc. Consider lobbying for the same if these are not immediately available.
Government Actor	Rank all UI collaboration invitations according to how ideal in scale they are and prioritize accordingly.	If the (UIG) partnership occurs at a sub-optimal scale encourage frequent face to face interaction – the possession of unique assets and facilities can be used as leverage in negotiating who travels where and when.

Table 24 (continued)

Policy-Makers	Incentive interaction at ideal scale of engagement (using the levers mentioned in preceding proposals). When constructing new federal labs consider their strategic placement in locations likely to optimize performance (based on ideal scales of engagement). Identify federal labs housed in regions with a significant university and industry presence but that are not competitive in terms capabilities with leading labs and arrange for (greater) technology transfer (along with the transfer of other assets) to these labs (from leading labs).	NA
Regional Planners	Survey the local landscape with an eye for a sizeable university and industry presence but no major federal lab activity. If this or similar scenario exists lobby policy makers to consider the placement or relocation of federal laboratories in this vicinity (or construction of satellite office for the same). If a federal lab preexists in the region, but its contribution to UIG research is negligible and the reason for this is a lack of capabilities on par with leading labs, lobby policymakers for the transfer technology and other assets to the point where the lab is competitive.	NA

Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: NA

Given that optimal scales of interaction are shown to differ by discipline, the argument can be made that policy implications should be made domain-specific. For example, among Porter's four Meta Disciplines proximity is shown to have a significantly greater ability to influence research value for 'Biology and Medicine' and

‘Physical Science and Engineering’ than it does for ‘Environmental S&T’ and ‘Psychology and Social Sciences’. Accordingly, the preceding proposals are more relevant to the former than the latter. It is noted, however, that the vast majority of nanopublications analyzed in this study are affiliated with Meta Disciplines whose research value is amenable to spatial mediation. It is also noted the responsiveness of research value is to engagements by individual UIG collaborators can vary across disciplines as well. This is discussed further in the next section.

In addition to the above, R&D managers should be made cognizant, not only of the positive externalities associated with proximity, but also the negative. Policies that discourage too much proximity can serve to preempt inertia and lock-in (Boschma, 2005). Brian Darmody and Richard Bendis have called for the establishment of a congressionally chartered federal lab authority to assign federal lab assets to the private sector (2012). This study posits that such an authority can play a useful role in the allocation of federal assets at scales that optimize their value within the context of UIG relations.

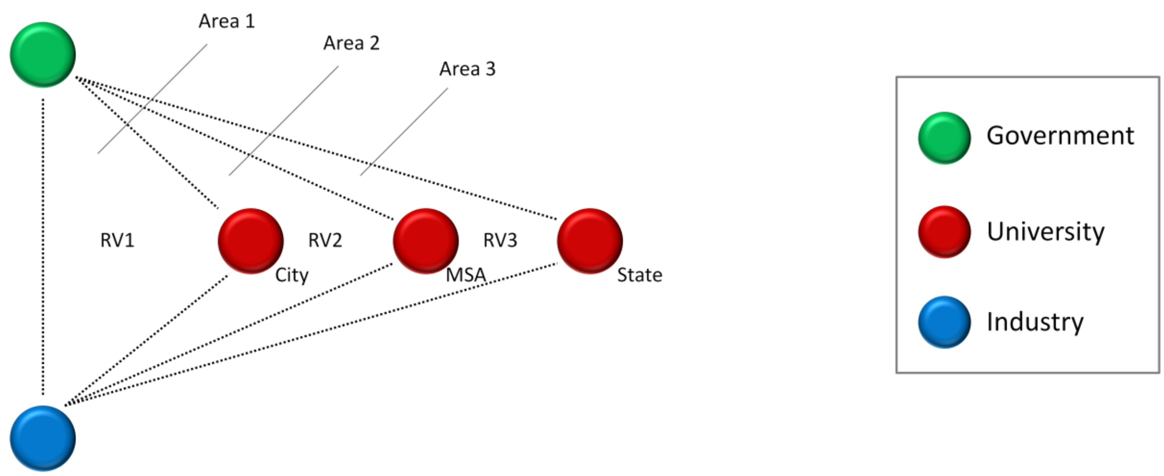
Guidance for Future Research

Future research is encouraged to extend the present analysis to countries and disciplines not covered in this study. While the argument can be made that the nanotechnology industry in the United States provides a good initial case study, this analysis stands to significantly benefit from application to other countries and technologies. Previous work (Frenken et al., 2010) has shown that proximity dynamics can significantly differ across different technology domains. It is anticipated that these dynamics are likely to differ across nation states as well (i.e. it is hypothesized that smaller countries will have different proximity dynamics than countries that are spatially large). Applying the present analysis to other countries and technology platforms can only serve to better inform policy.

Future research is also encouraged to apply this framework to scales at which Universities and Industry engage (with their UIG partners) and compare results with the results in this analysis to see which of the three UIG actors has the greatest ability to influence research outputs via proximity dynamics. This study has shown that proximity between Industry and Government collaborators has a stronger effect on research value than proximity between University and Government collaborators. Accordingly, it is hypothesized that Industry's ability to influence research value via proximity dynamics will generally be stronger than those of University actors. If this hypothesis is confirmed it is interesting to then see whether Industry or Government collaborators have a greater ability to influence research value via proximity dynamics.

One technique for implementing the above suggestions is PSM. The author had originally intended to use this tool to address the questions raised in this study, but encountered difficulty obtaining good match criteria between treatment and control groups. Accordingly, other quantitative techniques were used. Incorporating PSM results, however, would only serve to illuminate the preceding. Charting the incremental value added introduced by Government collaborators (V_G) (in addition to the total value of the research produced by the UIG collaboration—V_{UIG}) in relation to scale of interaction is of special interest. If and when good match criteria become available future research is encouraged to apply PSM to the questions raised in this study – not only to identify the incremental value introduced by Government collaborators (V_G), but also to identify the incremental value introduced by University (V_U) and Industry (V_I) collaborators. A comparison of how responsive V_U, V_I and V_G scores are to different scales of interaction would only serve to better inform policy.

An alternative (to PSM) for identifying how responsive research value is to different scales of engagement by the three UIG actors is to implement a Research Value Responsiveness Index (RVRI) based on the ratio of change in research value (RV) to change in scale of interaction (measured in UIG triangle area) for a given UIG collaborator. By way of illustration: University interaction at the City/MSA/State level with Industry and Government collaborators (separated by a fixed distance) can be visually depicted as follows:



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

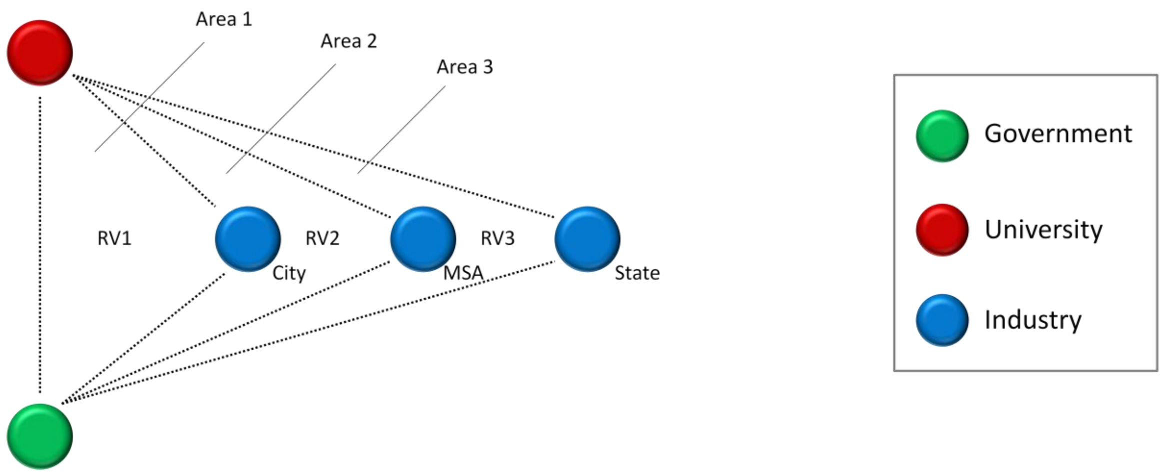
Figure 20: Research Value Responsiveness Index Illustrated for the Engagement of Industry and Government Collaborators by Universities

In the above figure the distance between Industry and Government collaborators is held constant (in the same way UI Distance Groups are held constant in Table 12), and each

UIG triangle provides: (1) an RV (measured in terms of citation impact), and (2) a scale of interaction (measured in terms of UIG triangle area). Changes in the first variable with respect to changes in the second variable provide insight into how responsive research quality is to different scales of interaction by Universities. As Universities move from an MSA to a City scale of engagement this Index can be expressed as follows:

$RVRI_U = [\Delta(RV)/\ \Delta(Area)] = [(RV1-RV2)/(Area\ 2-Area\ 1)]$[58]

Proceeding in a similar fashion, all Industry interaction at the City/MSA/State scales with University and Government collaborators (separated by a fixed distance) can be visually depicted as follows:



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

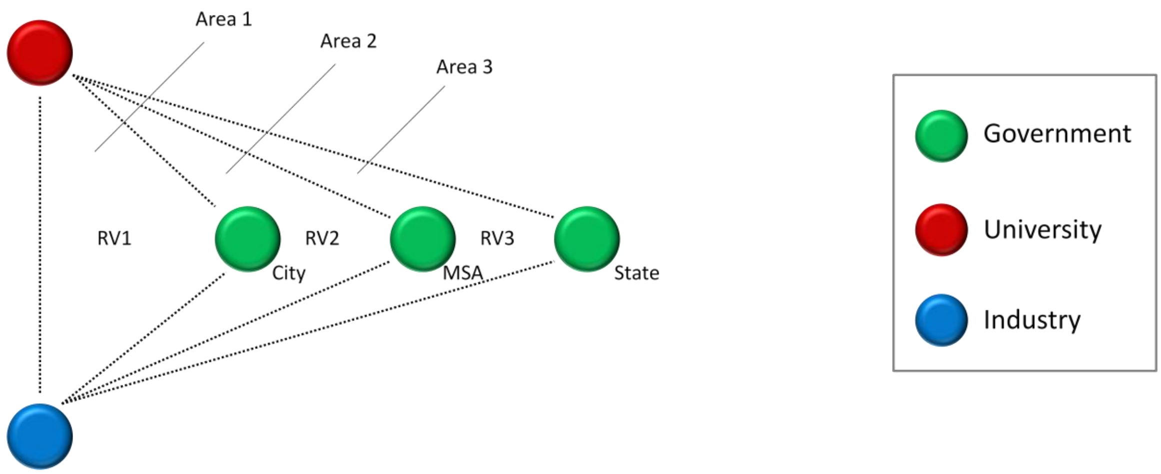
Figure 21: Research Value Responsiveness Index Illustrated for the Engagement of University and Government Collaborators by Industry

[58] Note: this identify subtracts RV2 from RV1 (instead of vice versa) because RV1 is expected to be larger than RV2. Hence, $RVRI_U$ is expected to have a positive value (in most instances).

In the above figure the distance between University and Government collaborators is fixed and each UIG triangle again provides: (1) an RV (measured in terms of citation impact), and (2) a scale of interaction (measured in terms of UIG triangle area). As Industry moves from an MSA to a City scale of engagement this Index is expressed as follows:

$RVRI_I = [\Delta(RV)/\ \Delta(Area)] = [(RV1\text{-}RV2)/(Area\ 2\text{-}Area\ 1)]$

Finally, all Government collaborator interaction at the City/MSA/State scales with University and Industry collaborators (separated by a fixed distance) can be visually depicted as follows:



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 22: Research Value Responsiveness Index Illustrated for the Engagement of University and Industry by Government Collaborators

In the above figure the distance between University and Industry is fixed and each UIG triangle again provides: (1) an RV (measured in terms of citation impact), and (2) a scale of interaction (measured in terms of UIG triangle area). As Government collaborators move from an MSA to a City scale of engagement this Index can be expressed as follows: $RVRI_G = [\Delta(RV) / \Delta(Area)] = [(RV1-RV2)/(Area\ 2-Area\ 1)]$

Future research is encouraged to apply the RVRI metric[59] within the context of the above (or a similar) study to identify which UIG actor possesses a greater ability to influence research value via proximity dynamics. If, for instance, Industry has a better ability than Universities to influence research value via scale of engagement (i.e. if $RVRI_I > RVRI_U$) this has implications in terms which UIG actor policymakers should most encourage (or incentivize) to narrow the proximity gap as well as which spatial arrangements should be prioritized. It is noted that RVRI (for individual UIG actors) is likely to vary across technology domain and/or the type of research being conducted. For example, Industry might demonstrate a superior ability to influence research value via proximity dynamics for 'Biology and Medicine' and a lesser ability to influence research value via proximate interaction for 'Physical Science and Engineering'. Results along these lines produce implications for policy.

A final suggestion for future research is more semantic in nature. Some scholars (e.g. Boschma, 2005; Mattes, 2012) argue that proximity can be categorized in a number of ways. Some of the dimensions they propose can be a challenge to measure. As new indicators become available for alternate forms of proximate interaction future research is encouraged to apply these within the context of this study. Identifying how much

[59] As an aside note, it is not difficult for the author to write a script ('RVRI Calculator'), for any given UIG dataset, that prompts the user for (i) an affiliation to calculate an RVRI score for (e.g. Industry), (ii) a Distance Group for the remaining UIG collaborators (e.g. all instances where University and Government collaborators are separated by at least 5 but no more than 10 miles), (iii) a scale of engagement change for the affiliation from (i) (e.g. when Industry moves from an MSA to a City scale of engagement), and then calculates an RVRI score for the affiliation from (i) based on these inputs.

proximity is desirable within alternative classification schemes, as well as how these relate, is expected to better inform policy.

Limitations

It is acknowledged this study is not without limitation. To begin with, UIG is not the only form of knowledge production, and that the indicator advanced in this study will not be compatible with most other modes of knowledge production—i.e. this approach is not likely to generalize well to non-UIG forms of knowledge production. Indeed, in critiquing the literature the author argues that UIG proximity dynamics represent a unique form of interaction, distinct in nontrivial ways from non-UIG forms of interaction, and must therefore be analyzed in their own rite (i.e. as a subfield within proximity studies). It is acknowledged as well that the primary unit of analysis in this study (i.e. nanotechnology publications) provides an important, but not comprehensive, piece of the UIG knowledge production puzzle. It is also acknowledged there are other (less direct) ways for Government collaborators to engage with Universities and Industry that this study does not control for. Finally, it is acknowledged that critics have long contended that citation impact is a less than perfect indicator of research quality.

Conclusion

The indicator for proximate interaction advanced in this study finds that Government collaborators add (scientific) value to UI partnerships at select scales of engagement. Closer scales are found to be generally more profitable for most domains within the nanotechnology framework, but citation optimizing scales of Government collaborator engagement in large part depend on the proximity between University and Industry actors. This study also finds that research value appreciates relatively more quickly when Government collaborators engage at increasingly close scales with Industry than when Government collaborators engage at increasingly close scales with Universities. Finally, results of this analysis indicate that Government collaborators engage at citation optimizing scales not more than 30% of the time.

From the preceding it is noted that the role federal labs play in the NIS is increasing over time. This study argues for a policy that guides additional increases by optimal scales of engagement with collaborating entities. A policy conducive to optimizing the value of collaborative research should remove impediments to UIG partnerships making collaboration decisions based on ideal scales of engagement. It is natural to view the location of Government collaborators as fixed—and scales of engagement somewhat predetermined. This study argues, however, that collaboration decisions do not have to be seen as spatially predetermined (i.e. choice exists for policy purposes). Federal lab location can be viewed as variable from the perspective that a large number of these exist, giving UI partnerships some choice in which to interact with—i.e. if all federal labs are viewed as a single entity with the ability to assume multiple locations (one for each lab along with their satellite offices) various proximity configurations (and policies) become more viable.

In addition to viewing the location of federal labs as ‘less fixed’, policy options are available for making the location of federal labs ‘less fixed’ (for collaborative purposes). Key among these is to make federal labs more equal in terms of capabilities. Increased technology transfer (along with transfer of other assets) between federal labs will disseminate capabilities and increase lab competitiveness. If federal labs are more competitive in terms of capabilities and resources the decision of which labs UI partners collaborate with can be guided more by ideal scales of engagement and less by the unique assets of a lab located on the other side of the country. By breaking down barriers to UIG collaboration decisions based on ideal scales of engagement resulting research values for this important form of knowledge production will significantly appreciate, as will the benefit to all those with a vested interest in results.

In conclusion it is anticipated critics are likely to contend that the relationships unearthed in this study will (eventually) diminish. In her book, "The Death of Distance: How the Communications Revolution will Change Our Lives", Frances Cairncross posits: "it can take many years for…technology-driven transitions to occur", but seems to put a timeframe of approximately 50 years on her death of distance forecasts when she writes: "[t]he death of distance and the communications revolution will be among the most important forces shaping economics and society in the next fifty years or so" (1997). The author concludes by going on record that distance will still matter in 50 years from now. It will not be dead. In closing it is suggested that no digital substitute exists for certain forms of human interaction and knowledge transfer, and the spatial dynamics governing research valuation will be as alive 50 years henceforth as they are today.

APPENDIX A

RECORD COUNTS FOR UI, UG, IG AND UIG COLLABORATIONS

This section provides record counts for all UI, UG, IG and UIG nanopublications in the continental United States. As mentioned in the Overview and Methodology and Data sections, UIG collaborators are identified by applying a thesaurus,[60] provided by Search Technology,[61] to Georgia Tech's global nanopublication dataset. Every classification made by this thesaurus is manually verified. After all affiliation assignments are determined, every nanopublication involving a University, Industry and Government collaborator, co-located in the continental United States, is designated UIG. Every nanopublication involving University and Industry affiliations (but no Government collaborator), co-located in the continental United States, is designated UI. Every nanopublication involving University and Government collaborators (but no industrial affiliation), co-located in the continental United States, is designated UG. Every nanopublication involving Industry and Government collaborators (but no University affiliation), co-located in the continental United States, is designated IG. Table 8 provides an overview of annual record counts produced using this approach:

[60] AcadCorpGov.the is the name of the thesaurus used in this study.
[61] See www.thevantagepoint.com

Table 25: Record Counts for all University-Industry, University-Government, Industry-Government and University-Industry-Government NanoPublication Collaborations Co-Located in the Continental United States

Publication Year	Industry-Government	University - Government	University-Industry	University-Industry-Government
1990	2	14	49	3
1991	13	75	150	14
1992	25	115	162	16
1993	19	134	169	19
1994	20	141	171	17
1995	31	149	199	15
1996	26	167	210	23
1997	32	227	233	29
1998	52	380	374	40
1999	55	403	394	54
2000	50	464	418	48
2001	45	532	418	80
2002	47	647	381	57
2003	52	843	565	96
2004	83	973	596	96
2005	72	1,241	652	112
2006	78	1,303	753	148
2007	90	1,511	858	131
2008	73	1,548	867	129
2009	72	1,234	666	100
2010	60	1,295	646	110
2011	30	876	383	81
TOTAL	1,027	14,272	9,314	1,418

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 1,027 IG records, 14,272 UG records, 9,314 UI records, 1,418 UIG records; Timespan = 1990-2011; Unit of Analysis: nanopublications

APPENDIX B

DESCRIPTIVE STATISTICS AND GRAPHS FOR THE CITATION IMPACT OF UG, IG, UI AND UIG NANOPUBLICATIONS CO-LOCATED IN THE CONTINENTAL UNITED STATES

This section provides descriptive statistics for the citation intensity of all UG, IG, UI and UIG nanopublications whose collaborators are co-located in the continental United States. The unit of analysis statistics in this section are based on are citations to individual nanotechnology publications belonging to a given collaboration type[62]. We note that citation statistics decline in more recent years given that these publications have had less time to be cited.

