J Technol Transf (2013) 38:1–67
DOI 10.1007/s10961-012-9281-8

Research collaboration in universities and academic entrepreneurship: the-state-of-the-art

Barry Bozeman · Daniel Fay · Catherine P. Slade

Published online: 28 November 2012

Abstract There is abundant evidence that research collaboration has become the norm in every field of scientific and technical research. We provide a critical overview of the literature on research collaboration, focusing particularly on individual-level collaborations among university researchers, but we also give attention to university researchers' collaborations with researchers in other sectors, including industry. We consider collaborations aimed chiefly at expanding the base of knowledge (knowledge-focused collaborations) as well as ones focused on production of economic value and wealth (property-focused collaborations), the latter including most academic entrepreneurship research collaborations. To help organize our review we develop a framework for analysis, one that considers attributes of collaborators, collaborative process and organization characteristics as the affect collaboration choices and outcomes. In addition, we develop and use a "Propositional Table for Research Collaboration Literature," presented as an "Appendix" to this study. We conclude with some suggestions for possible improvement in research on collaboration including: (1) more attention to multiple levels of analysis and the interactions among them; (2) more careful measurement of impacts as opposed to outputs; (3) more studies on 'malpractice' in collaboration, including exploitation; (4) increased attention to collaborators' motives and the social psychology of collaborative teams.

Keywords Research collaboration · Knowledge transfer · Technology transfer · Research productivity · Academic entrepreneurship · Contributorship · Research effectiveness

JEL Classification O31 · O32 · O38 · L23 · M38

B. Bozeman (✉) · D. Fay
University of Georgia, Athens, GA, USA
e-mail: bbozeman@uga.edu

D. Fay
e-mail: dfay@uga.edu

C. P. Slade
Georgia Regents University Augusta, Augusta, GA, USA
e-mail: cslade@gru.edu

1 Introduction

While the term “additionality” has as yet failed to enter standard dictionaries, it has increasingly made its way into the parlance of innovation and research and development (R&D) studies (Aerts and Schmidt 2008; Clarysse et al. 2009; Gulbrandsen and Etzkowitz 1999; Luukkonen 2000). One definition of the term is provided by Buisseret et al. (1995, p. 588): “Additionality in R&D performance is defined as a measure of the extent to which public support stimulates new R&D activity as opposed to subsidizing what would have taken place anyway.”(Buisseret et al. 1995).

We are concerned here with a literal human additionality, the addition of research collaborators. There is abundant evidence that research collaboration has become the norm in every field of scientific and technical research. One recent study (Gazni and Didegah 2011) examining 22 different fields of science shows that in all these fields, at least 60 % of publications are co-authored. The fact of increasing collaboration is well known, but what *difference* does it make if a researcher collaborates as opposed to working in the solitary mode more common in decades past? It is perhaps fair to say that there is a pro-collaboration bias in the research, technology and innovation literatures and, indeed, one that may be warranted. Collaboration tends to increase productivity (Subramanyam 1983), though the relationship is more nuanced than it appears at first glance. One reason that the relationship of research collaboration to productivity is not at straightforward is that not everyone means the same thing by “research collaboration.”

2 What *is* research collaboration?

Studies on research collaboration sometimes have utterly different meanings for the focal concept and, thus, there is some degree of conceptual ambiguity one must be concerned about, especially in a literature review. For our purposes, one major type of conceptual ambiguity in research collaboration is easily dispensed with—differences in level of analysis. The term “research collaboration” is used to describe relationships between individuals but also relationships between organizations (as well as relationships of individuals with organizations). As we explain in more detail below, the focus here is on individual collaboration. To be sure, it is not always easy to distinguish individual collaborations from organizational collaborations. After all, when organizations collaborate, it is actually individuals who are relating to one another. Organizations are such a part of daily life that it is sometimes easy to forget that “organization” organizations are convenient social constructs based on patterns of human behavior. Nevertheless, when researchers are asked to identify their collaborators, unless they are explicitly asked about organizations they tend to identify individuals.

The chief distinction, and a source of ambiguity, in identifying individual collaborators is the breadth of meaning for collaboration. Many university researchers tend to think of collaboration in terms of co-authorship. For this reason, and also because co-authorship is conveniently measured, much of the published work about research collaboration focuses on co-authorship. As Katz and Martin (1997) point out, in one of the best known and most comprehensive reviews of research collaboration, the co-author concept of collaboration has several advantages, including verifiability, stability over time, data availability and ease of measurement. However, they note that co-authorship is at best a partial indicator of collaboration.

While agreeing fully that co-authorship-as-collaboration has many advantages, we would go even beyond the limitations noted by Katz and Martin to suggest that co-authorship is not so much a partial indicator of collaboration as just one of many possible outcomes of the social processes encompassed by collaboration. In our view, co-authorship is neither necessary nor sufficient to collaboration. We define collaboration as "social processes whereby human beings pool their human capital for the objective of producing knowledge." By this definition, collaboration need not be focused on publishing articles and, indeed, collaborations often are more concerned with technology development, software or patents and may have no publication objective at any point. Notably, collaboration requires no direct, person-to-person interaction. Increasingly very large teams of specialists interact to produce research and publications and, in some cases at least, some of the collaborators never meet or even interact with one another. Still, this seems to us a collaboration since it is a bringing together of talents for the purpose of knowledge creation and usually results in an identifiable knowledge product (e.g. scientific paper, patent).

By our definition, there is no implication that a collaboration will succeed or even that it will be brought to full term, resulting in a knowledge product. Our definition requires activities aimed at "the objective of producing knowledge." We do not require that the objective be achieved. Research collaborations, even useful ones, sometimes go down blind alleys. Researchable phenomena are inherently unpredictable, otherwise there would be no need for the research. Collaborations can collapse for social reasons as well including, for example, exhausted resources, choices to redirect energies to a study viewed as more promising, or incompatibility and disagreements among collaborators. There are many reasons why research collaborations do not bear fruit.

In our definition, collaboration is about human capital, not other resources. Obviously, financial resources are vital to the success of many research collaborations, but our definition suggests that one who *only* provides resources is not a collaborator but a patron. Sometimes patrons become co-authors, and sometimes this co-authorship without human capital contribution can present problems, but by our definition patrons are not collaborators. But our idea of human capital is not a sharply limited one. Thus, a person who has knowledge of laboratory equipment may bring that form of human capital to a relationship and, by our definition, be a collaborator, whether or not recognized as a co-author or whether or not assigned any patent rights. Stokes and Hartley (1989) showed that sometimes a researcher might be listed as a co-author because he or she has provided material or performed an assay. In some cases an individual may make a major contribution to research and neither obtain nor desire co-author credit. For example, a mentor may help shape a vital part of a doctoral student's dissertation, perhaps even providing the core idea. Such a relationship can be a true collaboration, but it is not conventional for the advisor to be credited other than in an acknowledgment (but often the advisor becomes a co-author on a later publication).

Broader notions of collaboration are not often easy to measure. Focusing on co-authorship alleviates many measurement problems and, thus, many useful studies (e.g. Heffner 1981; Vinkler 1993; Wagner 2005; Heinze and Bauer 2007; Mattsson et al. 2008) of research collaboration begin and end with the co-authored publication.

Despite the challenges of research with a broader concept of research collaboration, several studies do examine collaborations with measures seeking to tap more than co-authorship. Most of these studies (e.g. Melin 2000; Bozeman and Corley 2004; Bozeman and Gaughan 2011) rely on researchers to nominate their collaborators or provide a broader definition of collaboration (Jeong et al. 2011) and then develop indicators based on the broader definition.

3 Knowledge-focused and property-focused collaborations

We examine two different types of R&D productivity here, each quite relevant, even crucial, to research collaboration. *Increments to knowledge* are generally measured in terms of scientific and technical articles produced, cited or, more rarely, demonstrably used. *Increments to wealth* are typically measured in terms of patents, new technology, new business start-ups, and, more rarely, profits. The categories are not mutually exclusive. In particular, most property-focused collaborations at some point have a knowledge-focused phase or aspect. Still, the terminology is helpful in delineating research work according to its primary objectives and in helping gauge whether the collaboration has contributed to the objective.

A number of studies employing different data and methods have provided strong evidence that collaboration tends to enhance productivity of scientific knowledge (Pravdić and Olujić-Vuković 1986; Lee and Bozeman 2005; Wuchty et al. 2007; Huang and Lin 2010). In the case of collaboration's effects on profits, wealth and economic development, the models tend to be more complex and over determined, but here too the preponderance of evidence is that research collaboration has salutary effects (Franklin et al. 2001; Shane 2004; Dietz and Bozeman 2005; Link and Siegel 2005; Perkmann and Walsh 2009).

If research collaboration enhances productivity, or, to put it another way, if researchers give rise to additionality, then there are good and practical reasons for describing, organizing and assessing the state-of-the-art. Indeed, if research collaboration *fails* to contribute additionality then there may be even better reason for its close scrutiny. We feel that the evidence is clear that collaboration provides benefits. However, countless resources and human energies are invested in facilitating, inducing, and managing collaboration (Allen 1977; Hagedoorn et al. 2000; Sonnenwald 2007) and, thus, the question is not *whether* it provides benefits but whether those benefits are sufficient to warrant the prodigious investment of resources. In addition to the "is it worth it?" question, it is certainly the case that some collaborations are highly productive and other less so, ergo the "what works best?" question.

Even if one easily accepts rationales for a review and critique of the research collaboration literature, where does one begin and where does one draw the boundary? Several excellent reviews have already been produced (Melin and Persson 1996; Katz and Martin 1997; Melin 2000). One begins, of course, with these reviews and thus we focus disproportionately on more recent work for this rapidly growing research topic, i.e. work published since 2000.

Most R&D collaboration takes place in private industry because most researchers work in these firms. We know that the objectives, composition, and content of research in industry tend to be quite different from those found in universities, government or non-governmental organizations (NGOs) (Crow and Bozeman 1998; Cohen et al. 2002; Guellec et al. 2004). Much of industrial research draws from public domain research produced in universities (Mansfield 1995). *Our primary focus is on university research.* We do not ignore university researchers' collaborations with those in industry or other sectors, but in this review academic researchers are the collaborators of interest.

Focusing on university research, we examine two quite different strains of research outputs including: (1) work focused on collaborations aimed chiefly at expanding the base of knowledge and enhancing academic researchers' reputation and careers; and (2) work focused on collaborations dedicated, at least in part, on producing economic value and wealth for the researchers. The former literature we refer to as *knowledge-focused research collaborations* and the other as *property-focused research collaborations*, including most academic entrepreneurship research collaborations. Naturally, these are not hard and fast categories inasmuch as a great deal of the work on academic entrepreneurship considers the impacts and practical uses of knowledge-focused research. Likewise, there is a growing literature, mostly sharply critical, examining the effects of flows in the other direction, the impact of academic entrepreneurship (pejoratively referred to as "academic capitalism") on product-focused research (Slaughter and Leslie 1997; Rhoades and Slaughter 1997). The chief arguments of the academic capitalism critique are (1) industrial involvement has unduly affected university researchers' choice of research topics and, perhaps more important (Mendoza 2007; Cooper 2009), (2) led to an exploitation of graduate students, who have become "tokens of exchange between academe and industry" (Slaughter et al. 2002).

The focus on both knowledge-focused and property-focused output and impacts of research collaborations may seem at first blush to encompass everything pertaining to research collaboration. However, the academic entrepreneurship and capitalism literature is actually much larger than its research collaboration component. We do not address academic entrepreneurship unless the studies focus explicitly on the research role and the contributions of research from academia. As such we give no attention to studies focused on such important topics as start-ups, spin-offs, patenting strategies and venture capital.

Another major boundary condition for our review is that we examine (with just a few conspicuous exceptions) literature about *individual-level researcher collaborations*. A great deal of work, especially in industrial and organizational economics, focuses on institutional level research partnerships (Poyago-Theotoky et al. 2002). Naturally, institutions deeply affect the nature of individual collaborations, but we do not consider studies unless the individual researcher and his or her research knowledge products (e.g. publications, citations, patents) is the focus of theory or empirical evidence. This restriction excludes the majority of work on university–industry partnerships and cooperative R&D, most of which does not operate at the individual level of analysis. Much of this work has been critiqued in an excellent review paper by Hagedoorn et al. (2000).

We also acknowledge that many of the articles reviewed here do not fit neatly within the conceptual framework we employ (presented in detail below). Much of the literature on research collaboration examines multiple categories and subcategories presented in Fig. 1 below. As such, our review will discuss a given article in every category and subcategory appropriate in our conceptual framework. For instance an article may focus on commercialization of university research, but could also focus on the personal attributes of the participants involved. The articles addressed therefore receive ample attention below in both the personal attributes and property-focused research sections.

Finally, in a bit of a departure from previous work reviewing the research collaboration literature, we pay special attention here to what we refer to as the "dark side of research collaboration" (Bozeman et al. 2012). Our focus here is a bit different from the academic capitalism literature. Whereas most of the academic capitalism literature is concerned with ways in which institutions adversely affect individuals, we focus on the possibilities for individuals to adversely affect other individuals through unethical or exploitative actions in research collaborations.

4 An organizing framework

Even with the many limitations we adopt, the research collaboration literature remains quite extensive. Thus, one contribution of our study is to provide an organizing framework

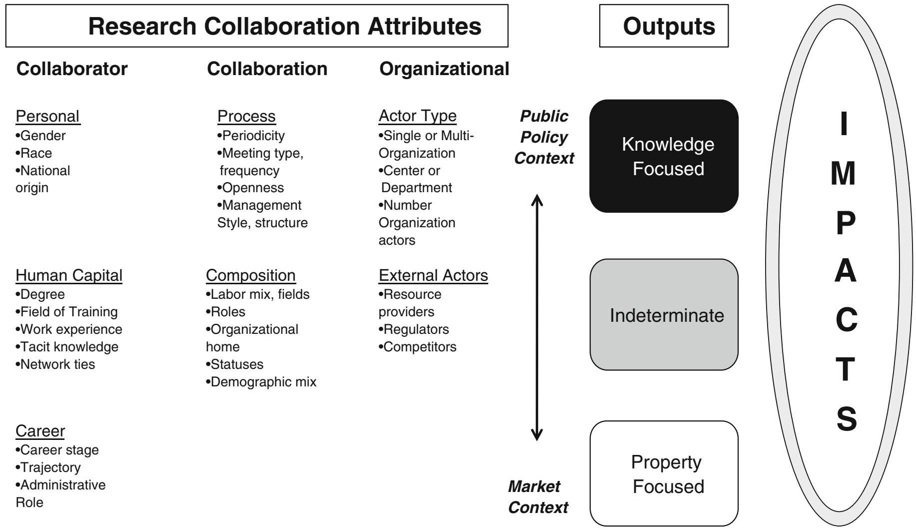

Fig. 1 Framework for organizing the research collaboration literature

for the research collaboration literature. The depiction of the framework is presented in Fig. 1.

As can be seen in Fig. 1 we organize the literature on research collaboration based on the topical foci of the relevant published research papers. We identify three main attribute categories that are consistently analyzed in the literature including collaborator attributes, attributes about the collaboration in general, and specific organizational or institutional attributes. Each of these categories contains subcategories that further organize the literature into a cohesive framework that contributes to understanding of the relationship between additionality and R&D impacts and we include articles from each subcategory. We begin with a systematic review of articles focusing on each of our attribute categories and subcategories, focusing heavily on articles published *after* Katz and Martin's 1997 review.

Let us also note that much of this analysis is supported by the "Propositional Table for Research Collaboration Literature" we developed for this study. The table appears here as an "Appendix".

4.1 Collaborator attributes

The first category in our conceptual organization framework concerns studies focusing on individual collaborator attributes in the collaboration process. Many articles in the field of science and technology policy have addressed questions about research collaboration concerning the scientists involved in collaborative groups. It is understandable that many aim to answer the fundamental question of "Who collaborates with whom?" A number of articles answer this question by identifying the personal attributes of collaborators such as age, gender, race or national origin. Others focus more on the human capital aspects such as training or experience that collaborators bring to the collaboration team. Still other articles focus on the career stages of the collaborators as the important factor of collaboration. Within our organizational framework we can classify these articles into three subcategories of collaborator attributes: Personal, Career Development and Human Capital.

4.1.1 Personal attributes and research collaboration

In our organizational framework we define personal attributes as demographic characteristics of collaborators that either contribute to or hinder the collaboration process with other researchers. These attributes include, but are not limited to race, gender and national origin. It is important to note that these are objective measures of individual identity for scientists involved in collaborative work. One would expect that researchers collaborate more frequently with scientists who share similar demographic characteristics. Our subcategories of collaborator attributes are not mutually exclusive. As such we include articles that discuss human capital and career attributes, but we also focus on personal characteristics of scientists such as age and gender.

4.1.2 Age

Age is certainly one of the most apparent personal factors one might expect to have an effect on collaborations. Thus, it is surprising that relatively few studies have examined the effects of age and career age on collaboration. Perhaps some assume that the effects are "obvious," that those who are older will have more collaborators and a richer and more diverse collaboration network. That expectation seems intuitively appealing. However, the few studies focused on the relation of age to collaboration show mixed results.

Ponomariov and Boardman (2010), examining academic faculty affiliated with university research centers, find no significant relationship between researchers' career age and their number of publications with industrial collaborators, at least not after controlling for a number of potentially confounding variables. This finding is perhaps less counter-intuitive than it might seems. In the first place, the percentage of faculty publishing with industry-based researchers is a minority (11.4 % for those not affiliated with centers, 20.7 % for those affiliated), whether young or old. Second, many of those who do work with centers develop early acquaintance with industry personnel, contacts that might otherwise (for those not so affiliated) take years.

Another study perhaps confounding expectations is Bercovitz and Feldman's (2008) study of the commercial activities of medical school faculty. They find that the likelihood being involved in patenting and licensing diminishes with career age. In contrast, Haeussler and Colyvas (2011), studying life scientists in German and the United Kingdom, find that older scientists are more likely to be engaged in a variety of commercial activities, including not only patenting and licensing, but also consulting and founding a firm.

Lee and Bozeman (2005), examining more than 600 academic scientists in the U.S., find that career age mitigates the relationship between collaboration and productivity. Those who are younger have considerable productivity (publications per collaboration) pay-off as do those who are mid-career. However, at a certain threshold, older researchers begin to have less "bang for the buck," that is, having more collaborations and collaborators has a lesser effect on enhancing productivity. A more recent study of faculty in one university in The Netherlands (Rijnsoever and Hessels 2011) finds that research experience is positively related to university faculty both disciplinary and interdisciplinary collaboration.

Aschoff and Grimpe (2011) look at age effects in a somewhat different way, investigating possible early "imprinting" effects of young researchers working with industry. Their study, employing citation data from 343 German academic scientists in biotechnology, finds that those who have co-authors who have publications with industry personnel are themselves more likely to be involved with industry, suggesting the strong effects of one's scientific peer group. Similarly, they find that those in academic departments with a relatively high percentage of academic faculty co-authoring with industry have a stronger likelihood themselves of industry involvement. Age does not moderate the effect of personal peers but does matter to the relationship between age and the industrial activity of department peers. The authors develop an imprinting hypothesis suggesting that those who engage with industry at a younger age are likely to have more intense and continuing industry relations.

When we consider the diversity of findings of these studies relating age to collaboration we might despair at the lack of consensus. But what appears a lack of consensus is in actuality different findings from quite different studies. Each of the studies cited above examines age but the dependent variables considered vary greatly. There is no reason to expect, for example, that age would have the same effects on engagement with industry as on the number of research collaborations. When we also consider the intermingling of age, career age, aging and cohort effects then we can see that the chief lesson from the research on age and collaboration is that more research is required to address a topic that is much more complex than it seems initially. There is every reason to believe that age has ubiquitous effects, especially as it interacts with careers and career trajectories, considered below.

4.1.3 Gender

Much of the work of Bozeman and colleagues (Bozeman and Corley 2004; Bozeman and Gaughan 2011) focuses on personal attributes, examining personal attributes, especially gender, in relation to collaboration patterns and accumulated "scientific and technical human capital" (Bozeman et al. 2001). Bozeman and Corley (2004) for example, argue that collaboration is part and parcel to human capital. Collaboration is therefore measured as a proxy to human capital and we are able to understand the determinants of collaboration levels, including personal attributes of the collaborators themselves. The authors constructed five regression models to examine collaboration patterns among academic scientists. One of these models analyzed the impact of tenure, grants, gender and field on the percent of female collaborators of an individual scientist (Bozeman and Corley 2004). Bozeman and Corley argue that, "female researchers who hold the rank of non-tenure track faculty, research faculty, tenure track faculty, research group leader or tenured faculty collaborate with a higher percentage of other females than male researchers in the same ranks do" (Bozeman and Corley 2004, p. 607). Although the determinants of female collaboration can generally be described as career attributes of the scientists, the outcome of female collaboration is highly personal.

Gender is obviously one of the most personal and salient issues in one's life, especially in groups where women and minorities are underrepresented, such as academic science (Pollak and Niemann 1998; Johnson and Bozeman 2012). Gender is therefore an important personal collaborator attribute in the scientific community. The authors go on further to say, "Especially noteworthy is the extent to which non-tenure track females collaborate with other females (83.33 %)" (Bozeman and Corley 2004, p. 607). Evidence from these findings supports the idea that collaboration patterns vary by gender.

Although this article does not directly address the concept of "additionality" it is useful to understand collaboration patterns. One could assume that more collaborators or more female collaborators is positively associated with our definition of additionality. Bozeman and Corley are limited in their analysis of gender and collaboration because the authors are only able to measure gender through objective measures of collaboration patterns. For instance, they draw conclusions based on the collaboration patterns of male and female academic scientists. The analysis does not offer any subjective analysis as to whether gender differences or similarities influenced the collaborative group or collaboration process. Although collaborative patterns offer useful conclusions, this analysis only shows half of the gender/collaboration picture. We must therefore understand what factors increase the number of collaborators. Of increasing concern to research collaboration literature is the nation of origin of members in a collaborative project.

In a more recent study, Bozeman and Gaughan (2011) examine gender as their primary focus in research collaboration, seeking explicitly to determine whether previously observed differences in men's and women's collaboration patterns are owing to actual difference in gender or to spurious relations related more to poorly specified models than to actual differences (such as, for example, the fact that in most samples of academic researchers, women tend to be younger than men and models not allowing for this can distort results). Having developed a new database under the U.S. National Survey of Academic Scientists, data including more than 1,700 respondents weighted by field and by gender, the study focused specifically on research collaborations with industry and collaboration motivations. The authors found that men and women differed considerably in the collaboration strategies with men being more oriented to collaborations based on instrumentality and previous experiences. The study found that simply having a coherent collaboration strategy was associated with having more collaborators. Perhaps most important, the Bozeman and Gaughan study was the first to give evidence of women have slightly more collaborators, at least if one controls for tenure, age, family status, and field.