[62] e.g. 189 is the most number of citations any UG nanopublication received that was published in 1990 (whose collaborators are co-located in the continental US)

Table 26: Descriptive Statistics for the Citation Impact of all University-Government NanoPublications whose Collaborators are Co-Located in the Continental United States

Publication Year	Minimum	Maximum	Mean	Median	Mode	Standard Deviation
1990	0	189	34	20	31	49
1991	0	1,154	71	16	12	185
1992	0	355	44	26	0	59
1993	0	548	33	16	0	58
1994	0	432	32	14	0	55
1995	0	393	34	16	0	54
1996	0	370	30	14	0	52
1997	0	509	27	14	0	47
1998	0	923	30	11	0	68
1999	0	548	25	11	0	45
2000	0	293	22	12	0	32
2001	0	508	23	10	0	44
2002	0	385	16	8	0	28
2003	0	495	14	6	0	33
2004	0	284	8	4	0	19
2005	0	75	3	1	0	7
2006	0	142	7	4	0	12
2007	0	458	10	5	0	20
2008	0	272	5	3	0	11
2009	0	241	9	5	0	17
2010	0	152	4	2	0	8
2011	0	17	0	0	0	1

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 14,272 UG records; Timespan = 1990-2011; Unit of Analysis: citations to nanopublications

Table 27: Descriptive Statistics for the Citation Impact of all Industry-Government NanoPublications whose Collaborators are Co-Located in the Continental United States

Publication Year	Minimum	Maximum	Mean	Median	Mode	Standard Deviation
1990	0	3	2	2	NA	2
1991	1	326	47	10	9	91
1992	0	209	30	20	0	42
1993	0	85	18	8	0	23
1994	0	87	17	6	1	23
1995	0	34	14	12	16	10
1996	0	226	24	14	1	44
1997	0	1,085	64	20	0	194
1998	0	294	21	9	0	45
1999	0	112	20	7	0	29
2000	0	210	23	8	0	38
2001	0	61	13	9	2	15
2002	0	57	14	9	2	15
2003	0	66	11	5	1	14
2004	0	35	5	3	0	7
2005	0	58	4	1	0	8
2006	0	39	5	3	0	7
2007	0	60	7	4	1	11
2008	0	119	6	2	0	16
2009	0	54	8	4	0	12
2010	0	16	2	2	0	3
2011	0	2	0	0	0	1

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 1,027 IG records; Timespan = 1990-2011; Unit of Analysis: citations to nanopublications

Table 28: Descriptive Statistics for the Citation Impact of all University-Industry NanoPublications whose Collaborators are Co-Located in the Continental United States

Publication Year	Minimum	Maximum	Mean	Median	Mode	Standard Deviation
1990	0	456	42	16	0	75
1991	0	1383	50	16	0	126
1992	0	895	43	17	0	89
1993	0	9805	98	17	0	756
1994	0	1198	44	24	0	100
1995	0	1139	42	14	0	108
1996	0	990	39	20	0	85
1997	0	1519	54	16	0	140
1998	0	3268	47	19	0	177
1999	0	1309	52	20	0	122
2000	0	1907	59	21	0	155
2001	0	3384	47	16	0	181
2002	0	658	48	23	0	77
2003	0	1083	48	21	0	93
2004	0	1816	45	16	0	112
2005	0	1784	35	14	0	88
2006	0	738	31	13	0	58
2007	0	379	24	11	0	40
2008	0	649	19	9	0	38
2009	0	279	16	8	0	26
2010	0	361	10	5	0	21
2011	0	53	5	3	0	6

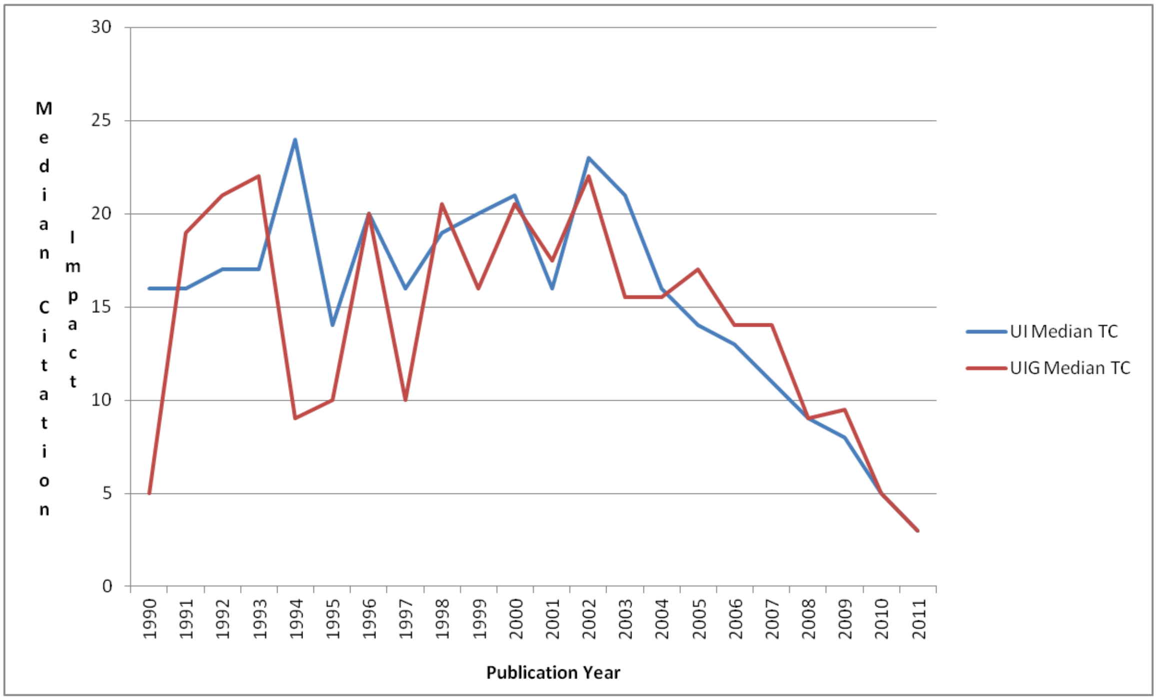
Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 9,314 UI records; Timespan = 1990-2011; Unit of Analysis: citations to nanopublications

Table 29: Descriptive Statistics for the Citation Impact of all University-Industry-Government NanoPublications whose Collaborators are Co-Located in the Continental United States

Publication Year	Minimum	Maximum	Mean	Median	Mode	Standard Deviation
1990	0	201	69	5	NA	115
1991	0	355	59	19	19	94
1992	2	194	47	21	7	60
1993	0	210	39	22	13	54
1994	0	192	28	9	2	47
1995	0	218	30	10	12	59
1996	0	110	29	20	7	30
1997	0	212	28	10	4	42
1998	0	111	28	21	1	30
1999	0	965	61	16	0	148
2000	0	997	83	21	0	174
2001	0	4624	106	18	0	521
2002	1	836	51	22	12	115
2003	0	847	45	16	10	106
2004	0	1028	53	15	0	141
2005	0	286	32	17	7	42
2006	0	337	32	14	0	52
2007	0	270	30	14	0	43
2008	0	975	36	8	0	119
2009	0	501	28	9	9	72
2010	0	104	11	5	1	18
2011	0	130	7	3	0	19

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 1,418 UIG records; Timespan = 1990-2011; Unit of Analysis: citations to nanopublications

While most analyses in this study are based on mean TC values, it is interesting to consider TC values for alternate descriptive statistics as well. Drawing on data from Tables 28 and 29 the figure below provides a corollary to Figure 9 in that it charts median (instead of mean) citation impact for UI and UIG partnerships:

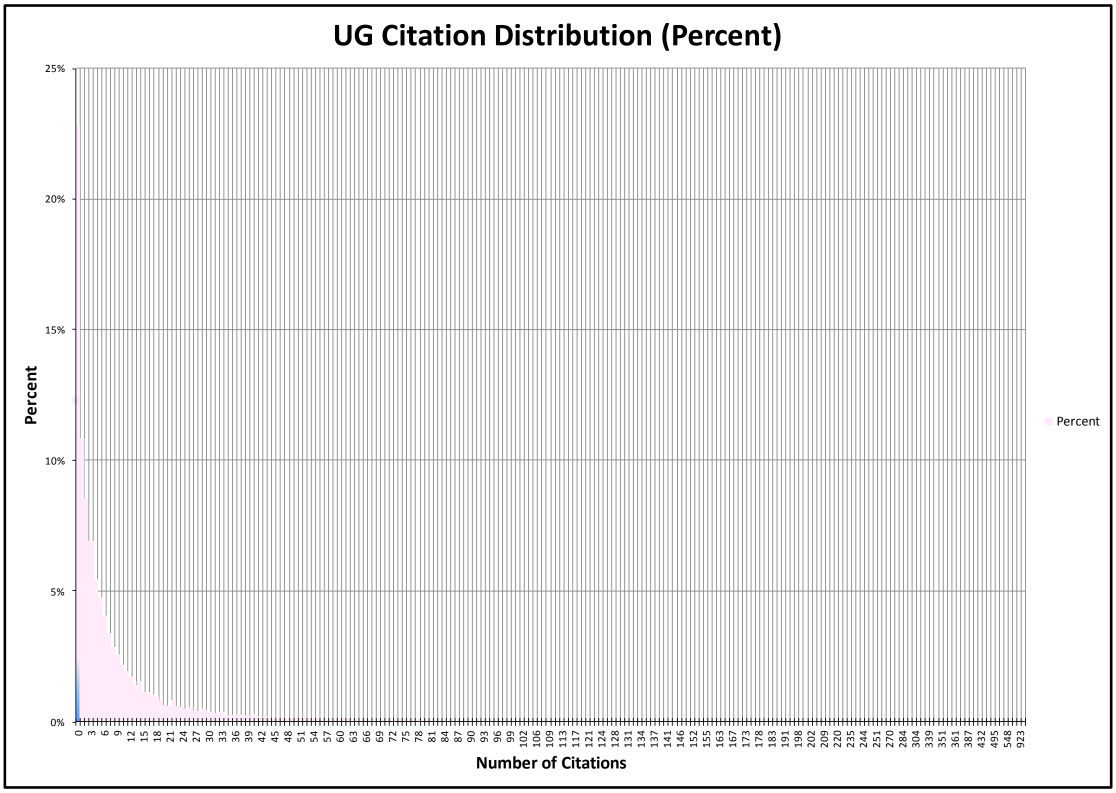


Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = Median citations, by year, for 1,418 UIG and 9,312 UI records; Timespan = 1990-2011 (cited records); Unit of Analysis: nanopublications (cited records); publications indexed on WOS (citing records)

Figure 23: Median Annual Citation Values for University-Industry and University-Industry-Government Nano-Partnerships Co-Located in the Continental United States, 1990-2011

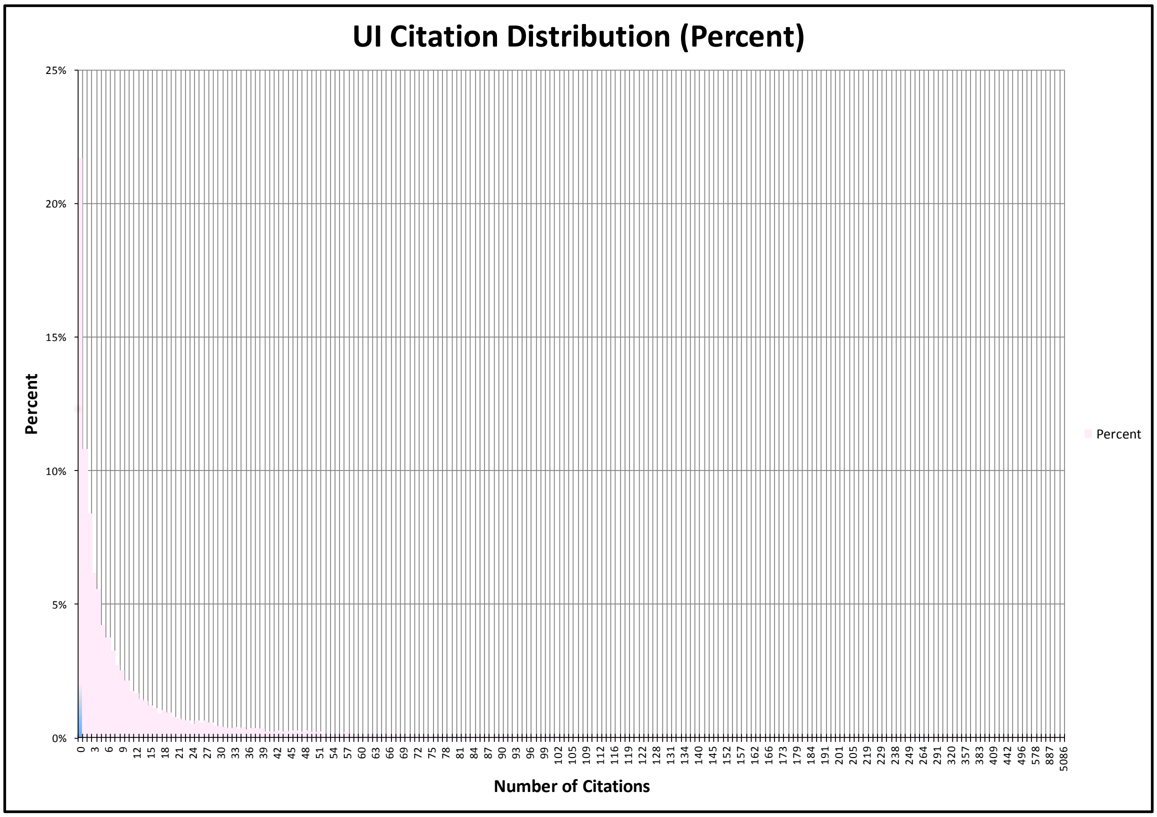
We note that the (UI and UIG) citation values in this figure are more closely aligned than they are in Figure 9. We note as well that, for most years in this figure (i.e. 13), the median citation impact of UI partnerships is greater than or equal to the median citation impact of UIG partnerships, making it even more difficult to conclude that Government collaborator involvement adds value to UI partnerships (in the aggregate).

Figures 24 through 27 (below) provide citation distribution charts for each of the collaboration types (i.e. UG, IG, UI and UIG) analyzed in this study (whose publication years span 1990 to 2011). In these graphs the horizontal axis represents citation counts and the vertical axis represents the percentage of nanopublications in a given collaboration type whose citation rate assumes a given x-axis value. As can be seen from each of these figures, the percentage distribution of citations for the collaboration types analyzed in this study look to conform reasonably well to the curve f(x)=1/x.



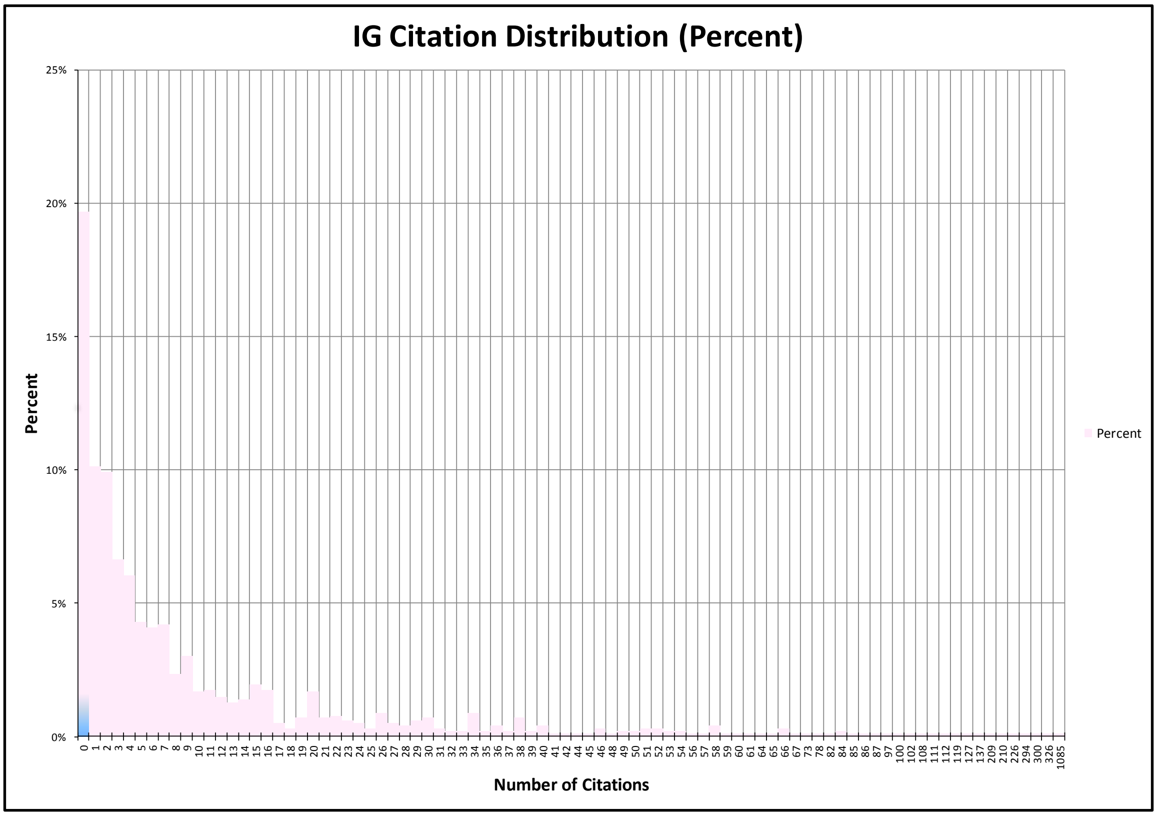
Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2011 (cited records); Unit of Analysis: UG nanopublications (cited records); publications indexed on WOS (citing records)

Figure 24: Percentage Citation Distribution for University-Government Nanotechnology Collaborations (Co-Located in the Continental United States)



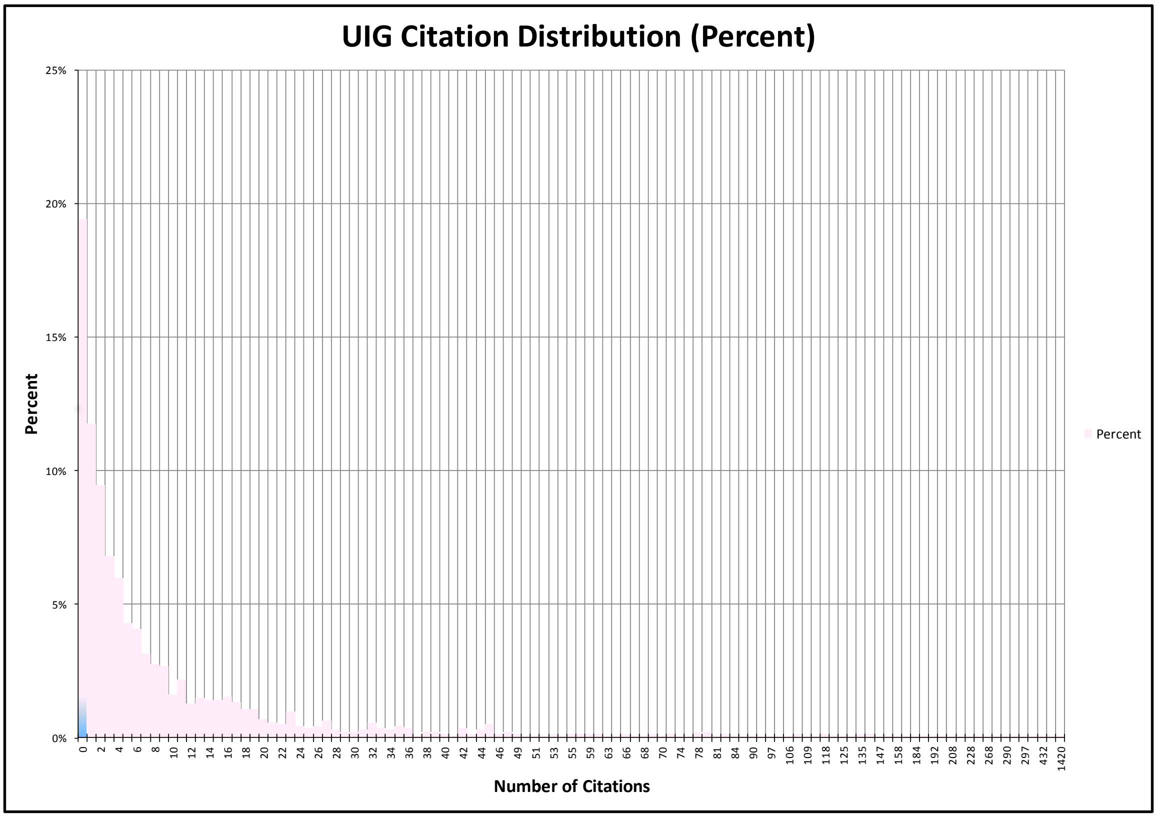
Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2011 (cited records); Unit of Analysis: UI nanopublications (cited records); publications indexed on WOS (citing records)

Figure 25: Percentage Citation Distribution for University-Industry Nanotechnology Collaborations (Co-Located in the Continental United States)



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2011 (cited records); Unit of Analysis: IG nanopublications (cited records); publications indexed on WOS (citing records)

Figure 26: Percentage Citation Distribution for Industry-Government Nanotechnology Collaborations (Co-Located in the Continental United States)



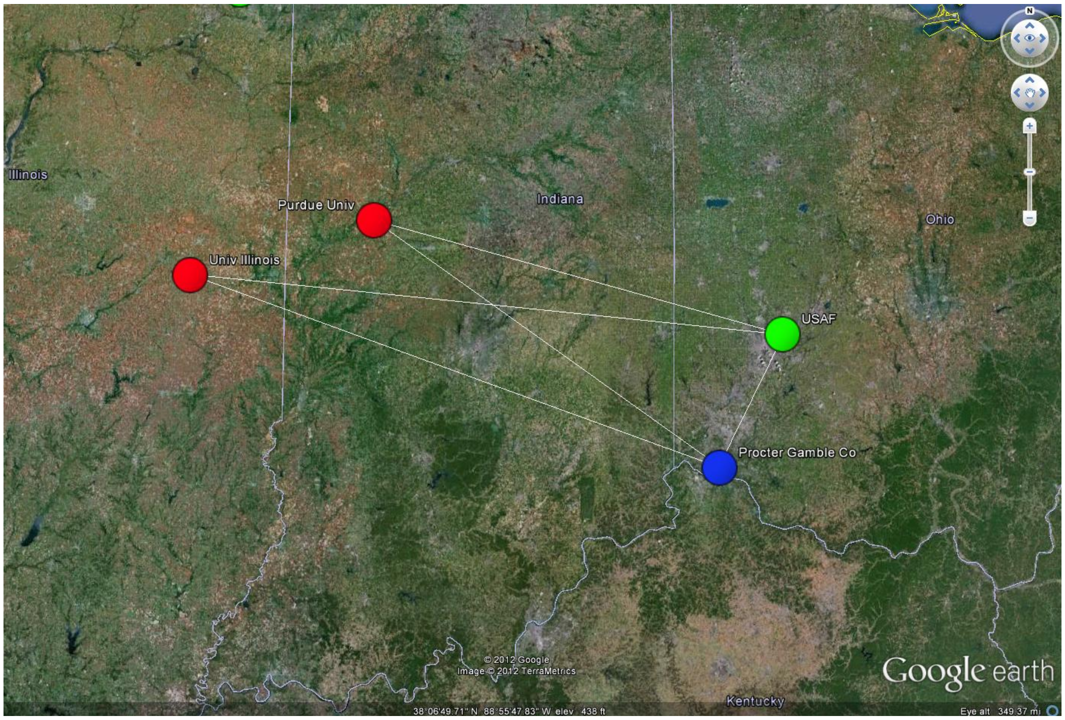
Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = NA; Timespan = 1990-2011 (cited records); Unit of Analysis: UIG nanopublications (cited records); publications indexed on WOS (citing records)

Figure 27: Percentage Citation Distribution for University-Industry-Government Nanotechnology Collaborations (Co-Located in the Continental United States)

APPENDIX C

CONTROLLING FOR MORE THAN THREE AFFILIATIONS IN A UIG COLLABORATION

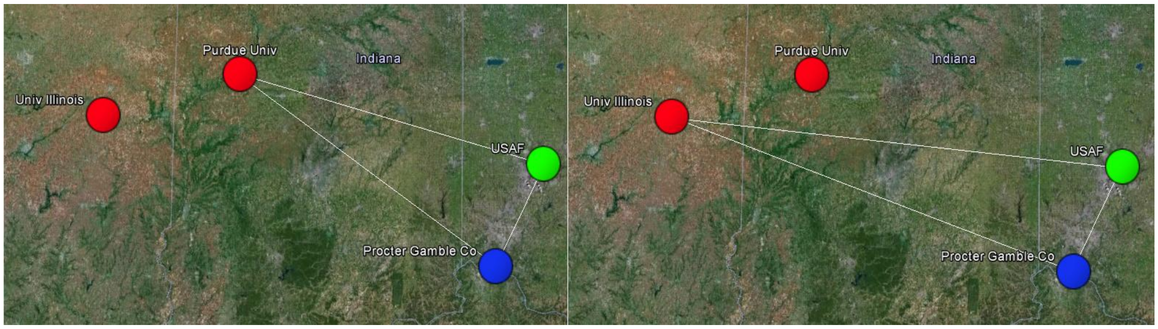
While the collaboration in Figure 2 contains individual University, Industry and Government entities, we make room for the possibility that a given UIG collaboration may contain more than one of the same affiliation type. It is possible to calculate the area contained within four (or more) geographic points, but the larger the number of points (covering a given geography) used to calculate a given area, the less meaningful results will be in terms of their ability to inform proximity policy. Evaluating UIG collaborations on the basis of three points allows for more standard and objective comparisons. Figure 28 considers a situation where collaborative academic entities (one of which is the lead affiliation on the publication of interest) outnumber corporate and government entities. This is defined to be a University-Heavy UIG Triangle.



Source: Own analysis
Notes: N = 1; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 28: University-Industry-Government Collaboration for a Triangle with more than Three Affiliations

We note that triangles with four or more collaborative entities are likely to be spatially larger, on average, than triangles with three collaborative entities. A technique to control for the effect of multiple affiliations on average triangle size is to disaggregate sub-triangles within a larger collaboration. Figure 29 is based on the same collaborative arrangement as Figure 28, but it separates individual sub-triangles within this partnership. Average areas and perimeters of sub-triangles can be used in lieu of the total area and perimeter covered by more than three collaborators in the regression and other analyses performed in this study to avoid biasing results in favor of multiple affiliations.



Source: Own analysis
Notes: N = 1; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 29: Disaggregation of a University-Industry-Government Triangle with more than Three Affiliations

A similar technique to control for the effect of multiple affiliations on average triangle size (one convenient for a large number of affiliations—i.e. more than 20) is to calculate the average distance between all University and Industry affiliations, the average distance between all University and Government entities and the average distance between all Industry and Government entities, and then calculate triangle area on the basis of these three means (using Heron's Formula).

APPENDIX D

RECORD COUNTS FROM DIVIDING UI DISTANCES INTO FIVE MILES INCREMENTS (IN FIGURE 10)

Table 30: University-Industry Distances in Increments of Five Miles for all University-Industry-Government Nanopublications with Exactly Three Affiliations (1990-2011)

UI Distance (miles)	Number of Records in UI Group	Max TC (for UI Group)	Mean TC (for UI Group)	Triangle Area that Optimizes TC (for UI Group)
0 to 5	52	763	55	0
6 to 10	10	153	47	4,152
11 to 15	10	50	17	1,030
16 to 20	19	1045	81	0
21 to 25	12	123	39	22
26 to 30	10	128	31	0
31 to 35	3	24	9	396
36 to 40	5	70	22	30,009
41 to 45	4	223	71	0
46 to 50	2	84	50	186
51 to 55	4	37	23	2,110
56 to 60	4	10	4	40
61 to 65	4	194	50	20,364
66 to 70	1	8	8	0
71 to 75	2	148	81	6,374
81 to 85	6	49	13	0
86 to 90	2	63	41	729
91 to 95	2	16	13	775
96 to 100	1	88	88	20,822
101 to 105	2	58	35	266
111 to 115	1	40	40	0
116 to 120	2	62	35	0
141 to 145	1	355	355	4,768
146 to 150	1	3	3	1,771
151 to 155	2	37	22	4,793
156 to 160	4	19	12	341

Table 30 (continued)

161 to 165	3	36	14	5,470
166 to 170	1	12	12	72
171 to 175	2	62	33	126,159
181 to 185	1	18	18	11,501
186 to 190	1	66	66	33,911
191 to 195	3	39	21	0
201 to 205	2	321	163	0
206 to 210	1	6	6	7,974
226 to 230	3	39	19	53,517
236 to 240	2	31	30	2,131
241 to 245	6	18	7	1,244
246 to 250	2	21	19	1,331
251 to 255	1	9	9	2,255
256 to 260	1	101	101	344
261 to 265	1	38	38	3,791
271 to 275	3	22	16	0
276 to 280	1	5	5	0
281 to 285	8	92	19	31,188
286 to 290	1	24	24	13,855
291 to 295	1	4	4	0
296 to 300	1	37	37	156,124
301 to 305	2	58	55	261
306 to 310	1	33	33	173,721
311 to 315	3	23	12	1,456
326 to 330	1	10	10	1,039
331 to 335	1	17	17	185,370
341 to 345	1	81	81	272,842
351 to 355	2	52	26	30,945
356 to 360	1	106	106	1,539
361 to 365	1	45	45	58,989
371 to 375	2	2	1	411,902
381 to 385	5	60	17	1,821
391 to 395	2	4	2	146,186
396 to 400	2	10	9	1,753
401 to 405	2	44	33	3,534
406 to 410	4	73	30	466,860
411 to 415	1	46	46	40,908

Table 30 (continued)

416 to 420	1	3	3	0
421 to 425	1	7	7	306,791
441 to 445	3	7	5	34,871
446 to 450	2	131	73	272,365
456 to 460	1	90	90	559,116
476 to 480	3	37	18	821
481 to 485	2	24	19	10,766
496 to 500	2	74	74	36,641
501 to 505	1	57	57	11,957
526 to 530	1	33	33	4,896
551 to 555	2	13	11	2,881
591 to 595	2	217	128	365,345
601 to 605	1	7	7	0
606 to 610	2	196	98	2,638
611 to 615	2	838	455	567
616 to 620	1	2	2	205,346
621 to 625	3	12	7	473,129
626 to 630	1	26	26	31,215
631 to 635	1	101	101	6,181
636 to 640	1	65	65	307,359
656 to 660	2	20	17	105,105
671 to 675	3	39	20	20,528
676 to 680	2	1010	508	103,265
691 to 695	1	6	6	268,347
696 to 700	1	0	0	2,179
711 to 715	2	202	108	8,533
716 to 720	1	5	5	4,889
721 to 725	1	91	91	124,134
726 to 730	4	192	90	40,701
741 to 745	1	38	38	27,527
766 to 770	1	16	16	29,194
771 to 775	1	28	28	40,973
781 to 785	2	153	90	31,071
786 to 790	2	629	345	32,526
791 to 795	1	15	15	5,675
796 to 800	3	55	24	100,192
846 to 850	1	1	1	39,907

Table 30 (continued)

851 to 855	5	17	9	8,294
856 to 860	2	72	38	83,496
861 to 865	1	26	26	196,347
866 to 870	1	68	68	179,115
876 to 880	2	969	594	0
881 to 885	5	148	40	342,062
901 to 905	5	37	22	138,524
916 to 920	2	88	48	1,015,831
926 to 930	3	38	17	144,063
931 to 935	1	16	16	25,731
936 to 940	2	11	8	425,930
951 to 955	1	1	1	1,099,761
986 to 990	1	29	29	0
991 to 995	3	34	25	385,879
1021 to 1025	1	6	6	46,113
1036 to 1040	4	39	16	284,502
1051 to 1055	1	39	39	5,120
1056 to 1060	1	6	6	169,675
1066 to 1070	1	9	9	15,352
1071 to 1075	1	3	3	540,254
1086 to 1090	1	0	0	783,890
1096 to 1100	1	7	7	0
1101 to 1105	1	20	20	81,717
1111 to 1115	1	17	17	1,789
1121 to 1125	1	17	17	352,198
1161 to 1165	1	10	10	1,653
1166 to 1170	1	32	32	240,325
1171 to 1175	2	10	7	0
1211 to 1215	2	97	54	327,816
1221 to 1225	1	28	28	3,792
1226 to 1230	2	13	12	721,263
1261 to 1265	1	78	78	21,146
1266 to 1270	1	6	6	387,567
1271 to 1275	3	13	5	385,404
1291 to 1295	1	110	110	45,248
1341 to 1345	1	20	20	33,067
1371 to 1375	1	19	19	0

Table 30 (continued)

1381 to 1385	3	132	53	434,762
1386 to 1390	1	2	2	158,087
1396 to 1400	1	34	34	698,115
1461 to 1465	1	3	3	43,955
1471 to 1475	1	12	12	2,096
1476 to 1480	1	43	43	717,022
1496 to 1500	1	49	49	6,830
1506 to 1510	2	14	8	7,408
1516 to 1520	1	5	5	381,977
1521 to 1525	1	25	25	232,639
1536 to 1540	1	12	12	49,425
1541 to 1545	2	12	9	0
1556 to 1560	1	27	27	0
1591 to 1595	1	12	12	2,433
1596 to 1600	2	12	9	62,563
1621 to 1625	2	56	52	221,561
1641 to 1645	1	8	8	14,818
1661 to 1665	1	4	4	509,418
1681 to 1685	1	8	8	455,321
1726 to 1730	1	36	36	42,777
1736 to 1740	2	60	31	142,579
1756 to 1760	1	2	2	430,605
1776 to 1780	3	187	69	14,683
1781 to 1785	1	38	38	149,957
1811 to 1815	1	9	9	98,442
1836 to 1840	1	32	32	39,840
1841 to 1845	1	6	6	24,286
1866 to 1870	1	284	284	3,807
1881 to 1885	2	30	25	5,155
1886 to 1890	2	306	194	593,598
1906 to 1910	1	0	0	288,997
1931 to 1935	1	5	5	22,530
1936 to 1940	2	27	23	0
1941 to 1945	1	63	63	24,388
1946 to 1950	1	16	16	238,740
1951 to 1955	1	5	5	6,711
1996 to 2000	2	170	85	219,833

Table 30 (continued)

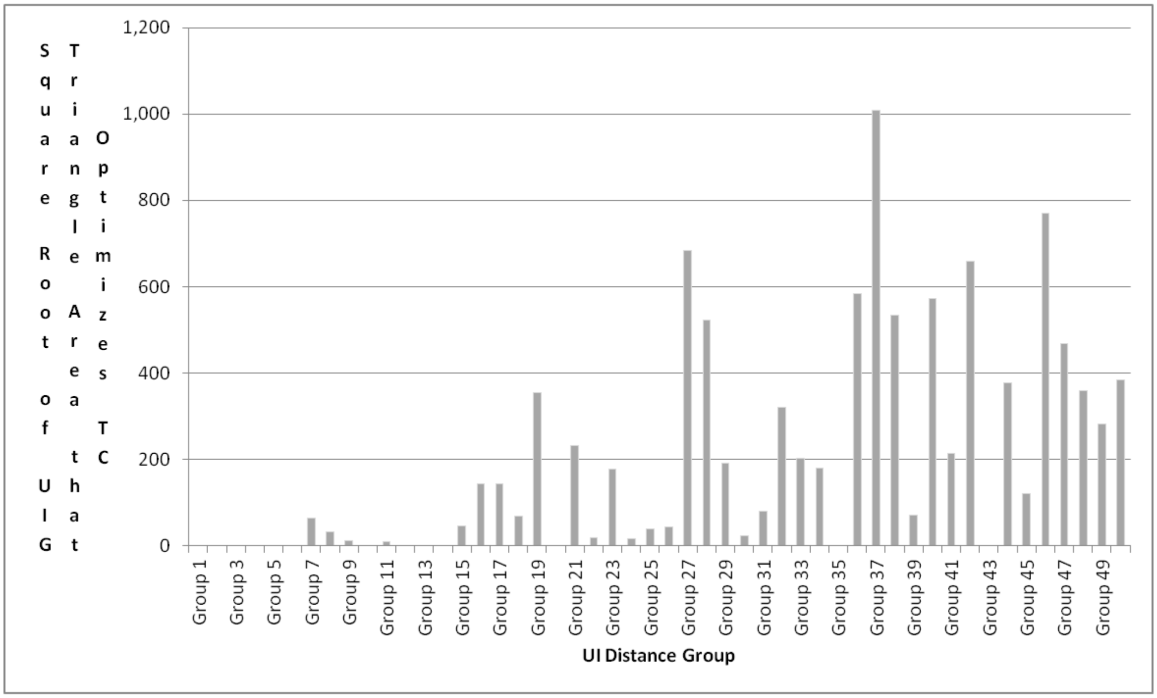
2026 to 2030	1	2	2	224,752
2061 to 2065	1	119	119	180,499
2096 to 2100	1	12	12	264,875
2111 to 2115	1	0	0	104,970
2116 to 2120	1	27	27	624,584
2191 to 2195	2	67	40	1,055,084
2261 to 2265	1	0	0	0
2286 to 2290	1	21	21	339,892
2361 to 2365	1	32	32	0
2381 to 2385	1	107	107	129,572
2386 to 2390	2	21	15	0
2406 to 2410	1	35	35	19,451
2411 to 2415	1	6	6	438,664
2416 to 2420	2	8	7	18,217
2431 to 2435	1	57	57	11,959
2441 to 2445	1	1	1	79,122
2451 to 2455	1	302	302	79,682
2476 to 2480	2	210	111	50,563
2516 to 2520	1	71	71	463,349
2536 to 2540	1	8	8	509,845
2541 to 2545	1	16	16	0
2551 to 2555	1	22	22	0
2581 to 2585	1	10	10	0
2596 to 2600	1	62	62	324,172
2606 to 2610	1	1	1	20,821
2666 to 2670	1	142	142	147,991
2676 to 2680	1	5	5	351,937

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 450 UIG records partitioned into 201 UI distance groups; Timespan = 1990-2006; Unit of Analysis: UI distance groups

APPENDIX E

THE SQUARE ROOT OF UIG TRIANGLE AREA AS A PROXY FOR PROXIMITY

It was noted by one of the committee members of this dissertation that the use of triangle area as a proxy for proximity can potentially skew results given that a squared measure of distance may lend disproportionate weight to larger UIG triangles. To accommodate this concern this appendix replicates the analysis performed in Figure 11 except that it uses the square root of UIG triangle area as the vertical unit of measurement (instead of UIG triangle area). As is the case with Figures 10 and 11 the figure presented in this appendix appears to generally conform to a bell-shaped curve with negative skew. The point is made again that citation optimizing scales of Government collaborator engagement are not uniform across the spectrum of UI proximities.



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013) (cited data); Publications indexed on WOS (citing data)
Notes: N = 450 UIG records partitioned into 50 UI distance groups; Timespan = 1990-2006; Unit of Analysis: UI distance groups

Figure 30: Square Root of Optimal University-Industry-Government Triangle Sizes by 50 UI Distance Groups of the Same Record Count (1990 to 2006)

APPENDIX F

REGRESSION RESULTS FOR THE 6 META DISCIPLINES

This appendix replicates the same regression model used in Tables 13 through 15 to Porter's 6 Meta Discipline classification scheme. Results are comparable to what appear in Tables 13 through 15—i.e. the only significant scale of Government collaborator engagement is the City level.

Table 31: Regressions (for University and Industry Engagements) for the Physical S&T 6-Classification Meta Discipline Scheme (1990-2006)

Citation Impact	**Physical S&T**		**Citation Impact**	**Physical S&T**
G engages with U at City Level	38.11 (22.62)*		G engages with I at City Level	18.56 (26.74)
G engages with U at MSA Level	0.85 (19.37)		G engages with I at MSA Level	-2.26 (15.44)
G engages with U at State Level	8.21 (17.61)		G engages with I at State Level	-4.14 (15.64)
Star Scientist	-22.38 (50.79)		Star Scientist	-9.56 (51.84)
Basic v Applied	22.11 (8.52)***		Basic v Applied	21.81 (8.61)**
Number of Authors	-2.42 (2.38)		Number of Authors	-3.19 (2.40)
Number of Affiliations	dropped		Number of Affiliations	dropped
Constant	-16.13 (29.93)		Constant	-3.44 (30.16)
N	396		N	396
R squared	0.0359		R squared	0.0217

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 396 Physical S&T records (for Government collaborator engagement of Universities) and 396 Physical S&T records (for Government collaborator engagement of Industry); Timespan = 1990-2006; Unit of Analysis: nanopublications

Table 32: Regressions (for University and Industry Engagements) for the Environmental S&T 6-Classification Meta Discipline Scheme (1990-2006)

Citation Impact	Environmental S&T		Citation Impact	Environmental S&T
G engages with U at City Level	dropped		G engages with I at City Level	-117.06 (133.55)
G engages with U at MSA Level	40.43 (133.91)		G engages with I at MSA Level	49.57 (172.56)
G engages with U at State Level	45.88 (117.91)		G engages with I at State Level	-108.85 (161.11)
Star Scientist	dropped		Star Scientist	dropped
Basic v Applied	-12.02 (49.28)		Basic v Applied	19.03 (66.77)
Number of Authors	0.85 (38.71)		Number of Authors	-43.06 (50.48)
Number of Affiliations	dropped		Number of Affiliations	dropped
Constant	79.91 (209.53)		Constant	307.99 (253.32)
N	9		N	9
R squared	0.2168		R squared	0.4247

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 9 Environmental S&T records (for Government collaborator engagement of Universities) and 9 Environmental S&T records (for Government collaborator engagement of Industry); Timespan = 1990-2006; Unit of Analysis: nanopublications

Table 33: Regressions (for University and Industry Engagements) for the Biology and Medicine 6-Classification Meta Discipline Scheme (1990-2006)

Citation Impact	Biology and Medicine		Citation Impact	Biology and Medicine
G engages with U at City Level	140.62 (133.59)		G engages with I at City Level	251.16 (85.04)***
G engages with U at MSA Level	5.53 (131.11)		G engages with I at MSA Level	4.01 (68.96)
G engages with U at State Level	-73.14 (171.62)		G engages with I at State Level	-39.67 (67.83)
Star Scientist	dropped		Star Scientist	dropped
Basic v Applied	62.15 (59.60)		Basic v Applied	40.81 (50.57)
Number of Authors	-7.28 (9.11)		Number of Authors	-2.25 (7.86)
Number of Affiliations	dropped		Number of Affiliations	dropped
Constant	-66.64 (205.49)		Constant	-40.15 (164.82)
N	27		N	27
R squared	0.1203		R squared	0.3664

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 27 Biology and Medicine records (for Government collaborator engagement of Universities) and 27 Biology and Medicine records (for Government collaborator engagement of Industry); Timespan = 1990-2006; Unit of Analysis: nanopublications

Regression results for the remaining Meta Disciplines in this classification scheme could not be obtained due to insufficient observations.

APPENDIX G

INTERVIEW RESULTS

INTERVIEW #1

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

The institute I'm with - almost 10 years now. It's a university affiliation. No other affiliations – I've been with a university affiliation all the time.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I've collaborated on 2 projects w/ the government, and in total we produced approximately eight papers where I'm a coauthor.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

There was a solicitation from a government organization to participate on a project and write a proposal. The government collaborator was the project manager.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

The government had goals we could achieve – so we sought this out. They (the government) tell us what they want and we work and get the results for those particular goals.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No. They were in a different state. Research quality would probably be the same if they had have been close. We interacted using online mediums. Well, it could have been different if the collaborator was close – getting more funding could have been easier (depending on the local requirement). The government agent could understand our situation better, but the outcome of the research itself probably wouldn't have been different. We did occasionally meet face to face, which was more helpful than a phone meeting.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

They bring the value of what they're looking for. In our project we're working for making coating that repels ice. This is useful for harsh northeast winter weather. That kind of real world problem provided direction (as opposed to studying something for its own sake). They also provided funding.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

(1) Direction (for the problems that most require attention)

(2) Funding/citation impact

(3) Facilities/equipment

(4) Expanding research capabilities of university

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

Yes. The (government-directed) problem we're trying to solve is relevant, important and attracts attention. The citation of our work could be higher as a result of government involvement, and that's a positive consideration.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

We never had that kind of research direction in our center before. We knew the problem we were facing during winter weather, but with the help of the government actor we realized this is a good problem to focus on. So we might not have pursued this research at all had they not become involved. They provided guidance/direction. It (the nature of the research) would have been very different had they not become involved.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

To gain access to their equipment, yes. But communication...not so much. Face to face helps, but proximity isn't a deal breaker for communication purposes (we have phones/Skype/etc). Once in a while we meet face to face. Gaining access to equipment matters more (for purposes of proximity).

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

For this project, no, we haven't visited the facility so far (and might not ever). We haven't visited because of distance (it's far away). It would have been different if they were closer – so yes, proximity makes a difference. If they were close we would have visited.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Face to face meetings brings an additional dimension. We can explain the problem and communicate important things much better in person. This is true of any communication. When people meet face to face they can talk openly. When information is required we can sit down and look into it. That's why once in a while having face to face meetings helps.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Outcome of research isn't so much affected by proximity, but in terms of moving forward proximity makes a difference - for moving to the next phase. The ongoing research and outcomes won't change, but in terms of defining future goals, and building a strategy or direction, proximity makes a difference. Proximity especially matters if you're involved with something relating to biological applications (most of the time if you want to use the government facility – most of these biological cells can't be kept outside for a long time – you have to transport them quickly and analyze them quickly. Samples are not stable in that type of research). In the case of our research samples were stable.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

If we needed to use the government facility, then yes, proximity would make a difference. We didn't need to go visit the government lab that much, however, so proximity didn't matter so much. Proximity wasn't a requirement for us but would have added an additional dimension.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

Na – this collaboration occurred at distance.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

No, no surprise. Government is closer to industry. They know what kind of support or research they need to do for further development and what needs to be done, so then they will be better equipped to then tell university actors what to do and where to spend their money.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Citations alone can't capture the value of research, but it is one of the criteria. It is one type of measurement. Depending on the number of people involved in a given area and the area itself you can get more citations. Citations can be lower for a lower number of people working in a given area. Citations are one criteria.

Question 18: What are the challenges or costs involved in working with Government labs?

Costs aren't so much a problem. Bureaucracy is one of the downsides of working with government. That's the only negative I see.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

There's not a worst collaboration. The two I've done so far have both been good. I had a good program manager who understood the value of the project and our potential and what needed to be done.

Question 20: Is there anything I didn't ask you think might be important to share?

No, I don't think so.

INTERVIEW #2

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been with my current university for 25 years. As far as other universities: I started at NC State, and have been at several other places (e.g. Jackson State University, UGA, etc).