Another study shows that traditional gender patterns in collaboration seem to be changing. Rijnsoever and Hessels (2011), in their study comparing disciplinary and interdisciplinary collaboration patterns find that women are more likely than men to engage in interdisciplinary collaborations. However, the findings must be treated with caution inasmuch as it is based on survey data from a single university in The Netherlands and though there are more than 300 respondents the response rate is only 17 %.

With respect to gender and interactions with industry, Bozeman and Gaughan (2011) employed the "industrial involvement index" (Lin and Bozeman 2006; Bozeman and Gaughan 2007; Gaughan and Corley 2010; Ponomariov and Boardman 2008, 2010) to compare men's and women's collaboration with industry. The industrial involvement index is a weighted gradient (see Bozeman and Gaughan 2007 for detailed explanation) that aggregates a variety of types of interaction, ranging from modest and low effort (e.g. providing research papers upon request) to intensive (e.g. co-development of patents). Bozeman and Gaughan found that even in a more fully specified model men continue to be more involved with industry but that women's affiliation with multidisciplinary research centers tended to mitigate the effect (a finding complementing Gaughan and Corley 2010).

4.1.4 S&T human capital and research collaboration

Especially with regards to collaborations between universities and industry research shows that knowledge is transferred from universities to the business sector largely through human capital (Schartinger et al. 2001). As shown in Fig. 1 above we conceptualize human capital as the degree, field of training, experience, tacit knowledge, or network ties that an individual collaborator brings to the collaborative group.

"Scientific and technical human capital" (S&T human capital) has been defined as the sum of researchers' professional network ties and their technical skills and resources (Bozeman et al. 2001). There are multiple articles that focus not only on the personal attributes of the collaborators, but also S&T human capital attributes such as network ties and field of training. We can also see evidence in the literature that prior experience in industry negatively influences career publications of academic scientists (Lin and Bozeman 2006), though such experience may increase the propensity for interdisciplinary collaborations (Rijnsoever and Hessels 2011).

Lee and Bozeman's study (2005) illustrates the importance of personal S&T human capital attributes. Using a sample of 443 research scientists at university research centers, Lee and Bozeman examine the impacts of collaboration on research productivity. Research productivity is measured by the "normal count" of articles published (total number), but also "fractional count" of articles published (total number divided by number of co-authors). Findings indicate that collaboration is positively and significantly related to the "normal count" of research productivity. This article also suggests that there is not a significant relationship to research collaboration and "fractional count" research productivity. We can see that collaboration influences one possible definition of "additionality", but does not influence another equally valid, yet distinct, measure of "additionality."

By performing a two stage least squares analysis, Lee and Bozeman were able to examine determinants of collaboration and then subsequently determine how each influences measures of productivity. We can therefore see evidence that human capital attributes of individual researchers influence collaboration, despite the mixed evidence regarding productivity measures. It is important to note that this study is knowledge-focused; the authors only consider publication counts and not patents or property measures. The authors find significant field effects for scientific collaboration. Lee and Bozeman control for field by identifying researchers as either "basic" or "applied". "Basic" fields include physics, chemistry and biology whereas "applied" includes all engineering scientists. The authors find a significant and positive relationship for applied scientists and research collaboration, indicating that engineering scientists are more collaborative. It is important to note that this analysis is limited to collaboration of U.S. scientists.

Duque et al. (2005) find alternative evidence for scientists in Ghana, Kenya and the State of Kerala in southwestern India. These authors find that "(1) collaboration is not associated with any general increment in productivity; and (2) while access to email does attenuate research problems, such difficulties are structured more by national and regional context than by the collaborative process itself" (Duque et al. 2005, p. 755).

Another example of how research productivity is not necessarily related to the total number of publications is Cronin's 2001 article *Hyperauthorship: A Postmodern Perversion or Evidence of a Structural Shift in Scholarly Communication Practices*. Cronin describes a different meaning of authorship in the biomedical literature in which there is a large number of authors listed on a particular article, but not necessarily a large number of writers (Cronin 2001). Cronin terms this practice "hyperauthorship". He states, "[there has been a] bifurcation of authorship into contributorship and guarantorship, since what is implied by a byline in these cases is typically a very precise, often specialized input to a complex, multidisciplinary project" (Cronin 2001, p. 567). Cronin's version of hyperauthorship begs the question, why are these scientists receiving authorship credit when they have not worked on the project in question (a question we consider in a later section of this paper)? These possibly peripheral authors are often senior researchers with large amounts of human and physical capital that contributes to the research, or at least to its publication and its impact, regardless of the individual's involvement (Cronin 2001).

Garg and Padhi (2001) examine hyperauthorship in laser science and technology. The authors find that hyperauthorship accounts for a substantial number of papers published in laser science and technology journals, with authors based in Japan, France, Italy and The Netherlands. Arguing that hyperauthorship (termed mega-authorship in this analysis) is largely regional, the authors find a greater proportion of hyperauthored papers for scientists in Japan, France, Italy, and The Netherlands, but in Canada, China, and Australia there is a greater proportion of single authored papers. The authors also examined the international nature of collaborations finding more extensive international collaboration in China, Israel, The Netherlands, and Switzerland and lesser international collaboration in the USA, Japan, France and Australia (Garg and Padhi 2001, p. 415). Hyperauthorship is an excellent example of how network ties and science and technology human capital can increase publish counts without much effort from a scientist who already possesses an extensive amount of S&T human capital. The implications for enhancing scientific outcomes, as opposed to career outcomes, remain unclear.

Bozeman and Corley's (2004) study is among those most focused on the relation of research collaboration to S&T human capital (see also Jeong et al. 2011). They examine how research collaboration can contribute to human capital for academic research scientists. The authors consider collaboration as part and parcel of S&T human capital. They argue, "that it is a particular sort of social tie that both draws from human capital endowments and enriches them, that collaboration enables and is re-enforced by other sorts of ties" (Bozeman and Corley 2004, p. 630). Examining the determinants of research collaboration, Bozeman and Corley develop a series of models that cover most aspects of this paper's organizational framework and this is of course no accident inasmuch as the current model was strongly influenced by that earlier work. Thus, as shown above, the authors include personal collaborator attributes in the models to analyze relationship between these attributes and the number of collaborators with whom individuals interact.

Dietz and Bozeman (2005) also examine the influence of human capital on research productivity, here focusing on property-focused research collaborations.

They analyze the impact of changes in job sectors throughout one's career on research productivity as an academic scientist. Using curriculum vitae of 1,200 research scientists and engineers and information on patents from the U.S. Patent and Trademark Office, the authors are able to examine both knowledge-focused research and property-focused research in the form of patents. The core question in this study centers on the diversity of job experiences for academic scientists. According to the authors, S&T human capital theory "implies that a diversity of job experiences will affect collaborative patterns and the exchange of human capital through the building of a wider variety of network ties and social capital" (Dietz and Bozeman 2005, p. 350). The authors classify job transitions by the origin sector (academic, industry, government, consulting or medical) and the destination sector (academic, industry, government, consulting or medical). The most common job transition was academic-to-academic (62.5 %) followed by industry-to-academic (8.2 %). The authors find a weak positive relationship between research precocity and career homogeneity and research productivity (as measured by publications), but did not find a statistically significant relationship between career homogeneity and patent productivity (Dietz and Bozeman 2005). The authors argue that the evidence supporting the hypotheses that inter and intrasectoral changes in jobs throughout the career will result in higher research productivity (due to the opportunity provided to build S&T human capital) (Dietz and Bozeman 2005, p. 362). Evidence supporting this hypothesis is shown in the descriptive statistics, specifically that higher patent rates are found among those with a higher percentage of their career in industry (Dietz and Bozeman 2005, p. 362).

The authors also acknowledge that this career diversity may be more relevant to patent productivity rather than publication productivity.

Our operationalization of S&T human capital includes network ties, which are explicitly examined in contemporary R&D research. Some empirical studies focus on general network behavior (e.g. Audretsch et al. 2002) and other studies explicitly examine the difference between active and passive networking among scientists (e.g. Faria and Goel 2010; Goel and Grimpe 2011). The former paper (Faria and Goel 2010) focuses on active and passive networking between academic scientists and journal editors and not network activity in the research process. The paper's approach is a game theory model of the publication process, related to our focus on collaboration but not directly on point.

Audretsch et al. (2002) provide a comprehensive examination of science and technology invention and innovation in the 2002 article *The Economics of Science and Technology*. Relevant to the current discussion of networks ties in collaboration and our chosen context of academic scientists is the authors' discussion of collaboration with universities. The authors argue that "the literature on universities as research partners is sparse" (Audretsch et al. 2002, p. 181), but they do offer some general conclusions. First, they offer that firms with network ties to universities tend to have greater R&D productivity as well as a higher level of patenting (Audretsch et al. 2002, p. 181). They go further positing that firms are motivated to maintain these network ties with universities in order to have access to the human capital from faculty and students at universities (Audretsch et al. 2002). These positive outcomes suggest that private industry network ties with universities are beneficial to additionality with current research as well as future endeavors, because the network ties provide access to human capital.

Goel and Grimpe (2011) distinguish between active and passive networking among German academic scientists. The authors operationalize active networking as participation in academic conferences. Although this is somewhat problematic because it assumes that conference participants engage and "network" with other participants, it is nonetheless a useful finding. One can assume that conferences allow researchers to meet other researchers with similar interests or from complementary fields. The researchers examine the difference between this "active" networking and other "passive" networking behavior. "Active" networking involves conscious effort from the researcher and often requires the individual to spend time and money to engage in such behavior. The authors provide conference attendance as an example of "active" networking. "Passive" networking requires no conscious effort from the researcher. "Passive" networks usually develop from one's degree granting institution or collaboration with a scholar that has a highly developed network (Goel and Grimpe 2011). The latter example suggests that researchers may assimilate the network ties of a prominent scholar without conscious effort. The authors also examine geographic factors and research bottlenecks that influence on networking.

Findings indicate that passive networking is both complementary and substitutes for active networking depending on the type of passive networking (Goel and Grimpe 2011). The authors argue that research group leadership and university employment, which both represent passive networking are complements to conference participation. However, the authors also find that "passive networking by being associated with a particular academic discipline, appears to aid some types of conference participation in certain disciplines, while discouraging participation in conferences closer to home" (Goel and Grimpe 2011, p. 14). Other determinants of active network behavior among academic scientists include scholarly publications and patenting. The authors also present interesting non-findings in terms of active networking. Contrary to what one would expect in terms of S&T human capital theory, experience, career age and gender do not have significant effects on active network behavior.

Evidence does show that network ties between industry and universities are often very strong bonds. Mattias Johansson, Merle Jacob and Tomas Hellström provide empirical results that indicate that "relations are characterized by a small number of strong ties to universities, which a high degree of trust and informality" (Johansson et al. 2005, p. 271). Variables pertaining to trust and informal relationships present themselves often in the literature surrounding research collaboration (e.g. Clark 2011; Ubfal and Maffioli 2011; Bruneel et al. 2010). In Bruneel et al.'s (2010) survey research-based study shows the importance of having previous collaboration experience to engendering the trust required for success in collaboration and, related, that collaboration experience reduces barriers to subsequent collaboration, suggesting important learning effects from collaboration.

Martinelli et al. (2008) emphasize the importance of external relations to collaboration, arguing that academic researchers who have few external ties (i.e. S&T human capital) have especial difficulties developing collaborations. Another study (Nilsson et al. 2010) discusses the importance of a supportive infrastructure in universities, especially with respect to bolstering the researcher's confidence that he or she has sufficient social capital to partner with industry. Ponomariov and Boardman (2008) find that informal interactions between university scientists and private sector companies trigger more formal and more intense collaborations with industry. We can also see the importance of individual beliefs about the proper role of universities in the dissemination of knowledge which, according to Renault (2006) is influential in determining collaboration patterns with industry.

Human capital analysis is very well represented in the literature surrounding research collaboration. The examination of human capital is not, however, complete. A more complete body of knowledge needs to be developed surrounding the positive and negative consequences of collaboration with disparate levels of human capital. We can see the beginnings of this body of work through the analyses of hyperauthorship.

Authorship on a collaborative work is increasingly a name game of including the most prominent scientist on the final product, but it is unclear how this process affects other team members. We can expect from Merton's (1968, 1995) classic work on the "Matthew Effect" that credit will inevitably be disproportionate to more senior researchers, regardless of the particular nature or extent of their contribution compared to less well known collaborators. One would expect that the collaborators and co-authors who receive less recognition from a given co-authorship would in some cases feel exploited, especially on those instances where they perceive their own contribution to be more significant than that of a more senior and well known researcher. Empirical studies are needed to sort out these dynamics and possible negative consequences.

Another topic worthy of study is the effect of different levels of human capital. It would be useful to know if "star scientists" tend to rest on their laurels in collaborative groups or if they work as long and hard as junior colleagues. This issue cannot be clarified looking only at publication and co-authoring data. (We briefly discuss the issue of contributorship later in this paper). Related, it would also be interesting to know is collaborators with less human capital are motivated or demotivated by the interaction with these big name scientists. Do they feel that an association with a famous research is rewarding even if their recognition is lessened? Or do they feel that simply having their name closely associated with a famous colleague provides sufficient reward to recompense any possible diminution in their own credit? In sum, although the human capital aspect of collaboration has by now received considerable attention, there is still more to be done to truly understand how S&T human capital influences collaboration.

4.1.5 Researcher career and research collaboration

As previously discussed, we are also concerned with the career stage, trajectory and administrative roles in the collaborative group. Although individual career attributes could certainly contribute to one's human capital, the two are distinct and thus should be examined separately. Here we review studies that analyze career attributes such as networks and mobility, and career advancement. Many of the same studies that provide analysis of personal attributes also consider careers and career trajectories.

4.1.6 Researcher mobility

Recent literature on collaboration, networks and mobility tends to focus on relatively few parts of the globe and particularly collaborations between US and European Union scientists and organizations. Scholars argue that collaboration in the scientific community is increasingly global in nature (Carayannis and Laget 2004). Not only do collaboration projects often span national borders, but increasing span sectors as well (i.e. government, industry and academic) as well (Carayannis and Laget 2004).

At the same time, some recent studies, including Ponds (2009) suggest that the research collaboration globalization trend has reached its peak and is no longer growing. Ponds also finds that international collaboration is most likely to occur between academic organizations rather than academic and industry organizations.

One issue in collaboration studies is differences between "organic," voluntary collaborations and ones developed chiefly through the efforts of administrators and policymakers. Some studies have argued that collaboration works best as a voluntary process, and individuals involved in a collaborative project must commit to the process and the group structure (Chompalov et al. 2002; Melin 2000). There must therefore be a latent demand within individual scientists to work with other scientists thus forming collaborative groups. Melin (2000) argues that there are background causes for individual collaboration that are either structural or personal. Although Melin touches on it, there is a large hole in the literature addressing the personal and social attributes of the individual scientists that influence collaboration.

Certainly we can see many studies on the effects of demographic characteristics on the adoption of collaborative groups, but what about the intangible characteristics of the researchers and the interpersonal relationships amongst them? It seems plausible that interpersonal relationships would have a great influence on the development of a collaborative research team. If an individual scientist cannot interact with a colleague outside of a research team, he or she would probably be less likely to seek out that individual to work on a project that would last months or even years. However, it is also unclear if these personal relationships are somewhat secondary to the resources (i.e. funding, lab equipment, or human capital) that an individual brings to the collaboration. Personal skills, in particular, are difficult to research in connection with collaboration because there are no easy and direct measures. Thus, research often examines productivity (publications, citations) as a proxy. However, it is likely that in many collaborations there is a recognition and assessment of the skills of one's colleagues and it seems equally likely that these assessments would have a bearing on collaboration choices. The literature remains largely silent on this point.

Although our review focuses chiefly on individual collaboration, a study by Chang and Dozier (1995) is relevant in that it assesses the effects of a technology transfer experiment that Hughes Electronics Corporation conducted with California State University, Los Angeles (a large minority-serving institution). Although this experimental program (and, thus, the research focus) is at the organizational rather than individual level, it is useful for our review because it illustrates the influence of racial diversity on collaboration patterns. Hughes Electronics Corporation had a history of racial diversity as a top organizational priority. As such, they developed a research collaboration entitled "Presence on Campus" with a large minority institution to pair racial minorities within the corporation with racial minorities within the institution.

Focusing on racial diversity, the authors conclude that the "culture gap between industry and academia is real, although not as great as sometimes claimed" (Chang and Dozier 1995, p. 94). Although not explicitly stated in the article, the authors allude to the fact that pairing minority students and faculty with minority industry researchers will increase positive outcomes for the partnerships. The authors do argue that the program yielded "encouraging results" for collaborative research projects that were funded and initiated. These findings suggest that race is an important personal attribute for individual collaborators.

4.1.7 University careers

Understandably, given its implications for job security and career progress, tenure is a factor examined in many studies of research collaboration. Tenure is one of the most significant aspects of the academic reward structure and discussions of collaboration often take into account the need for one or more collaborators to obtain tenure (Boardman and Ponomariov 2007). However, not all studies find tenure to be a major determinant of collaboration choices. For example, Bozeman and Corley (2004) find no statistically significant relationship between tenure status and either the number of collaborators or the percentage of female collaborators for a given year. Nor, at least in this study, does tenure seem to weigh heavily in collaboration strategies. The authors do not find statistically significant relationship between tenure status and the proximity of collaborators nor do they find that the untenured are more "tactical" in their collaboration choices and strategies. However, tenure status does have a significant and positive relationship to a "mentor" collaboration strategy (Bozeman and Corley 2004). That is, among those who say that their collaboration choices are in part based on a desire to mentor, persons expressing that choice are, not surprisingly, more often tenured. The authors argue that the relationship shown may be a result of mentoring opportunity in that tenured faculty have the most opportunity to serve as mentors (Bozeman and Corley 2004).

Job satisfaction is one of the most influential attributes for research collaboration, but not necessarily for research productivity. Lee and Bozeman (2005) find that job satisfaction has a significant positive relationship to collaborations for researchers, but does not have a significant relationship to productivity (measured in terms of "fractional count" of total publications). This suggests that the more satisfied a scientist is with his or her position, the more he or she collaborates. It is possible, of course, that the causality is in the other direction (or both directions, i.e. reciprocal causality), that collaboration increases job satisfaction. The research is not presently sufficient to provide a confidence inspiring parsing of causality between job satisfaction and collaboration.

4.2 Collaboration attributes

Central to our review of research collaboration literature are the studies that examine research collaboration processes and composition. In this section we review literature that examines how the attributes of the collaborative groups interact and affect collaboration activities and outcomes.

4.2.1 Collaboration process and research collaboration

Cummings and Kiesler's (2005) research on cross-disciplinary boundaries provides important insights into the ways in which collaboration processes can diverge according to context. The authors find that collaborations across *disciplinary* boundaries report as many positive outcomes as single-discipline projects, but projects spanning *university* boundaries more often have negative outcomes. Multiple university collaborations tend to be improved when collaborators are interacting face-to-face (Cummings and Kiesler 2005). These findings suggest that physical meetings and other coordination mechanisms increase the productivity of collaborations. The authors offer suggestions for mechanisms to assist in the coordination of projects that span organizational boundaries:

- tools to manage and track the trajectory of tasks over time;
- tools to reduce information overload;
- tools for ongoing conversation (perhaps some version of instant messages for scientists);
- tools for awareness with reasonable interruption for spontaneous talk;
- tools to support simultaneous group decision-making;
- tools to schedule presentations and meetings across distance. (Cummings and Kiesler 2005, pp. 718–719)

These suggestions indicate that physical interaction and communication are crucial for the collaboration process. Research collaboration is a continuous process with ongoing concerns that require frequent interactions among project members. This implies, of course, that disparate inter-organizational research collaborations may be prone to problems owing to lesser communication and interaction. Collaborators often have more success traversing discipline boundaries than they do geographic and institutional boundaries. Several studies (e.g. Abramo et al. 2011) have emphasized the role of geographic proximity in promoting collaboration.

Beaver (2001) offers a comprehensive examination of research collaboration in his review article. Among other aspects of collaboration, Beaver examines research collaboration processes, including synergy, feedback, dissemination, recognition and visibility, all of which he views as advantages of collaboration (Beaver 2001). While his points generally seem on the mark he may be a bit too sanguine about benefits of research collaboration. For example, he argues in the case of "synergy" that multiple viewpoints enhance the project outcomes, which seems likely in most cases, but only if all viewpoints in the collaboration process are heard. Less experienced or less powerful collaborators may be overlooked, especially in larger and more hierarchical collaborations. Similarly, Beaver (2001) suggests that research collaboration allows more feedback, dissemination, recognition and visibility in that each member of the collaboration brings to the collaboration a network of colleagues who will likely be attentive to the research. Again, this assumes that each member of the collaboration is invested in the project is a visible member of the team. It also assumes that collaborators bring a favorable reputation to the project. Recent research (Liao 2011) suggests that it is not the number of collaborators that is important to productivity but the intensity of collaborations and the degree to which collaborators are embedded in the network.

Chompalov et al. (2002) provide some especially useful findings about the impact of management style in research collaboration. They identify four basic structures for collaboration including bureaucratic collaborations, leaderless collaborations, non-specialized collaborations, and participatory collaborations. Bureaucratic collaborations are most successful when the project involves multiple organizations and there must be a clear hierarchy to ensure that no one organization's interests are disproportionately served (Chompalov et al. 2002). Leaderless collaborations are similar to bureaucratic structures in that both are highly formalized and differentiated (Chompalov et al. 2002). This organizational structure defines specific roles and responsibilities for each of the members of the collaboration, but does not identify a hierarchy of leadership and responsibility. This structure could prove effective in some collaborations because it forces each member to be accountable for his or her responsibilities to the rest of the collaboration team. However, the leaderless collaboration seems to require experienced collaborators and valued, specialized roles.

In collaborations that involve scientists with disparate levels of human capital, the non-specialized organizational structure may be the most appropriate. Chompalov et al. (2002) identify this organizational structure as similar to a bureaucratic structure in terms of hierarchy, but less formal in terms of roles and responsibilities. This structure can clearly be seen in academic collaborations that involve a principal investigator (PI) that is awarded a large grant to conduct a specific research project. If the PI brings on other collaborators to the project he or she is still ultimately responsible for the project and thus has a clear leadership role. Other roles and responsibilities can be informal and less differentiated, but there is still a clear hierarchy, at least at the top.