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I've mostly participated with government collaborators. I've worked with the Naval Research Laboratory for approximately 10 years. It's 75 miles from where I was and I used to drive there every week. I've also worked with Sandia and NRL (in Washington, DC). Now I mostly work with the Air Force Research Lab. I've worked c.a. 10 years with NRL and 7-8 years with the Air Force.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

I was introduced through a professional conference I had been attending 20-30 years. I met a scientist from the Air Force research lab there who was very active in this conference. He invited me to give a talk at the Air Force research lab, and I gave the talk, and we've collaborated since then. It's been a great partnership with tremendous intellectual value.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

Both, I would say. I was very curious to talk with them (for funding reasons) in the beginning, but they also expressed interest in working with me.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No, Dayton, Ohio is very far from where I am. My collaboration with the Naval Research laboratory did occur in close proximity, however. We (i.e. myself and the Air Force) do meet 2-3 times a year at least (at conferences, etc). If the collaboration had been in close proximity it would have made a difference, yes, in a positive way (but geographic distance doesn't hinder my relations with them). Proximity would have helped in terms of funding and access to resources and would have had more grad students, and more communication with them. You can't do everything via email—you need face to face interaction to facilitate scientific research.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

Funding was number one. Also, they have a big lab. They have leading scientists and researchers. They have considerable resources that I've benefited from. I've been able to work with their post-docs and scientists. Interaction with their personnel has been tremendously helpful – learning what they do in the lab, etc.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

Huge. They bring tremendous value to universities, both financially as well as intellectually. It's not just the money but the intellectual interaction that's been very valuable.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

Yes, JIF is a benefit (they tend to publish in high impact journals).

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Sure, of course. This whole area of nanotechnology is very much driven by the government. Had the Air Force not become involved I would have had to beg for money from someone else to make this happen, or I would have moved much more slowly.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Yes, it does. Proximity would have benefited me very much in this last collaboration. It would have probably accelerated some of the work we're doing.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes, many times, especially at the start of the collaboration.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

What they have – they have something called a 'mini-meeting' among all collaborators in a specific area. I have to be there in person to collect information from their mini-meetings. Proximity is key for charting out a future plan – I would give every visit a big plus – they are very, very important.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Yes, the nature of our involvement…experimental research benefits from proximity. Certain questions in the area can't be addressed via email – meeting in person is the only way to address certain questions.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yes, when different types of diverse (integrative) groups are involved, proximity helps. When multiple areas and researchers are involved, close proximity facilitates communicating and learning from each other.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA – this collaboration occurred at distance.]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

I think your finding is correct. That's my observation too. Silicon Valley, which has a lot of industry, and government labs in that area have harnessed synergies. There's something special/powerful about close proximity between industry and government labs. It can depend on the type of university, however – I think close proximity between government and universities that are more research-oriented might count for more [than close proximity between government laboratories and universities that are less research-oriented].

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

When it comes to journal citations and impact factor, I'm not sure that tells the whole story. Networking counts for a lot (which can facilitate getting published in better journals and higher journal impact factor).

Question 18: What are the challenges or costs involved in working with Government labs?

With the Air Force lab the challenges involved the classified nature of the facilities– reaching their sites, and getting through the gate is hard. Many times we meet outside the lab (i.e. a nearby restaurant). Access to their computer is very difficult to get. There's a lot of red tape. I can't put my usb in my collaborator's computer easily. Apart from the red tape everything's ok.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

My current Air Force collaboration is one of the best. I don't have any 'worst' experiences to speak of. I've been lucky to have very good experiences with the right people and the right area of research.

Question 20: Is there anything I didn't ask you think might be important to share?

It might be helpful to interview people involved in ongoing/unpublished research as well.

<u>INTERVIEW #3</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been at my present university since 2009.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

About four times.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

At the Center for Integrated Nanotechnologies (CINT), they made an effort to reach out to industry and university partners. One of my industry partners at the time applied to be a user in the CINT program, and I was working with him at the time, so that's how I got involved.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

Both.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

Yes. Everyone was within 10 miles of each other. Being able to sit down in a room with someone and look them in the eye made a difference. We had much easier access to the facility and its resources, which was a big plus. We had group meetings on a fairly regular basis and even had Christmas parties together. It was a pretty tight group.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

The CINT facility has a lot of core instrumentation that isn't available at my university and is out of the budget range of the small companies I'm working with. The provide cutting edge technologies and human expertise to go with that.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

Basically what I just said [for Question #6]. Expensive equipment and facilities, as well as expertise. This especially helps small business and the cash strapped.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

Yeah, I mean I would say there were aspects of the work that wouldn't have been done nearly as well, or at all, so I'm sure that helped the quality of the journal we were able to get published in.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Yes, we would have been flying blind on certain aspects of what we were doing without the measurements and expertise they provided. We wouldn't have made as much progress.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

There are times when if you can give someone a call and say: hey, we really need this sample run right now and proximity really helps. Modern [telecommunication] technologies can overcome proximity barriers, but I would still say yes, it matters.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes, a number of times for group meetings, and I was back in the lab areas twice. Students from my university would go work there on a daily basis.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

It was mostly phone and email, but we definitely met face to face. Those were typically times we had group meetings and wanted to go over data together. We could have done webinars, but I hate those – it's hard to hear and you can't see people's reactions and where they're at. It's helpful to have everyone being access to all the information (and it's hard to do that over the phone). And it was only 15 minutes to get there (so travel costs were low).

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Not sure the answer to that question, but I think it depends on the national lab. I think that for nanotechnology, because it involves a number of fields, each field can bear on the other, and having proximity helps.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

I expect so. I don't stay in touch as much with one of my collaborators, from [another state], and we aren't as productive.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

We didn't collaborate at distance because everything we needed was right there in town. There was no reason in that case to look elsewhere. There's also a loyalty dynamic – we were already established as collaborators.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

Wow. I'm not a business person. I'm totally an academic. I think that maybe, even more so in the business environment, it's important that everyone sits down and looks everyone in the eye to establish trust. Any venture involves risk – and you need to establish trust, and maybe that's more important to business people than to academics, I think. But I'm not really sure. That is interesting. I think motivations for business people are different and they have shorter time horizons.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Citations measure value to academics really well. Well, citations and grants. Because that's the currency we deal in. I think it probably misses value on the industry side more than the academic side. There are instances of good work that has not yet been published.

Question 18: What are the challenges or costs involved in working with Government labs?

The biggest challenge for us is that there were a lot of users. When we could get time with him [our Government collaborator] it was awesome, but sometimes it was hard to get on his dance card. Also, if you want to write a grant with a government lab on it their indirect rates are screaming high.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I've had an all-in-all positive experience that has led to a lot of papers. On the negative side, not being organized on our end has caused a few collaboration problems.

Question 20: Is there anything I didn't ask you think might be important to share?

No.

<u>INTERVIEW #4</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been at my current university a little less than three years. Before I was here I worked for a private company in California.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

At least twice. It's a common thing, at least in my field.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

Dr. X is my boss. He hired me to run his labs. I met Dr. Y by asking around at the university who had access to a piece of equipment I needed, which led me to Dr. Z's lab. So that's how I met Dr. Y and he ran experiments for me. So we met through the grapevine.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

I went to them.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

Yes. Absolutely. I found that, a lot of the time, when you're close to your collaborator there's more opportunity to exchange samples and discuss outcomes and plans. When your collaboration is far away you've always got to mail them your samples and that always adds more time to the process, and you can never really see their setup unless you go there, and that can raise barriers to understanding, especially when you're using a new technique.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

Expertise, resources. I was given access to an x-ray photoelectron spectrometer (XPS).

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

The same (as my previous response). The government has access to greater resources than universities. I think oak ridge has the most powerful supercomputer in the world. When you engage in cutting edge research you need to go to the people who have this stuff, and government labs have people who are experts at using this equipment.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

No, not explicitly. The work stands on its own merits. I don't think there's any artificial prestige granted by having a government collaborator. But if you can learn something about what you're studying that's what increases the prestige and value and impact of the publication. I don't go to the government labs to influence how people view my paper. I go because they're going to make my paper better.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Sure. I would have been missing some key results, which would have certainly impacted the publication negatively.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

I answered that already, but absolutely it does, yes.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yep.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Email (a couple times a month), personal visits (at least once or twice a year – if we're working on something we're going to go over there more). Usually it's because there's some other expediency to being there in person – if I want to drop off some delicate samples in person I might stop by and talk with other collaborators – it's a matter of convenience. Sometimes I want to see a particular geometry or setup to get a better idea of what I need to deliver for my measurements. When phone or email does the job I use those.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Yes, certain areas benefit more. The area I'm in—often requires a large central facility to characterize the materials you're using. In some areas, where you're not benefiting from large central facilities – I think those can be done more easily in a self-contained lab environment. But take that with a grain of salt because I'm not a chemist or biologist.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

It can – there are certainly collaborations carried on at great distance, but these are not going to be ad hoc collaborations. Because of the proximity I have to oak ridge we have more opportunities to do these types of ad hoc measurements. I think distance throws up a barrier but it's not an insurmountable one.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

Not an issue. I would not turn down a beneficial collaboration because of the inconvenience of collaborating at distance. The reason I work with oak ridge is because I think their facilities and personnel are as good as anyone else. Certainly the convenience [of their proximate location] makes me collaborate with them more often, but I wouldn't let inconvenience hinder me from collaborating with someone else if oak ridge didn't have a certain capability.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

It doesn't surprise me that much. I've worked in both environments. At the university we're educating trainees. The people doing the research are learning as they go (a lot of time they don't know what they're doing). So, when government and industry work together it's two groups of highly competent professionals that are doing work. When government and industry collaborate a lot of times its high value research. But we're training people here at the university, so we don't have the same kind of firepower that industry and the government does.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Everyone is subject to the process of quantifying research, especially at universities, where tenure and promotion can revolve around hard metrics. Thomson Reuters sort of has a monopoly on this with their h-index. So, it's questionable what the value of citations is. In some cases certain papers get cited because they're cited. They're not adding value to the discussion. It's the papers you cite by default when you're talking about something. I don't think it tells the whole story, but it's hard to find a better metric. It can be something of a circle jerk – friends will cite their friends and not cite their enemies. If you have two papers that say the same thing, you're going to cite the one authored by your friend. So I don't think anyone has a completely accurate method of quantifying research value.

Question 18: What are the challenges or costs involved in working with Government labs?

Yes, if you want to go away from ad hoc collaborations and have a formalized collaboration where you're working together on a well defined project over 3+ years the overhead of working with government labs is 3-4 times higher than the overhead of working with a university. They're very expensive. When working with government personal you need 3-4 times the productivity.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I don't think I've had a worst (and I'm a young guy, so maybe I've just been lucky up to this point), but I've had an overall positive experience – they've all been pretty good. I'll leave it at that.

Question 20: Is there anything I didn't ask you think might be important to share?

No, nothing to get off my chest if that's what you're asking.

<u>INTERVIEW #5</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

Affiliated with industry for 26 years. I did two post docs, both in universities.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I've had many collaborations with many universities and do an awful lot of my work at national labs. Over the years I've found it a very fruitful way to disseminate information and cross-fertilize ideas, etc. I've benefited from the high tech facilities at national labs, and the universities bring in top notch researchers with leading ideas, so it tends to work out very well.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

My government collaborator is Argonne. How was I introduced? It's been a long time…it was through my company. The collaboration was in place, and when I joined the company I just kept the collaboration going. The stimulus for this collaboration was that they have capabilities at Argonne that we simply don't have at our company. This is a major research facility (c.a. $1billion to build) that only makes sense for a national lab to build and operate. We have an ongoing collaboration with this lab (Argonne). I've probably spent, on average, 1 week per month collaborating with them.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

We sought them.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

Government and industry were in same MSA for this collaboration (but we've also worked with Brookhaven/Standford/Pacific NW national labs). Proximity is huge. It makes it so much easier. Proximity makes a difference.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

Facilities and equipment. Part of the value is that the research that is typically funded at a national lab, the fact that they're prime motivation is not profit motivated. They are driven by fundamental research (which is a nice compliment to industry, who is driven by market results). We (industry) sometimes miss the basic component of research. Labs can provide understanding/insight that we wouldn't have obtained by ourselves.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

Basic research orientation/facilities/equipment/etc.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

It might be for some industries, but I can't say in my particular case/company that is a driver.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Yes, it probably wouldn't have happened (without the capabilities they provided).

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Yes, it does. We always have this driver that we want to access and work with the best, but in times of financial constraint (when travel budgets come intro scrutiny) it's so much easier to get in the car and drive to a lab than to fly to Europe or Asia.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes, many times.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Phone and email, but most meetings were in person. Maybe it's a generational thing, but in face to face meeting you get far more information, and far more happens, than in an electronic meeting (where someone is often distracted and multi-tasking). Much more information exchange and much more happens. Face to face is often necessary to fully push something through. You can do a lot of the pre-work electronically, but face to face is often required to achieve the final goal.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

The more complex the topic, requiring a lot of participation by a lot of people, proximity helps. The more simpler the work, electronic communication is ok.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

More complex research benefits.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

Yes, we could have collaborated at distance. The reason we didn't is for that sole fact: the ability to meet in person, get in a car and drive, shipping costs, etc makes it more cost effective, more productive, more likely to succeed and to last the test of time. You're developing bonds/networks/trusts. You can't ignore the geographic component.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

I'm not surprised. Interesting you have that conclusion. I know some of the national labs are reaching out trying to form ties to industry and facilitate participation. I think it comes down to face-to-face meetings (than if you have to do that via phone). Proximity just makes a difference. I've got this long standing collaboration with people at the University of Washington and we lament the fact that we can't meet in person more often.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

The citation rate is one of the standard measures of the value of research, as you know. It has become a de facto measurement of one's impact on the community in a given area. One has no option but to try to compete in this arena. It does over-emphasize the current hot topic research areas, and not necessarily a body of work in a little known area that by itself makes a great step forward in our understanding. But if it is not in a current sexy field then it will not be highly cited.

Question 18: What are the challenges or costs involved in working with Government labs?

Yes, there are many challenges. Mostly these revolve around IP ownership and the burden of meeting government requirements. Some of the labs are participating in a trial of the Agreements to Commercialize Technology (ACT) that is supposed to make the lab/industry partnership work better. Time will tell if this really has an impact – but it is an important step in the right direction.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

Nothing dramatic. The things that go into what makes something work is commitment by all parties/trust/common goals/ full and open communication/well defined goals/progress meetings/open and clear communication. Things that fail are those that get pushed aside and don't work out.

Question 20: Is there anything I didn't ask you think might be important to share?

No, not that I can think of.

INTERVIEW #6

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been at this industry since 2006 (c.a. 7 years). I was previously affiliated with Bell Labs.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

Maybe a dozen times--we've very collaboration oriented. We're largely dependent on outside collaborators.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

I already had contacts with people at NIH at the time of this UIG collaboration. I had built an instrument with potential for imaging on the nanometer scale (10 times finer resolution than a regular optimal microscope in 3 dimensions). NIH researchers learned about it and came to us (and we benefited from their expertise in biology).

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

They came to us.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

Yes, I think that was a very important factor. It was less than an hour drive, which made it convenient for them to prepare samples at their lab, drive it over, do the experiments and go back in the same day. The collaboration you refer to involved c.a. 20-30 trips going back and forth. The proximity was definitely a plus in terms of being able to follow through on things.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

It was very complementary. They had a biological question, and they had expertise in preparing the biological samples, and how to label these with fluorescent molecules, which is critical for our microscope. Those are expertise and skills we didn't have. Our focus was on tuning up and tweaking the microscope itself. They brought the biology to the table and we brought the microscope technology to the table.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

Knowledge and expertise in their area of interest.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

I usually don't focus on that. Usually you think more about the science, its value, and how well it's suited to a particular instrument. Which journal it ends up in afterwards usually depends on how well the experiment or results go.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Oh yes. It was absolutely essential to have them there.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Yes…yes. Usually things often have to go by iteration – trial and error. The ability to have access, both at the remote lab and at home I think speeds up the development time cycle a lot. We've learned how to mitigate this a little bit for collaborations at distance, but distance collaborations put a dent in how quickly you can cycle experiments.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes, but they often came to our facilities. The critical piece of infrastructure was the microscope, which wasn't very moveable, but the biological samples were moveable, so they came to our facilities more than vice versa.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

It sometimes depends on the depth of the discussion taking place. Initial discussion are usually over the phone, but once we agree that this is something we want to get going on we often collaborated (in person) via the Postdoc at the government lab.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Yeah, I think if the project is such that it requires a bit of iteration (which was the case in our project), or has multiple components to it, I think that proximity is nice.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yeah, it might self-select a little bit to slightly different projects. Or one might organize the timing a little bit different too. My project involved about 20 mini experiments that combined into one comprehensive experiment. More remote (i.e. at distance) collaboration is typically characterized by a fewer number of experiments – you'd have to figure out a different format for iteration.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

This wasn't an issue for my situation. The microscope itself is unwieldy, and un-transportable (you'll mess up its alignment if you try to move it). Collaborating at close quarters made more sense.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

Yeah…universities might try to be a little more self-sufficient in their style of how they do the research. In industry here you can't do everything – we're dependent on outside partners, whereas universities are less dependent on outside help. Whereas I'd have a microscope collecting dust if I didn't strike up collaborations.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Citation rate…I think is good. On the other end, more relative to industry, do patents come out of your collaboration? That's another more economic-oriented metric. That's one other thing to think about. That's more economic-impact value than research value.

Question 18: What are the challenges or costs involved in working with Government labs?

Not overly so. They can tend to be a little bureaucratic in terms of gaining access to it or getting in and out. They have a larger bureaucracy to deal with than industry would. That's not a major impediment.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

The one you're referring to, I'd consider that the best. An important part of making that a good collaboration was the go-between. The government lab Postdoc was very dedicated and did a good job. In the other collaborations the quality of the Postdoc might not have been as high. Having a solid student onboard can overcome just about everything. The biological problem you're working on can determine how good the collaboration is as well – but that can be luck of the draw.

Question 20: Is there anything I didn't ask you think might be important to share?

I think you covered most questions. I think coverage was good.

INTERVIEW #7

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been in this industry for 21 years.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

Maybe 20.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

I worked for many years at a national lab. Through that I got to know a lot of the people that worked there, and this happened to be one of them.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

We proactively pursued them.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

Nearby – close enough to drive.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

Facilities and expertise.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

It can be very significant. They provide facilities and expertise in general.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

It's always a consideration, but I don't know that this consideration is specifically oriented toward government involvement.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Probably, because we ended up using their facilities and expertise. If we wanted to do the research otherwise we would have had to have found other ways to do it.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Yes.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Yes, we met face to face. Meeting with multiple collaborators or persons at the facility, and since it's nearby sometimes it's convenient to have a meeting that way. If you have a face to face meeting it can sometimes help – it helps interaction. You can go to a bookshelf together. You can pull something up on the computer and share it with the other person. There's more of a personal connection. Things like that.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

I think some areas of research benefit more from proximate collaboration [he doesn't elaborate].

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

I suppose it depends. Some government facilities are expedited by Internet feedback and it's more efficient to have mail-in samples and automated handling, but I think other projects benefit more by direct meeting.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

Collaborating at distance wasn't an issue. We made use of some equipment at the government facility, but the university and the company personnel contributed – had to bring animals there, had to control the equipment there, etc. Everything we needed was local.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

I don't have awareness of that statistic until just now, so I can't comment on it. In industry there's a ban on pubs, where as in university it's the lifeblood, so university researchers are even more interested in pubs (they get promoted based on this), whereas in industry it's propriety/banned/forbidden.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

I think it's a pretty good measure. There are potential developments that go into products or clinical applications where publication is not the major focus. Those are examples of quality output not tied to citations, but I think citations are a pretty good measure of output.

Question 18: What are the challenges or costs involved in working with Government labs?

There are several downsides: 1) sometimes they ask for full cost recovery, which can be expensive. 2) they generally make you sign a very legal binding document that is actually very restrictive for businesses – documents written by lawyers to protect themselves and maximize benefits to that facility. There was one document I wouldn't sign until they changed it. One document said: "all research done was done at this facility", which was incorrect, but to use the facility you had to sign. There are also issues of patenting and intellectual property that are also very sticky. They can include wording which is unequally weighted in their favor. So it can impede scientific progress at times.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I would say on the whole I've had a satisfactory experience. There are the above downsides I just mentioned, but otherwise I would say things have been more or less uniformly acceptable.

Question 20: Is there anything I didn't ask you think might be important to share?

One other negative side of working with government labs: if you write a grant proposal the government—for security reasons or what have you—their overhead is like 120% (typical overhead is 40-50%), making it financially difficult to collaborate. This is way out of line with other universities and businesses.

<u>INTERVIEW #8</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

For 2.5 years.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I think three of my publications would qualify as UIG research.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

I'm familiar with her work, and it was inspirational for the paper we coauthored together, and I introduced myself to her at a conference.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

I invited them to join.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No, probably wouldn't have made a difference.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

She was an authority for one of the subjects on the paper – she verified that what I was writing was realistic.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

I'm not sure how to responding – expertise and facilities.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

No, not for me.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Probably not. What I was hypothesizing and concluding was correct (she validated it).

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

The latter yes. But in this day and age communication can be done online.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

No.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Face to face, conferences, etc. Because we were both happened to be at the same conference. Phone was sufficient for our work.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Yes, in my field (geochemistry) it probably would be help – because of the instruments. Anything that involves large equipment benefits from proximity.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

I guess it depends. If you have someone you need to train on a technique, then proximity helps.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's

their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

Hm…interesting. That's good news – it supports the merits of this institution.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

I've published two papers – and one is more highly cited so people are reading it more—but the first is a higher quality. Hence, the citation rate can distract attention from a higher to a less quality paper.

Question 18: What are the challenges or costs involved in working with Government labs?

Their facilities are less expensive than university facilities because the government subsidizes them.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I don't have a best or a worst.

Question 20: Is there anything I didn't ask you think might be important to share?

Are you including the level of effort or contribution by each partner?

<u>INTERVIEW #9</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

Since 1985 (c.a. 27 years). This is a FFRDC (Federally Funded R&D Center) – a nonprofit org sponsored by the US government. This is private industry (a private nonprofit). I taught for a couple of years at a local university.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I've collaborated with other government entities, but I think this is the first UIG. Wait, actually, I did one other collaboration involving government and industry. The government collaborator was Brookhaven.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

Can't remember. I think they called me. I supplied the materials for them to study – I grew some coatings in my lab, supplied it to them and they did some studies on it, then I added some additional data and we wrote a paper. I had a capability they didn't have and v.v. so it made sense.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

They came to me.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No, they were in New Mexico (Sandia) and I'm in LA. A small difference – I could have gone over and seen their facilities more, I'm not sure it would have altered the paper. It would have given me a better feeling for what their capabilities were.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

They had certain analytical techniques that they could apply to materials I had been studying – they had techniques I didn't have. They also had expertise.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

They bring what any collaborator brings: their expertise, analytical techniques…I can't identify anything that's truly different about a governmental collaborator as opposed to say, an academic collaborator. There's a lot of expertise available at government labs.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

It's not something I've thought about. Not per se, no. Generally the people I've worked with at government labs are high quality researchers, so I suppose having them as coauthors would increase the chances of having a paper accepted in a high impact journal. A big name researcher as a coauthor can make a difference. Yes.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

It would have been different, but not because they were a governmental entity, because they had the expertise/capabilities I needed.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

It hasn't really affected me – generally when people have equipment they don't want people coming from the outside and using it, they want their own people to use it. They're going to lend us access to the equipment whether I'm in town or across country. Proximity helps communication somewhat, but I have phone and email. There is a mild improvement if we can get together, but it wouldn't have significantly affected the work we did.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

I did, but the reason I did so was not related to my most recent UIG collaboration.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

We met at a conference – happened to be at the same conference at the same time so we sat down to discuss the results. The face to face was more helpful than a phone call.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

If there's a large amount of visual data it's much easier to meet in person and spread it out on a table so you can all look at it, understand it and be on the same page. There are also cases where it's important everyone understands how the equipment works (if complex equipment is involved). Sometimes you can't understand what the data means if you don't understand the complexity of the equipment. So these two conditions are well suited for proximity.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

It probably does. When you have distance the tasks of the individual collaborators are more well defined. One does task A at their facility, and so forth. When you're closer there's some blurring of the lines there so you can each work on each other's tasks, sometimes allowing new ideas/directions to develop. Well defined tasks are key for distance collaboration.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

It does surprise me. I'm wondering if industry may have different goals than university and government (e.g. max profit) – in which case if the government is closer they can have more influence. I'm not really sure why that's try.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

I think that's a pretty good measure. There are probably exceptions – valuable research that's not popular. But in general I'd say cites are a good measure.

Question 18: What are the challenges or costs involved in working with Government labs?

There are always budgets which can guide the course of research. A lot of my work if funded internally, and the collaborations I have are in-kind collaborations.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I don't think I've had any bad collaboration. There've been disagreements between our labs and government labs. There was a collaboration where we used certain data the government lab didn't think we used correctly or cite them correctly in the publication, but that can happen between any two collaborators. But in general, most of my collaborations have been very successful.

Question 20: Is there anything I didn't ask you think might be important to share?

I can't think of anything. I look for people who have expertise and are willing to collaborate – if this is government, great, if not, no worries.

<u>INTERVIEW #10</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been here for almost 11 years. This is industry. A venture capital backed company in Silicon Valley. I've also worked at Scripps Research Institute. That's pretty much it.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

About four or five times.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

Don't recall, but we ended up applying for a grant. It was probably suggested to us.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

It was initiated by them.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No. But I think it's better when you're in close proximity – better to have physical interaction than emails or phone calls. Although I did visit there several times but it's much more difficult.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

They brought the need. They brought the application for our technology.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

The government is a very large institution that creates markets almost in and of itself. For example: something required by the military has a large market. The main value they bring is an identified need for a military need or public good. In the language of economics they create a demand.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

No, I wouldn't consider that.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Definitely. I don't think we'd have done it.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Definitely, yes.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

I visited in person in addition to communicating via phone and email. Various reasons. When they were doing the testing of our devices I wanted someone from the lab to be present during that testing—as an observer/advisor—and that's hard to do over the phone. They would occasionally have meetings where they brought together several funded groups in a meeting environment. The other reason is general relationship management – it helps to have face time to maintain networks and relationships.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Yes, there are areas that benefit more. It's a tough one – I know primarily about what I specialize in. A lot of what we did didn't involve a direct need for proximate collaboration, but some of it did—e.g. the testing of the devices in development. But the actual development process didn't require direct physical interaction.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yes. I think it's different because if you have direct, daily interaction there will be different levels of input from collaborators than if you have a more distant relationship.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's

their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

It's somewhat surprising. I would have thought it [citation impact] might have correlated more with university-government interactions.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Citations are driven by a lot of different things. Maybe a better measure of research effectiveness are things that come out of that research (e.g. tangible products). By measuring citations you're assuming a contribution to the general thinking on that subject. I'm not sure citations = practicality. My vision is colored by my industry spectacles—if I can't make a product by the end of the day I don't see much point in doing it.

Question 18: What are the challenges or costs involved in working with Government labs?

They have a lot of reporting requirements. They have generally fairly onerous long format reports you have to fill on a quarterly basis, and you feel you have to do it because they're funding you, but it can be quite onerous. Also, you have to keep very close tabs on where the money's going, etc. So there's a lot of administrative overhead in working with the government.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

The best collaboration resulted in a developed product that was approved by the FDA, making it a successfully collaboration, and something we wouldn't have done without government help. I don't know that I have a worst experience.

Question 20: Is there anything I didn't ask you think might be important to share?

Don't think so, I think it sounded good.

<u>INTERVIEW #11</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been 26 years in industry. I have a university back ground as well (PhD and three Postdocs), but after that joined industry. I collaborate with any research center I can get my hands on.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I have a few ongoing collaborations. It's hard to say. 50% of what I do is R&D. I have 110 papers on the basic side and 80 on the applied side.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

In addition to my own company I publish papers with other research centers and industrial centers, and foreign universities. For my most recent collaboration, the us air force contacted someone I had been working with, so I contacted the air force to see if we could all do a project, and they expressed interest in collaborating with us. This was the first time I collaborated with the air force.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

Both: they went to my collaborator and then I went to them.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No. I never met them. I'm based in Houston and we interact with people all over the place. It probably would only have improved things if it had been in close proximity, but there's no way I could have this many papers published if I only collaborated with people I personally interact with. I can do much more without having a geographic constraint.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

They made measurements (very important for completing the project) that my university collaborator was unable to make. I couldn't make these measurements either.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

I'm in industry, so you'd have to ask what does the government bring to industry (to view things from my perspective). I think it's either good/better/best. Government institutions often have world leaders on their team. The one I've been working with is irreplaceable. I only work with the top. So, they (the government) provides world leaders. 2nd, we use equipment that is only available at government facilities. No industry or university is going to spend the billions to build this equipment. We've benefited from superb facilities. So there's the skill of the people and the equipment that's made available by the government.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

I'm obsessed with citations (in the words of one of my colleagues), so there's no question I always try to get the best paper we can, so yes, including authors that up citations is a plus. The quality of the work was certainly better with the air force on board.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Yes. We would know much less. It would limit the scope of what we can accomplish.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Yeah, it does. It's not essential, but is sure makes life a lot easier. The problem is it's a big country and a big world, so what are you going to do? Proximity always helps, but it's not required. Usually you need approval if you're collaborating at distance (as this takes more time and money). The converse is also true. There's a place in Japan I can't visit for this reason.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

No, but I'd like to. My collaborator[63] has visited it.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Almost always there are phone calls, emails and written reports. We've also had face to face meetings. We met in person because: the duty cycle (the actual productive time), is low in face to face meeting (as these involve travel, money and time), but it's the offhanded comment that typically drives the whole thing in a new direction. It depends on how novel the project is. So I go there and say I think we're seeing this, and they so no, we're seeing that. So proximity is highly desirable, especially if the stuff is more novel. If I need a yes/no answer that can be done by phone. A maybe answer can also be done by phone (to a specific thing). Sometimes we're not sure what we're looking for, and that's when it's best to ruminate. If we're trying to do something new and original, but not sure how to proceed, face to face meetings are very important.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

If you want to use a government facility, they're hard to get time and access to. There proximity is desirable. You get on a plane and spend days waiting for access. There's certain research I just can't conduct at distance.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

If I go to the applied side and you're really trying to push the envelope on stuff, it really depends. If you have a collaboration where everyone has a defined task, then proximity is not so important. By contrast, if you have a collaboration where you require all participants to jam together to build an overly picture of what's going on then proximity becomes very important.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (I) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

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[63] Mentioned in questions 3 and 4.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

No, it doesn't. Because a lot of government facilities have unique equipment, when you want to use that equipment proximity for industry matters a lot. My job is to make money for my company. My bosses let me do my research as a component of what is necessary for me. For industrial research my critical path doesn't involve publishable work (unlike university personnel). I'm essentially using government labs for publishable work. Proximity makes it easier for me to do stuff on the side, off my critical path.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

It misses a lot. The problem is this: you have different fields. I do all right in citations. I'm cited a lot more than my (outstanding) former boss is. There's a multi-trillion dollar industry that cares a lot about crude oil, so I get cited. If you don't normalize citations for the field you can make incorrect conclusions.

Question 18: What are the challenges or costs involved in working with Government labs?

There's not many downsides – it (collaborating with government actors) tends to be cheaper. The cost structure to staying at Brookhaven was lower (than standard hotel costs). So they made it pretty easy. I've used government research centers as much as I can and would love to use them more.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I've had a lot of positive experiences. On the negative side: I'm publishing a paper refuting a very well known scientist funded by the government, and he's a good friend and we've helped each other in the past. We're in a fight, it's not personal. The point being that at the end of the day this fight will be good for the field, to sort out what's going on. We're professional with it. It's the way science works – you put your best foot forward and hope to be on the winning side and see what happens.

Question 20: Is there anything I didn't ask you think might be important to share?

The only additional comment I have is that I have kind of the dual path (I have both an academic side for papers and a utilitarian side for projects working with oil companies), and the government figures much less prominently in the latter side because this stuff is highly confidential.

INTERVIEW #12

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been at this (government) facility since 2002. I'm also an associate professor at George Mason, but that's on paper only.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

I have quite a few papers (c.a. 5) with the same general group of authors (that appear on the UIG nanopublication this interview is based on).

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

[This interviewee is the government collaborator, so the author asked this person how he was introduced to his University/Industry partners.] In most cases it went from grad school, and then other people I've met at conferences.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

I had a request from the journal to contribute an invited paper. At that point I recruited the other coauthors to help me with it.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No, the industry guy wasn't (he's in San Diego). Everyone else was pretty close to me.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

This was a review paper – there's actually not much… it's hard to answer to answer your question in terms of scientific work for this particular paper. The scientists working here are professional scientists. They're very capable and have a wealth of experience and quite a bit more (than university and industry) in terms of equipment and resources. Collaborators make up for deficits among the other collaborators. Each person brings something to the table that the rest of the group needs.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

[Answered in previous question.]

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

That's a subjective question – it depends on who the researchers are, and which group and which field you're dealing with. In the institution I'm working at researchers are known as pioneers in certain scientific disciplines. Having their name on a paper would certainly up the citation rate (the same might also be true of big name coauthors in university and industry).

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Yes, each person makes up for deficits among other coauthors. I'm usually the initiator with my group, so I sort out people. I oversee a lot. In my case nothing would have happened had I not pursued. People pursue other people to get things done. You might get a different set of answers depending on the nature of the project.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Of course.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

[NA]

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

We arrange times to meet at conferences or do a special visit. I chose to meet in person because I wanted to sit down and go over experimental data, or have discussions that take a long time. In another example there was a need to use equipment at another facility.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

It depends on what you need from the other group. Collaboration tends not to work well when people are distant and there's not a lot of interaction. The converse is also true. If you're doing something which is obscure, then you might have to go far to find someone whose willing to do it for you.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yes, I would say you get better quality the more personal interaction you have.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

That is a bit surprising.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

I think the citation rate captures research quality within the scientific field itself. It's a good measure for how often people turn to a paper and how useful they find it. But in terms of the kind of collaboration you talking about – wouldn't one of the net goals of the collaboration be a product that industry is interested in? I think the citation rate captures how useful research is to a community or how they view it.

Question 18: What are the challenges or costs involved in working with Government labs?

There are plenty of negatives: the facility I work at request us to justify each of our interactions. Our time costs money and we have to justify it. This can push off a collaboration. The sheer amount of paperwork involved can also be a burden and take time. There's also issues of intellectual property that becomes complicating.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

The collaboration on the paper you're referring to is probably the best. The fellow I'm collaborating with is at a company and it's more about getting things done. The real facilitator in this process is having a personal relationship with my coauthors. Similar interests helped drive this as well.

Question 20: Is there anything I didn't ask you think might be important to share?

The only thing I can think to add is that the nature of government research is evolving. It used to be that the government focused on basic research (which made us the technological leader for so long). Now there's a shift in focus to more applied research. Secondly I'll mention that the huge costs associated with government research are shrinking, which changes what people can do and how much they can do in these type of collaborations. I think the nature of the (more applied) research being done will cause the government to collaborate with universities and industry more often.

<u>INTERVIEW #13</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I'm affiliated with a government lab, for 11 years.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

A handful, but not a whole lot.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

It was the result of a friendship from a long time ago.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

They were pursued.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No. No difference. Email worked.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

Funding.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

Funding.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

I don't think so.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Yes, there would be no funding. It wouldn't have happened.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

It helps personal discussion and communication. Equipment wasn't important for this – we were doing numerical simulations for the electromagnetic wave transfer through materials.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

No. Everything is publication based – didn't use any equipment or technology for this research.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

We mainly used email and phone. Met in person at conference. We had no travel funds for face to face meetings.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

For a theoretical studies proximity is not so much important – communication technologies are ok. Collaborations involving complicated equipment that needs training needs proximity more.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yes. If you want to use advanced instruments to measure complex phenomena proximity is important.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's

their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

It doesn't surprise me. Funding is under the management of government – if you have one or the other close to the government you have more face to face talks. You get more results. When Industry has face to face talks it counts for more than when universities have face to face talks.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Citations does ok for some science, but for new technologies I'm not so sure. There is some very good research out there with a low number of citations.

Question 18: What are the challenges or costs involved in working with Government labs?

If you want to get funding from the government it can be hard at times, especially in times of budget cuts.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I don't think I have a best or worst collaboration. It's been a fairly positive experience overall.

Question 20: Is there anything I didn't ask you think might be important to share?

The government should focus more resources and attention on university and industry personnel engaged in more fundamental research.

<u>INTERVIEW #14</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been 11 years with this Government affiliation. I don't have any other affiliations in the US

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

Maybe 3-4 times.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

I was interested in the topic, and I knew that certain people were experts in this field, so I called them and asked them whether they were willing to do a project with me. We needed someone with the technology to do this research – someone I met in a meeting, from Industry, had the technology and was willing to collaborate with us.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

I went to them, but they were looking for someone with a population to test their methods. So we both had a need that we could meet for each other.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

No. It wouldn't have made a difference.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

It provided the population, the original idea, participated in analyses, drafted the paper, and participated in discussion with all the collaborators.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

Expertise. Industry people tend to be very focused on one specific problem, while people in University and Government have a much broader perspective, which helps Industry. Industry is good at specific, in depth, technical tasks, but they tend not have an open mind.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

No.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Without the government this science could not have been produced.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

No, we had email. I work on large datasets and numbers – we don't produce a product. We don't work in a lab. We don't analyze samples. We work on numbers. And so, when you work on numbers, whether you're close or not, it really doesn't matter. Of course being close makes a difference in other areas that require interaction.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

[NA]

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Yes, we met face to face, usually in the occasion of meetings. The face to face interaction is usually more effective than any other type of interaction. You accomplish a lot more. Nonverbal communication and the ability to write on paper, work on team, observe facial expressions and body language can only be done face to face. Not even video conference allows for this.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Molecular Biology requires continuous meetings – proximity is a good idea for this type of research.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

No.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

No [the interviewee does not elaborate].

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

The number of citations is a function of the type of science you're doing. Within a given field I think citations is a good metric, but if you want to compare across fields it's a bad metric.

Question 18: What are the challenges or costs involved in working with Government labs?

Ethical issues are raised on a frequent basis. Before working with industry we have to go through enormous authorization, which delays progress and our ability to reach out to Industry. Our Intellectual Property (IP) office wants to retain rights to IP, which Industry often isn't comfortable with. There is often conflict of interest.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

My best was the one you reference – it was mutually respectful and we each got something from each other. We had common objectives. [On the negative side] Some UIG collaborations didn't work out because we couldn't agree on IP issues.

Question 20: Is there anything I didn't ask you think might be important to share?

No, I think you asked most of the questions that are relevant.

<u>INTERVIEW #15</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been working at this government lab for nine years.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

Maybe 10.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

[NA]

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

Government involvement was pursued.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

Yes. It definitely helped – it was very convenient to be able to talk to people face to face.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

The government provided funding. It was also involved in the design and project direction. It was involved in lab research as well.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

They play a very important role. They provide funding and are involved in research direction.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

It could possibly increase citations, but I don't think this is the most important consideration.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

I would say yes. This work wouldn't be possible without funding. That's very important in this line of research.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

Yes, it does. It makes things much easier. We can have several meetings per week, whenever we want. We had an outside collaborator as well, but we only communicated a couple times a month – communication and feedback was much slower with this person. Problems get solved much faster with proximity.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

Yes.

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

Sometimes it's convenient to meet [in person] if you're both at the same conference. When meeting in person you have more time to talk. Communication is much easier when you're face to face.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

Lab research involving complex equipment, where you need to learn how to use it—face to face definitely helps. Talking on the phone can be unclear at times and cause confusion.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yes, I think so. If you work close the collaboration will have more time to share information and understand one another, making things happen quicker. At distance you can have communication issues. People can be reluctant to call each other at times. Close distance facilitates frequency of interaction.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

This wasn't an issue.

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

No, I think that sounds reasonable [the interviewee doesn't elaborate].

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

Yes, I think it's a good measure. More citations are reflective of a larger impact.

Question 18: What are the challenges or costs involved in working with Government labs?

There are a few small problems, but nothing major. One issue is how to distribute funding and which direction to go in. Deciding between a basic and applied direction can be a challenge.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

The best collaboration resulted in a good publication from favorable results. I don't have a worst UIG collaboration.

Question 20: Is there anything I didn't ask you think might be important to share?

No, I think you got a pretty broad range for your questions. I don't have anything else to add.

<u>INTERVIEW #16</u>

Question 1: How long have you been associated with your present (U / I / G) affiliation for? Do you have any other (present or past) affiliations?

I've been with the government for 14 years. There are several national labs in the US most are run by DOE and DOD. We are the only national lab that is party of dept of commerce – we're focused on economic security. UIGs and IGs are core to our business.

Question 2: How many times have you collaborated (i.e. coauthored) in a University-Industry-Government (UIG) partnership? If agreeable, I'd like to discuss your most recent collaboration.

50-100 I guess.

Question 3: [For University and Industry partners] How were you introduced to your Government collaborator? What motivated this collaboration to come about? How many times have you collaborated together?

It's all personal contacts. The industry I worked with was a small startup and they had a very interesting material. We were able to understand some details about these materials that had not been realized before. I knew the founder of this company, and he suggested I know a way to make this work really well.

Question 4: In your UIG collaboration, was involvement by the Government actor proactively pursued, or did they seek involvement?

Government involvement was proactively pursued.

Question 5: Did your collaboration occur in close proximity—i.e. was at least one of your collaborators co-located in the same metro area as yourself? If yes, did this make a difference? If no, would it have made a difference?

In this case, no, but I think that probably happens a lot and is a big factor. Proximity lets you get to know the people at the other place and how to interact and become familiar. In this case I knew the professor I was working with from the University of Michigan – he was in the same department as me when I studied there.

Question 6: When you participated in a UIG collaboration, what value did the Government collaborator add to this partnership?

The government organization I'm with is primarily a measurement and standards organization and it was our advanced characterization techniques that revealed what the structural basis should be for performance. They had innovative materials and we had innovative measurements.

Question 7: What value do you think Government collaborators add to University-Industry partnerships in general?

I can comment specifically for my organization (which hires about 3,000 scientists) - expertise. Another benefit of government involvement is that our budgets are a lot bigger than university budgets. We also have cutting edge equipment.

Question 8: Is increasing the citation rate, journal quality or translating university research into industrial technology an important objective or result of including Government actors in University-Industry partnerships?

I don't think that's a big motivator.

Question 9: Would the outcome of your UIG collaboration have been any different had the Government actor not become involved? If yes, how? If no, why not?

Yes, it would. In this case a $300,000 piece of equipment was used, that the university and industry partners didn't have. So this wouldn't have occurred without government involvement.

Question 10: Does proximity between collaborators make it easier to communicate or gain access to equipment?

The latter – absolutely. In terms of the former: some, but not really. Everybody gets busy with what they're doing, making face to face meetings less frequent, but they still have value. When following up face to face helps. Face to face helps for getting things done. If I'm just a voice on a computer it's not as effective as getting to know someone in person – you can get them to do a lot more if you know them personally.

Question 11: [For University and Industry partners] Have you ever visited the Government facility you collaborated with or sent researchers to it?

[NA]

Question 12: Did you communicate with your collaborators using methods other than email (e.g. Skype/WebEx/etc)? When communicating did you use telecommunication technologies, or meet in person? If the latter, why did you do that if you could have communicated over the phone?

I'm not allowed to use Skype at my facility. We've communicated via phone and email and face to face. We met face to face because this was not an intended collaboration. It was an ad hoc side project that got initiated because we met face to face. Once something gets very specific, and it's a day-to-day routine, then phone and Internet are fine. The idea creation I don't think would have happened, however, unless we had a chance to sit down and brainstorm together. It was ad hoc at first, and as soon as we know what we were working on proximity was less important. Proximity facilities idea generation – if we all sat in our cubicles and confined our communication to email this wouldn't have happened.

Question 13: Under what research areas or conditions does proximate collaboration increase research value?

I can imagine in medicine and biomedical research - if you're trying to build something that goes into the human body you really do need to be next to a medical school.

Question 14: Do you think the nature of research conducted at more proximate collaboration differs from the nature of research conducted at distance?

Yes, I do. I think when a collaboration is proximate it's probably more spontaneous. If you're collaborator is right next door they're always there to physically remind you and you keep focused on it. Whereas when we work at larger distances, it depends on how committed or excited you are about what's going on – it's easier to work in spurts at distance and progress isn't as fast. There's a bit of a delay in the urgency of finishing when things are distant.

Question 15: [For proximate UIG collaborations] Do UI collaborators have resources (or alternatives) to go outside of local UIG triangles, or do they collaborate at close scales because it's their only option. Ask local collaborations [i.e. those with small UIG triangles]: (i) did you have outside/alternative options? (ii) could you have collaborated at distance, and if so, why didn't you?

[NA]

Question 16: When Industry collaborates in close proximity with Government this seems to count for more than when Universities do. Does that surprise you?

That's an interesting finding. My experience working with industry is they are very driven. They're driven more than academics. Academics will get involved in research that is for academic sake. Industry wants to get into research because they see a commercial value in it—i.e. they're motivated by it and its value (as opposed to studying it for its own sake). So they [industry] move at a faster and more determined pace. I'm not saying that academics are not driven, but this has been my experience. I can also tell you that i can find a million academic partners, but i can't find that many industry partners.