The final organizational structure defined by Chompalov et al. (2002) is participatory collaboration. This organizational structure is egalitarian in nature, with team members having similar status, at least in the project, and a high degree of autonomy. According to the authors, participatory collaboration is especially common in particle physics (the domain to which they give greatest attention). While participatory collaboration can be quite effective, it requires that participants hold egos in check and respect one another's opinion.

Although Champolov and colleagues create a typology of organizational structure for scientific research collaborations, they argue that hierarchy is not the defining characteristic of collaboration. Consensus, they argue, is the true defining characteristic of collaboration because regardless of the level of hierarchy involved in a project, participation is always voluntary and a collaborator is rarely coerced to accept a given hierarchy.

Beyond organizational structure, some literature focuses on the roles of collaborators within a project or more specifically the role conflict and ambiguity associated with collaborations (Duque et al. 2005). In their study of 918 scientists in three developing nations, Duque and colleagues found a paradox—the factors that undermine the productivity of collaborations (e.g. transactions costs) are not mitigated by and may even be exacerbated by new information and communication technologies and remote collaboration.

Garrett-Jones et al. (2010), in a recent contribution to this journal, provide empirical evidence of how the management of collaborations can affect the actors and the output of the process. Based on both questionnaire data and interviews of researchers in Australian Cooperative Research Centers, the "important management issues of trust, governance, and competition between functional domains, which emerge from IOR and which have been inadequately recognized in the context of collaborative R&D centers" (Garrett-Jones et al. 2010, p. 527). The authors specifically stress the role of trust between different actors in the collaborative arrangements. We can see from these findings that management behavior is crucial to develop a productive and encouraging environment for scientists (Turpin et al. 2011). Although intangible, fostering a sense of trust among research scientists collaborating with other scientists across sectors contributes to effective research.

An important aspect of the collaboration process pertaining to management is the set of incentives pursued in choosing collaborators. Bozeman and colleagues (Bozeman and Corley 2004; Lee and Bozeman 2005; Bozeman and Gaughan 2011) have given special attention to the management style of individuals within the research team. Based on questionnaire data, the researchers identify archetypal collaboration motives and strategies as follows:

- The "Taskmaster" tends to choose a collaborator based on work ethic attribution and whether or not the person sticks to a schedule.
- "Nationalist" collaborators, the least common archetype among the STEM researchers in the sample, is drawn to collaborators who are fluent in their language or who are of the same nationality.
- "Mentors," more common among senior researchers, are motivated to a large degree by their interest in helping junior colleagues and graduate students by collaborating with them and, in the process, mentoring them.
- The "Follower" chooses collaborators mostly because someone in administration requested that they work in the collaboration or, in some instances, because they wish to partner with a collaborator who has a strong science reputation.
- The "Buddy" chooses collaborators based on the length of time they have known the person, the quality of previous collaborations and whether or not the collaborator is fun and entertaining.
- Finally, the "Tactician" chooses collaborators based on whether or not the collaborator has skills complementary to their own (Bozeman and Corley 2004, p. 610).

Bozeman and Corley (2004) aim to understand which factors predict collaboration strategies for individual scientists. They find that tenure status, percent of female collaborators, number of graduate student collaborators, and the scientists' cosmopolitan scale all were significantly and positively related to the "mentor" collaboration strategy. Amount of grant money is significantly and positively associated with the "tactician" strategy. Evidence also suggests that women are less likely to adopt a "tactician" strategy (Bozeman and Gaughan 2011).

Lee and Bozeman (2005) take a different approach and use the collaboration strategies to predict the extent of research collaboration and collaboration productivity through a two stage least squares analysis of questionnaire data. The authors find significant relationships between the roles of the academic scientists and productivity, providing evidence that strategies matter to "additionality." The authors report significant and negative relationships between a "nationalist" collaboration motivation and number of collaborators. The STEM researchers who engage in collaboration in order to mentor junior scholars and doctoral students (mentor strategy) have more collaborators. Those that collaborate because of a shared national identity or language tend to collaborate less Taken together, these findings indicate that research collaboration strategies and motives to matter in terms of collaboration outcomes. In terms of productivity, the authors only find a significant and positive relationship between a "tactician" strategy and both the normal and fractional count of research productivity (Lee and Bozeman 2005).

While there is a good deal of research on the topic of research management and motives and their relation to research effectiveness (e.g. Carayol and Matt 2004) relatively little research focuses on the interrelation of management, collaboration and effectiveness

(Vasileiadou 2012). Many important topics receive scant attention. For example, we know little about the relation of collaborations' management structure to problem choice or to the sustaining of longer term and serial collaborations. Nor is there research on the actual costs (in terms of money but also career costs and foregone opportunities) of managing research collaborations. Everyone who has participated in research collaborations is well aware to the time and energy required to management them but there are not rigorous research studies documenting these costs.

4.2.2 Collaboration composition and research collaboration

Our conceptualization of collaboration includes the labor mix, the organizational home, status and demographic mix of the collaborators in the collaborative group. Although our focus of this review centers on individual collaboration, we cannot ignore the larger organizational context of the collaborative group. This includes not only the organization of the group itself, but also the organizational ties and associations that individual group members bring into the collaborative group.

Beaver (2001) discusses the typical structure of a collaborative project at a university, including the demographic composition of collaborative academic groups. He states that "The typical group *structure* at a major research university consists of: A Principal Investigator (PI), together with postdocs, graduate students (and perhaps undergraduates)—or—A senior professor, perhaps an assistant or junior professor, postdocs, graduate students (and perhaps undergraduates)" (Beaver 2001, p. 369). Beaver's description rings true, but is based on anecdotal evidence, developed chiefly through discussion with his colleagues at Williams College.

Beaver (2001) also offers his views about the advantages and disadvantages to this basic collaborative composition. Beaver argues (2001, p. 370) that because of the collaboration composition the, "PI loses touch with direct research." This disadvantage occurs because the PI has subordinate members of the group to perform the basic tasks of the project and, as a result, the PI loses tacit knowledge of how things work in practice and, instead, invests more time in routine project administration. Later research (Bozeman and Gaughan 2007) based on questionnaire data from more than a thousand U.S. university researchers, provides convergent evidence that the most common personnel configuration of research projects may channel too many resources to line administration. When asked to identify the single most important problem in their research work, respondents mentioned time writing and administering grants as the most important obstacles.

In terms of organizational home, it is important to consider how the geographic location of the organization contributes to collaboration. A recent study examines the influence of geographic proximity on increased collaboration between universities and private industry organizations (Abramo et al. 2011). Defining collaboration as any partnership between universities and industry that result in a coauthored scientific article, the authors conclude that collaboration is often "exclusive" between universities and companies, but often can involve multiple universities collaborating with a single company. Findings suggest that significant inefficiencies occur in the market between university and private firm collaborations, but these inefficient patterns provide useful insight into how the organizational home can influence collaboration behavior. Abramo et al. (2011) find that private companies are more likely to partner with universities in close proximity rather than the most qualified institution. The authors argue that 93 % of collaborations within the study could have been conducted with a "higher ranking" academic partner. This suggests that researchers tend to collaborate with those who are in closer proximity.

Lee and Bozeman (2005) provide complementary findings. In terms of nationality and composition of a collaboration team, Lee and Bozeman (2005) offer findings indicating that researchers engaged in collaborations with scholars outside of normal work groups, including other nations, tend to collaborate more than their peers. Referred to as the individual's "cosmopolitan scale", this suggests that those scholars collaborating with more distant scholars collaborate more than do those who chiefly collaborate with persons in their immediate environment. However, most university scientists (more than 60 %) collaborate almost exclusively with persons in their university research center or laboratory (Bozeman and Corley 2004).

A more recent study shows the importance of distinguishing research collaboration according to the level of development of the researchers' national locale. Focusing on developing nations, Ynalvez and Shrum (2011) indicate that collaboration has no especial productivity pay off for researchers in developing nations and that collaborations, when they are undertaken at all, often are done so in the face of major impediments and institutional barriers. Research by Toivanen and Ponomariov (2011) focuses on collaboration in Africa and, similarly, notes important structural impediments to collaboration.

4.3 Organizational/institutional attributes of research collaboration

Our conceptualization of organizational and institutional attributes is distinct from the previous discussion of collaboration composition in that we are here concerned with the macro level organizational and institutional attributes rather than the individual organizational attributes of the collaborators. Here we review studies concerned with both internal and external actors of the research project. Organizational and institutional arrangements of collaborative research projects have received a great deal of attention in the literature in recent years. Many scholars are concerned with the process of university/industry partnerships and how the organizational arrangement influences research policy. Our chief focus in this section is the role of individual academic scientists and their roles in university/industry partnerships. Other papers are focused less on university/industry partnerships than on issues emerging from collaborations among researchers working in different universities or hybrid settings.

4.3.1 Organizational actors and research collaboration

Within our organizational framework we include actor type as a subcategory of organizational/institutional attributes in research collaboration. Actors within a collaborative project can certainly influence the process and outcome of the research project and therefore it is vital to provide an appropriate review of literature addressing actor type issues.

We begin with further discussion of Cumming and Kiesler's (2005) paper on collaboration across disciplines and organizations. The authors examine "collaborations across disciplinary and university boundaries to understand the need for coordination in these collaborations and how different levels of coordination predict success" (Cummings and Kiesler 2005, p. 703) and find that collaborative projects across multiple disciplines report positive outcomes whereas collaborations across multiple universities face higher coordination costs. Cummings and Kiesler (2005) argue that the problems pertaining to principal investigators associated with multiple universities could be alleviated with more coordination mechanisms. However, they also find that "having PI universities involved in a project significantly reduced the likelihood that PIs would actually employ sufficient coordination mechanisms" (Cummings and Kiesler 2005, p. 715). The authors offer some implications for practice discussed above as they address collaboration process attributes.

In their study of the relation of organizational and work characteristics to researchers' publication productivity, Fox and Mohapta (2007) examine the relevant literature and their own questionnaire data. They ask four chief questions about the relationship of university researchers' productivity to "social-organizational characteristics" of the work setting. Specifically, they consider "What are the effects upon publication productivity of (1) team composition (number of persons/positions, by gender, on a research team); (2) collaboration (inside and outside of department and university); (3) work practices; and (4) workplace climate?" (Fox and Mohapta 2007, p. 543). The authors use data from a survey conducted in 1993–1994 of 1,215 faculty in doctoral-granting departments of computer science, chemistry, electrical engineering, microbiology, and physics. They measure publication productivity as the number of articles published or accepted for publication reported by respondents in the 3 years prior to the survey. Team composition focuses on the number of and gender of graduate students and the gender of the faculty member on the research team. Collaboration is measure by the number of collaborations with faculty within one's own department, outside one's own department but on the same campus and those on other campuses. Work practices and departmental climate, while important, are not relevant to the current review of literature.

The authors find a significant and positive relationship between being a male faculty member together with having higher numbers of male graduate students and research productivity. Evidence does not show a significant relationship between gender of faculty and productivity or number of female student and productivity.

Fox and Mohapta (2007) find significant and positive relationships to collaborations with other faculty within one's own department or at another institution. Evidence shows no significant relationship between collaboration with faculty outside one's own department, but within the same campus and research productivity. These results are distinct from the Cummings and Kiesler (2005) article that suggests that collaborations across organizational boundaries increase coordination costs and are therefore problematic. In contrast, Fox and Mohapatra find that such collaborations are the ones with the highest productivity. The respective findings are not inherently contradictory. It is certainly possible for collaborations to at the same time be highly productive and to exert a major toll in terms of coordination costs.

Just as important as inter-university collaboration is international collaboration. In that regard, Carayannis and Laget (2004) suggest that researchers are increasingly configured into collaboration networks that are global in nature. Academic scientists are more likely to collaborate with scientists from other countries and in other sectors. According to Beaver (2001, 2004) global collaborations could prove problematic in terms of coordination, but the evidence for management of such cross-national collaborations remains scant.

Whereas academics seem to be increasingly drawn to international collaborations, this is not necessarily the case for industry–university research collaborations, as suggested by Abramo et al. (2011). Industrial groups partnering with academics seem to have a preference for collaborations with nearby universities and academic researchers. This seems in line with both intuition and previous research findings. Whereas knowledge development, as embodied in publications, seems to have few significant geographic boundaries, industries partnering with academic researchers in property-focused collaborations continue to prefer nearby research partners. Technology transfer often works best when supported by regular face-to-face interaction that enables tailoring of research and application (see Bozeman 2000 for a review of research relevant to this topic).

Katz and Hicks (1997) provide evidence about the value of research collaboration. Using bibliometric data, the authors analyze collaboration's value in terms of citation rates. They find that, compared to single-authored papers, collaboration with domestic researchers increases the citation rate by .75 citations, whereas collaboration with researchers in other countries increases by 1.6 citations.

Beyond the individual scientists involved in the collaboration process, it is also important to consider the organizational environment in which these individuals interact (Liao and Yen 2012). Katz (2000) specifically addresses this concern. He argues that conventional measures used to evaluate research do not account for the non-linear relationship between the size institutions associated with collaborations and the research performance (Katz 2000). He goes further to argue that traditional measures of size and performance result in an exponential power-law relationship between size of the research group, institution or nation and the perceived research performance. Katz (2000, p. 24) makes his argument based on a variety of performance-related measures including number of published papers, number of citations to papers, citations per paper, and number of co-authored papers.

Katz makes arguments about the size of institutions and the propensity to collaborate among the members of the institution, noting that "smaller educational institutions have a greater propensity than larger ones to collaborate domestically, particularly with industrial partners and other educational institutions" (Katz 2000, p. 29). He also reports that larger institutions are more likely to engender collaborations, both internal ones and international collaborations and that collaborations tend to exhibit linear increases as the size of institutions increase. One recent paper focused on Taiwan suggests that international collaborations tend to have greater impact, but that level of impact from international collaboration is field specific (Liu et al. 2012). However, a study (Gazni and Didegah 2011) of U.S. researchers shows that publications with U.S. and foreign collaborators tend to receive fewer citations than publications by U.S. collaborators only.

Returning to Katz's (2000) study, we can see that additionality can vary by organizational size. Larger academic institutions have the infrastructure and human capital necessary to provide internal collaboration networks. Scientists at large institutions may not need to go far to collaborate. This would explain the increased internal collaborations at larger institutions. Larger academic institutions generally have the resources to attract researchers with large amounts of human capital. By the same token, the propensity for researchers in smaller institutions to collaborate domestically with industry partners and other academic institutions more than likely has to deal with the resource limitations of smaller institutions.

4.3.2 External actors and research collaboration

In our conceptual model, external actors of particular importance include resource providers, regulators and competitors. We can see evidence of external actors negatively contributing to the collaboration process (e.g. Hall et al. 2001), but also evidence that external actors positively contribute to collaborative R&D (e.g. Johnson 2009). Funding from different sources can strongly influence the process of collaboration (Bozeman and Gaughan 2007; Matt et al. 2011). However even if it is clear that external actors affect collaboration and effectiveness, the specific causal paths are not always obvious.

The research reviewed in this section helps clarify the ways in which external actors affect research collaboration.

Geisler (1986) provides one of the most important studies of external actors in the research collaboration process. The external actors of interest to Geisler (1986, p. 33) are persons on Industrial Advisory Boards (IAB), individuals who have "a significant, yet sometimes underestimated role in the transfer of technology between universities and industry, in the context of university–industry collaborative arrangements." Findings suggest that IABs facilitate the transfer of technology by creating a locus for the interaction university researchers and industrial personnel.

In the United States and many other nations, the national government is among the most significant and pervasive external parties to research (as well as an internal actors inasmuch as many nations maintain extensive government personnel engaged in R&D activities). Inevitably, institutions that shape research generally also affect patterns of research collaboration. In their study of the relationship of academic research to industrial performance, Grossman et al. (2001) consider, among other factors, the ways in which funding can affect research collaboration patterns. As is well known, the U.S. federal government has been the primary funder for academic research and industry financial support has been modest, at least on a percentage basis. Despite this funding disparity, industry has proved to be an important actor for research collaboration. The authors (Grossman et al. 2001, p. 151) argue "industry has provided a large stimulus to fundamental long-term research in many fields, posing new questions to academic researchers and exposing gaps in knowledge through their innovative activities." The authors also suggest that many industrial actors are unsatisfied with the federal government's funding levels to sustain long-term researcher, but they are not increasing their own funding levels for university–industry collaborations (Grossman et al. 2001). As funding from government has slowed and that many institutions have come to rely on alternative funding methods including own source institutional funding and industry sources (Jankowski 1999; Morgan and Strickland 2001; National Academy of Engineering 2003).

Beyond funding, external actors such as regulators can influence collaboration patterns. Given our focus on academic researchers, an important external actor with a regulatory role is that of the institutional technology transfer office at most research universities. In a series of related studies, Siegel et al. (2003a, b, 2004) provide broad-based empirical analyses of university technology transfer offices. Siegel et al. (2003a) report results from interviews with university administrators, scientists, and business professionals. The authors provide examples of numerous barriers to effective technology transfer and some recommendations for improving the process. As can be seen, most of these recommendations are specifically targeting the technology transfer offices (TTO) at institutions.

- "Universities need to improve their understanding of the needs of their true 'customers,' i.e., firms that can potentially commercialize their technologies
- Adopt a more flexible stance in negotiating technology-transfer agreements and streamline UITT policies and procedures
- Hire licensing officers and TTO managers with more business experience
- Switch to incentive compensation in the TTO
- Hire managers/research administrators with a strategic vision, who can serve as effective boundary spanners (tie to boundary spanning literature)
- Devote additional resources to the TTO and patenting

- Increase the rewards for faculty participation in UITT by valuing patents and licenses in promotion and tenure decisions and allowing faculty members to keep a larger share of licensing revenue (as opposed to their department or university)
- Recognize the value of personal relationships and social networks, involving scientists, graduate students, and alumni" (Siegel et al. 2003a, p. 122)

These recommendations aim to increase the efficiency and effectiveness of university/industry collaboration. Although the TTO is not mentioned specifically in all of the above recommendations, the TTO would most likely be responsible for implementation of the more general suggestions. We can see from Siegel et al. (2003a) not only an example of an effective TTO, but more importantly a negative example of how a TTO could discourage collaboration between universities and industry. Effective TTOs generally have more business experience and create incentives and procedures that benefit the industry side of the university/industry collaboration. These findings are consistent with other studies (Renault 2006) that find that institutional policies negatively influence collaboration with industry.

It would appear that the empirical evidence shows that university administration often discourages collaboration between universities and industry. Even in instances where higher-level university administration is committed to industrial partnership, middle- and lower-levels of bureaucracy sometimes sabotage these goals (Audretsch et al. 2002). Nevertheless, industry outcomes often are net positive for university interactions. Hisrich and Smilor (1988) find positive outcomes for companies as a result of these university programs, specifically university business incubators. The authors identify four key factors that must be linked for successful university business incubators technology transfer to industry: talent, technology, capital and know-how (Hisrich and Smilor 1988). Findings also suggest that these incubator programs benefit companies by "helping them build credibility, shorten the learning curve and solve problems faster, and by providing access to entrepreneurial networks"(Hisrich and Smilor 1988, p. 14). We can see here that not all regulatory external actors negatively affect industry collaborations with academia. In fact, universities often target businesses and use resources and human capital to develop the companies further. Evidence shows that a number of university-associated patents are used in startup companies, but most are used in established large firms (Meyer 2006).

Drawing from a sample of projects funded by the Advanced Technology Program, Hall et al. (2001) offer some general conclusions on the effects of regulations on collaboration patterns between universities and industry. Their research focuses on the barriers that limit collaboration or partnering behavior between industry and universities, primarily intellectual property concerns. Implicit in this analysis is the notion that universities are subject to more stringent regulations compared to private industry. According to the authors (Hall et al. 2001, p. 94) "we have demonstrated that IP issues between firms and universities do exist, and in some cases those issues represent an insurmountable barrier which prevents the sought-after research partnership from ever coming about." The authors also identify determinants of such situations occurring. IP barriers are more likely to occur when the research is expected to lead to results that are not easily appropriable and when there is a lesser degree of public goods aspects to the work. Industry is more likely to avoid partnering with university researchers when the research is expected to be short term. These results are consistent with the (Hagedoorn et al. 2000) of research on industry university partnerships.

Researchers have borrowed from other disciplines to understand the nature of interaction between internal and external actors, most notably from psychology and the "Not Invented Here or NIH" construct often examined in industry. Grosse Kathoefer and Leker (2010) apply the NIH syndrome to knowledge transfer in academia. They identify four factors related to the syndrome. The first two, the preference for internally generated knowledge and the perception of the professors on how important outsiders regard internal knowledge generation, are consistent with the NIH syndrome core of "having prejudices against external knowledge" (Grosse Kathoefer and Leker 2010, p. 10). The final two factors deal specifically with the focus of our review: reluctance to collaboration and reluctance to knowledge sharing. The results presented regarding the determinants of the NIH Syndrome can therefore be closely linked to a lack of desire for collaboration with external actors because a perception of competition.

The authors offer some general conclusions as to what produces this distrust of external actors in the form of NIH syndrome. First, they offer that NIH can be "regarded as a psychological issue being individual-based" (Grosse Kathoefer and Leker 2010, p. 11). The respondents examined in the analysis came from two distinct academic fields, physics and engineering, however the two groups showed no systematic differences in levels of NIH. The authors therefore conclude the syndrome is individual in nature. Findings do indicate a systematic difference between scientists focusing on basic research and those focused on applied research. The latter group shows lower levels of the syndrome. The authors argue this is due to direct ties with industry to produce research products thus increasing trust and acceptance of external actors.

4.4 Outputs and impacts from research collaboration

Unavoidably, previous sections of this paper have dealt with the "dependent variables" from collaboration. But in this section the chief focus is on outputs and impacts and we include some research findings that do not conveniently fit into the categories developed above.

As noted above, this review is concerned with distinction between knowledge-focused research and property-focused research. Naturally, different stakeholders in research collaborations have different values for various outputs and these differences in values, goals and perspectives affect the collaboration processes and perceived effectiveness (Siegel et al. 2003b).

As stated above we define knowledge-focused research as that research that contributes to the general scientific knowledge of a field but offers little monetary or property gain for the researchers of the project. We define property-focused research as research that typically results in some form of monetary or property benefit for the researchers including patents, new technology, new business start-ups or more rarely monetary profits. We acknowledge in our conceptualization that these two foci or outputs are not mutually exclusive. As such we include a third type of output: *indeterminate*.

D'Este and Perkmann (2011) present an excellent analysis of the tension between knowledge-focused, property-focused and indeterminate-focused research collaborations. They focus on the motivations of academic researchers to collaborate, both formally and informally with industry (D'Este and Perkmann 2011). The authors identify four main motivations that are consistent with our three main outputs of collaboration. The first is commercialization, which they define as "commercial exploitation of technology or knowledge" (D'Este and Perkmann 2011, p. 330). Commercialization resembles our operationalization of property-focused research. The next motivation identified by D'Este and Perkmann is learning, defined as "informing academic research through engagement with industry" (D'Este and Perkmann 2011, p. 330). Learning as a motivation to collaborate is consistent with our operationalization of knowledge-focused research. The final two motivations for academics to engage in collaborative research with industry are less obvious. Access to funding and access to in-kind resources as a motivation to collaborate are both indeterminate-focused outputs. Although both are resource related, it is not always apparent if the resources are devoted to monetary gain or increased knowledge production. Below we offer further review of articles that discuss the outputs of collaborations.

4.4.1 Knowledge focus and research collaborations

As indicated above, we define knowledge-focused research collaborations as "collaborations aimed chiefly at expanding the base of knowledge and enhancing academic researchers' academic reputation." As can be seen in the literature, knowledge-focused and property-focused research are not mutually exclusive (Hessels and Van Lente 2008). Applied studies can contribute to fundamental knowledge and that fundamental studies can be somewhat applied in nature. Although industry partnership is most often applied, industry also funds basic research thus contributing to knowledge-focused outputs. Much of this funding comes to develop equipment that could be used for future applied research (Nedeva et al. 1999). There is evidence that access to equipment and additional research resources is a major incentive for many research collaborations (Tartari and Breschi 2011).

This section reviews literature that examines collaborations influence on knowledge-focused research. It is important to note that often knowledge-focused outputs are not the motivating factor for collaboration, but an aspect serving researchers' values and, as such, an incentive to continue to collaborate even in cases where not all parties to the collaboration have exactly the same goals.

Lee (2000) uses data from two surveys of academic research and their industrial partners to examine the sustainability of collaborations. Findings are distinguished between expected and unexpected benefits of the collaboration, but also between benefits for industry and for universities. One might expect industry managers to identify monetary benefits as the motivating factor for continued collaboration, but Lee reports that the most important benefit for firms is "an increased access to new university research and discoveries" (Lee 2000, p. 111). The author also finds that faculty engage in research in order to secure funds for graduate students and lab equipment. Despite the fact that knowledge-focused outputs are not the motivating factor in the expected group,[1] we can still see empirical evidence that knowledge-focused outputs influence research collaboration. Lee's findings are consistent with other research on expectations from industry–university partnerships (Feller and Roessner 1995; Gray and Steenhuis 2003).

One study focusing explicitly on knowledge-focused research outputs is Landry et al.'s (2007) analysis of knowledge transfer among Canadian university researchers in natural sciences and engineering. The authors answer three research questions: the first distinguishing between knowledge and technology transfer, the second identifying differences

[1] There is evidence that industry collaborations with universities most often produce increased knowledge-focused outputs rather than property-focused outputs (Levy et al. 2009). Given private industry's profit-maximizing goal, however, we would expect firms to be motivated by increased property-focused outputs to engage in collaborative projects.

between disciplines in terms of knowledge transfer, and finally discussing the determinants of knowledge transfer. Their findings indicate that researchers produce knowledge-focused outputs more actively "when no commercialization was involved than when there was commercialization of protected intellectual property" (Landry et al. 2007, p 561). The authors also found significant field effects suggesting that researchers in certain disciplines were more active in knowledge-focused research than others, engineering being the most active, followed by earth sciences, mathematics, statistics, physics and space sciences. Focus on user needs and relationships between researchers and research users positively influence knowledge transfer across all disciplines, but findings also indicate that determinates of knowledge transfer vary across disciplines. The authors argue that "different policies would be required to increase knowledge transfer in different research fields" (Landry et al. 2007, p. 561).

Boardman and Ponomariov (2007) develop an empirical model focusing on academic scientists' desire to produce knowledge-focused research. In this article the authors are primarily concerned with the impact of tenure on a desire to produce knowledge-focused or property-focused research. Boardman and Ponomariov (2007) analyze survey responses from a sample of 348 tenured or tenure track academic faculty researchers at university research centers. The authors construct two models, the first based on responses to a questionnaire item "Worrying about possible commercial applications distracts one from doing good research," and the second dependent variable based on the item "I am more interested in developing fundamental knowledge than in the near-term economic or social applications of science and technology" (Boardman and Ponomariov 2007, p. 61). Both models include personal attributes of the respondents, including age, gender, if the respondent is tenured, field of study, if the respondent had a job in industry prior to current position, especially important for present purposes, the respondents' proportion of collaborative papers (Boardman and Ponomariov 2007). The authors find a significant and negative relationship between tenure and both the "distraction of commercial interests" and the "interest in developing fundamental knowledge" variables (Boardman and Ponomariov 2007). Evidence shows that junior faculty are more likely to value basic rather than applied research and do not value property-focused research as highly as senior colleagues (Boardman and Ponomariov 2007). These findings are largely consistent with another study that suggests that faculty members that are more embedded in academia value basic research more than property-focused research (Ambos et al. 2008). Evidence is mixed over which output is valued most by senior researchers, but both studies include measures of collaboration thus suggesting that collaboration does not drastically affect the research output (either knowledge-focused or property-focused). It is important to remember that the respondents in the Boardman and Ponomariov article are all affiliated with university research centers, which could imply that they have a deeper commitment to industrial partnerships and perhaps property-focused research collaborations.

In terms of "additionality", a strong argument can be made from the evidence presented in Beaver's 2004 article *Does Collaborative Research have Greater Epistemic Authority*? This article provides evidence that suggests that collaborative projects do indeed have greater epistemic authority than individual research projects (Beaver 2004). The author measures epistemic authority of an individual project with the number of citations, both in number, probability of citation and length of citation history (Beaver 2004).

As a theoretical introduction to his study, Beaver makes sociological, philosophical and historical arguments supporting his hypothesis that collaboration produces more cited results. One philosophical and sociological argument is that collaboration provides inter-subjective verifiability to the project, "the ability to establish or prove truth (or falsity) through arriving at a free, unforced agreement among many different 'subjectivities' or people" (Beaver 2004, p. 401).

This argument seems warranted to the extent that collaborative projects are subjected to more scrutiny from the multiple authors. The results may be viewed as more valid because they have survived a rigorous test from multiple rather than a single subjectivity (Beaver 2004). This argument is not compelling in instances of hyper-authorship. If an author is listed merely because of his or her human capital, then the author may provide no oversight or expertise at all. In some cases there is a false epistemic authority because the audience would expect an author to evaluate a project attached to his or her name and this expectation would not be met. However, in cases where each collaborator does provide at least some attention to the given project, then collaborative nature of the work should provide added validity to the knowledge product.

Beaver further supports his position by using Kuhn's (1996) *Structure of Scientific Revolutions* as a conceptual framework. Kuhn argues that scientific revolutions occur as the result of challenges to existing paradigms, often played out as a struggle between young and established scholars. Beaver (2004, p. 404) argues that "Each collaborator having something of an 'outsider's viewpoint' increases the likelihood of recognizing significant novelty, and of detecting important error." Beaver makes an assumption that the collaborative process is typically a tension between established and not established scientists. Although this tension could possibly improve scientific results, it is unclear if this tension is always present in scientific collaboration.

Beyond the philosophical issues associated with Beaver's argument, the author provides an empirical model assessing the epistemic effects of collaboration. Using qualitative analysis of 660 refereed research articles from 33 professors at Williams College, Beaver examined the collaboration patterns of professors and the resulting citations of the publications. The evidence suggests that "collaborative research produces significantly more authoritative research, as reflected in acknowledgements through citations, and in the longer intellectual influence indicated by greater citation lifetimes" (Beaver 2004, p. 407). Methodologically, the study is somewhat problematic. Beaver's study is limited to professors at Williams College, certainly not a representative group. Nevertheless, despite problems with external validity, the study provides many directions for future researchers to follow. Beaver's evidence suggests that additionality is created through collaboration. The proposition that research involving more than one author has more epistemic authority than single-authored projects cannot be said to have been proved by Beaver's work but he does frame a tantalizing questions and present relevant, if not conclusive, evidence.

Industry–university cooperation also seems to have many positive effects on knowledge outcomes. While one might assume that industry is primarily motivated by property-focused outcomes such as patents or profitable products, Caloghirou et al. (2001) show that industry partners often are strongly motivated by less targeted work aimed at generally enriching the knowledge available to them. Although the authors limit their analysis to cases in Europe, the findings may be broadly generalizable. Their analysis investigates research joint ventures between privates firms and European Universities. The authors make several valuable conclusions to research on collaboration. First, they argue that firms are increasingly turning to universities for R&D collaboration and present evidence to support this view. Second, they argue "when collaborating with universities, firms primarily aim at achieving research synergies, keeping up with major technological developments, and sharing R&D costs" (Caloghirou et al. 2001, p. 160). The study concludes that the major benefit to firms from collaborating with universities is "enhancing their knowledge base, followed by improvements in production processes" (Caloghirou et al. 2001, p. 160). Although the decreased costs and improvements in the production processes could be viewed as property-focused incentives, their findings indicate that these industry partnerships are just as often motivated by knowledge-based incentives.

Much of the empirical research on collaboration uses research outputs as dependent variables to show how different research patterns and behaviors influence either property-focused or knowledge-focused outputs. Recent research has used research outputs as determinants of collaboration or network patterns among academic scientists.

Goel and Grimpe (2011) present findings that suggest that knowledge-focused outputs in the form of scholarly articles promote conference participation, thus increasing the network behavior of the scientist. The authors also show that property-focused outputs in the form of increased patenting positively affects conference participation. Although Goel and Grimpe are primarily concerned with active versus passive networking among academics, their findings show that the character of research outputs can influence networking behavior. We see evidence that collaboration increases both knowledge and property-focused outputs, but also that knowledge and property-focused outputs causally affect active networking among academics and, thus, the potential for collaboration. It would be useful for future research to examine this complex relationship more explicitly. Scholars would do well to examine research output not only as dependent variables but also as possible causes of collaboration and additionality. The review below focuses on articles that view research outputs as the dependent variable in question (because that is the most common approach in the literature), but we look forward to future articles that examine outputs from different perspectives.

4.4.2 Indeterminate outputs and research collaboration

Empirical studies focus on how collaboration produces both tangible (Tartari and Breschi 2011) and intangible benefits for the research process. Garrett-Jones et al. (2010) examine Australian academics' perceptions about collaboration and the management of s conflict between the career goals of individuals' and their organizations' productivity goals. Findings indicate that the research scientists, including those in research centers, engage in collaborations because of intangible motivations including "better access to industry partners and working with a larger cohort of scholars with similar scientific interests" (Garrett-Jones et al. 2010, pp. 534–535). The research centers are also shown to provide both financial and human resources for the actors. We can therefore see that often collaboration, even collaboration across universities, industry and government, often focus on both knowledge and property, with different actors playing somewhat different technical roles. The authors conclude that often the researchers interviewed saw the benefits of their collaboration first in terms of effects on their own career and second in terms of how potential benefit to the larger scientific community (Garrett-Jones et al. 2010, p 542). Although the authors warn against generalizing their findings to other countries and research center networks, they do contend that the findings could well be applicable to the U.S.

4.4.3 Property-focused outputs and research collaboration

For at least 30 years, many researchers have studies the role of universities as providers of knowledge and technology to industry (Niosi 2006). Some argue that there has been an increase in patenting at universities due to biotechnology, but others claim that patent statistics could be an erroneous indicator of productivity or (Saragossi and van Pottelsberghe de la Potterie 2003).

Research has examined the effect of university licensing on research behavior, including collaboration (Thursby et al. 2001). Thursby and colleagues provide some general conclusions about licensing behavior at the university level. The authors conclude (Thursby et al. 2001, p. 59) "Patent applications grow one-to-one with disclosures, while sponsored research grows similarly with licenses executed. Royalties are typically larger the higher the quality of the faculty and the higher the fraction of licenses that are executed at latter stages of development." Although these findings are not specifically related to collaboration, some could inform collaboration research by helping understand incentives for partnering and the possible outcomes of collaboration.

Property-focused research in our conceptualization is research that provides economic benefits (or has the potential to do so) to researchers or research that may provide commercial benefits to industry, with the academic researcher benefiting either directly or indirectly through industry's provision of resources.

Studies of knowledge-focused research often employ bibliometric data and examine citation or publications rates, but studies of property-focused research more often use patent, licensing and royalties data. An interesting and illustrative property-focused study that is comparative in nature is provided by Morgan et al. (2001) who compare the patenting and invention activity of scientists in the academic sector to counterparts in industry. They examine patent activity rates, patent activity shares and patent success rates. These measures could easily be expanded and applied to studies of collaboration productivity.

A common concern in property-focused research is with the dynamics and costs and benefits of collaboration between universities and industry. Most studies find a positive relationship between collaboration and firms' property-related output (Lööf and Broström 2008). A excellent paper by Ambos et al. (2008) focuses not only on identifying factors related to the commercialization of university research but also suggest routs to greater "ambidexterity" for university research. The authors focus on projects that have produced patents, licenses, spin-off companies or some combination of these and develop four statistical models pertaining to the commercialization of academic research. Their full model includes not only individual and organizational-determinants, but also controls for other factors such as collaboration on the specific project. Interestingly, their findings indicate that collaboration on a given project has no statistically significant relationship with research commercialization. Research with multiple authors is no more likely to be commercialized. The authors do find statistically significant relationships between the amount of previous grants associated with the researchers, the academic staff time, organizational-level determinants and individual level determinants and the likelihood that the research is commercialized. The authors argue in their conclusion that perhaps the greatest organizational predictor of commercial success is the presence of a technology transfer office (TTO) within the university. However, the he breadth of support and experience of the TTO office are not significant predictors, indicating that the mere presence of a TTO office signals and organizational commitment to commercialization (Ambos et al. 2008).

Ambos and colleagues' concept of "ambidexterity" pertains to the ability to have multiple uses for research, a feature Bozeman and Rogers (2002) have pointed to has one of the main indicators or research value and innovation. According to Ambos et al. (2008), ambidexterity is the ability simultaneously to produce scientific contributions (i.e. knowledge-focused research) and commercial contributions (i.e. property-focused research). A principal investigator's (PI) "embeddedness" (number of years served) in academia decreases the probability of commercial output, but the PI's scientific excellence, measured in citations, is significantly and positively associated with the probability of commercialization. The authors argue (p. 1442) that the faculty members "who are both motivated to pursue commercial activity *and* who believe it will not harm their academic careers are more likely to generate commercial outputs." We can see here an implicit negative connotation towards commercial or property-focused research in the scientific community.

Possible negative impacts of university and industry research engagement receives more attention in Behrens and Gray's (2001) study of the relationship of industry sponsorship of university work, especially impacts for graduate students. The authors developed a stratified sample of graduate students from the same two engineering departments at six US universities and distributed a survey about research experiences. All of these research experiences were collaborative in that the student was working with a faculty member within the department. Findings indicate that there is not a significant difference between students engaged in a collaborative project that is sponsored by industry versus students engaged in a collaborative project that is not sponsored by industry (Behrens and Gray 2001). Behrens and Gray find significantly different student experiences and outcomes between students collaborating on projects with external funding compared to students on unfunded projects. Funded projects produced more positive experiences and outcomes for graduate students. This is consistent with empirical studies presented above, indicating that resources can drastically influence the collaboration process and product (Lee and Bozeman 2005). This indicates that the end goal of the research (i.e. knowledge vs. property-focus) does not influence the experience and outcomes of collaborators, but rather funding at the front end of the process can affect collaborators.

Beyond funding, the literature also examines the role of sector switching in patent productivity (property-focused research). The Dietz and Bozeman (2005) article discussed above addresses this concern directly. The authors examine the role of inter or intrasectoral switching throughout the career of an academic scientist. This career diversity concerns collaboration conceptually because the central theory behind the analysis is that sector switching will provide researchers with human capital (i.e. network ties, tacit knowledge, etc.) that will foster productivity. Logically, network ties contribute to more collaboration possibilities. Evidence does not support the same positive relationship between sector switching in jobs and publication productivity (i.e. knowledge-focused research).

Another 2008 study that deals with property-focused research is *Re-thinking New Knowledge Production: A Literature Review and a Research Agenda* by Hessels and van Lente (2008). Their article is a systematic review of the Gibbons-Nowotny concept of "Mode 2 knowledge production". Mode 2 knowledge-production deserves attention in a discussion of collaboration and property focused research. This mode of knowledge production is not meant to replace the traditional mode of knowledge production, but rather supplement it (Hessels and Van Lente 2008).

Hessels and van Lente begin their review by discussing the differences between Mode 1 and Mode 2 knowledge production. Mode 1 is defined by an academic context, maintaining disciplinary boundaries, homogeneity, autonomy and traditional quality control. Mode 2 knowledge production is defined by a context of application, transdisciplinary collaboration, heterogeneity, social accountability and novel quality control (Hessels and Van Lente 2008). Mode 2 knowledge production is therefore consistent with a collaborative property-focused research process.

Perhaps the most applicable concepts of Mode 2 knowledge production discussed in the piece to our discussion of knowledge focused research is that of the context of application and the transdisciplinarity. The context of application goes beyond the distinction between basic and applied research. The authors argue that the commonly held distinction is fallacious because, "fundamental research has always been inspired by more applied knowledge and applied research has always shown interest in fundament understanding of the relevant phenomena" (Hessels and van Lente 2008, p. 750). This is an important distinction in terms of this study's focus. It allows researchers examining collaboration to understand that a project can be property focused, but also concerned with fundamental knowledge production. The two are not mutually exclusive.

Mode 2 knowledge production literature argues that science is becoming increasingly transdisciplinary (Hessels and Van Lente 2008). The work of Godin (1998) is used to illustrated the controversy associated with this assertion. Godin does not agree with the dichotomy between disciplinary research and interdisciplinary research (Godin 1998). Godin argues that "the development of disciplines with specialisations and hybrid formations is typical of any scientific practice" (Hessels and van Lente 2008, p. 751). Transdisciplinary research, on the contrary, implies cooperation of different disciplines, co-evolution of a common guiding framework and the diffusion of results during the research process (Hessels and Van Lente 2008). Although Godin is correct that interdisciplinary and hybrid formations of discipline has occurred for a long period, the authors describe the new developments asserted by Mode 2 production through a discussion of the rise of transdisciplinary journals. The authors argue that although most scientific production is disciplinary in nature, there has also been a rise in transdisciplinary journals (Hessels and Van Lente 2008; Hicks and Katz 1996).

When discussing property-focused research in the context of academic research it is important to understand the influence of university pressures to produce property from research endeavors. Davis et al. (2011) examine the effects of university patenting on academic researchers perceptions of academic freedom in their article *Scientists' Perspectives Concerning the Effects of University Patenting on the Conduct of Academic Research in the Life Sciences*. The authors argue that "the most important finding of our analysis is that basic researchers were significantly more skeptical about the impact of university patenting on academic freedom and highly productive scientists were significantly less skeptical" (Davis et al. 2011, p. 29). What is significant to the current discussion of collaboration, however, is the lack of finding between collaboration behavior and the belief that university patenting negatively affects academic freedom. One would expect that if an academic researcher felt hindered by collaborating with industry in the name of increased property-focused outputs for the institution she would view patenting requirements as negatively effecting academic freedom (Davis et al. 2011). Their findings, or lack thereof, are somewhat problematic because collaboration is generally voluntary in nature. If a researcher felt that collaboration negatively influenced academic freedom then she would simply not engage in collaboration. Despite this limitation it is useful to understand that collaboration does not influence one's perception of university patenting.

It is important to note here that not all patents or property-focused research is equal. Feller and Feldman (2010) offer some important conclusions that aggregate patent data on patents and licensing provides a limited picture of collaboration between universities and industry. Instead of aggregate data, the authors use the case study approach to examine the complex interrelated relationships between faculty and firms that result in a university patent, patent held by the firm, or research that is eventually brought to market. Similar to the above discussion of TTOs, the Feller and Feldman find that these organizations often behave in ways that hinder the collaborative process, but unlike Siegel et al. (2003b), the current study argues that this is often because of the influence from the industry rather than the institutional culture of the TTO. Whereas Siegel et al. (2003a, b) argue that the TTOs should be more business-like and use business means to further the collaboration process, Feller and Feldman argue that often the behaviors of TTOs and other regulatory commissions are influenced by the "strategies and experiences of the firms with which they are engaged" (Feller and Feldman 2010, p. 614). Of course TTOs are seen as barriers to collaboration in other empirical articles (Siegel et al. 2003b).

Much of the literature that examines property-focused research deals with collaborations between industry and universities. Hanel and St-Pierre (2006) are no exception, but the authors limit their analysis to Canadian manufacturing firms in their 2006 article. Findings are consistent with much of the previous literature discussed regarding motivations for industry to partner with universities and the positive outputs associated with collaborative behavior. The authors argue that, "the major incentive to collaborate with a university is the access to research and critical competencies, which allows firms to reach the very edge of contemporary technology" (Hanel and St-Pierre 2006, p. 496).

In terms of the positive outcomes of collaborative research, the authors provide conclusions that are clearly property-focused (as we conceptualize it). The authors conclude,

> Collaborations with universities has a positive impact on the originality of innovations and their contribution to the perceived economic performance of the innovating firm such as to maintain their competitive position, the maintain of their profit margins, the increase in their share of the international market and their increase of profitability (Hanel and St-Pierre 2006, p. 496).

This study provides evidence that collaboration is often motivated by a desire to engage with universities because these institutions provide access to cutting edge technology. Although this motivation may appear to be knowledge-focus, the desire to access cutting edge technology is most likely an underlying desire to produce the most innovative product that has the potential to generate the most profit. Although these motivations and outcomes seem less than altruistic, we hesitate in making a normative assessment of motivations and outcomes of these collaborations. Although profitability is a powerful motivator, the result of these collaborations is often an increase in knowledge base and potential funding to the academic community. The Hanel and St-Pierre (2006) article provides the most clear assessment of collaboration on property-focused outputs, but the benefits of these outputs can also increase the knowledge base of the academic community. We can see that the research outputs of collaboration are not quite so distinct.