Question 17: I'm trying to get at the value of research and am using citations to do this. How well does that capture value? Does it miss anything?

I would say writing a paper is an activity. A citation to that is recognition to that, but the real impact is: did you change the way somebody did something? That's the way we measure impact. Do citations change the way people do things? Um, maybe not. Also, there are certainly fields that are extremely hot these days, in an academic sense. Any paper you write in a hot field will naturally attract more citations. But it's almost impossible to come up with a unified measure of impact. Citations are good from an academic perspective.

Question 18: What are the challenges or costs involved in working with Government labs?

There are huge challenges: the biggest challenge is for industry - I am a government agency and paid by tax dollars. I shouldn't pick just one company to help and not help the others. What I do falls into the realm of the public domain. Companies are unwilling to engage with us sometime because they'll have to reveal their intellectual property (IP), and then they're competitive advantage is gone. That's especially true of smaller companies, where their IP is all they have. Some company cultures are very closed and protective.

Question 19: Would you care to discuss your best (or worst) UIG collaboration and what made it the best (or worst)?

I think the best one we had was…we had a four year collaboration with Intel on semi-conductor lithography. We developed characterization techniques that would elucidate what aspects of the resistant materials they used to pattern the nanoscale transistors. We developed measurements that were very analytical and quantitative to measure transistor performance for smaller transistors. Intel was very engaged with us on this. They put some scientists in our lab, right next door. It was the impact – the fact that we devised a test method they could then impose. We changed the way Intel did business with their vendors.

On the negative side, government is obliged to help everyone it seems, and a lot of times people will come to us and expect us to do all the work. We have to evaluate what's being asked of us with the priorities of the government and the country, etc. The good collaborators provide people to help us and to learn.

Question 20: Is there anything I didn't ask you think might be important to share?

No, I've inserted a few things and i think you pretty much hit on the main points.

APPENDIX H

PROFESSOR PORTER'S (GEORGIA TECH) 4 META DISCIPLINE CLASSIFICATION SCHEME

Table 34: Professor Porter's (Georgia Tech) 4 Meta Discipline Classification Scheme

WEB OF SCIENCE CATEGORY	4 META DISCIPLINE CLASSIFICATION
AGRICULTURE, DAIRY & ANIMAL SCIENCE	BIOLOGY AND MEDICINE
ALLERGY	BIOLOGY AND MEDICINE
ANATOMY & MORPHOLOGY	BIOLOGY AND MEDICINE
ANDROLOGY	BIOLOGY AND MEDICINE
ANESTHESIOLOGY	BIOLOGY AND MEDICINE
BEHAVIORAL SCIENCES	BIOLOGY AND MEDICINE
BIOCHEMICAL RESEARCH METHODS	BIOLOGY AND MEDICINE
BIOCHEMISTRY & MOLECULAR BIOLOGY	BIOLOGY AND MEDICINE
BIOLOGY	BIOLOGY AND MEDICINE
BIOPHYSICS	BIOLOGY AND MEDICINE
BIOTECHNOLOGY & APPLIED MICROBIOLOGY	BIOLOGY AND MEDICINE
CARDIAC & CARDIOVASCULAR SYSTEMS	BIOLOGY AND MEDICINE
CELL & TISSUE ENGINEERING	BIOLOGY AND MEDICINE
CELL BIOLOGY	BIOLOGY AND MEDICINE
CHEMISTRY, MEDICINAL	BIOLOGY AND MEDICINE
CLINICAL NEUROLOGY	BIOLOGY AND MEDICINE
CRITICAL CARE MEDICINE	BIOLOGY AND MEDICINE
DENTISTRY, ORAL SURGERY & MEDICINE	BIOLOGY AND MEDICINE
DERMATOLOGY	BIOLOGY AND MEDICINE
DEVELOPMENTAL BIOLOGY	BIOLOGY AND MEDICINE
EDUCATION, SCIENTIFIC DISCIPLINES	BIOLOGY AND MEDICINE
EMERGENCY MEDICINE	BIOLOGY AND MEDICINE
ENDOCRINOLOGY & METABOLISM	BIOLOGY AND MEDICINE
ENGINEERING, BIOMEDICAL	BIOLOGY AND MEDICINE
FOOD SCIENCE & TECHNOLOGY	BIOLOGY AND MEDICINE
GASTROENTEROLOGY & HEPATOLOGY	BIOLOGY AND MEDICINE

Table 34 (continued)

GENETICS & HEREDITY	BIOLOGY AND MEDICINE
GERIATRICS & GERONTOLOGY	BIOLOGY AND MEDICINE
HEALTH CARE SCIENCES & SERVICES	BIOLOGY AND MEDICINE
HEMATOLOGY	BIOLOGY AND MEDICINE
IMMUNOLOGY	BIOLOGY AND MEDICINE
INFECTIOUS DISEASES	BIOLOGY AND MEDICINE
INTEGRATIVE & COMPLEMENTARY MEDICINE	BIOLOGY AND MEDICINE
MATERIALS SCIENCE, BIOMATERIALS	BIOLOGY AND MEDICINE
MATHEMATICAL & COMPUTATIONAL BIOLOGY	BIOLOGY AND MEDICINE
MEDICAL ETHICS	BIOLOGY AND MEDICINE
MEDICAL INFORMATICS	BIOLOGY AND MEDICINE
MEDICAL LABORATORY TECHNOLOGY	BIOLOGY AND MEDICINE
MEDICINE, GENERAL & INTERNAL	BIOLOGY AND MEDICINE
MEDICINE, LEGAL	BIOLOGY AND MEDICINE
MEDICINE, RESEARCH & EXPERIMENTAL	BIOLOGY AND MEDICINE
MICROBIOLOGY	BIOLOGY AND MEDICINE
MICROSCOPY	BIOLOGY AND MEDICINE
MULTIDISCIPLINARY SCIENCES	BIOLOGY AND MEDICINE
MYCOLOGY	BIOLOGY AND MEDICINE
NEUROIMAGING	BIOLOGY AND MEDICINE
NEUROSCIENCES	BIOLOGY AND MEDICINE
NUTRITION & DIETETICS	BIOLOGY AND MEDICINE
OBSTETRICS & GYNECOLOGY	BIOLOGY AND MEDICINE
ONCOLOGY	BIOLOGY AND MEDICINE
OPHTHALMOLOGY	BIOLOGY AND MEDICINE
ORTHOPEDICS	BIOLOGY AND MEDICINE
OTORHINOLARYNGOLOGY	BIOLOGY AND MEDICINE
PARASITOLOGY	BIOLOGY AND MEDICINE
PATHOLOGY	BIOLOGY AND MEDICINE
PEDIATRICS	BIOLOGY AND MEDICINE
PERIPHERAL VASCULAR DISEASE	BIOLOGY AND MEDICINE
PHARMACOLOGY & PHARMACY	BIOLOGY AND MEDICINE
PHYSIOLOGY	BIOLOGY AND MEDICINE
PRIMARY HEALTH CARE	BIOLOGY AND MEDICINE
RADIOLOGY, NUCLEAR MEDICINE & MEDICAL IMAGING	BIOLOGY AND MEDICINE

Table 34 (continued)

REHABILITATION	BIOLOGY AND MEDICINE
REPRODUCTIVE BIOLOGY	BIOLOGY AND MEDICINE
RESPIRATORY SYSTEM	BIOLOGY AND MEDICINE
RHEUMATOLOGY	BIOLOGY AND MEDICINE
SPORT SCIENCES	BIOLOGY AND MEDICINE
SURGERY	BIOLOGY AND MEDICINE
TOXICOLOGY	BIOLOGY AND MEDICINE
TRANSPLANTATION	BIOLOGY AND MEDICINE
TROPICAL MEDICINE	BIOLOGY AND MEDICINE
UROLOGY & NEPHROLOGY	BIOLOGY AND MEDICINE
VETERINARY SCIENCES	BIOLOGY AND MEDICINE
VIROLOGY	BIOLOGY AND MEDICINE
ACOUSTICS	PHYSICAL SCIENCE AND ENGINEERING
ASTRONOMY & ASTROPHYSICS	PHYSICAL SCIENCE AND ENGINEERING
AUTOMATION & CONTROL SYSTEMS	PHYSICAL SCIENCE AND ENGINEERING
CHEMISTRY, ANALYTICAL	PHYSICAL SCIENCE AND ENGINEERING
CHEMISTRY, APPLIED	PHYSICAL SCIENCE AND ENGINEERING
CHEMISTRY, INORGANIC & NUCLEAR	PHYSICAL SCIENCE AND ENGINEERING
CHEMISTRY, MULTIDISCIPLINARY	PHYSICAL SCIENCE AND ENGINEERING
CHEMISTRY, ORGANIC	PHYSICAL SCIENCE AND ENGINEERING
CHEMISTRY, PHYSICAL	PHYSICAL SCIENCE AND ENGINEERING
COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	PHYSICAL SCIENCE AND ENGINEERING
COMPUTER SCIENCE, CYBERNETICS	PHYSICAL SCIENCE AND ENGINEERING
COMPUTER SCIENCE, HARDWARE & ARCHITECTURE	PHYSICAL SCIENCE AND ENGINEERING
COMPUTER SCIENCE, INFORMATION SYSTEMS	PHYSICAL SCIENCE AND ENGINEERING

Table 34 (continued)

COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	PHYSICAL SCIENCE AND ENGINEERING
COMPUTER SCIENCE, SOFTWARE ENGINEERING	PHYSICAL SCIENCE AND ENGINEERING
COMPUTER SCIENCE, THEORY & METHODS	PHYSICAL SCIENCE AND ENGINEERING
CONSTRUCTION & BUILDING TECHNOLOGY	PHYSICAL SCIENCE AND ENGINEERING
CRYSTALLOGRAPHY	PHYSICAL SCIENCE AND ENGINEERING
ELECTROCHEMISTRY	PHYSICAL SCIENCE AND ENGINEERING
ENERGY & FUELS	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, AEROSPACE	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, CHEMICAL	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, ELECTRICAL & ELECTRONIC	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, INDUSTRIAL	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, MANUFACTURING	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, MARINE	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, MECHANICAL	PHYSICAL SCIENCE AND ENGINEERING
ENGINEERING, MULTIDISCIPLINARY	PHYSICAL SCIENCE AND ENGINEERING
INSTRUMENTS & INSTRUMENTATION	PHYSICAL SCIENCE AND ENGINEERING
MATERIALS SCIENCE, CERAMICS	PHYSICAL SCIENCE AND ENGINEERING
MATERIALS SCIENCE, CHARACTERIZATION & TESTING	PHYSICAL SCIENCE AND ENGINEERING
MATERIALS SCIENCE, COATINGS & FILMS	PHYSICAL SCIENCE AND ENGINEERING
MATERIALS SCIENCE, COMPOSITES	PHYSICAL SCIENCE AND ENGINEERING

Table 34 (continued)

MATERIALS SCIENCE, MULTIDISCIPLINARY	PHYSICAL SCIENCE AND ENGINEERING
MATERIALS SCIENCE, PAPER & WOOD	PHYSICAL SCIENCE AND ENGINEERING
MATERIALS SCIENCE, TEXTILES	PHYSICAL SCIENCE AND ENGINEERING
MATHEMATICS	PHYSICAL SCIENCE AND ENGINEERING
MATHEMATICS, APPLIED	PHYSICAL SCIENCE AND ENGINEERING
MATHEMATICS, INTERDISCIPLINARY APPLICATIONS	PHYSICAL SCIENCE AND ENGINEERING
MECHANICS	PHYSICAL SCIENCE AND ENGINEERING
METALLURGY & METALLURGICAL ENGINEERING	PHYSICAL SCIENCE AND ENGINEERING
MINING & MINERAL PROCESSING	PHYSICAL SCIENCE AND ENGINEERING
NANOSCIENCE & NANOTECHNOLOGY	PHYSICAL SCIENCE AND ENGINEERING
NUCLEAR SCIENCE & TECHNOLOGY	PHYSICAL SCIENCE AND ENGINEERING
OPERATIONS RESEARCH & MANAGEMENT SCIENCE	PHYSICAL SCIENCE AND ENGINEERING
OPTICS	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, APPLIED	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, ATOMIC, MOLECULAR & CHEMICAL	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, CONDENSED MATTER	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, FLUIDS & PLASMAS	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, MATHEMATICAL	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, MULTIDISCIPLINARY	PHYSICAL SCIENCE AND ENGINEERING
PHYSICS, NUCLEAR	PHYSICAL SCIENCE AND ENGINEERING

Table 34 (continued)

PHYSICS, PARTICLES & FIELDS	PHYSICAL SCIENCE AND ENGINEERING
POLYMER SCIENCE	PHYSICAL SCIENCE AND ENGINEERING
ROBOTICS	PHYSICAL SCIENCE AND ENGINEERING
SPECTROSCOPY	PHYSICAL SCIENCE AND ENGINEERING
STATISTICS & PROBABILITY	PHYSICAL SCIENCE AND ENGINEERING
TELECOMMUNICATIONS	PHYSICAL SCIENCE AND ENGINEERING
THERMODYNAMICS	PHYSICAL SCIENCE AND ENGINEERING
TRANSPORTATION SCIENCE & TECHNOLOGY	PHYSICAL SCIENCE AND ENGINEERING
AGRICULTURAL ECONOMICS & POLICY	PSYCHOLOGY AND SOCIAL SCIENCES
ANTHROPOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
AREA STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
BUSINESS	PSYCHOLOGY AND SOCIAL SCIENCES
BUSINESS, FINANCE	PSYCHOLOGY AND SOCIAL SCIENCES
COMMUNICATION	PSYCHOLOGY AND SOCIAL SCIENCES
CRIMINOLOGY & PENOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
CULTURAL STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
DEMOGRAPHY	PSYCHOLOGY AND SOCIAL SCIENCES
ECONOMICS	PSYCHOLOGY AND SOCIAL SCIENCES
EDUCATION & EDUCATIONAL RESEARCH	PSYCHOLOGY AND SOCIAL SCIENCES
EDUCATION, SPECIAL	PSYCHOLOGY AND SOCIAL SCIENCES

Table 34 (continued)

ENVIRONMENTAL STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
ERGONOMICS	PSYCHOLOGY AND SOCIAL SCIENCES
ETHICS	PSYCHOLOGY AND SOCIAL SCIENCES
ETHNIC STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
FAMILY STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
GEOGRAPHY	PSYCHOLOGY AND SOCIAL SCIENCES
GERONTOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
HEALTH POLICY & SERVICES	PSYCHOLOGY AND SOCIAL SCIENCES
HISTORY	PSYCHOLOGY AND SOCIAL SCIENCES
HISTORY & PHILOSOPHY OF SCIENCE	PSYCHOLOGY AND SOCIAL SCIENCES
HISTORY OF SOCIAL SCIENCES	PSYCHOLOGY AND SOCIAL SCIENCES
HOSPITALITY, LEISURE, SPORT & TOURISM	PSYCHOLOGY AND SOCIAL SCIENCES
INDUSTRIAL RELATIONS & LABOR	PSYCHOLOGY AND SOCIAL SCIENCES
INFORMATION SCIENCE & LIBRARY SCIENCE	PSYCHOLOGY AND SOCIAL SCIENCES
INTERNATIONAL RELATIONS	PSYCHOLOGY AND SOCIAL SCIENCES
LAW	PSYCHOLOGY AND SOCIAL SCIENCES
LINGUISTICS	PSYCHOLOGY AND SOCIAL SCIENCES
MANAGEMENT	PSYCHOLOGY AND SOCIAL SCIENCES
NURSING	PSYCHOLOGY AND SOCIAL SCIENCES
PLANNING & DEVELOPMENT	PSYCHOLOGY AND SOCIAL SCIENCES

Table 34 (continued)

POLITICAL SCIENCE	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHIATRY	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, APPLIED	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, BIOLOGICAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, CLINICAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, DEVELOPMENTAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, EDUCATIONAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, EXPERIMENTAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, MATHEMATICAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, MULTIDISCIPLINARY	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, PSYCHOANALYSIS	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, SOCIAL	PSYCHOLOGY AND SOCIAL SCIENCES
PUBLIC ADMINISTRATION	PSYCHOLOGY AND SOCIAL SCIENCES
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL ISSUES	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL SCIENCES, BIOMEDICAL	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL SCIENCES, INTERDISCIPLINARY	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL SCIENCES, MATHEMATICAL METHODS	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL WORK	PSYCHOLOGY AND SOCIAL SCIENCES

Table 34 (continued)

SOCIOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
SUBSTANCE ABUSE	PSYCHOLOGY AND SOCIAL SCIENCES
TRANSPORTATION	PSYCHOLOGY AND SOCIAL SCIENCES
URBAN STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
WOMEN	PSYCHOLOGY AND SOCIAL SCIENCES
AGRICULTURAL ENGINEERING	ENVIRONMENTAL S&T
AGRICULTURE, MULTIDISCIPLINARY	ENVIRONMENTAL S&T
AGRONOMY	ENVIRONMENTAL S&T
BIODIVERSITY CONSERVATION	ENVIRONMENTAL S&T
ECOLOGY	ENVIRONMENTAL S&T
ENGINEERING, CIVIL	ENVIRONMENTAL S&T
ENGINEERING, ENVIRONMENTAL	ENVIRONMENTAL S&T
ENGINEERING, GEOLOGICAL	ENVIRONMENTAL S&T
ENGINEERING, OCEAN	ENVIRONMENTAL S&T
ENGINEERING, PETROLEUM	ENVIRONMENTAL S&T
ENTOMOLOGY	ENVIRONMENTAL S&T
ENVIRONMENTAL SCIENCES	ENVIRONMENTAL S&T
EVOLUTIONARY BIOLOGY	ENVIRONMENTAL S&T
FISHERIES	ENVIRONMENTAL S&T
FORESTRY	ENVIRONMENTAL S&T
GEOCHEMISTRY & GEOPHYSICS	ENVIRONMENTAL S&T
GEOGRAPHY, PHYSICAL	ENVIRONMENTAL S&T
GEOLOGY	ENVIRONMENTAL S&T
GEOSCIENCES, MULTIDISCIPLINARY	ENVIRONMENTAL S&T
HORTICULTURE	ENVIRONMENTAL S&T
IMAGING SCIENCE & PHOTOGRAPHIC TECHNOLOGY	ENVIRONMENTAL S&T
LIMNOLOGY	ENVIRONMENTAL S&T
MARINE & FRESHWATER BIOLOGY	ENVIRONMENTAL S&T
METEOROLOGY & ATMOSPHERIC SCIENCES	ENVIRONMENTAL S&T
MINERALOGY	ENVIRONMENTAL S&T
OCEANOGRAPHY	ENVIRONMENTAL S&T
ORNITHOLOGY	ENVIRONMENTAL S&T

Table 34 (continued)

PALEONTOLOGY	ENVIRONMENTAL S&T
PLANT SCIENCES	ENVIRONMENTAL S&T
REMOTE SENSING	ENVIRONMENTAL S&T
SOIL SCIENCE	ENVIRONMENTAL S&T
WATER RESOURCES	ENVIRONMENTAL S&T
ZOOLOGY	ENVIRONMENTAL S&T

Source: 4 Meta Discipline Classification Scheme provided by Search Technology
Notes: N = 4 Meta Disciplines; Timespan = NA; Unit of Analysis: Meta Disciplines

APPENDIX I

PROFESSOR PORTER'S (GEORGIA TECH) 6 META DISCIPLINE CLASSIFICATION SCHEME

Table 35: Professor Porter's (Georgia Tech) 6 Meta Discipline Classification Scheme

WEB OF SCIENCE CATEGORY	6 META DISCIPLINE CLASSIFICATION
AGRICULTURE, DAIRY & ANIMAL SCIENCE	BIOLOGY AND MEDICINE
ALLERGY	BIOLOGY AND MEDICINE
ANATOMY & MORPHOLOGY	BIOLOGY AND MEDICINE
ANDROLOGY	BIOLOGY AND MEDICINE
ANESTHESIOLOGY	BIOLOGY AND MEDICINE
BIOCHEMICAL RESEARCH METHODS	BIOLOGY AND MEDICINE
BIOCHEMISTRY & MOLECULAR BIOLOGY	BIOLOGY AND MEDICINE
BIOLOGY	BIOLOGY AND MEDICINE
BIOPHYSICS	BIOLOGY AND MEDICINE
BIOTECHNOLOGY & APPLIED MICROBIOLOGY	BIOLOGY AND MEDICINE
CARDIAC & CARDIOVASCULAR SYSTEMS	BIOLOGY AND MEDICINE
CELL & TISSUE ENGINEERING	BIOLOGY AND MEDICINE
CELL BIOLOGY	BIOLOGY AND MEDICINE
CHEMISTRY, MEDICINAL	BIOLOGY AND MEDICINE
CRITICAL CARE MEDICINE	BIOLOGY AND MEDICINE
DENTISTRY, ORAL SURGERY & MEDICINE	BIOLOGY AND MEDICINE
DERMATOLOGY	BIOLOGY AND MEDICINE
DEVELOPMENTAL BIOLOGY	BIOLOGY AND MEDICINE
EMERGENCY MEDICINE	BIOLOGY AND MEDICINE
ENDOCRINOLOGY & METABOLISM	BIOLOGY AND MEDICINE
ENGINEERING, BIOMEDICAL	BIOLOGY AND MEDICINE
FOOD SCIENCE & TECHNOLOGY	BIOLOGY AND MEDICINE
GASTROENTEROLOGY & HEPATOLOGY	BIOLOGY AND MEDICINE
GENETICS & HEREDITY	BIOLOGY AND MEDICINE
GERIATRICS & GERONTOLOGY	BIOLOGY AND MEDICINE
HEMATOLOGY	BIOLOGY AND MEDICINE
HISTORY & PHILOSOPHY OF SCIENCE	BIOLOGY AND MEDICINE

Table 35 (continued)