There is a general theme in the literature surrounding research collaborations to examine how collaborative behavior influences the innovativeness of the firm that partners with the academic institution. Huang and Yu (2011) examine the effect of competitive versus non-competitive collaboration on firm innovation. Although the study provides other important information in terms of collaboration, the key finding for our discussion is that non-competitive R&D collaboration specifically those collaborations conducted with universities is positively correlated with innovation. Again, we see empirical findings that suggest that collaborating with universities provide material benefits for industry in terms of innovative products that increase the likelihood of profits.

5 Research collaboration: the dark side

During the past decade or so, researchers, especially those in the biomedical sciences (e.g. Rennie et al. 2000; Wainwright et al. 2006; Cohen et al. 2004), have begun to focus on ethical issues and the "dark side" of collaboration. Lagnado (2003) argues that trust in the meaning of co-authorship has eroded. Levsky et al. (2007) describe a number of potentially troubling trends in authorship in medical journals between 1995 and 2005, including honorary authorship, ghost authorship, duplicate and redundant publications and most important, authors' refusal to accept responsibility for their articles despite their readiness to accept credit for professional purposes. They note that causes of the trends continue to be unknown but that the relationship between authorship and career pressures on academic physicians is clear.

Outside of biomedical fields, research on the ethics and socio-political dynamics of scientific collaboration (Shrum et al. 2001, 2007) remains scarce. Perhaps this scarcity is owing to the view that such problems are neither as pervasive nor as troublesome in other science and technology fields as they are in biomedical research. To be sure, biomedical research is different. Medical research has special hazards resulting from unethical behavior, in part because of its massive operation of clinical trials (Devine et al. 2005; Klingensmith and Anderson 2006). Similarly, medical research has ties to pharmaceutical industry, including some representatives eagerly providing services as "phantom" co-authors.

Even if medical research poses particular challenges, the potential for unethical behavior in research and collaboration remains pervasive. Far from being restricted to biomedical fields, problems in scientific collaboration are ubiquitous in science. Some of these problems are ethical (Shrum et al. 2001), others practical (Bozeman and Corley 2004), some pertain to collaboration among individuals (Katz and Martin 1997), and some to collaboration among institutions (Chompalov and Shrum 1999).

The literature on scientific collaboration not only identifies problems in collaboration but also possible solutions. For example, Marusic et al. (2004) and Pichini et al. (2005) describe the many international Uniform Requirements for coauthorship information and the complex but poorly understood relationship among coauthorship, grants, promotion, and admittance to professional associations. While some articles (e.g. Mullen and Ramirez 2006) provide a conceptual analysis of coauthorship and collaboration issues, most do not provide exacting specification of alleged problems. Most work is case-based or anecdotal and, as a result, neither the scientific community nor policy-makers have much systematic, empirically based evidence of the possible pitfalls of collaboration, co-authorship, and the various social mechanisms created for assigning credit.

The few studies available on the ethics of collaboration tend to focus on questions associated with scholarly manuscript authorship (Chompalov et al. 2002). This focus is understandable and welcome. Allocation of credit and responsibility for authorship is an important issue and it must be resolved if research results are to be managed and used effectively (Devine et al. 2005). Due to increasingly interdisciplinary work and the demands of large-scale collaborative work, the assignment of authorship for publication is complex and sometimes confusing.

Some attribute problems with sorting out co-authorship and crediting to the explosion in research and the funding imperatives driving collaboration among investigators from multiple sites and numerous disciplines (Devine et al. 2005; Drenth 1998). Ultimately the system of scientific authorship is built on trust that the published work reflects the data and analysis of the authors (Lagnado 2003).

While few studies of co-authoring ethics have been undertaken, research on other ethical issues in collaboration is even scarcer, sometimes non-existent.

Almost as important as co-author credit is the decision process by which co-authorship is decided. As decision analysts have known for years, often process is the primary determinant of outcome (Brockner and Wiesenfeld 1996). While there is remarkably little evidence about collaboration and co-authorship decision processes and norms, most agree (Katz and Martin 1997; Melin 2000) that these vital processes affect not only scientific career trajectories and advancement but very course of science. The choice of scientific topics and the configuration of research teams depend in part on collaborative and co-authorship norms. In the vast majority of instances, researchers have considerable autonomy in their collaboration choices and collaboration strategies are based in part of judgments about the conferring of co-authorship and status (Heffner 1981). The issue is who decides.

Partly because of a high level of threat, biomedical researchers and editors have taken the lead in identifying and moving to resolve ethical problems in collaboration. The International Committee of Medical Journal Editors (ICMJE, known as the Vancouver Group) created a set of "Uniform Requirements" for authorship in 1985. But by the mid-1990s, these protocols were still employed by only a handful of journals. Drummond Rennie, a deputy editor of the *Journal of the American Medical Association*, and a strong proponent of collaboration policies, acknowledged this deficit in an editorial colorfully subtitled, Guests, Ghosts, Grafters, and the Two-sided Coin (Rennie and Flanagin 1994). Rennie uses the term "contributorship" to refer to the process entail as authors declare in detail, usually at time of submission, their individual contributions to scholarly papers in the spirit of scientific transparency (Rennie 2001, p. 1274). Following a series of articles that describe a growing problem with irresponsible authorship of medical research articles, Rennie proposed a major change in instructions to authors to JAMA (2000, p. 89). These changes in contributorship requirements have provided clear signals where none were given before and, presumably, have enhanced collaborators' ability to communicate effectively with one another about contribution and credit. However, even in journals adopting contributorship policies, we still know little about the *validity* of contributorship statements or the social and potential power dynamics entailed in developing them. To date, no research systematically assesses the effects of contributorship statements despite the fact that they have been widely adopted in medical and health sciences fields.

One research ethics problem that has received a good deal of attention is conflict of interest (McCrary et al. 2000; see Mowery and Sampat 2001 for an overview). We only note this ethical issue in passing, however, inasmuch as they occur in many cases in single researcher work or, when occurring in collaborations, are sometimes individual separable breaches of ethics even if occurring in a collaborative context.

As mentioned above, some "dark side" aspects of collaboration have received very little attention. While there is widespread concern about the possibilities for student exploitations in collaborations, especially collaborations to which industrial firms are partners (e.g. Slaughter et al. 2002), most of the evidence thus far is anecdotal or unsystematic. The few systematic case studies (e.g. Baldini 2008) available suggest problems but give no clues about the extensiveness of student exploitation in collaborations. Moreover, there is some evidence that collaborations rooted in industry–university partnerships often have salutary effects for students including early publication, job offers and mentoring (see Welsh et al. 2008; Bozeman and Boardman, in press).

It certainly seems plausible that collaboration, including collaborations involving industry, sometimes has negative consequences for students and postdoctoral researchers but it seems just as likely that they often benefit tremendously from such experiences. The real issue is the balance of benefits and costs and the factors that govern the quality of the collaboration experience. More evidence is needed.

6 Conclusion

We began this overview and assessment asking whether the literal "addtionality" of research collaboration, additions in the sense of adding other researchers beyond the single investigator, enhances additionality in the usual sense of that term (Buisseret et al. 1995, p. 268) as "enhancing what would have taken place anyway." We have not been able to provide a precise answer to that question since a valid study would likely require an experiment, not yet performed as far as we know, comparing researchers, some in teams and some working individually, on an identical research project. Since such a study seems unlikely (who is going to convince researchers to enter themselves and their life's work into treatment and control groups?), we have strived for a second best, examining the extant literature on research collaboration.

At first glance it would appear that scientific research collaboration studies are incredibly disjointed and somewhat ambiguous in focus. The conceptual model we employ here in no was improves upon the fragmentation of the literature but, rather brings it into relief. The literature, variant as it is not only in findings but in its theoretical approaches, methods, analytical tool and most basic purposes, is not yet rife for any true meta-analysis. However, the more conventional literature review we have provided at least shows the foci of the field, some basis and sometimes consensual findings and, perhaps most important, shows in its omissions research gaps needed more attention. In this concluding section we focus on some of those gaps as and provide the broad outline of a research agenda for future study of research collaboration.

1. **Level of analysis**. We begin this review noting that our primary attention would be focused o the individual level of analysis, relationships among individual researchers, rather than relationships among organizations are the relationship of individuals 2 institutions. Naturally, that has not been entirely possible to do. In the 1st place, it is often the case that studies work at more than one level of analysis at the same time, but without necessarily making this explicit or worse, at least a few studies are sufficiently ambiguous that it is not possible to truly determine the level of analysis. The literature were would surely be improved with an increasing number of studies simultaneously working at different levels of analysis, with research designs explicitly addressing interactions whose design allowed them explicitly to address interactions among nested variables. This prescription is not methodological nitpicking. One of the major limitations of current research is the tendency for researchers to either (1) focus intensely on either the world of the individual researcher while, unfortunately, ignoring the larger context within which the researcher operates, or (2) focus on collaborating organizations at a level of abstraction sufficiently general as to permit no consideration of the role of individual dynamics that may shape the outcomes of collaborating organizations. We understand of course, why this strategy is not often employed. The analytical requirements in the data requirements generally are

prohibitive. But one of the nice things about research assessments is that authors have the chance to consider the ideal.

2. **Beyond outputs**. A good deal of the research on collaboration includes reasonable and valid output measures. Indeed, this is an improvement over much of the work in fields related to technology and knowledge management. Less, and are studies that go beyond such outputs as patents and licenses produced to examine whether, in fact, the volume of such outputs made any difference at all. This is a problem one finds more often in property focused studies of collaboration. For those interested in knowledge focused collaborations advances and bibliometric techniques have been useful for at least determining one sort of impact, citations.
3. **Worst practice**. Very few studies focus on failed collaborations ones that bore little fruit. Perhaps even more of an oversight, few studies systematically compare nonproductive and productive collaborations (at least beyond running straightforward regression models with output variables). This is entirely understandable area and most realms there is usually a great deal more demand for what works and what does not work. But it is also a limitation. It is especially problematic that so many studies began with high-performing collaborations, putting a de facto limit on their ability to say much about the population of collaborations.
4. **The *other* "dark side**." As we see from the section above, there has of late been a considerable increase and studies focusing on the dark side of collaboration, including exploitation, negative impacts on students, and unethical behavior. At least to our knowledge, there have been few such studies examining product-focused collaborations (an exception being studies of the impact on university–industry collaboration on graduate students and junior faculty careers). Studies that have been performed that are examining product-focused collaborations tend to be case oriented or historical in form, understandable given the difficulties of gathering data about bad behavior. Still, we might expect that bad behavior on the industrial side of university–industry partnerships is no less common than on the university side. It would be good for this perspective to catch up.
5. **Methods**? As discussed above many knowledge-focused collaboration studies use bibliometric techniques to examine the citations of published works to measure the impact of the collaboration. This process also gives extra weight to studies with significant lag time to allow for more citations. A successful collaborative project could be recent, but highly revolutionary and contributing a great deal to the fundamental knowledge in a scientific field. Collaboration research must find a better way to measure the impact to fundamental knowledge beyond citation rates. Presently, using citation rates and impact factors is appealing because it has the seduction of convenience.

Another concern we have in regards to collaboration research is that few studies examine the personal relationships between collaborators and the collaboration process in general. This is a theory problem but also one of method. In order to truly examine interpersonal relationships and the comprehensive process of collaboration, researchers must move beyond simple demographic measures of subjects. Large surveys and interviews of academic scientists must be conducted so we can understand if these demographic factors are actually salient in the decision-making process when considering a collaborative project. We must also understand the intangibles that cannot be measured by bibliometric analysis of published works and the demographic characteristics of the authors. We must in particular understand more about the psychological antecedents to research collaboration choice. Collaboration research should examine the positive and negative outcomes of collaboration, but also the positive and negative aspects of the *processes* of collaboration.

6. **Collaboration motives**. In studies of research collaboration, and especially those centered on product-focused collaborations, it is easy to lose sight of the fact that the objects of are flesh and blood human beings pursuing multiple, complex and often conflicting motives. It would certainly be convenient if collaborations could be understood fully as efforts to maximize economic pay-off from research, but qualitative studies show us that even in those cases where economic gain is paramount, there is nonetheless much more going on than that. In some cases, the unraveling the motives behind collaboration may be exceedingly difficult. Thus, for example, the young researcher working at a university research center may, all at the same time, be pushed by the center to cooperate with industry on technology development, be pushed by her academic department to develop the type of publications that are the currency of academic reputations, be concerned for the futures of the students and postdocs in her lab, be thinking about the next job, whether in a university or in industrial setting, and making choices based on the perceived competence, fairness, and the complementarities of potential collaborators. Throw in such factors as the need to maintain access to scarce and expensive research equipment, pressures and commitments related to grants-writing and funding, geographic proximity of collaborators and well-documented competition among collaborators and we see a volatile mix of conditions possibly affecting collaboration motives, with the outcomes playing out an enormous variety of different ways.

While some research attempts to get at motives, usually either through surveys or interviews, but motive-centered, researcher-centered studies are not the norm. But there is now greater need to understand the complexity of collaboration calculus. Conflicts among centers, industries and traditional academic departments were not so important decades ago. Abundant resources, no longer the norm, also had a tendency to reduce complexity. But with declining grant money and fewer academic positions in most fields, competitive dynamics intercede to a degree not common in the past. It seems to us that the research has had a very difficult time keeping pace with the changes in the researchers' environment.

Despite these and other limitations of the literature on research collaboration, it seems to us that considerable strides have been made. If we take as a chronological benchmark Katz and Martin's (1997) excellent review of collaboration literature, one that was in some respects similar to our own review, we can see signs of progress. The research proposition table provided in the "Appendix" of this paper well verifies this point. Not only have we seen many more studies since the turn of millennium, but also entirely new aspects of collaboration have been examined, often with entirely new analytical tools. Summary assessment: much progress, much work remaining.

Appendix

See Table 1.

Table 1 Propositional table for research collaboration art literature review

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Abramo et al. (2011)	Abramo, G., D'Angelo, C. A., Di Costa, F., & Solazzi, M. (2011). The role of information asymmetry in the market for university–industry research collaboration. *The Journal of Technology Transfer*, 36(1), 84–100	Geographic proximity on increases collaboration between universities and private industry organizations
Collaboration attributes	Aerts and Schmidt (2008)	Aerts, K., & Schmidt, T. (2008). Two for the price of one? Additionality effects of R&D subsidies: A comparison between Flanders and Germany. *Research Policy*, 37(5), 806–822	This manuscript addresses human *additionality* in R&D
Collaborator attributes	Allen (1977)	Allen, T. J. (1977). *Managing the flow of technology: Technology transfer and the dissemination of technological information with the R&D organization*. Boston: MIT Press	Allen (1977) found that engineers and scientists were roughly five times more likely to turn to a person for information than to an impersonal source such as a database or file cabinet
Collaborator attributes	Ambos et al. (2008)	Ambos, T. C., Mäkelä, K., Birkinshaw, J., & D'Este, P. (2008). When does university research get commercialized? Creating ambidexterity in research institutions. *Journal of Management Studies*, 45(8), 1424–1447	Faculty members that are more embedded in academia value basic research more than property-focused research
Collaborator attributes	Aschoff and Grimpe (2011)	Aschoff, B. & Grimpe, C. (2011). *Localized norms and academics' industry involvement: The moderating role of age on professional imprinting*. Unpublished paper downloaded February 3, 2012 from http://ftp.zew.de/pub/zew-docs/veranstaltungen/innovationpatenting2011/papers/Grimpe.pdf	Young faculty are "imprinted" by their collaboration with industry personnel
Collaboration attributes	Audretsch et al. (2002)	Audretsch, D. B., Bozeman, B., Combs, K. L., Feldman, M., Link, A. N., Siegel, D. S., & Wessner, C. (2002). The economics of science and technology. *The Journal of Technology Transfer*, 27(2), 155–203	Network behavior in S&T human capital
The dark side of research collaborations	Baldini (2008)	Baldini, N. (2008). Negative effects of university patenting: myths and grounded evidence. *Scientometrics*, 75(2), 289–311	There is no evidence of the extent of student exploitation in research collaborations, only clues that it exists

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Beaver (2001)	Beaver, D. D. (2001). Reflections on scientific collaboration (and its study): Past, present, and future. *Scientometrics*, 52(3), 365–377	Synergy, feedback, dissemination, recognition and visibility are the advantages of collaboration
Collaboration attributes	Beaver (2004)	Beaver, D. D. (2004). Does collaborative research have greater epistemic authority? *Scientometrics*, 60(3), 399–408	This article provides evidence that collaborative research projects have greater epistemic authority than individual research projects
Collaboration attributes	Behrens and Gray (2001)	Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: Impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy*, 30(2), 179–199	There is not a significant difference between students engaged in a collaborative project that is sponsored by industry versus students engaged in a collaborative project that is not sponsored by industry
Collaborator attributes	Bercovitz and Feldman (2008)	Bercovitz, J. & Feldman, M. (2008). Academic entrepreneurs: Organizational change at the individual level. *Organization Science*, 19, 69–89	Patenting and licensing activities of medical school faculty decrease with age
Collaboration attributes	Boardman and Corley (2008)	Boardman, P. C., & Corley, E. A. (2008). University research centers and the composition of research collaborations. *Research Policy*, 37(5), 900–913	This is one of many useful studies of collaboration where coauthorship is a unit of measure
Collaborator attributes	Boardman and Ponomariov (2007)	Boardman, P. C., & Ponomariov, B. L. (2007). Reward systems and NSF university research centers: The impact of tenure on university scientists' valuation of applied and commercially relevant research. *The Journal of Higher Education*, 78(1), 51–70	The authors develop an empirical model focusing on academic scientists desire to produce knowledge-focused research. They find tenure impacts collaboration patterns
Organizational collaboration attributes	Bozeman (2000)	Bozeman, B. (2000). Technology transfer and public policy: a review of research and theory. *Research Policy*, 29, 627–655	This article summarizes the literature on industry-academic collaborations and technology transfer
The dark side of research collaborations	Bozeman and Boardman (in press)	Bozeman, B. & C. Boardman. (In Press) Academic faculty working in university research centers: Neither capitalism's slaves nor teaching fugitives. *The Journal of Higher Education*	Collaborations rooted in industry–university partnerships often have salutary effects for students including early publication, job offers and mentoring

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Contributor attributes	Bozeman and Corley (2004)	Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Imp*lications for scientific and technical human capital.* Research Policy, 33(4), 599–616	Collaboration is an aspect of human capital. Female researcher collaboration is highly personal. Tenure impacts collaboration, perhaps as a result of the mentoring process
Collaborator attributes	Bozeman et al. (2001)	Bozeman, B., Dietz, J. S., & Gaughan, M. (2001). Scientific and technical human capital: An alternative model for research evaluation. *International Journal of Technology Management*, 22(7), 716–740	Scientific and technical human capital (S&T human capital) has been defined as the sum of researchers' professional network ties and their technical skills and resources
Collaboration attributes	Bozeman and Gaughan (2007)	Bozeman, B., & Gaughan, M. (2007). Impacts of grants and contracts on academic researchers' interactions with industry. *Research Policy*, 36(5), 694–707	Development of the industrial involvement index
Collaboration attributes	Bozeman and Gaughan (2011)	Bozeman, B., & Gaughan, M. (2011) How do men and women differ in research collaborations? An analysis of the collaborative motives and strategies of academic researchers, *Research Policy*, 40(10), December 2011, 1393–1402.	Men and women differ in research collaboration strategies.
Collaboration attributes	Bozeman and Rogers (2002)	Bozeman, B. & J. Rogers (2002) A churn model of knowledge value: Internet researchers as a knowledge value collective. *Research Policy*, 31(4), 769–794	Having multiple uses for research is an indicator for research value and innovation
The dark side of research collaborations	Bozeman et al. (2012)	Bozeman, B., Youtie, J., Slade, C. P. & Gaughan, M. (2012). *The "dark side" of academic research collaborations: Case studies in exploitation, bullying and unethical behavior*. Paper prepared for the Annual Meeting of the Society for Social Studies of Science (4S) October 17–20, 2012, Copenhagen Business School, Frederiksberg, Denmark	Individuals can often adversely influence other individuals to the detriment of research collaborations and their outputs
The dark side of research collaborations	Brockner and Wiesenfeld (1996)	Brockner, J. & Wiesenfeld, B. M. (1996). An Integrative Framework for Explaining Reactions to Decisions: Interactive Effects of Outcomes and Procedures, *Psychological Bulletin*, 120(2), 189–208	Decision making process is the primary determinant of outcome

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaborator attributes	Bruneel et al. (2010)	Bruneel, J., D'Este, P. & Salter, A. (2010). Investigating the factors that diminish the barriers to university–industry collaboration. *Research Policy*, 39(7), 858–868	Survey research shows the importance of having previous collaboration experience to engendering the trust required for success in collaboration
Collaboration attributes	Buisseret et al. (1995)	Buisseret, T. J., Cameron, H. M., & Georghiou, L. (1995). What difference does it make additionality in the public support of RD in large firms. *International Journal of Technology Management*, 10, 4(5), 587–600	This article defines additionality in R&D as the extent to which public scrutiny and discourse produce more than what would have been produced without public input
Organizational collaboration attributes	Caloghirou et al. (2001)	Caloghirou, Y., Tsakanikas, A., & Vonortas, N. S. (2001). University–industry cooperation in the context of the European framework programmes. *The Journal of Technology Transfer*, 26(1), 153–161	Firms are increasingly turning to universities for R&D collaboration. When collaborating with universities, firms primarily aim at achieving research synergies, keeping up with major technological developments, and sharing R&D costs. The major reported benefit to firms from collaborating with universities is enhancing their knowledge base, followed by improvements in production processes
Collaboration attributes	Carayannis and Laget (2004)	Carayannis, E. G., & Laget, P. (2004). Transatlantic innovation infrastructure networks: Public-private, EU–US R&D partnerships. *R&D Management*, 34(1), 17–31	Collaboration in the scientific community is increasingly global in nature
Collaboration attributes	Carayol and Matt (2004)	Carayol, N., & Matt, M. (2004). Does research organization influence academic production? Laboratory level evidence from a large European university. *Research Policy*, 33, 1081–1112	There is a great deal of research on the topic of research management and motives and their relation to research effectiveness
Collaboration attributes	Chang and Dozier (1995)	Chang, D. B., & Dozier, K. (1995). Technology transfer and academic education with a focus on diversity. The *Journal of Technology Transfer*, 20(3), 88–95	Racial diversity affects collaboration patterns
The dark side of research collaborations	Chompalov and Shrum (1999)	Chompalov, I., & Shrum, W. (1999). Institutional collaboration in science: A typology of technological practice. *Science Technology and Human Values,* 24(3), 338–372	Some problems in scientific collaboration have to do with the institutions themselves

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Chompalov et al. (2002)	Chompalov, I., Genuth, J., & Shrum, W. (2002). The organization of scientific collaborations. *Research Policy*, 31(5), 749–767	This article offers a typology of organizational structures (bureaucratic, leaderless, non-specialized and participatory) for scientific collaborations. Collaboration works best as a voluntary process
Collaboration attributes	Clark (2011)	Clark, B. Y. (2011). Influences and conflicts of federal policies in academic–industrial scientific collaboration. *The Journal of Technology Transfer*, 36(5), 514–545	Research collaborations are often based on informal relationships and trust
Collaboration attributes	Clarysse et al. (2009)	Clarysse, B., Wright, M., & Mustar, P. (2009). Behavioural additionality of R&D subsidies: A learning perspective. *Research Policy*, 38(10), 1517–1533	This manuscript addresses *additionality* in R&D
The dark side of research collaborations	Cohen et al. (2004)	Cohen, M. B., Tarnow, E., & De Young, B. R. (2004). Coauthorship in pathology, a comparison with physics and a survey-generated and member-preferred authorship guideline. *MedGenMed*, 63(1), 1–5	Appropriate authorship assignment is of considerable importance to both scientists and the public. Knowing who did a particular piece of work is important—scientists can contact the appropriate colleague, ask questions, and obtain data or reagents, and the public can shift funds to better scientists and optimize its return on investment in the scientific market
Organizational collaboration attributes	Cohen et al. (2002)	Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and impacts: The influence of public research on industrial R&D. *Management Science*, 48(1), 1–23	Research in industry tends to be quite different from that found in universities, government or NGO's
Organizational collaboration attributes	Collins and Wakoh (2000)	Collins, S., & Wakoh, H. (2000). Universities and technology transfer in Japan: Recent reforms in historical perspective. *The Journal of Technology Transfer*, 25(2), 213–222	Unlike knowledge development industry–academia partnerships have geographic boundaries
Organizational collaboration attributes	Cooper (2009)	Cooper, M. H. (2009). Commercialization of the university and problem choice by academic biological scientists. *Science Technology Human Values*, 34(5), 629–653	Industrial involvement has unduly affected university researchers' choice of research topics

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Cronin (2001)	Cronin, B. (2001). Hyperauthorship: A postmodern perversion or evidence of a structural shift in scholarly communication practices? *Journal of the American Society for Information Science and Technology*, 52(7), 558–569	Discusses hyper-authorship and the effect of collaboration
Organizational collaboration attributes	Crow and Bozeman (1998)	Crow, M. M., & Bozeman, B. (1998). *Limited by design: R&D laboratories in the US national innovation system.* Columbia University Press	Research in industry tends to be quite different from that found in universities, government or NGO's
Collaboration attributes	Cummings and Kiesler (2005)	Cummings, J. N., & Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science*, 35(5), 703	Collaborations across disciplinary boundaries report as many positive outcomes as projects with fewer disciplines, but projects spanning university boundaries are positively associated with negative outcomes for research
Collaborator attributes	D'Este and Perkmann (2011)	D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *The Journal of Technology Transfer*, 36(3), 316–339	The authors provide four main motivations (commercialization, learning, access to funding and access to in-kind resources) that are consistent with the three main outputs of collaboration in our model
Collaborator attributes	Davis, Larsen and Lotz (2011)	Davis, L., Larsen, M. T., & Lotz, P. (2011). Scientists' perspectives concerning the effects of university patenting on the conduct of academic research in the life sciences. *The Journal of Technology Transfer*, 36(1), 14–37	Basic researchers are significantly more skeptical about the impact of university patenting on academic freedom and highly productive scientists are significantly less skeptical. There is no relationship between collaboration behavior and the belief that university patenting negatively affects academic freedom
The dark side of research collaboration	Devine et al. (2005)	Devine, E. B., Beney, J., & Lisa A. Bero, L. A. (2005). Equity, accountability, transparency: Implementation of the contributorship concept in a multi-site study. *American Journal of Pharmaceutical Education*, 69(4), 455–459	Sorting out co-authorship and crediting may result from the explosion in research and the funding imperatives driving collaboration among investigators from multiple sites and numerous disciplines

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Dietz and Bozeman (2005)	Dietz, J. S. & Bozeman, B. (2005).Academic careers, patents, and productivity: industry experience as scientific and technical human capital. *Research Policy*, 34(3), 349–367	Research collaboration may not have direct economic impact
The dark side of research collaboration	Drenth (1998)	Drenth, J. P. H. (1998). Multiple authorship: The contribution of senior authors. *JAMA*, 280(3), 219–221	Sorting out co-authorship and crediting may result from the explosion in research and the funding imperatives driving collaboration among investigators from multiple sites and numerous disciplines
Collaboration attributes	Duque et al. (2005, p. 755)	Duque, R. B., Ynalvez, M., Sooryamoorthy, R., Mbatia, P., Dzorgbo, D. B. S., & Shrum, W. (2005). Collaboration paradox. *Social Studies of Science*, 35(5), 755	National and regional context affects the collaborative process, due in part to differences in access to technology. The article discusses the role of conflict in collaborations
Collaboration attributes	Faria and Goel (2010)	Faria, J. R., & Goel, R. K. (2010). Returns to networking in academia. *Netnomics*, 11(2), 103–117	Explaining differences between active and passive networking among scientists
Organizational collaboration attributes	Feller and Feldman (2010)	Feller, I., & Feldman, M. (2010). The commercialization of academic patents: Black boxes, pipelines, and Rubik's cubes. *The Journal of Technology Transfer*, 35(6), 597–616	Technology transfer organizations often hinder collaboration
Organizational collaboration attributes	Feller and Roessner (1995)	Feller, I., & Roessner, D. (1995). What does industry expect from university partnerships? Congress wants to see bottom-line results from industry/government programs, but that's not what the participating companies are seeking. *Issues in Science and Technology*, 12(1) 80–84	Knowledge-focused outputs influence university-academic research collaborations
Organizational collaboration attributes	Fox and Mohapta (2007)	Fox, M. F., & Mohapta, S. (2007). Social-organizational characteristics of work and publication productivity among academic scientists in doctoral-granting departments. *Journal of Higher Education*, 78(5), 542–571	This article focuses on the work of academic scientists and how their research is affected by the social-organizational characteristics of their professional setting

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Franklin et al. (2001)	Franklin, S. J., Wright, M., & Lockett, A. (2001). Academic and surrogate entrepreneurs in university spin-out companies. *The Journal of Technology Transfer*, 26(1), 127–141	Research collaboration may not have direct economic impact
Collaborator attributes	Garrett-Jones et al. (2010)	Garrett-Jones, S., Turpin, T., & Diment, K. (2010). Managing competition between individual and organizational goals in cross-sector research and development centers. *The Journal of Technology Transfer*, 35(5), 527–546	The article describes how the management of collaborations can affect the actors and the output of the process. Research scientists engage in collaborations because of intangible motivations including better access to industry partners and working with a larger cohort of scholars with similar scientific interests
Collaboration attributes	Garg and Padhi (2001)	Garg, K. C., & Padhi, P. (2001). A study of collaboration in laser science and technology. *Scientometrics*, 51(10), 415–427	This article describes hyper-authorship in laser S&T and how it varies by country
Collaborator attributes	Gaughan and Corley (2010)	Gaughan, M., & Corley, E. A. (2010). Science faculty at US research universities: The impacts of university research center-affiliation and gender on industrial activities, *Technovation,* 30(3), 215–222	The article uses the industrial involvement index and includes a discussion of gender impact on industrial R & D activities
Collaboration attributes	Gazni and Didegah (2011)	Gazni, A., & Didegah, F. (2011). Investigating different types of research collaboration and citation impact: a case study of Harvard University's publications. *Scientometrics*, 87(2), 251–265	A study of manuscripts from 22 fields showed that 60 % of the publications were coauthored
Organizational collaboration attributes	Geisler (1986)	Geisler, E. (1986). The role of industrial advisory boards in technology transfer between universities and industry. *The Journal of Technology Transfer*, 10(2), 33–42	External actors (i.e. the Industrial Advisory Boards) have a significant, yet sometimes underestimated role in the transfer of technology between universities and industry
Collaboration attributes	Godin (1998)	Godin, B. (1998). Writing performative history: The new new Atlantis? *Social Studies of Science*, 28(3), 465–483	The author does not agree with the dichotomy between disciplinary research and interdisciplinary research

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Goel and Grimpe (2011)	Goel, R. K., & Grimpe, C. (2011) Active versus passive academic networking: Evidence from micro-level data. *The Journal of Technology Transfer*, 1–19	This article explains differences between active and passive networking among scientists
Organizational collaboration attributes	Gray and Steenhuis (2003)	Gray, D. O., & Steenhuis, H. J. (2003). Quantifying the benefits of participating in an industry university research center: An examination of research cost avoidance. *Scientometrics*, 58(2), 281–300	Knowledge-focused outputs influence university-academic research collaborations
Collaboration attributes	Grimpe and Fier (2010)	Grimpe, C. & Fier, H. (2010). Informal university technology transfer: A comparison between the United States and Germany, *The Journal of Technology Transfer*, 35(6), 637–650	This article explains differences between active and passive networking among scientists
Collaborator attributes	Grosse Kathoefer and Leker (2010)	Grosse Kathoefer, D., & Leker, J. (2010), Knowledge transfer in academia: An exploratory study on the not-invented-here syndrome. *The Journal of Technology Transfer*, 1–18	The authors apply the Not Invented Here (NIH) syndrome to knowledge transfer in academia. They find it relates to individual characteristics
Organizational collaboration attributes	Grossman et al. (2001)	Grossman, J. H., Reid, P. P., & Morgan, R. P. (2001). Contributions of academic research to industrial performance in five industry sectors. *The Journal of Technology Transfer*, 26(1), 143–152	The authors offer some important remarks regarding how funding can influence collaboration patterns within and across sectors
Organizational collaboration attributes	Guellec et al. (2004)	Guellec, D., & Van Pottelsberghe de la Potterie, B. (2004). From R&D to productivity growth: Do the institutional settings and the source of funds of R&D matter? *Oxford Bulletin of Economics and Statistics*, 66(3), 353–378	Research in industry tends to be quite different from that found in universities, government or NGO's
Collaborator attributes	Gulbrandsen and Smedby (2005)	Gulbrandsen, M & Smeby, J. C. (2005). Industry funding and university professors' research performance. *Research Policy*,34(6), 932–950	Industry funding for university research varies by country
Collaboration attributes	Gulbrandsen and Etzkowitz (1999)	Gulbrandsen, M., & Etzkowitz, H. (1999). Convergence between Europe and America: The transition from industrial to innovation policy. *The Journal of Technology Transfer*, 24(2), 223–233	R&D requires innovation. Human additionality is inferred

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Hagedoorn et al. (2000)	Hagedoorn, J., Link, A. N., & Vonortas, N. S. (2000). Research partnerships. *Research Policy*, 29(4–5), 567–586	R&D collaboration provides benefits, yet countless resources and human energies are invested in facilitating, inducing, and managing collaboration
Organizational collaboration attributes	Hall, Link and Scott (2001)	Hall, B. H., Link, A. N., & Scott, J. T. (2001). Barriers inhibiting industry from partnering with universities: Evidence from the advanced technology program. *The Journal of Technology Transfer*, 26(1), 87–98	External actors such as regulators negatively contribute to the collaboration process. Certain barriers limit collaboration or partnering behavior between industry and universities, primarily intellectual property concerns; universities are subject to more stringent regulations compared to private industry
Organizational collaboration attributes	Hanel and St-Pierre (2006)	Hanel, P., & St-Pierre, M. (2006). Industry–University collaboration by Canadian manufacturing firms. *The Journal of Technology Transfer*, 31(4), 485–499	The major incentive to collaborate with a university is the access to research and critical competencies, which allows firms to reach the very edge of contemporary technology (i.e. property focused outputs)
Collaborator attributes	Haeussler and Colyvas (2011)	Haeussler, C., & J. A. Colyvas (2011), Breaking the Ivory Tower: Academic Entrepreneurship in the Life Sciences in UK and Germany, *Research Policy,* 40(1), 41–54	Older scientists are likely to be engaged in a variety of R&D commercialization activities
The dark side of research collaborations	Heffner (1981)	Heffner, A. G. (1981). Funded research, multiple authorship, and subauthorship collaboration in four disciplines. *Scientometrics*, 3(1), 5–12	Researchers have considerable autonomy in their collaboration choices and collaboration strategies are based in part of judgments about the conferring of co-authorship and status
Collaboration attributes	Heinze and Bauer (2007)	Heinze, T. & Bauer, G. (2007). Characterizing creative scientists in nano-S&T: Productivity, multidisciplinarity, and network brokerage in a longitudinal perspective. *Scientometrics*, 70(3), 811–830	This is one of many useful studies of collaboration where coauthorship is a unit of measure

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Hessels and Van Lente (2008)	Hessels, L. K., & Van Lente, H. (2008). Re-thinking new knowledge production: A literature review and a research agenda. *Research Policy*, 37(4), 740–760	Knowledge-focused and property-focused research are not mutually exclusive. Mode 2 knowledge production (transdisciplinary research) is not meant to replace the traditional mode of knowledge production, but rather supplement it. Mode 2 knowledge production is consistent with collaborative property-focused research
Organizational collaboration attributes	Hicks and Katz (1996)	Hicks, D. M., & Katz, J. S. (1996). Where is science going? *Science, Technology & Human Values*, 21(4), 379	There has been an increase in transdisciplinary journals
Organizational collaboration attributes	Hisrich and Smilor (1988)	Hisrich, R. D., & Smilor, R. W. (1988). The university and business incubation: Technology transfer through entrepreneurial development. *The Journal of Technology Transfer*, 13(1), 14–19	University-based business incubators encourage technology transfer through entrepreneurial development
Collaboration attributes	Huang and Lin (2010)	Huang, M. H., & Lin, C. S. (2010). International collaboration and counting inflation in the assessment of national research productivity. *Proceedings of the American Society for Information Science and Technology*, 47(1), 1–4	Research collaboration tends to enhance productivity of scientific knowledge
Organizational collaboration attributes	Huang and Yu (2011)	Huang, K. F., & Yu, C. M. J. (2011). The effect of competitive and non-competitive R&D collaboration on firm innovation. *The Journal of Technology Transfer*, 36(4), 383–403	Non-competitive R&D collaboration, specifically those collaborations conducted with universities, is positively correlated with innovation and provides material benefits to industry
Organizational collaboration attributes	Jankowski (1999)	Jankowski, J. E. (1999). Trends in academic research spending, alliances, and commercialization. *The Journal of Technology Transfer*, 24(1), 55–68	Funding from government has slowed and many institutions have come to rely on alternative funding methods including own source institutional funding and industry funding

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Jeong et al. (2011)	Jeong, S., Choi, J. Y. & Kim, J. (2011) The determinants of research collaboration modes: exploring the effects of research and researcher characteristics on co-authorship. *Scientometrics*, 89, 3, 967–983	These researchers provide a broader definition of collaboration than our current study
Collaboration attributes	Johansson et al. (2005)	Johansson, M., Jacob, M., & Hellström, T. (2005). The strength of strong ties: University spin-offs and the significance of historical relations. *The Journal of Technology Transfer*, 30(3), 271–286	Network ties between industry and academia create strong bonds for collaboration
Organizational collaboration attributes	Johnson (2009)	Johnson, W. H. A. (2009). Intermediates in triple helix collaboration: The roles of 4th pillar organisations in public to private technology transfer. *International Journal of Technology Transfer and Commercialisation*, 8(2), 142–158	External actors such as regulators positively contribute to collaborative R&D
Collaborator attributes	Johnson and Bozeman (2012)	Johnson, J., & Bozeman, B. (2012). Perspective: Adopting an asset bundles model to support and advance minority students' careers in academic medicine and the scientific pipeline. *Academic Medicine, 87*(11), 1488–1495	Minority underrepresentation in academic science affects collaboration patterns
Organizational collaboration attributes	Katz (2000)	Katz, J. S. (2000). Scale-independent indicators and research evaluation. *Science and Public Policy*, 27(1), 23–36	Beyond the individual scientists involved in the collaboration process, it is also important to consider the organizational environment in which these individuals interact
Collaboration attributes	Katz and Hicks (1997)	Katz, J. S., & Hicks, D. (1997). How much is a collaboration worth? A calibrated bibliometric model. *Scientometrics*, 40(3), 541–554	This article analyzes how collaboration influences the value of the final product through a measure of citation rates; collaboration with a domestic scientists increases the citation rate

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Katz and Martin (1997)	Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, 26(1), 1–18	Foundational review and critique of the research collaboration literature. The co-author concept of collaboration has several advantages, including verifiability, stability over time, data availability and ease of measurement. However, co-authorship is at best a partial indicator of collaboration
The dark side of research collaboration	Klingensmith and Anderson (2006)	Klingensmith, M. E. & Anderson, K. A. (2006). Educational scholarship as a route to academic promotion: A depiction of surgical education scholars. *The American Journal of Surgery*, 191(4), 533–537	The authors test whether educational scholarship is a viable pathway to academic promotion and the perverse impacts it may have on authorship attribution
Collaborator attributes	Kuhn (1996)	Kuhn, T. S. (1996). *The structure of scientific revolutions*. University of Chicago Press	Beaver (2004) uses Kuhn's conceptual framework of research paradigms to address challenges in the collaboration process
The dark side of research collaborations	Lagnado (2003)	Lagnado, M. (2003). Professional writing assistance: effects on biomedical publishing. *Learned Publishing*, 16(1), 21–27	Trust in the meaning of co-authorship has eroded
Organizational collaboration attributes	Landry, Amara and Ouimet (2007)	Landry, R. J., Amara, N., & Ouimet, M. (2007). Determinants of knowledge transfer: evidence from Canadian university researchers in natural sciences and engineering. *Journal of Technology Transfer*, 32(6), 561–592	The authors answer three research questions: the first distinguishing between knowledge and technology transfer, the second identify differences between disciplines in terms of knowledge transfer, and finally discussing the determinants of knowledge transfer
Organizational collaboration attributes	Lee (2000)	Lee, Y. S. (2000). The sustainability of university–industry research collaboration: An empirical assessment. *The Journal of Technology Transfer*, 25(2), 111–133	The most important benefit for firms from industry academia collaborations is an increased access to new university research and discoveries.
Collaborator attributes	Lee and Bozeman (2005)	Lee, S., & Bozeman, B. (2005). The impact of research collaboration on scientific productivity. *Social Studies of Science*, 35(5), 673	Research collaboration tends to enhance productivity of scientific knowledge. Younger and mid career scientists have greater productivity pay off. Job satisfaction impacts collaboration

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
The dark side of research collaborations	Levsky et al. (2007)	Levsky, M. E. Rosin, A. Coon, T. P. Enslow, W. L. & Miller, M. A. (2007). A descriptive analysis of authorship within medical journals, 1995–2005. *Southern Medical Journal*, 100(4), 371–375	There are potentially troubling trends in authorship in medical journals
Organizational collaboration attributes	Levy, Roux and Wolff (2009)	Levy, R., Roux, P., & Wolff, S. (2009). An analysis of science–industry collaborative patterns in a large European university. *The Journal of Technology Transfer*, 34(1), 1–23	Industry collaborations with universities most often produce increased knowledge-focused outputs rather than property-focused outputs
Collaboration attributes	Liao (2011)	Liao, C. H. (2011) How to improve research quality? Examining the impacts of collaboration intensity and member diversity in collaboration networks. *Scientometrics*, 86(3), 747–761	It is not the number of collaborators that is important to productivity but the intensity of collaborations and the degree to which collaborators are embedded in the network
Collaboration attributes	Liao and Yen (2012)	Liao, C. H. & Yen, H. R. (2012). Quantifying the degree of research collaboration: A comparative study of collaborative measures. *Journal of Informetrics*, 6(1), 27–33	It is important to consider the organizational environment in which researchers interact
Collaborator attributes	Lin and Bozeman (2006)	Lin, M. W., & Bozeman, B. (2006). Researchers' industry experience and productivity in university–industry research centers: A "scientific and technical human capital" explanation. *The Journal of Technology Transfer*, 31(2), 269–290	This article uses the industrial involvement index
Collaboration attributes	Link and Siegel (2005)	Link, A. N., & Siegel, D. S. (2005). University-based technology initiatives: Quantitative and qualitative evidence. *Research Policy*, 34(3), 253–257	Research collaboration may not have direct economic impact
Organizational collaboration attributes	Link et al. (2007)	Link, A. N., Siegel, D. S. & Bozeman, B. (2007). An empirical analysis of the propensity of academics to engage in informal university technology transfer, industrial & corporate change. *Research Policy*, 16(4), 641–655	Academics often prefer informal industry–university research collaborations

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Collaboration attributes	Liu et al. (2012)	Liu, H., Chang, B. & Chen, K. (2012) Collaboration patterns of Taiwanese scientific publications in various research areas. *Scientometrics*, 29(1), 145–165	International collaborations tend to have greater impact on outcomes, but that level of impact from international collaboration is field specific
Organizational collaboration attributes	Lööf and Broström (2008)	Lööf, H., & Broström, A. (2008). Does knowledge diffusion between university and industry increase innovativeness? *The Journal of Technology Transfer*, 33(1), 73–90	Often a positive relationship is found between collaboration and innovative property-focused outputs for a firm
Collaboration attributes	Luukkonen (2000)	Luukkonen, T. (2000). Additionality of EU framework programmes. *Research Policy*, 29(6), 711–724	This manuscript uses the concept of *additionality* in R&D programs in the EU
Collaboration attributes	Martinelli et al. (2008)	Martinelli, A., Meyer, M., & Tunzelmann, N. (2008). Becoming an entrepreneurial university? A case study of knowledge exchange relationships and faculty attitudes in a medium-sized, research-oriented university. *The Journal of Technology Transfer*, 33(3), 259–283	It is difficult for academics without external relations to begin collaboration outside one's own organization
Organizational collaboration attributes	Mansfield (1995)	Mansfield, E. (1995). Academic research underlying industrial innovations: Sources, characteristics, and financing. *The Review of Economics and Statistics*, 77(1), 55–65	Much of industrial research draws from public domain research produced in universities
The dark side of research collaborations	Marusic et al. (2004)	Marusić, M., Bozikov, J., Katavić, V., Hren, D., Kljaković-Gaspić, M., & Marusić, A. (2004). Authorship in a small medical journal: a study of contributorship statements by corresponding authors. *Science And Engineering Ethics*, 10(3), 493–502	Authors address uniform requirements for coauthorship
Organizational collaboration attributes	Matt et al. (2011)	Matt, M., Robin, S., & Wolff, S. (2011). The influence of public programs on inter-firm R&D collaboration strategies: Project-level evidence from EU FP5 and FP6. *The Journal of Technology Transfer*, 1–32. doi:10.1007/s10961-011-9232-9	Funding from different sources can influence the process of collaboration
Collaboration attributes	Mattsson et al. (2008)	Mattsson, P., Laget, P., Nilsson, A. & Sundberg, C. (2008). Intra-EU vs. extra-EU scientific co-publication patterns in EU. *Scientometrics*, 75(3), 555–574	This is one of many useful studies of collaboration where coauthorship is a unit of measure