IMMUNOLOGY	BIOLOGY AND MEDICINE
INFECTIOUS DISEASES	BIOLOGY AND MEDICINE
INTEGRATIVE & COMPLEMENTARY MEDICINE	BIOLOGY AND MEDICINE
MATHEMATICAL & COMPUTATIONAL BIOLOGY	BIOLOGY AND MEDICINE
MEDICAL LABORATORY TECHNOLOGY	BIOLOGY AND MEDICINE
MEDICINE, GENERAL & INTERNAL	BIOLOGY AND MEDICINE
MEDICINE, LEGAL	BIOLOGY AND MEDICINE
MEDICINE, RESEARCH & EXPERIMENTAL	BIOLOGY AND MEDICINE
MICROBIOLOGY	BIOLOGY AND MEDICINE
MICROSCOPY	BIOLOGY AND MEDICINE
MULTIDISCIPLINARY SCIENCES	BIOLOGY AND MEDICINE
MYCOLOGY	BIOLOGY AND MEDICINE
NEUROSCIENCES	BIOLOGY AND MEDICINE
NUTRITION & DIETETICS	BIOLOGY AND MEDICINE
OBSTETRICS & GYNECOLOGY	BIOLOGY AND MEDICINE
ONCOLOGY	BIOLOGY AND MEDICINE
OPHTHALMOLOGY	BIOLOGY AND MEDICINE
ORTHOPEDICS	BIOLOGY AND MEDICINE
OTORHINOLARYNGOLOGY	BIOLOGY AND MEDICINE
PARASITOLOGY	BIOLOGY AND MEDICINE
PATHOLOGY	BIOLOGY AND MEDICINE
PEDIATRICS	BIOLOGY AND MEDICINE
PERIPHERAL VASCULAR DISEASE	BIOLOGY AND MEDICINE
PHARMACOLOGY & PHARMACY	BIOLOGY AND MEDICINE
PHYSIOLOGY	BIOLOGY AND MEDICINE
PLANT SCIENCES	BIOLOGY AND MEDICINE
PRIMARY HEALTH CARE	BIOLOGY AND MEDICINE
RADIOLOGY, NUCLEAR MEDICINE & MEDICAL IMAGING	BIOLOGY AND MEDICINE
REPRODUCTIVE BIOLOGY	BIOLOGY AND MEDICINE
RESPIRATORY SYSTEM	BIOLOGY AND MEDICINE
RHEUMATOLOGY	BIOLOGY AND MEDICINE
SPORT SCIENCES	BIOLOGY AND MEDICINE
SURGERY	BIOLOGY AND MEDICINE
TOXICOLOGY	BIOLOGY AND MEDICINE
TRANSPLANTATION	BIOLOGY AND MEDICINE

Table 35 (continued)

TROPICAL MEDICINE	BIOLOGY AND MEDICINE
UROLOGY & NEPHROLOGY	BIOLOGY AND MEDICINE
VETERINARY SCIENCES	BIOLOGY AND MEDICINE
VIROLOGY	BIOLOGY AND MEDICINE
ASTRONOMY & ASTROPHYSICS	PHYSICAL S&T
CHEMISTRY, ANALYTICAL	PHYSICAL S&T
CHEMISTRY, APPLIED	PHYSICAL S&T
CHEMISTRY, INORGANIC & NUCLEAR	PHYSICAL S&T
CHEMISTRY, MULTIDISCIPLINARY	PHYSICAL S&T
CHEMISTRY, ORGANIC	PHYSICAL S&T
CHEMISTRY, PHYSICAL	PHYSICAL S&T
CONSTRUCTION & BUILDING TECHNOLOGY	PHYSICAL S&T
CRYSTALLOGRAPHY	PHYSICAL S&T
ELECTROCHEMISTRY	PHYSICAL S&T
ENERGY & FUELS	PHYSICAL S&T
ENGINEERING, CHEMICAL	PHYSICAL S&T
ENGINEERING, MECHANICAL	PHYSICAL S&T
INSTRUMENTS & INSTRUMENTATION	PHYSICAL S&T
MATERIALS SCIENCE, BIOMATERIALS	PHYSICAL S&T
MATERIALS SCIENCE, CERAMICS	PHYSICAL S&T
MATERIALS SCIENCE, CHARACTERIZATION & TESTING	PHYSICAL S&T
MATERIALS SCIENCE, COATINGS & FILMS	PHYSICAL S&T
MATERIALS SCIENCE, COMPOSITES	PHYSICAL S&T
MATERIALS SCIENCE, MULTIDISCIPLINARY	PHYSICAL S&T
MATERIALS SCIENCE, PAPER & WOOD	PHYSICAL S&T
MATERIALS SCIENCE, TEXTILES	PHYSICAL S&T
MECHANICS	PHYSICAL S&T
METALLURGY & METALLURGICAL ENGINEERING	PHYSICAL S&T
MINING & MINERAL PROCESSING	PHYSICAL S&T
NANOSCIENCE & NANOTECHNOLOGY	PHYSICAL S&T
NUCLEAR SCIENCE & TECHNOLOGY	PHYSICAL S&T
OPTICS	PHYSICAL S&T
PHYSICS, APPLIED	PHYSICAL S&T
PHYSICS, ATOMIC, MOLECULAR & CHEMICAL	PHYSICAL S&T
PHYSICS, CONDENSED MATTER	PHYSICAL S&T

Table 35 (continued)

PHYSICS, FLUIDS & PLASMAS	PHYSICAL S&T
PHYSICS, MULTIDISCIPLINARY	PHYSICAL S&T
PHYSICS, NUCLEAR	PHYSICAL S&T
PHYSICS, PARTICLES & FIELDS	PHYSICAL S&T
POLYMER SCIENCE	PHYSICAL S&T
SPECTROSCOPY	PHYSICAL S&T
THERMODYNAMICS	PHYSICAL S&T
AGRICULTURAL ENGINEERING	ENVIRONMENTAL S&T
AGRICULTURE, MULTIDISCIPLINARY	ENVIRONMENTAL S&T
AGRONOMY	ENVIRONMENTAL S&T
BIODIVERSITY CONSERVATION	ENVIRONMENTAL S&T
ECOLOGY	ENVIRONMENTAL S&T
ENGINEERING, CIVIL	ENVIRONMENTAL S&T
ENGINEERING, ENVIRONMENTAL	ENVIRONMENTAL S&T
ENGINEERING, GEOLOGICAL	ENVIRONMENTAL S&T
ENGINEERING, OCEAN	ENVIRONMENTAL S&T
ENGINEERING, PETROLEUM	ENVIRONMENTAL S&T
ENTOMOLOGY	ENVIRONMENTAL S&T
ENVIRONMENTAL SCIENCES	ENVIRONMENTAL S&T
EVOLUTIONARY BIOLOGY	ENVIRONMENTAL S&T
FISHERIES	ENVIRONMENTAL S&T
FORESTRY	ENVIRONMENTAL S&T
GEOCHEMISTRY & GEOPHYSICS	ENVIRONMENTAL S&T
GEOGRAPHY, PHYSICAL	ENVIRONMENTAL S&T
GEOLOGY	ENVIRONMENTAL S&T
GEOSCIENCES, MULTIDISCIPLINARY	ENVIRONMENTAL S&T
HORTICULTURE	ENVIRONMENTAL S&T
IMAGING SCIENCE & PHOTOGRAPHIC TECHNOLOGY	ENVIRONMENTAL S&T
LIMNOLOGY	ENVIRONMENTAL S&T
MARINE & FRESHWATER BIOLOGY	ENVIRONMENTAL S&T
METEOROLOGY & ATMOSPHERIC SCIENCES	ENVIRONMENTAL S&T
MINERALOGY	ENVIRONMENTAL S&T
OCEANOGRAPHY	ENVIRONMENTAL S&T
ORNITHOLOGY	ENVIRONMENTAL S&T
PALEONTOLOGY	ENVIRONMENTAL S&T
REMOTE SENSING	ENVIRONMENTAL S&T

Table 35 (continued)

SOIL SCIENCE	ENVIRONMENTAL S&T
WATER RESOURCES	ENVIRONMENTAL S&T
ZOOLOGY	ENVIRONMENTAL S&T
BEHAVIORAL SCIENCES	PSYCHOLOGY AND SOCIAL SCIENCES
CLINICAL NEUROLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
CRIMINOLOGY & PENOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
EDUCATION & EDUCATIONAL RESEARCH	PSYCHOLOGY AND SOCIAL SCIENCES
EDUCATION, SCIENTIFIC DISCIPLINES	PSYCHOLOGY AND SOCIAL SCIENCES
EDUCATION, SPECIAL	PSYCHOLOGY AND SOCIAL SCIENCES
ERGONOMICS	PSYCHOLOGY AND SOCIAL SCIENCES
ETHNIC STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
FAMILY STUDIES	PSYCHOLOGY AND SOCIAL SCIENCES
GERONTOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES
HEALTH CARE SCIENCES & SERVICES	PSYCHOLOGY AND SOCIAL SCIENCES
HEALTH POLICY & SERVICES	PSYCHOLOGY AND SOCIAL SCIENCES
LINGUISTICS	PSYCHOLOGY AND SOCIAL SCIENCES
MEDICAL ETHICS	PSYCHOLOGY AND SOCIAL SCIENCES
NEUROIMAGING	PSYCHOLOGY AND SOCIAL SCIENCES
NURSING	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHIATRY	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY	PSYCHOLOGY AND SOCIAL SCIENCES

Table 35 (continued)

PSYCHOLOGY, BIOLOGICAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, CLINICAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, DEVELOPMENTAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, EDUCATIONAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, EXPERIMENTAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, MATHEMATICAL	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, MULTIDISCIPLINARY	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, PSYCHOANALYSIS	PSYCHOLOGY AND SOCIAL SCIENCES
PSYCHOLOGY, SOCIAL	PSYCHOLOGY AND SOCIAL SCIENCES
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH	PSYCHOLOGY AND SOCIAL SCIENCES
REHABILITATION	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL ISSUES	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL SCIENCES, BIOMEDICAL	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL SCIENCES, INTERDISCIPLINARY	PSYCHOLOGY AND SOCIAL SCIENCES
SOCIAL WORK	PSYCHOLOGY AND SOCIAL SCIENCES
SUBSTANCE ABUSE	PSYCHOLOGY AND SOCIAL SCIENCES
TRANSPORTATION	PSYCHOLOGY AND SOCIAL SCIENCES
WOMEN	PSYCHOLOGY AND SOCIAL SCIENCES
AGRICULTURAL ECONOMICS & POLICY	SOCIAL SCIENCES
ANTHROPOLOGY	SOCIAL SCIENCES
AREA STUDIES	SOCIAL SCIENCES
BUSINESS	SOCIAL SCIENCES
BUSINESS, FINANCE	SOCIAL SCIENCES

Table 35 (continued)

COMMUNICATION	SOCIAL SCIENCES
CULTURAL STUDIES	SOCIAL SCIENCES
DEMOGRAPHY	SOCIAL SCIENCES
ECONOMICS	SOCIAL SCIENCES
ENVIRONMENTAL STUDIES	SOCIAL SCIENCES
ETHICS	SOCIAL SCIENCES
GEOGRAPHY	SOCIAL SCIENCES
HISTORY	SOCIAL SCIENCES
HISTORY OF SOCIAL SCIENCES	SOCIAL SCIENCES
HOSPITALITY, LEISURE, SPORT & TOURISM	SOCIAL SCIENCES
INDUSTRIAL RELATIONS & LABOR	SOCIAL SCIENCES
INFORMATION SCIENCE & LIBRARY SCIENCE	SOCIAL SCIENCES
INTERNATIONAL RELATIONS	SOCIAL SCIENCES
LAW	SOCIAL SCIENCES
MANAGEMENT	SOCIAL SCIENCES
PLANNING & DEVELOPMENT	SOCIAL SCIENCES
POLITICAL SCIENCE	SOCIAL SCIENCES
PSYCHOLOGY, APPLIED	SOCIAL SCIENCES
PUBLIC ADMINISTRATION	SOCIAL SCIENCES
SOCIAL SCIENCES, MATHEMATICAL METHODS	SOCIAL SCIENCES
SOCIOLOGY	SOCIAL SCIENCES
URBAN STUDIES	SOCIAL SCIENCES
ACOUSTICS	COMPUTER SCI. AND ENGINEERING
AUTOMATION & CONTROL SYSTEMS	COMPUTER SCI. AND ENGINEERING
COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	COMPUTER SCI. AND ENGINEERING
COMPUTER SCIENCE, CYBERNETICS	COMPUTER SCI. AND ENGINEERING
COMPUTER SCIENCE, HARDWARE & ARCHITECTURE	COMPUTER SCI. AND ENGINEERING
COMPUTER SCIENCE, INFORMATION SYSTEMS	COMPUTER SCI. AND ENGINEERING
COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	COMPUTER SCI. AND ENGINEERING

Table 35 (continued)

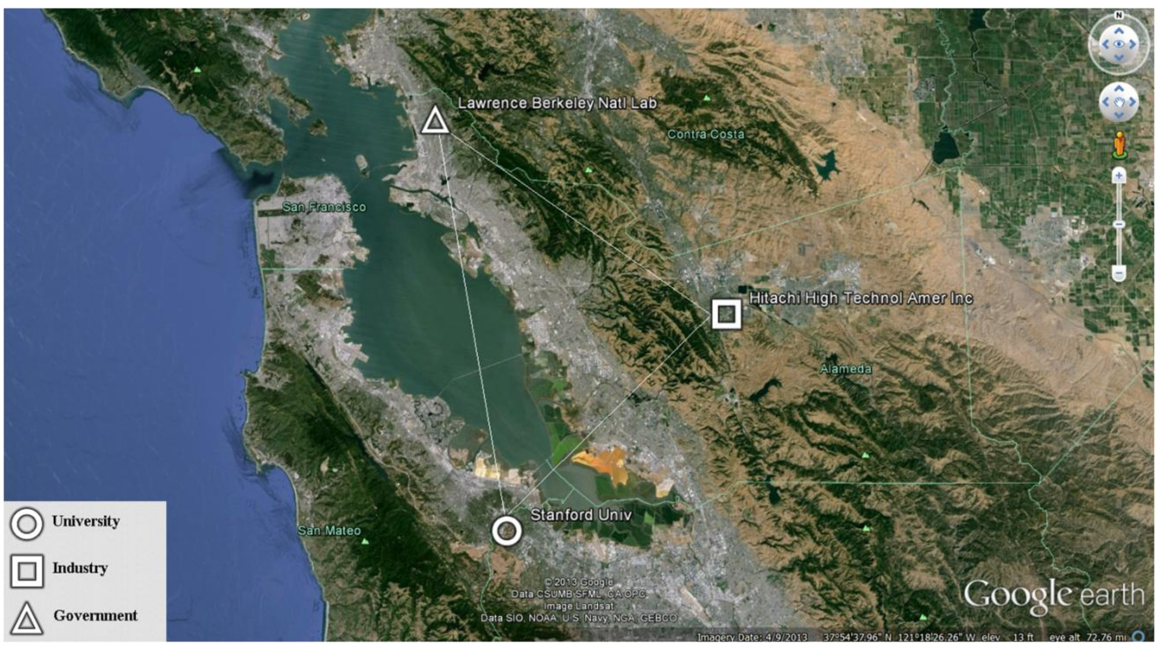
COMPUTER SCIENCE, SOFTWARE ENGINEERING	COMPUTER SCI. AND ENGINEERING
COMPUTER SCIENCE, THEORY & METHODS	COMPUTER SCI. AND ENGINEERING
ENGINEERING, AEROSPACE	COMPUTER SCI. AND ENGINEERING
ENGINEERING, ELECTRICAL & ELECTRONIC	COMPUTER SCI. AND ENGINEERING
ENGINEERING, INDUSTRIAL	COMPUTER SCI. AND ENGINEERING
ENGINEERING, MANUFACTURING	COMPUTER SCI. AND ENGINEERING
ENGINEERING, MARINE	COMPUTER SCI. AND ENGINEERING
ENGINEERING, MULTIDISCIPLINARY	COMPUTER SCI. AND ENGINEERING
MATHEMATICS	COMPUTER SCI. AND ENGINEERING
MATHEMATICS, APPLIED	COMPUTER SCI. AND ENGINEERING
MATHEMATICS, INTERDISCIPLINARY APPLICATIONS	COMPUTER SCI. AND ENGINEERING
MEDICAL INFORMATICS	COMPUTER SCI. AND ENGINEERING
OPERATIONS RESEARCH & MANAGEMENT SCIENCE	COMPUTER SCI. AND ENGINEERING
PHYSICS, MATHEMATICAL	COMPUTER SCI. AND ENGINEERING
ROBOTICS	COMPUTER SCI. AND ENGINEERING
STATISTICS & PROBABILITY	COMPUTER SCI. AND ENGINEERING
TELECOMMUNICATIONS	COMPUTER SCI. AND ENGINEERING
TRANSPORTATION SCIENCE & TECHNOLOGY	COMPUTER SCI. AND ENGINEERING

Source: 6 Meta Discipline Classification Scheme provided by Search Technology
Notes: N = 6 Meta Disciplines; Timespan = NA; Unit of Analysis: Meta Disciplines

APPENDIX J

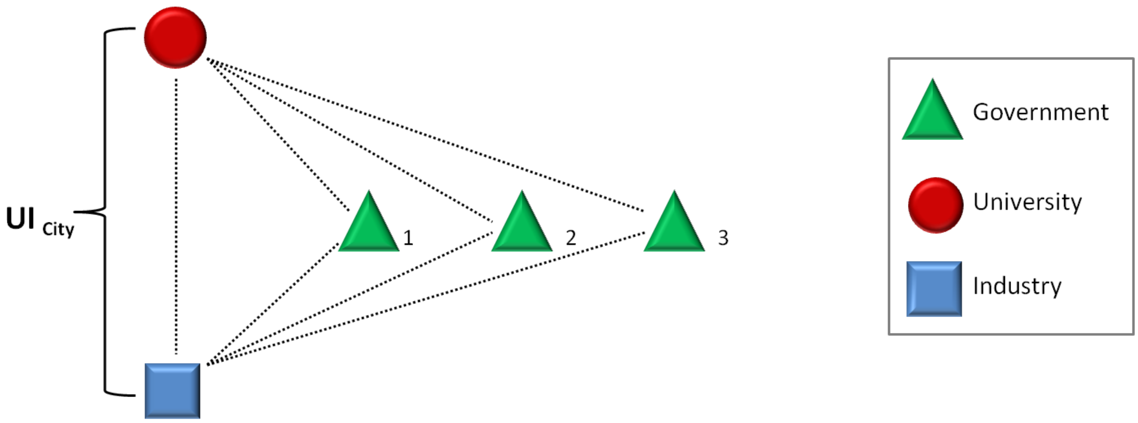
COLOR NEURTRAL MAPS

A number of the maps in this study employ a UIG color scheme. Out of consideration for readers who have difficulty distinguishing map colors this appendix replicates maps from preceding analyses whose features are color-coded on a color neutral basis.



Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 1; Timespan = 2008; Unit of Analysis: UIG triangle area of an individual nanopublication

Figure 31: Color Neutral Rendition of Figure 2



Source: Own analysis
Notes: N = 3; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 32: Color Neutral Rendition of Figure 5

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 50; Timespan = 1990-2011; Unit of Analysis: UIG affiliations

Figure 33: Color Neutral Rendition of Figure 6

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 50; Timespan = 1990-2011; Unit of Analysis: UIG affiliations

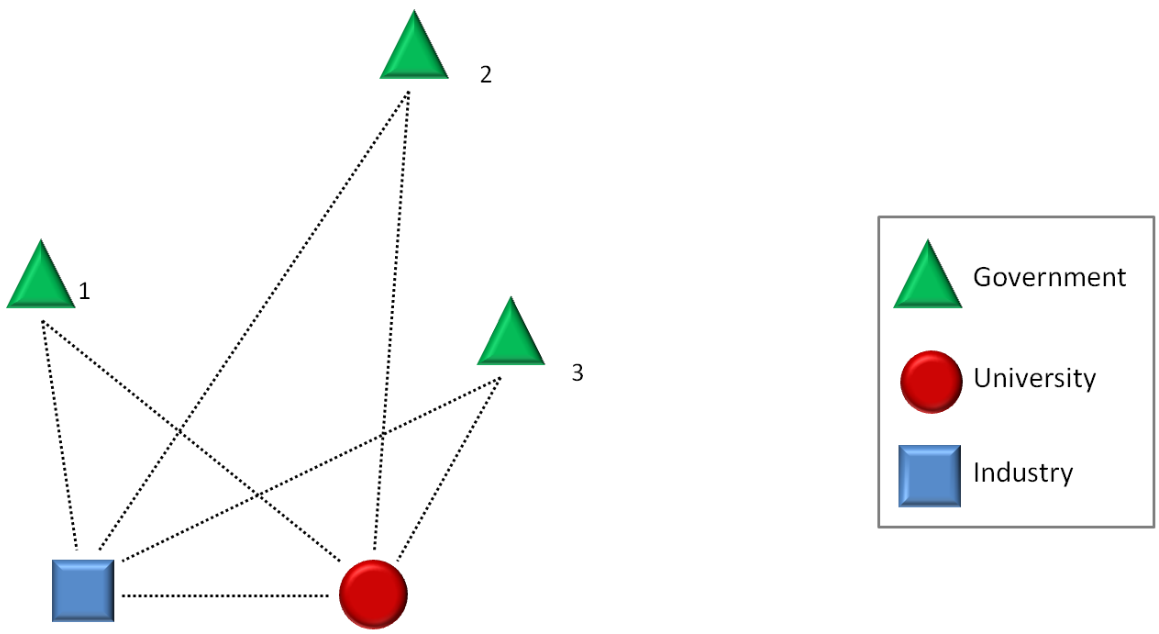
Figure 34: Color Neutral Rendition of Figure 7

Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 50; Timespan = 1990-2011; Unit of Analysis: UIG affiliations

Figure 35: Color Neutral Rendition of Figure 8

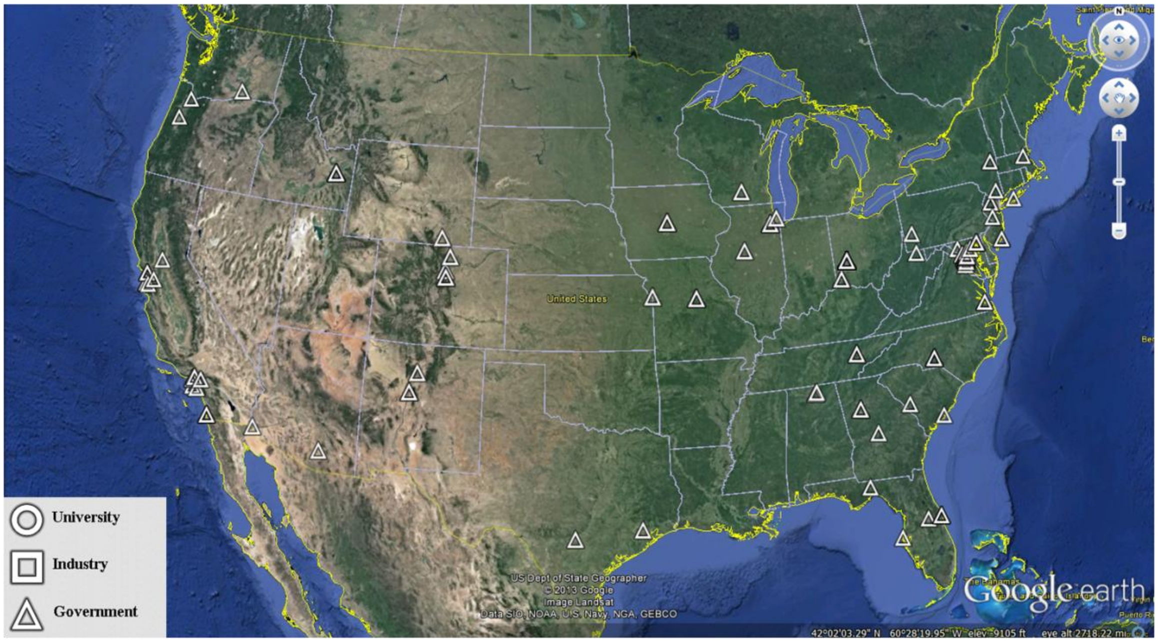
Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 1,161; Timespan = 1990-2011; Unit of Analysis: individual UIG actors

Figure 36: Color Neutral Rendition of Figure 17



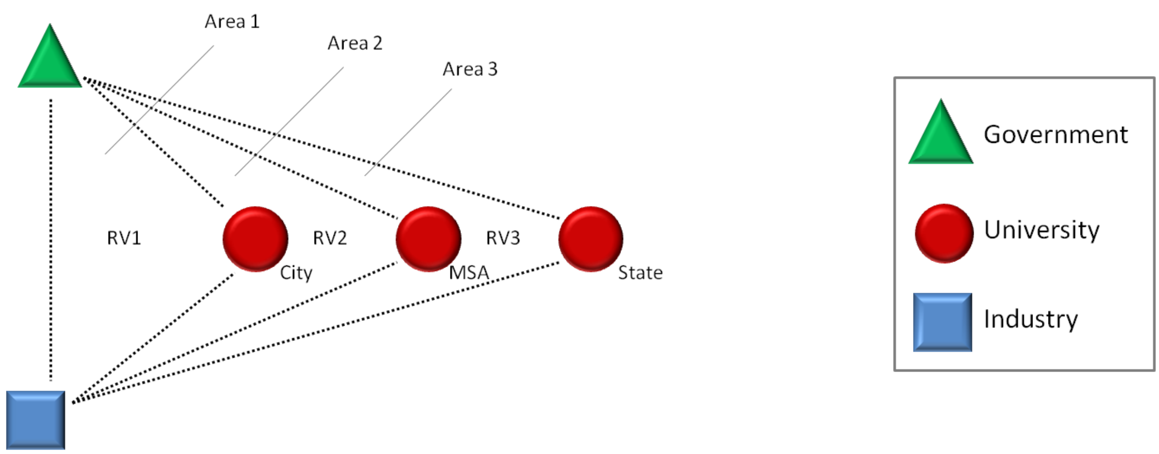
Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 37: Color Neutral Rendition of Figure 18



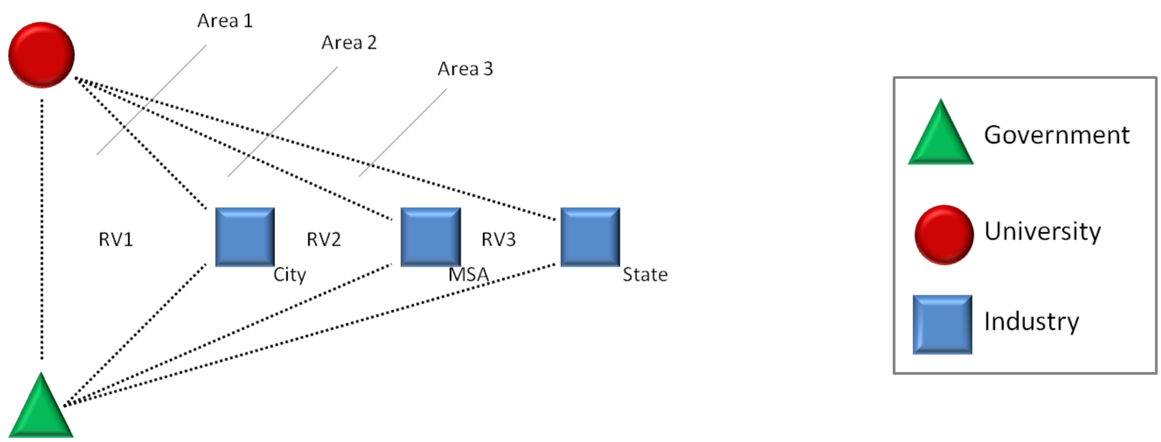
Source: Nanotechnology dataset developed by Porter et al. (2008) and refined by Arora et al. (2013)
Notes: N = 158; Timespan = 1990-2011; Unit of Analysis: individual Government actors

Figure 38: Color Neutral Rendition of Figure 19



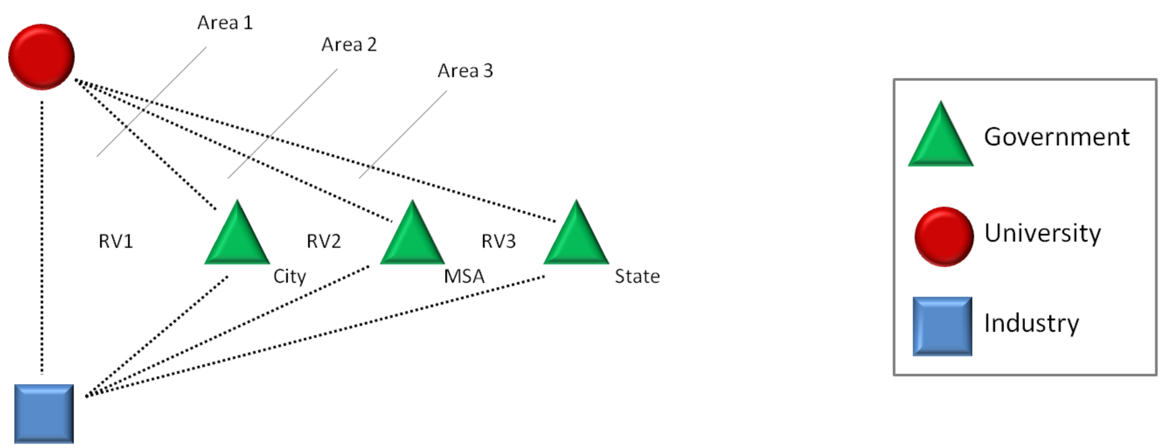
Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 39: Color Neutral Rendition of Figure 20



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 40: Color Neutral Rendition of Figure 21



Source: Own analysis
Notes: N = NA; Timespan = NA; Unit of Analysis: UIG collaboration

Figure 41: Color Neutral Rendition of Figure 22

REFERENCES

Adams, James D., Eric P. Chiang and Jeffrey L. Jensen (2003). The influence of federal laboratory R&D on industrial research. *Review of Economics and Statistics*, 85 (4): 1003-1020.

Alston, Lee, Thrainn Eggertsson and Douglass North. *Empirical Studies in Institutional Change: Political Economy of Institutions and Decisions*. Cambridge: Cambridge University Press, 1996. Print.

Amin, Ash and Frank Wilkinson (1999). Learning, proximity and industrial performance: an introduction. *Cambridge Journal of Economics*, 23 (2): 121-125.

Amin, Ash and Kevin Robins (1990). The re-emergence of regional economies - the mythical geography of flexible accumulation. *Environment and Planning D-Society & Space*, 8 (1): 7-34.

Arora, Sanjay, Alan L. Porter, Jan Youtie and Philip Shapira (2013). Capturing new developments in an emerging technology: an updated search strategy for identifying nanotechnology research outputs. *Scientometrics,* 95 (1): 351-370.

Ashley, Steven (1996). Federal labs and industry come together. *Mechanical Engineering*, 118 (10): 80-84.

Atalik, Gunduz and Manfred Fischer. *Regional Development Reconsidered*. New York: Springer, 2002. Print.

Audretsch, David and Maryann Feldman (1996). R&D spillovers and the geography of innovation and production. *American Economic Review,* 86 (3): 630-640.

Autant-Bernard, Corinne, Pascal Billand, David Frachisse and Nadine Massard (2007). Social distance versus spatial distance in R&D cooperation: Empirical evidence from European collaboration choices in micro and nanotechnologies. *Papers In Regional Science*, 86 (3): 495-519.

Battard, Nicolas (2012). Convergence and multidisciplinarity in nanotechnology: Laboratories as technological hubs. *Technovation*, 32 (3-4): 234-244.

Borrás, Susana (2004). System of innovation theory and the European Union. *Science and Public Policy*, 31 (6): 425-433.

Boschma, Ron (2005). Proximity and Innovation: A Critical Assessment. *Regional Studies,* 39 (1): 61-74.

Cairncross, Frances. *The Death of Distance: How the Communications Revolution will Change Our Lives*. Cambridge: Harvard Business School Publishing, 1997. Print.

Carayannis, Elias G. and David F. J. Campbell (2009). 'Mode 3' and 'Quadruple Helix': toward a 21st century fractal innovation ecosystem. *International Journal of Technology Management*, 46 (3/4): 201-234.

Carley, Stephen and Alan L. Porter (2012). A forward diversity index. *Scientometrics*, 90 (2): 407-427.

Carley, Stephen, Alan L. Porter and Jan Youtie (2013). Toward a More Precise Definition of Self-Citation. *Scientometrics*, 94 (2): 777-780.

Cavusgil, S. Tamer, Roger J. Calantone, Yushan Zhao (2003). Tacit knowledge transfer and firm innovation capability. *Journal of Business & Industrial Marketing*, 18 (1): 6 - 21.

Chang, Chen-Chi (2008). The value of knowledge created by individual scientist and research groups. *Journal of Scholarly Publishing*, 39 (3): 274-293.

Chatterton, Paul and John Goddard (2000). The response of higher education institutions to regional needs. *European Journal of Education*, 35 (4): 475–496.

Chudnovsky, Daniel, Jorge Niosi and Nestor Bercovich (2000). National innovation systems, learning processes and technology policy: Comparison of Canada and Argentina. *Desarrollo Economico-Revista De Ciencias Sociales*, 40 (158): 213-252.

Cooke, Philip, Mikel Uranga and Goio Etxebarria (1997). Regional innovation systems: Institutional and organisational dimensions. *Research Policy*, 26 (4-5): 475-491.

Cooke, Philip (2001). Regional Innovation Systems, Clusters, and the Knowledge Economy. *Industrial and Corporate Change*, 10 (4): 945-974.

Crow, Michael and Barry Bozeman. *Limited by Design*. New York: Columbia University Press, 1998. Print.

Cunningham, Scott and Claudia Werker (2012). Proximity and collaboration in European nanotechnology. *Papers in Regional Science*, 91 (4): 723-742.

Darmody, Brian and Richard Bendis (2012). Why we need a Federal Lab Innovation Authority: Unlocking Our Federal Lab Resources for Economic Growth. Retrieved May 21, 2012, from http://www.innovationamerica.us/index.php/innovation-daily/21633-why-we-need-a-federal-lab-innovation-authority-unlocking-our-federal-lab-resources-for-economic-growth-?utm_source=innovation-daily---your-daily-newsletter-highlighting-global-innovation-news-and-trends&utm_medium=gazetty&utm_campaign=05-21-2012

DeCanio, Stephen J (1993). Barriers within firms to energy-efficient investments. *Energy Policy*, 21 (9): 906-914.

Etzkowitz, Henry and Loet Leydesdorff (1996). A triple helix of academic-industry-government relations: development models beyond 'capitalism versus socialism'. *Current Science*, 70 (8): 690-693.

Etzkowitz, Henry and Loet Leydesdorff. *Universities and the Global Knowledge Economy: A Triple Helix of University-Industry-Government Relations*. London: Pinter Publishers, 1997. Print.

Etzkowitz, Henry and Loet Leydesdorff (1998). The endless transition: a "triple helix" of university-industry-government relations. *Minerva*, 36 (3): 203-208.

Etzkowitz, Henry and Loet Leydesdorff (2000). The dynamics of innovation: from national systems and "mode 2" to a triple helix of university-industry-government relations. *Research Policy*, 29 (2): 109-123.

Foregger, Thomas (2004). PlanetMath. Retrieved April 29, 2013 from http://planetmath.org/areaofasphericaltriangle

Frenken, Koen, Roderik Ponds and Frank van Oort (2010). The citation impact of research collaboration in science-based industries: a spatial-institutional analysis. *Papers In Regional Science*, 89 (2): 351-371.

Frenken, Koen, Sjoerd Hardeman and Jarno Hoekman (2009). Spatial scientometrics: Towards a cumulative research program. *Journal of Informetrics*, 3 (3): 222-232.

Frenken, Koen, Werner Holzl and Friso de Vor (2005). The citation impact of research collaborations: the case of European biotechnology and applied microbiology (1988-2002). *Journal of Engineering and Technology Management*, 22 (1-2): 9-30.

Goodall, Amanda H. (2009). Highly cited leaders and the performance of research universities. *Research Policy*, 38 (7): 1079-1092.

Google Earth (2001). Google Earth. Retrieved March 13, 2012, from http://www.google.com/earth

Gingras, Yves and Matthew L. Wallace, (2010). Why it has become more difficult to predict Nobel Prize winners: a bibliometric analysis of nominees and winners of the chemistry and physics prizes (1901-2007). *Scientometrics*, 82 (2): 401-412.

Heilbroner, Robert. *The Worldly Philosophers: The Lives, Times and Ideas of the Great Economic Thinkers, Rev. 7th Edition*. New York: Simon and Schuster, 1999. Print.

Heimeriks, Gaston (2013). Interdisciplinarity in biotechnology, genomics and nanotechnology. *Science and Public Policy*, 40 (1): 97-112.

Hoekman, Jarno, Koen Frenken and Robert J. W. Tijssen (2010). Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. *Research Policy*, 39 (5): 662-673.

Howells, Jeremy (1996). Tacit knowledge, innovation and technology transfer. *Technology Analysis & Strategic Management*, 8 (2): 91-106.

Howells, Jeremy (2002). Tacit knowledge, innovation and economic geography. *Urban Studies*, 39 (5-6): 871-884.

Howells, Jeremy, Dimitri Gagliardi and Khaleel Malik (2008). The growth and management of R&D outsourcing: evidence from UK pharmaceuticals. *R&D Management*, 38 (2): 205-219.

Johnson, Bjorn, Edward Lorenz and Bengt-Ake Lundvall (2002). Why all this fuss about codified and tacit knowledge? *Industrial and Corporate Change*, 11 (2): 245-262.

Journal Subfield & Level Classification, 2011 edition. *The Patent Board and National Science Foundation*. September 2012.

Katz, J. Sylvan (1994). Geographical proximity and scientific collaboration. *Scientometrics*, 31 (1): 31-43.

Katz, J. Sylvan (2006). Indicators for complex innovation systems. *Research Policy*, 35 (7): 893-909.

Kim, Jang Hyun (2012). A Hyperlink and Semantic Network Analysis of the Triple Helix (University-Government-Industry): The Interorganizational Communication Structure of Nanotechnology. *Journal of Computer-Mediated Communication*, 17 (2): 152-170.

Klain, Daniel (2004). An Intuitive Derivation of Heron's Formula. *American Mathematical Monthly*, 111 (8): 709-712.

Klopsteg, Paul, Monroe Spaght and Kenneth Pitzer (1955). Government, Industry, the University, and Basic Research. *Science*, 121 (3153): 781-792.

Lam, Alice (2000). Tacit Knowledge, Organizational Learning and Societal Institutions: An Integrated Framework. *Organization Studies*, 21 (3): 487-513.

Lawani, Stephen (1986). Some bibliometric correlates of quality in scientific-research. *Scientometrics*, 9 (1-2): 13-25.

Liao, Chien Hsiang (2011). How to improve research quality? Examining the impacts of collaboration intensity and member diversity in collaboration networks. *Scientometrics*, 86 (3): 747-761.

Lu, Lucy and Henry Etzkowitz (2008). Strategic challenges for creating knowledge-based innovation in China: Transforming triple helix university-government-industry relations. *Journal of Technology Management in China*, 3 (1): 5 - 11.

Lundvall, Bengt-Ake. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers, 1992. Print.

Lundvall, Bengt-Ake and Björn Johnson (1994). The Learning Economy. *Journal of Industry Studies*, 1 (2): 23-42.

Lundvall, Bengt-Ake and Peter Nielsen (2007). Knowledge management and innovation performance. *International Journal of Manpower*, 28 (3): 207-223.

Mattes, Jannika (2012). Dimensions of Proximity and Knowledge Bases: Innovation between Spatial and Non-spatial Factors. *Regional Studies*, 46 (8): 1085-1099.

Metz, Philip. "The Role of the National Laboratories in Technological Innovation." In *Federal Lab Technology Transfer*. Ed. Gordon Bopp. New York: Praeger Publishers, 1988. Print.

Miao, Lin, Su Jun and Chen Junrui. "Emergence of a Triple Helix of Academia-Industry-Government Relations in ICT R&D in Developing Countries: Private, Professional and Public Dimensions of China's 3rd Generation Mobile Communications System Task Force." *Technology and society* (2002): 353-358.

Morgan, Kevin (2004). The exaggerated death of geography: learning, proximity and territorial innovation systems. *Journal of Economic Geography*, 4 (1): 3-21.

Narin, Francis, Kimberly S. Hamilton and Dominic Olivastro (1997). The increasing linkage between US technology and public science. *Research Policy*, 26 (3): 317-330.

Nelson, Richard. *National Innovation Systems: A Comparative Analysis*. Oxford: Oxford University Press, 1993. Print.

Nonaka, Ikujiro (1994). A Dynamic Theory of Organizational Knowledge Creation. *Organization Science*, 5 (1): 14-37.

OECD (1996). The Knowledge-Based Economy. Retrieved July 3, 2013, from http://www.oecd.org/sti/sci-tech/1913021.pdf

Owen-Smith, Jason, Massimo Riccaboni, Fabio Pammolli and Walter Powell (2002). A comparison of US and European university-industry relations in the life sciences. *Management Science*, 48 (1): 24-43.

Polanyi, Michael (1962). Tacit knowing - its bearing on some problems of philosophy. *Reviews of Modern Physics*, 34 (4): 601-616.

Polanyi, Michael (1966a). Logic of tacit inference. *Philosophy*, 41 (155): 1-18.

Polanyi, Michael. *The Tacit Dimension*. London: The University of Chicago Press, 1966b. Print.

Ponds, Roderik, Frank van Oort and Koen Frenken (2007). The geographical and institutional proximity of research collaboration. *Papers In Regional Science*, 86 (3): 423-443.

Porter, Alan L., Alex Cohen, David Roessner and Marty Perreault (2007). Measuring researcher interdisciplinarity. *Scientometrics*, 72 (1): 117-147.

Porter, Alan L., Jan Youtie, Philip Shapira, and David Schoeneck (2008). Refining search terms for nanotechnology. *Journal of Nanoparticle Research*, 10 (5): 715-728.

Rogers, Juan (2010). Citation analysis of nanotechnology at the field level: implications of R&D evaluation. *Research Evaluation*, 19 (4): 281-290.

Rosenbaum, Paul and Donald Rubin (1983). The Central Role of the Propensity Score in Observational Studies for Causal Effects. *Biometrika*, 70 (1): 41-55.

Ruttan, Vernon. *Is war necessary for economic growth?* New York: Oxford University Press, 2006. Print.

Ruuska, Inkeri and Robin Teigland (2009). Ensuring project success through collective competence and creative conflict in public-private partnerships-A case study of Bygga Villa, a Swedish triple helix e-government initiative. *International Journal of Project Management*, 27 (4): 323-334.

Saxenian, AnnaLee. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge: Harvard University Press, 1996. Print.

Schultz, Laura I. (2011). Nanotechnology's triple helix: a case study of the University at Albany's College of Nanoscale Science and Engineering. *Journal of Technology Transfer*, 36 (5): 546-564.

Schultz, Laura I. and Frederick L. Joutz (2010). Methods for identifying emerging general purpose technologies: a case study of nanotechnologies. *Scientometrics*, 85 (1): 155-170.

Schneider, Adam (2003). GPS Visualizer. Retrieved March 15, 2012, from http://www.gpsvisualizer.com

Shinn, Terry (2002). The Triple Helix and New Production of Knowledge: Prepackaged Thinking on Science and Technology. *Social Studies of Science*, 32 (4): 599-614.

Small, Henry 2010. Referencing through history: how the analysis of landmark scholarly texts can inform citation theory. *Research Evaluation*, 19 (3), 185–193.

Teece, David (2000). Strategies for Managing Knowledge Assets: the Role of Firm Structure and Industrial Context. *Long Range Planning*, 33 (1): 35-54.

Teigland, Robin and Goeran Lindqvist (2007). Seeing eye-to-eye: How do public and private sector views of a biotech cluster and its cluster initiative differ? *European Planning Studies*, 15 (6): 767-786.

Tuunainen, Juha (2002). Reconsidering the Mode 2 and the Triple Helix: A Critical Comment Based on a Case Study. *Science Studies*, 15 (2): 36–58.

US Census Bureau (2012). US Department of Commerce. Retrieved October 25, 2012, from www.census.gov

VantagePoint (2012). Search Technology. Retrieved January 7, 2012, from www.thevantagepoint.com

Vincenty, Thaddeus (1975). Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations. *Survey Review*, 23 (176): 88-93.

Web of Science (2012). Thomson Reuters. Retrieved March 19, 2012 from http:// www.isiknowledge.com

Westwick, Peter. *The National Labs: Science in an American System, 1947-1974*. Cambridge: Harvard University Press, 2003. Print.

Weterings, Anet and Ron Boschma (2009). Does spatial proximity to customers matter for innovative performance? Evidence from the Dutch software sector. *Research Policy*, 38 (5): 746-755.

Wong, Poh Kam, Yuen Ping Ho and Casey K. Chan (2007). Internationalization and evolution of application areas of an emerging technology: The case of nanotechnology. *Scientometrics*, 70 (3): 715-737.

Youtie, Jan, Juan Rogers, Thomas Heinze, Philip Shapira and Li Tang. 2012. "Career-based influences on scientific recognition in the United States and Europe: Longitudinal evidence from curriculum vitae data" Working Paper, Georgia Tech Program in Science, Technology and Innovation Policy, Atlanta, GA, USA Available at: http://works.bepress.com/pshapira/49