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
The dark side of research collaborations	McCrary et al. (2000)	McCrary, S., Anderson, C., Jakovljevic, J., Khan, T., McCullough, L., Wray, N., & Brody, B. (2000). A national survey of policies on disclosure of conflicts of interest in biomedical research. *The New England Journal Of Medicine*, 343(22), 1621–1626	Conflicts of interest in research collaboration has received a good deal of attention in the literature
Collaboration attributes	Melin (2000)	Melin, G. (2000). Pragmatism and self-organization: Research collaboration on the individual level. *Research Policy*, 29(1), 31–40	Foundational review and critique of the research collaboration literature that suggests that collaboration works best as a voluntary process
Collaboration attributes	Melin and Persson (1996)	Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. Scientometrics, 36(3), 363–377	Foundational review and critique of the research collaboration literature
Organizational collaboration attributes	Mendoza (2007)	Mendoza, P. (2007) Academic capitalism and doctoral student socialization: A case study. *The Journal of Higher Education*, 78(1), 71–96	Industrial involvement has unduly affected university researchers' choice of research topics
Collaboration attributes	Merton (1968)	Merton, R. K. (1968) The Matthew effect in science. *Science,* 159(3810), 56–63	Authorship is a name game and credit will inevitably be disproportionate to more senior researchers, regardless of the particular nature or extent of their contribution compared to less well known collaborators
Collaboration attributes	Merton (1995)	Merton, R. K. (1995) The Thomas Theorem and the Matthew Effect. *Social Forces,* 74(2), 379–422	Authorship is a name game and credit will inevitably be disproportionate to more senior researchers, regardless of the particular nature or extent of their contribution compared to less well known collaborators
Organizational collaboration attributes	Meyer (2006)	Meyer, M. (2006). Academic inventiveness and entrepreneurship: On the importance of start-up companies in commercializing academic patents. *The Journal of Technology Transfer*, 31(4), 501–510	A number of university associated patents are used in startup companies, but most are used in established large firms

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Morgan et al. (2001)	Morgan, R. P., Kruytbosch, C., & Kannankutty, N. (2001). Patenting and invention activity of US scientists and engineers in the academic sector: Comparisons with industry. *The Journal of Technology Transfer*, 26(1), 173–183	The authors compare patenting and invention activity of scientists in the academic sector to counterparts in industry, indentifying several indicators that could be used in future research to examine property-focused outputs
Organizational collaboration attributes	Morgan and Strickland (2001)	Morgan, R. P., & Strickland, D. E. (2001) U.S. university research contributions to industry. *Science and Public Policy*, 28(2) 113–122	As funding from government has slowed many institutions have come to rely on alternative funding methods including own source institutional funding and industry sources
The dark side of research collaborations	Mowery and Sampat (2001)	Mowery, D. C., & Sampat, B. N. (2001). Patenting and licensing university inventions: Lessons from the history of the research corporation. *Industrial And Corporate Change*, 10(2), 317–355	Conflicts of interest in research collaboration has received a good deal of attention in the literature
The dark side of research collaborations	Mullen and Ramirez (2006)	Mullen, P.D., & Ramirez, G. (2006). The promise and pitfalls of systematic reviews, *Annual Review of Public Health,* 27:81–102	The authors use their experience as collaborators in systematic reviews of the literature to discuss the false sense of rigor implied by the terms "systematic review" and "meta-analysis"
Organizational collaboration attributes	National Academy of Engineering (2003)	National Academy of Engineering (2003). *The Impact of Academic Research on Industrial Performance*. Washington, DC: National Academies Press	As funding from government has slowed many institutions have come to rely on alternative funding methods including own source institutional funding and industry sources
Organizational collaboration attributes	Nedeva et al. (1999)	Nedeva, M., Georghiou, L., & Halfpenny, P. (1999). Benefactors or Beneficiary—The role of industry in the support of university research equipment. *The Journal of Technology Transfer*, 24(2), 139–147	Much of industry funding comes to develop equipment that could be used for future applied research
Collaboration attributes	Nilsson et al. (2010)	Nilsson, A. S., Rickne, A., & Bengtsson, L. (2010). Transfer of academic research: Uncovering the grey zone. *The Journal of Technology Transfer*, 35(6), 617–636	A supportive infrastructure in universities can foster a belief that an individual researcher has enough social capital to partner with industry

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Niosi (2006)	Niosi, J. (2006). Introduction to the symposium: Universities as a source of commercial technology. *The Journal of Technology Transfer*, 31(4), 399–402	Universities have been studied as a major provider of technology to industry for around 30 years
Collaboration attributes	Perkmann and Walsh (2009)	Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: Impacts of university–industry relations on public research. *Industrial and Corporate Change*, 18(6), 1033	Research collaboration may not have direct economic impact
The dark side of research collaborations	Pichini et al. (2005)	Pichini, S., Pulido, M., & García-Algar, O. (2005). Authorship in manuscripts submitted to biomedical journals: an author's position and its value. *Science and Engineering Ethics*, 11(2), 173–175	Authors address uniform requirements for coauthorship
Collaborator attributes	Pollak and Niemann (1998)	Pollak, K. I., & Niemann, Y. F. (1998). Black and white tokens in academia: A difference of chronic versus acute Distinctiveness1. *Journal of Applied Social Psychology*, 28(11), 954–972	Women are underrepresented in academia
Collaboration attributes	Ponds (2009)	Ponds, R. (2009). The limits to internationalization of scientific research collaboration. *The Journal of Technology Transfer*, 34(1), 76–94	Research collaboration is becoming more global
Collaboration attributes	Ponomariov (2008)	Ponomariov, B. L. (2008), Effects of university characteristics on scientists' interactions with the private sector: An exploratory assessment. *The Journal of Technology Transfer*, 33, 485–503	Informal interactions between university scientists and private sector companies increase both the likelihood and intensity of collaborative research
Collaboration attributes	Ponomariov and Boardman (2008)	Ponomariov, B., & Boardman, P. C. (2008). The effect of informal industry contacts on the time university scientists allocate to collaborative research with industry. *The Journal of Technology Transfer*, 33(3), 301–313	Informal interactions between university scientists and private sector companies increase both the likelihood and intensity of collaborative research
Collaborator attributes	Ponomariov and Boardman (2010)	Ponomariov, B. & Boardman, P. C. (2010). Influencing scientists' collaboration and productivity patterns through new institutions: university research centers and scientific and technical human capital. *Research Policy,* 39, 613–624	Age and career age do not affect collaboration

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Poyago-Theotoky et al. (2002)	Poyago-Theotoky, J., Beath, J., & Siegel, D. S. (2002). Universities and Fundamental Research: Reflections on the Growth of University–Industry Partnerships. *Oxford Review of Economic Policy,*18(1), 10–21	A great deal of work, especially in industrial and organizational economics, focuses on institutional level research partnerships
Collaboration attributes	Pravdić and Oluić-Vuković (1986)	Pravdić, N., & Oluić-Vuković, V. (1986). Dual approach to multiple authorship in the study of collaboration/scientific output relationship. *Scientometrics*, 10(5), 259–280	Research collaboration tends to enhance productivity of scientific knowledge
Collaboration attributes	Renault (2006)	Renault, C. S. (2006). Academic capitalism and university incentives for faculty entrepreneurship. *The Journal of Technology Transfer*, 31(2), 227–239	Individual beliefs regarding the proper role of universities in the dissemination of knowledge is very influential in determining collaboration patterns with industry
The dark side of research collaborations.	Rennie and Flanagin (1994)	Rennie, D. & Flanagin, A. (1994). Authorship! Authorship! Guests, ghosts, grafters, and the two-sided coin. *JAMA,*271(6), 469–471	Uniform standards for authorship used only in a handful of journals
The dark side of research collaborations	Rennie et al. (2000)	Rennie, D., Flannagin, A, & Yank, Y. (2000). The contribution of authors. *J. Am. Med. Assoc*, 284: 89–91	There is increasing interest in the ethical dilemmas associated with research collaborations
The dark side of research collaborations	Rennie (2001)	Rennie, D. (2001) Who did what? Authorship and contribution in 2001. *Muscle & Nerve,* 24(10), 1097–4598	Contributorship refers to the process entail as authors declare in detail, usually at time of submission, their individual contributions to scholarly papers in the spirit of scientific transparency
Organizational collaboration attributes	Rhoades and Slaughter (1997)	Rhoades, G. & Slaughter, S. (1997). Academic Capitalism, Managed Professionals, and Supply-Side Higher Education. *Academic Labor*, 51, 9–38	There can be negative aspects of academic entrepreneurship, especially with a hyper focus on product production
Collaborator attributes	Rijnsoever and Hessels (2011)	Rignsoever, F. J. & Hessels, L. K. (2011). Factors associated with disciplinary and interdisciplinary research collaboration. *Research Policy*, 40(3), 463–472	Research experience is positively related to university faculty both disciplinary and interdisciplinary collaboration

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Saragossi and van Pottelsberghe de la Potterie (2003)	Saragossi, S., & van Pottelsberghe de la Potterie, B. (2003). What patent data reveal about universities: The case of Belgium. *The Journal of Technology Transfer*, 28(1), 47–51	Patent statistics could be an erroneous indicator of productivity or additionality
Organizational collaboration attributes	Schartinger et al. (2001)	Schartinger, D., Schibany, A., & Gassler, H. (2001). Interactive relations between universities and firms: Empirical evidence for Austria. *The Journal of Technology Transfer*, 26(3), 255–268	Knowledge is transferred from universities to the business sector largely through human capital
Collaboration attributes	Shane (2004)	Shane, S. A. (2004). *Academic entrepreneurship: University spinoffs and wealth creation*. Edward Elgar Publishing	Research collaboration may not have direct economic impact
The dark side of research collaborations	Shrum et al. (2001)	Shrum, W., Chompalov, I., & Genuth, J. (2001). Trust, conflict and performance in scientific collaborations. *Social Studies of Science*, 31(5), 681–730	Outside of biomedical sciences, research on the ethics and socio-political dynamics of scientific collaboration remains scarce
The dark side of research collaborations	Shrum et al. (2007)	Shrum, W., Genuth, J., & Chompalov, I. (2007). *Structures of scientific collaboration*. MIT Press	Outside of biomedical sciences, research on the ethics and socio-political dynamics of scientific collaboration remains scarce
Organizational collaboration attributes	Siegel et al. (2003a)	Siegel, D. S., Waldman, D. A., Atwater, L. E., & Link, A. N. (2003). Commercial knowledge transfers from universities to firms: Improving the effectiveness of university–industry collaboration. *The Journal of High Technology Management Research*, 14(1), 111–133	An important external actor with a regulatory role is that of the institutional technology transfer office at most research universities
Collaborator attributes	Siegel et al. (2003b)	Siegel, D. S., Waldman, D. & Link, A. (2003). Assessing the Impact of Organizational Practices on the Relative Productivity of University Technology Transfer Offices: An Exploratory Study, *Research Policy*, 32, 27–48	When discussing outputs and assessing the focus of said outputs, different stakeholders in the collaboration have different perspectives and foci
Organizational collaboration attributes	Siegel et al. (2004)	Siegel, D. S., Waldman, D. A., Atwater, L. E. & Link, A. N. (2004). Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: Qualitative evidence from the commercialization of university technologies. *Journal of Engineering and Technology Management*, 21, 115–142	This is one of several empirical studies of university technology transfer offices

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Slaughter and Leslie (1997)	Slaughter, S. & Leslie, L. L. (1997). *Academic Capitalism: Politics, Policies, and the Entrepreneurial University*. Johns Hopkins University Press	There can be negative aspects of academic entrepreneurship, especially with a hyper focus on product production
The dark side of research collaborations	Slaughter et al. (2002)	Slaughter, S., T. Campbell, M. H. Folleman, & E. Morgan (2002) The "traffic" in graduate students: Graduate students as tokens of exchange between academe and industry, *Science, Technology and Human Values*, 27(2), 282–313	There is widespread concern that students are exploited in research collaborations
Collaboration attributes	Sonnenwald (2007)	Sonnenwald, D. H. (2007). Scientific collaboration. *Annual Review of Information Science and Technology*, 41(1), 643–681	R&D collaboration provides benefits, yet countless resources and human energies are invested in facilitating, inducing, and managing collaboration
Collaborator contributorship	Stokes and Hartley (1989)	Stokes, T. D. & Hartley, J. A. (1989). Coauthorship, social structure and influence within specialties. *Social Studies of Science*, 19(1), 101–125	Sometimes researchers listed as co-authors simply because he or she provided material or performed an assay
Collaborator attributes	Stuart and Ding (2006)	Stuart, T. E. & Ding, W. W. (2006). When do scientists become entrepreneurs? The social structural antecedents of commercial activity in the academic life sciences, *American Journal of Sociology*, 112(1), 97–144	This article develops the concept of academic entrepreneurism
Collaboration attributes	Subramanyam (1983)	Subramanyam, K. (1983). Bibliometric studies of research collaboration: A review. *Journal of Information Science*. 6(1), 33–38	Scientific research is becoming an increasingly collaborative endeavor. The nature and magnitude of collaboration vary from one discipline to another, and depend upon such factors as the nature of the research problem, the research environment, and demographic factors
Organizational collaboration attributes	Tartari and Breschi (2011)	Tartari, V. & Breschi, S. (2011). Set them free: Scientists' evaluations of benefits and costs of university–industry research collaboration. *Industrial and Corporate Change*, 21(5), 1117–1147	Access to equipment and additional research resources is a major incentive for many research collaborations

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
Organizational collaboration attributes	Thursby et al. (2001)	Thursby, J. G., Jensen, R., & Thursby, M. C. (2001). Objectives, characteristics and outcomes of university licensing: A survey of major US universities. *The Journal of Technology Transfer*, 26(1), 59–72	Property-focused output is a valid research topic for examining collaboration
Collaboration attributes	Toivanen and Ponomariov (2011)	Toivanen, H. & Ponomariov, B. (2011) African regional innovation systems: bibliometric analysis of research collaboration patterns. *Scientometrics*, 88(2), 471–493	This article notes important structural impediments to collaboration
Collaborator attributes	Turpin et al. (2011)	Turpin, T., Garrett-Jones, S., Woolley, R. (2011) Cross-sector research collaboration in Australia: The Cooperative Research Centres Program at the crossroads. *Science & Public Policy*, 38, 2, 87–97	Management behavior is crucial to develop a productive and encouraging environment for scientists
Collaborator attributes	Ubfal and Maffioli (2011)	Ubfal, D., & Maffioli, A. (2011) The impact of funding on research collaboration: Evidence from a developing country. *Research Policy*, 40(9), 1269–1279	Research collaborations are often based on informal relationships and trust
Collaboration attributes	Vasileiadou (2012)	Vasileiadou, E. (2012). Research teams as complex systems: implications for knowledge management. *Knowledge Management of Research Practice,* 10(2), 118–127	Relatively little research focuses on the interrelation of management, collaboration and effectiveness
Collaboration attributes	Vinkler (1993)	Vinkler, P. (1993). Research contribution, authorship and team cooperativeness. *Scientometrics*, 26(1), 213–230	Coauthorship is not the best measure of collaboration but broader notions of collaboration are not often easy to measure. Focusing on co-authorship alleviates many measurement problems
Collaboration attributes	Wagner (2005)	Wagner, C. S. (2005). Six case studies of international collaboration in science. *Scientometrics*, 62(1), 3–26	This is one of many useful studies of collaboration where coauthorship is a unit of measure
The dark side of research collaborations	Wainwright et al. (2006)	Wainwright, S. P., Williams, C., Michael, M., Farsides, B., Cribb, A. (2006). Ethical boundary-work in the embryonic stem cell laboratory. *Sociology of Health & Illness*, 28(6), 1467–9566	There is increasing interest in the ethical dilemmas associated with research collaborations

Table 1 continued

Attribute category	In-text citation	Full citation	Relevant findings
The dark side of research collaborations	Welsh et al. (2008)	Welsh, R., L. Glenn, W. Lacy, and D. Biscotti (2008). Close enough but not too far: Assessing the effects of university–industry research relationships and the rise of academic capitalism. *Research Policy*, 37, 1255–1266	Collaborations rooted in industry–university partnerships often have salutary effects for students including early publication, job offers and mentoring
Collaboration attributes	Wuchty, Jones and Uzzi (2007)	Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science*, 316(5827), 1036	Research collaboration tends to enhance productivity of scientific knowledge
Collaboration attributes	Ynalvez and Shrum (2011)	Ynalvez, M. & Shrum, W. (2011) Professional networks, scientific collaboration, and publication productivity in resource-constrained research institutions in a developing country. Research Policy, 40(2), 204–216	Collaboration has no special productivity pay off for researchers in developing nations and that collaborations, when they are undertaken at all, often are done so in the face of major impediments and institutional barriers

References

Abramo, G., D'Angelo, C. A., Di Costa, F., & Solazzi, M. (2011). The role of information asymmetry in the market for university–industry research collaboration. *The Journal of Technology Transfer, 36*(1), 84–100.

Aerts, K., & Schmidt, T. (2008). Two for the price of one? Additionality effects of R&D subsidies: A comparison between Flanders and Germany. *Research Policy, 37*(5), 806–822.

Allen, T. J. (1977). *Managing the flow of technology: Technology transfer and the dissemination of technological information with the R&D organization*. Boston: MIT Press.

Ambos, T. C., Mäkelä, K., Birkinshaw, J., & D'Este, P. (2008). When does university research get commercialized? Creating ambidexterity in research institutions. *Journal of Management Studies, 45*(8), 1424–1447.

Aschoff, B., & Grimpe, C. (2011). *Localized norms and academics' industry involvement: The moderating role of age on professional imprinting*. Unpublished paper downloaded February 3, 2012 from http://ftp.zew.de/pub/zew-docs/veranstaltungen/innovationpatenting2011/papers/Grimpe.pdf.

Audretsch, D. B., Bozeman, B., Combs, K. L., Feldman, M., Link, A. N., Siegel, D. S., et al. (2002). The economics of science and technology. *The Journal of Technology Transfer, 27*(2), 155–203.

Baldini, N. (2008). Negative effects of university patenting: Myths and grounded evidence. *Scientometrics, 75*(2), 289–311.

Beaver, D. B. (2001). Reflections on scientific collaboration (and its study): Past, present, and future. *Scientometrics, 52*(3), 365–377.

Beaver, D. B. (2004). Does collaborative research have greater epistemic authority? *Scientometrics, 60*(3), 399–408.

Behrens, T. R., & Gray, D. O. (2001). Unintended consequences of cooperative research: Impact of industry sponsorship on climate for academic freedom and other graduate student outcome. *Research Policy, 30*(2), 179–199.

Bercovitz, J., & Feldman, M. (2008). Academic entrepreneurs: Organizational change at the individual level. *Organization Science, 19*, 69–89.

Boardman, P. C., & Ponomariov, B. L. (2007). Reward systems and NSF university research centers: The impact of tenure on university scientists' valuation of applied and commercially relevant research. *The Journal of Higher Education, 78*(1), 51–70.

Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy, 29*, 627–655.

Bozeman, B., & Boardman, C. (in press). Academic faculty working in university research centers: Neither capitalism's slaves nor teaching fugitives. *The Journal of Higher Education.*

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy, 33*(4), 599–616.

Bozeman, B., Dietz, J. S., & Gaughan, M. (2001). Scientific and technical human capital: An alternative model for research evaluation. *International Journal of Technology Management, 22*(7), 716–740.

Bozeman, B., & Gaughan, M. (2007). Impacts of grants and contracts on academic researchers' interactions with industry. *Research Policy, 36*(5), 694–707.

Bozeman, B., & Gaughan, M. (2011). How do men and women differ in research collaborations? An analysis of the collaboration motives and strategies of academic researchers. *Research Policy, 40*(10), 1393–1402.

Bozeman, B., & Rogers, J. (2002). A churn model of knowledge value: Internet researchers as a knowledge value collective. *Research Policy, 31*(4), 769–794.

Bozeman, B., Youtie, J., Slade, C. P., & Gaughan, M. (2012). *The "dark side" of academic research collaborations: Case studies in exploitation, bullying and unethical behavior*. Paper prepared for the annual meeting of the Society for Social Studies of Science (4S) October 17–20, 2012, Copenhagen Business School, Frederiksberg, Denmark.

Brockner, J., & Wiesenfeld, B. M. (1996). An integrative framework for explaining reactions to decisions: Interactive effects of outcomes and procedures. *Psychological Bulletin, 120*(2), 189–208.

Bruneel, J., D'Este, P., & Salter, A. (2010). Investigating the factors that diminish the barriers to university–industry collaboration. *Research Policy, 39*(7), 858–868.

Buisseret, T. J., Cameron, H. M., & Georghiou, L. (1995). What difference does it make additionality in the public support of RD in large firms. *International Journal of Technology Management, 10*(4–5), 587–600.

Caloghirou, Y., Tsakanikas, A., & Vonortas, N. S. (2001). University–industry cooperation in the context of the European framework programmes. *The Journal of Technology Transfer, 26*(1), 153–161.

Carayannis, E. G., & Laget, P. (2004). Transatlantic innovation infrastructure networks: Public-private, EU–US R&D partnerships. *R&D Management, 34*(1), 17–31.

Carayol, N., & Matt, M. (2004). Does research organization influence academic production? Laboratory level evidence from a large European university. *Research Policy, 33*, 1081–1112.

Chang, D. B., & Dozier, K. (1995). Technology transfer and academic education with a focus on diversity. *The Journal of Technology Transfer, 20*(3), 88–95.

Chompalov, I., Genuth, J., & Shrum, W. (2002). The organization of scientific collaborations. *Research Policy, 31*(5), 749–767.

Chompalov, I., & Shrum, W. (1999). Institutional collaboration in science: A typology of technological practice. *Science, Technology and Human Values, 24*(3), 338–372.

Clark, B. Y. (2011). Influences and conflicts of federal policies in academic–industrial scientific collaboration. *The Journal of Technology Transfer, 36*(5), 514–545.

Clarysse, B., Wright, M., & Mustar, P. (2009). Behavioural additionality of R&D subsidies: A learning perspective. *Research Policy, 38*(10), 1517–1533.

Cohen, W. M., Nelson, R. R., & Walsh, J. P. (2002). Links and impacts: The influence of public research on industrial R&D. *Management Science, 48*(1), 1–23.

Cohen, M. B., Tarnow, E., & De Young, B. R. (2004). Coauthorship in pathology, a comparison with physics and a survey-generated and member-preferred authorship guideline. *Medscape General Medicine, 63*(1), 1–5.

Collins, S., & Wakoh, H. (2000). Universities and technology transfer in Japan: Recent reforms in historical perspective. *The Journal of Technology Transfer, 25*(2), 213–222.

Cooper, M. H. (2009). Commercialization of the university and problem choice by academic biological scientists. *Science Technology Human Values, 34*(5), 629–653.

Cronin, B. (2001). Hyperauthorship: A postmodern perversion or evidence of a structural shift in scholarly communication practices? *Journal of the American Society for Information Science and Technology, 52*(7), 558–569.

Crow, M. M., & Bozeman, B. (1998). *Limited by design: R&D laboratories in the US national innovation system*. New York: Columbia University Press.

Cummings, J. N., & Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science, 35*(5), 703.

D'Este, P., & Perkmann, M. (2011). Why do academics engage with industry? The entrepreneurial university and individual motivations. *The Journal of Technology Transfer, 36*(3), 316–339.

Davis, L., Larsen, M. T., & Lotz, P. (2011). Scientists' perspectives concerning the effects of university patenting on the conduct of academic research in the life sciences. *The Journal of Technology Transfer, 36*(1), 14–37.

Devine, E. B., Beney, J., & Bero, L. A. (2005). Equity, accountability, transparency: Implementation of the contributorship concept in a multi-site study. *American Journal of Pharmaceutical Education, 69*(4), 455–459.

Dietz, J. S., & Bozeman, B. (2005). Academic careers, patents, and productivity: Industry experience as scientific and technical human capital. *Research Policy, 34*(3), 349–367.

Drenth, J. P. H. (1998). Multiple authorship: The contribution of senior authors. *JAMA: Journal of the American Medical Association, 280*(3), 219–221.

Duque, R. B., Ynalvez, M., Sooryamoorthy, R., Mbatia, P., Dzorgbo, D. B. S., & Shrum, W. (2005). Collaboration paradox. *Social Studies of Science, 35*(5), 755.

Faria, J. R., & Goel, R. K. (2010). Returns to networking in academia. *Netnomics, 11*(2), 103–117.

Feller, I., & Feldman, M. (2010). The commercialization of academic patents: Black boxes, pipelines, and Rubik's cubes. *The Journal of Technology Transfer, 35*(6), 597–616.

Feller, I., & Roessner, D. (1995). What does industry expect from university partnerships? Congress wants to see bottom-line results from industry/government programs, but that's not what the participating companies are seeking. *Issues in Science and Technology, 12*(1), 80–84.

Fox, M. F., & Mohapta, S. (2007). Social-organizational characteristics of work and publication productivity among academic scientists in doctoral-granting departments. *Journal of Higher Education, 78*(5), 542–571.

Franklin, S. J., Wright, M., & Lockett, A. (2001). Academic and surrogate entrepreneurs in university spin-out companies. *The Journal of Technology Transfer, 26*(1), 127–141.

Garg, K. C., & Padhi, P. (2001). A study of collaboration in laser science and technology. *Scientometrics, 51*(10), 415–427.

Garrett-Jones, S., Turpin, T., & Diment, K. (2010). Managing competition between individual and organizational goals in cross-sector research and development centres. *The Journal of Technology Transfer, 35*(5), 527–546.

Gaughan, M., & Corley, E. A. (2010). Science faculty at US research universities: The impacts of university research center-affiliation and gender on industrial activities. *Technovation, 30*(3), 215–222.
Gazni, A., & Didegah, F. (2011). Investigating different types of research collaboration and citation impact: A case study of Harvard University's publications. *Scientometrics, 87*(2), 251–265.
Geisler, E. (1986). The role of industrial advisory boards in technology transfer between universities and industry. *The Journal of Technology Transfer, 10*(2), 33–42.
Godin, B. (1998). Writing performative history: The new New Atlantis? *Social Studies of Science, 28*(3), 465–483.
Goel, R. K., & Grimpe, C. (2011) Active versus passive academic networking: Evidence from micro-level data. *The Journal of Technology Transfer*, 1–19. doi:10.1007/s10961-011-9236-5.
Gray, D. O., & Steenhuis, H. J. (2003). Quantifying the benefits of participating in an industry university research center: An examination of research cost avoidance. *Scientometrics, 58*(2), 281–300.
Grimpe, C., & Fier, H. (2010). Informal university technology transfer: A comparison between the United States and Germany. *The Journal of Technology Transfer, 35*(6), 637–650.
Grosse Kathoefer, D., & Leker, J. (2010). Knowledge transfer in academia: An exploratory study on the not-invented-here syndrome. *The Journal of Technology Transfer, 35*(1), 1–18.
Grossman, J. H., Reid, P. P., & Morgan, R. P. (2001). Contributions of academic research to industrial performance in five industry sectors. *The Journal of Technology Transfer, 26*(1), 143–152.
Guellec, D., & Van Pottelsberghe de la Potterie, B. (2004). From R&D to productivity growth: Do the institutional settings and the source of funds of R&D matter? *Oxford Bulletin of Economics and Statistics, 66*(3), 353–378.
Gulbrandsen, M., & Etzkowitz, H. (1999). Convergence between Europe and America: The transition from industrial to innovation policy. *The Journal of Technology Transfer, 24*(2), 223–233.
Gulbrandsen, M., & Smedby, J. C. (2005). Industry funding and university professors' research performance. *Research Policy, 34*(6), 932–950.
Haeussler, C., & Colyvas, J. A. (2011). Breaking the ivory tower: Academic entrepreneurship in the life sciences in UK and Germany. *Research Policy, 40*(1), 41–54.
Hagedoorn, J., Link, A. N., & Vonortas, N. S. (2000). Research partnership. *Research Policy, 29*(4–5), 567–586.
Hall, B. H., Link, A. N., & Scott, J. T. (2001). Barriers inhibiting industry from partnering with universities: Evidence from the advanced technology program. *The Journal of Technology Transfer, 26*(1), 87–98.
Hanel, P., & St-Pierre, M. (2006). Industry–University collaboration by Canadian manufacturing firms. *The Journal of Technology Transfer, 31*(4), 485–499.
Heffner, A. G. (1981). Funded research, multiple authorship, and subauthorship collaboration in four disciplines. *Scientometrics, 3*(1), 5–12.
Heinze, T., & Bauer, G. (2007). Characterizing creative scientists in nano-S&T: Productivity, multidisciplinarity, and network brokerage in a longitudinal perspective. *Scientometrics, 70*(3), 811–830.
Hessels, L. K., & Van Lente, H. (2008). Re-thinking new knowledge production: A literature review and a research agenda. *Research Policy, 37*(4), 740–760.
Hicks, D. M., & Katz, J. S. (1996). Where is science going? *Science, Technology and Human Values, 21*(4), 379.
Hisrich, R. D., & Smilor, R. W. (1988). The university and business incubation: Technology transfer through entrepreneurial development. *The Journal of Technology Transfer, 13*(1), 14–19.
Huang, M. H., & Lin, C. S. (2010). International collaboration and counting inflation in the assessment of national research productivity. *Proceedings of the American Society for Information Science and Technology, 47*(1), 1–4.
Huang, K. F., & Yu, C. M. J. (2011). The effect of competitive and non-competitive R&D collaboration on firm innovation. *The Journal of Technology Transfer, 36*(4), 383–403.
Jankowski, J. E. (1999). Trends in academic research spending, alliances, and commercialization. *The Journal of Technology Transfer, 24*(1), 55–68.
Jeong, S., Choi, J. Y., & Kim, J. (2011). The determinants of research collaboration modes: Exploring the effects of research and researcher characteristics on co-authorship. *Scientometrics, 89*(3), 967–983.
Johansson, M., Jacob, M., & Hellström, T. (2005). The strength of strong ties: University spin-offs and the significance of historical relations. *The Journal of Technology Transfer, 30*(3), 271–286.
Johnson, W. H. A. (2009). Intermediates in triple helix collaboration: The roles of 4th pillar organisations in public to private technology transfer. *International Journal of Technology Transfer and Commercialisation, 8*(2), 142–158.
Johnson, J., & Bozeman, B. (2012). Perspective: Adopting an asset bundles model to support and advance minority students' careers in academic medicine and the scientific pipeline. *Academic Medicine, 87*(11), 1488–1495.

Katz, J. S. (2000). Scale-independent indicators and research evaluation. *Science and Public Policy, 27*(1), 23–36.

Katz, J. S., & Hicks, D. (1997). How much is a collaboration worth? A calibrated bibliometric model. *Scientometrics, 40*(3), 541–554.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy, 26*(1), 1–18.

Klingensmith, M. E., & Anderson, K. A. (2006). Educational scholarship as a route to academic promotion: A depiction of surgical education scholars. *The American Journal of Surgery, 191*(4), 533–537.

Kuhn, T. S. (1996). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Lagnado, M. (2003). Professional writing assistance: Effects on biomedical publishing. *Learned Publishing, 16*(1), 21–27.

Landry, R. J., Amara, N., & Ouimet, M. (2007). Determinants of knowledge transfer: Evidence from Canadian university researchers in natural sciences and engineering. *The Journal of Technology Transfer, 32*(6), 561–592.

Lee, Y. S. (2000). The sustainability of university–industry research collaboration: An empirical assessment. *The Journal of Technology Transfer, 25*(2), 111–133.

Lee, S., & Bozeman, B. (2005). The impact of research collaboration on scientific productivity. *Social Studies of Science, 35*(5), 673.

Levsky, M. E., Rosin, A., Coon, T. P., Enslow, W. L., & Miller, M. A. (2007). A descriptive analysis of authorship within medical journals, 1995–2005. *Southern Medical Journal, 100*(4), 371–375.

Levy, R., Roux, P., & Wolff, S. (2009). An analysis of science–industry collaborative patterns in a large European university. *The Journal of Technology Transfer, 34*(1), 1–23.

Liao, C. H. (2011). How to improve research quality? Examining the impacts of collaboration intensity and member diversity in collaboration networks. *Scientometrics, 86*(3), 747–761.

Liao, C. H., & Yen, H. R. (2012). Quantifying the degree of research collaboration: A comparative study of collaborative measures. *Journal of Informetrics, 6*(1), 27–33.

Lin, M. W., & Bozeman, B. (2006). Researchers' industry experience and productivity in university–industry research centers: A "scientific and technical human capital" explanation. *The Journal of Technology Transfer, 31*(2), 269–290.

Link, A. N., & Siegel, D. S. (2005). University-based technology initiatives: Quantitative and qualitative evidence. *Research Policy, 34*(3), 253–257.

Link, A. N., Siegel, D. S., & Bozeman, B. (2007). An empirical analysis of the propensity of academics to engage in informal university technology transfer, industrial & corporate change. *Research Policy, 16*(4), 641–655.

Liu, H., Chang, B., & Chen, K. (2012). Collaboration patterns of Taiwanese scientific publications in various research areas. *Scientometrics, 29*(1), 145–165.

Lööf, H., & Broström, A. (2008). Does knowledge diffusion between university and industry increase innovativeness? *The Journal of Technology Transfer, 33*(1), 73–90.

Luukkonen, T. (2000). Additionality of EU framework programmes. *Research Policy, 29*(6), 711–724.

Mansfield, E. (1995). Academic research underlying industrial innovations: Sources, characteristics, and financing. *The Review of Economics and Statistics, 77*(1), 55–65.

Martinelli, A., Meyer, M., & Tunzelmann, N. (2008). Becoming an entrepreneurial university? A case study of knowledge exchange relationships and faculty attitudes in a medium-sized, research-oriented university. *The Journal of Technology Transfer, 33*(3), 259–283.

Marusić, M., Bozikov, J., Katavić, V., Hren, D., Kljaković-Gaspić, M., & Marusić, A. (2004). Authorship in a small medical journal: A study of contributorship statements by corresponding authors. *Science and Engineering Ethics, 10*(3), 493–502.

Matt, M., Robin, S., & Wolff, S. (2011). The influence of public programs on inter-firm R&D collaboration strategies: Project-level evidence from EU FP5 and FP6. *Journal of Technology Transfer*, 1–32. doi: 10.1007/s10961-011-9232-9.

Mattsson, P., Laget, P., Nilsson, A., & Sundberg, C. (2008). Intra-EU vs. extra-EU scientific co-publication patterns in EU. *Scientometrics, 75*(3), 555–574.

McCrary, S., Anderson, C., Jakovljevic, J., Khan, T., McCullough, L., Wray, N., et al. (2000). A national survey of policies on disclosure of conflicts of interest in biomedical research. *The New England Journal of Medicine, 343*(22), 1621–1626.

Melin, G. (2000). Pragmatism and self-organization: Research collaboration on the individual level. *Research Policy, 29*(1), 31–40.

Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. *Scientometrics, 36*(3), 363–377.

Mendoza, P. (2007). Academic capitalism and doctoral student socialization: A case study. *The Journal of Higher Education, 78*(1), 71–96.

Merton, R. K. (1968). The Matthew effect in science. *Science, 159*(3810), 56–63.
Merton, R. K. (1995). The Thomas theorem and the Matthew effect. *Social Forces, 74*(2), 379–422.
Meyer, M. (2006). Academic inventiveness and entrepreneurship: On the importance of start-up companies in commercializing academic patents. *The Journal of Technology Transfer, 31*(4), 501–510.
Morgan, R. P., Kruytbosch, C., & Kannankutty, N. (2001). Patenting and invention activity of US scientists and engineers in the academic sector: Comparisons with industry. *The Journal of Technology Transfer, 26*(1), 173–183.
Morgan, R. P., & Strickland, D. E. (2001). U.S. university research contributions to industry. *Science and Public Policy, 28*(2), 113–122.
Mowery, D. C., & Sampat, B. N. (2001). Patenting and licensing university inventions: Lessons from the history of the research corporation. *Industrial and Corporate Change, 10*(2), 317–355.
Mullen, P. D., & Ramirez, G. (2006). The promise and pitfalls of systematic reviews. *Annual Review of Public Health, 27*, 81–102.
National Academy of Engineering. (2003). *The impact of academic research on industrial performance*. Washington, DC: National Academies Press.
Nedeva, M., Georghiou, L., & Halfpenny, P. (1999). Benefactors or beneficiary: The role of industry in the support of university research equipment. *The Journal of Technology Transfer, 24*(2), 139–147.
Nilsson, A. S., Rickne, A., & Bengtsson, L. (2010). Transfer of academic research: Uncovering the grey zone. *The Journal of Technology Transfer, 35*(6), 617–636.
Niosi, J. (2006). Introduction to the symposium: Universities as a source of commercial technology. *The Journal of Technology Transfer, 31*(4), 399–402.
Perkmann, M., & Walsh, K. (2009). The two faces of collaboration: Impacts of university–industry relations on public research. *Industrial and Corporate Change, 18*(6), 1033.
Pichini, S., Pulido, M., & García-Algar, O. (2005). Authorship in manuscripts submitted to biomedical journals: An author's position and its value. *Science and Engineering Ethics, 11*(2), 173–175.
Pollak, K. I., & Niemann, Y. F. (1998). Black and white tokens in academia: A difference of chronic versus acute Distinctiveness. *Journal of Applied Social Psychology, 28*(11), 954–972.
Ponds, R. (2009). The limits to internationalization of scientific research collaboration. *The Journal of Technology Transfer, 34*(1), 76–94.
Ponomariov, B. L. (2008). Effects of university characteristics on scientists' interactions with the private sector: An exploratory assessment. *The Journal of Technology Transfer, 33*, 485–503.
Ponomariov, B., & Boardman, P. C. (2008). The effect of informal industry contacts on the time university scientists allocate to collaborative research with industry. *The Journal of Technology Transfer, 33*(3), 301–313.
Ponomariov, B., & Boardman, P. C. (2010). Influencing scientists' collaboration and productivity patterns through new institutions: University research centers and scientific and technical human capital. *Research Policy, 39*, 613–624.
Poyago-Theotoky, J., Beath, J., & Siegel, D. S. (2002). Universities and fundamental research: Reflections on the growth of university–industry partnerships. *Oxford Review of Economic Policy, 18*(1), 10–21.
Pravdić, N., & Oluić-Vuković, V. (1986). Dual approach to multiple authorship in the study of collaboration/scientific output relationship. *Scientometrics, 10*(5), 259–280.
Renault, C. S. (2006). Academic capitalism and university incentives for faculty entrepreneurship. *The Journal of Technology Transfer, 31*(2), 227–239.
Rennie, D. (2001). Who did what? Authorship and contribution in 2001. *Muscle and Nerve, 24*(10), 1097–4598.
Rennie, D., & Flanagin, A. (1994). Authorship! Authorship! Guests, ghosts, grafters, and the two-sided coin. *JAMA: Journal of the American Medical Association, 271*(6), 469–471.
Rennie, D., Flannagin, A., & Yank, Y. (2000). The contribution of authors. *JAMA: Journal of the American Medical Association, 284*, 89–91.
Rhoades, G., & Slaughter, S. (1997). Academic capitalism, managed professionals, and supply-side higher education. *Academic Labor, 51*, 9–38.
Rijnsoever, F. J., & Hessels, L. K. (2011). Factors associated with disciplinary and interdisciplinary research collaboration. *Research Policy, 40*(3), 463–472.
Saragossi, S., & de la Potterie, B. (2003). What patent data reveal about universities: The case of Belgium. *The Journal of Technology Transfer, 28*(1), 47–51.
Schartinger, D., Schibany, A., & Gassler, H. (2001). Interactive relations between universities and firms: Empirical evidence for Austria. *The Journal of Technology Transfer, 26*(3), 255–268.
Shane, S. A. (2004). *Academic entrepreneurship: University spinoffs and wealth creation*. Northampton: Edward Elgar Publishing.

Shrum, W., Chompalov, I., & Genuth, J. (2001). Trust, conflict and performance in scientific collaborations. *Social Studies of Science, 31*(5), 681–730.

Shrum, W., Genuth, J., & Chompalov, I. (2007). *Structures of scientific collaboration*. Cambridge: MIT Press.

Siegel, D. S., Waldman, D. A., Atwater, L. E., & Link, A. N. (2003a). Commercial knowledge transfers from universities to firms: Improving the effectiveness of university–industry collaboration. *The Journal of High Technology Management Research, 14*(1), 111–133.

Siegel, D. S., Waldman, D., Atwater, L. E., & Link, A. N. (2004). Toward a model of the effective transfer of scientific knowledge from academicians to practitioners: Qualitative evidence from the commercialization of university technologies. *Journal of Engineering and Technology Management, 21*, 115–142.

Siegel, D. S., Waldman, D., & Link, A. (2003b). Assessing the impact of organizational practices on the relative productivity of university technology transfer offices: An exploratory study. *Research Policy, 32*, 27–48.

Slaughter, S., Campbell, T., Folleman, M. H., & Morgan, E. (2002). The 'traffic' in graduate students: Graduate students as tokens of exchange between academe and industry. *Science, Technology and Human Values, 27*(2), 282–313.

Slaughter, S., & Leslie, L. L. (1997). *Academic capitalism: Politics, policies, and the entrepreneurial university*. Baltimore: Johns Hopkins University Press.

Sonnenwald, D. H. (2007). Scientific collaboration. *Annual Review of Information Science and Technology, 41*(1), 643–681.

Stokes, T. D., & Hartley, J. A. (1989). Coauthorship, social structure and influence within specialties. *Social Studies of Science, 19*(1), 101–125.

Stuart, T. E., & Ding, W. W. (2006). When do scientists become entrepreneurs? The social structural antecedents of commercial activity in the academic life sciences. *American Journal of Sociology, 112*(1), 97–144.

Subramanyam, K. (1983). Bibliometric studies of research collaboration: A review. *Journal of Information Science, 6*(1), 33–38.

Tartari, V., & Breschi, S. (2011). Set them free: Scientists' evaluations of benefits and costs of university–industry research collaboration. *Industrial and Corporate Change, 21*(5), 1117–1147.

Thursby, J. G., Jensen, R., & Thursby, M. C. (2001). Objectives, characteristics and outcomes of university licensing: A survey of major US universities. *The Journal of Technology Transfer, 26*(1), 59–72.

Toivanen, H., & Ponomariov, B. (2011). African regional innovation systems: Bibliometric analysis of research collaboration patterns. *Scientometrics, 88*(2), 471–493.

Turpin, T., Garrett-Jones, S., & Woolley, R. (2011). Cross-sector research collaboration in Australia: The Cooperative Research Centres Program at the crossroads. *Science & Public Policy, 38*(2), 87–97.

Ubfal, D., & Maffioli, A. (2011). The impact of funding on research collaboration: Evidence from a developing country. *Research Policy, 40*(9), 1269–1279.

Vasileiadou, E. (2012). Research teams as complex systems: Implications for knowledge management. *Knowledge Management of Research Practice, 10*(2), 118–127.

Vinkler, P. (1993). Research contribution, authorship and team cooperativeness. *Scientometrics, 26*(1), 213–230.

Wagner, C. S. (2005). Six case studies of international collaboration in science. *Scientometrics, 62*(1), 3–26.

Wainwright, S. P., Williams, C., Michael, M., Farsides, B., & Cribb, A. (2006). Ethical boundary-work in the embryonic stem cell laboratory. *Sociology of Health & Illness, 28*(6), 1467–9566.

Welsh, R., Glenn, L., Lacy, W., & Biscotti, D. (2008). Close enough but not too far: Assessing the effects of university–industry research relationships and the rise of academic capitalism. *Research Policy, 37*, 1255–1266.

Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science, 316*(5827), 1036.

Ynalvez, M., & Shrum, W. (2011). Professional networks, scientific collaboration, and publication productivity in resource-constrained research institutions in a developing country. *Research Policy, 40*(2), 204–216.