# Influences and Conflicts of Federal Policies in Academic-Industrial Scientific Collaboration

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Abstract:

This paper examines the role of the federal government in shaping the relationship between academics scientists and industry. There exists a potential conflict between government policies encouraging collaboration within academia and the policies encouraging collaboration between academia and industry. To test and model these potential conflicts, this paper uses data collected in a 2004-05 survey by the Research Valuing Mapping Project (a project based at Georgia Tech and led by Barry Bozeman) of more than 2000 academically based research scientists and engineers. The major finding in this paper shows that academic scientists working with industry collaborate more (with all types of collaborators) than those that do not collaborate with industry. However, when examining only those scientist that collaborate with industry, the results reveal a negative relationship between the amount of time spent collaborating with industry and the number of collaborators; implying that increasing collaboration with industry leads to less academic-academic collaboration.

INDEX WORDS: Collaboration; Academic Scientific Collaboration; Academic-Industrial Collaboration; Federal Research Funding

Increasing collaboration in academic science has been a US federal policy objective for decades. Government interest in encouraging collaboration between academic scientists and companies in the private sector (academic-industrial) collaboration is often a result of efforts to extract more social benefits (even if we are not yet sure what those benefits may be) (Brooks, 1994), economic benefits, and the associated spillover effects (Salter and Martin, 2001; Carayol, 2003; Zucker and Darby, 2001). These efforts have been manifested in numerous policies, some of which seek to increase academic-academic collaborations, while others have sought to increase collaborations between academics in other sectors (government and industry).

There is a potential for conflict between these two policies as collaborating with industry may limit how academics can collaborate or share their work with other scientists because of confidentiality requirements that come with some types of industrial collaboration (Blumenthal, et al., 1996b; Campbell, et al., 1998; Schachman, 2000). Previous studies have shed little light on how these two policies interact. They have provided only tentative answers to how being involved in academic-industrial collaborations might influence the overall pattern of collaboration of academic scientists. They have also fallen short in examining how the complexity of the relationship between academics and industry influence their collaborative behavior. The goal of this paper is to reconcile how the efforts to increase one type of collaboration (academic-industrial) may be neglecting or even diminishing the efforts to increase collaboration on other fronts (academic-academic). In that effort, this paper will investigate two of issues related to the role of industrial sector support of research and collaboration in academic scientific research. First, it will investigate whether industry influences the collaborations that an academic scientist has with other scientists (academic or otherwise). And second, it will examine whether the intensity of a scientist's involvement with industry influences their collaborative behavior.

The US federal government promotes various policies aimed at increasing the level of collaboration of academic scientists. Some of the policies are primarily directed towards increasing collaboration within academic science, such as those seen in recent grant solicitations from the National Science Foundation (NSF), the National Institutes of Health (NIH), the Food and Drug Administration (FDA), and the Department of Defense (DoD) (NSF, 2004, 2006c; NIH, 2008a, 2008b; FDA, 2006; Department of Defense, 2008a). It is clear from these requests, and many others like them, that these agencies are making direct efforts to increase collaboration between scientists in academia by funding cooperative research, rewarding joint efforts with larger contracts, and facilitating collaboration through conferences, networks, websites, or other means.

Governments throughout the developed world have initiated grant programs requiring collaboration as a stipulation for funding (Vest, 1994; Landry and Amara, 1998) because they believe that scientific research is best when executed collaboratively (Landry and Amara, 1998). Even grant solicitations have noted that past collaborations have increased our "fundamental understanding" of the solicitation's specific line of study (Department of Defense, 2008b).

The broader US federal government policy requiring collaboration manifests itself in a variety of types of collaboration. Collaboration within academia is one area in which the funding stipulations have manifested themselves. Some proposals are more specific regarding how many collaborators they would like to see. One example can be taken from a Department of Defense Autism research solicitation, where it is stated that the "Award requires collaboration between at least two independent investigators" (Department of Defense, 2008a). A similar statement can be seen in an NSF solicitation, in which at "least three PIs and co-PIs…must be listed on the cover page or on the budget page of the proposal" (NSF, 2005). Other examples are less exact, stating simply that the proposal "requires a collaborator (or collaborators)" (Department of Defense, 2006b).

The efforts of the federal government to increase collaboration go beyond the walls of academic institutions; the government has also been actively promoting greater links between academia and industry. These efforts are driven largely by the goal to increase economic competitiveness of the US or individual US states (Lee, 2000; Behrens and Gray, 2001; Blumenthal, 2003; Shane, 2004). These collaborations also provide for improvements in technology transfer (Behrens and Gray, 2001; Shane, 2004), increased support for academic research, networking opportunities, capacity improvements, and training for graduate students (Azagra-Caro, 2007). The efforts to increase academic-industrial collaborations are motivated, in large part, by a desire to improve economic competitiveness (Lee, 2000; Behrens and Gray, 2001; Blumenthal, 2003; Shane, 2004; NSF, 2008f). In some instances, collaboration is required to receive the funding (Guellec and Van Pottelsberghe de la Potterie, 2003; Tassey, 1996; Small Business Administration, 2001; Adams, et al, 2005). Some policy tools are directed more sharply towards industry, such as tax credits given to firms that collaborate with academics (Hall, 1993; Tassey, 1996; Hall and Van Reenen, 2000; Bloom, et al., 2002).

While these efforts to increase collaboration between academic and industrial researchers in the US have been ongoing for decades, support has become more intense in the last 30 years (Behrens and Gray, 2001; Lee, 1997; Lee, 2000; Adams, et al., 2005). Evidence of the US federal government policy to encourage collaboration between academia and industry is clear from the language seen in many grant solicitation announcements and program descriptions (see: NSF, 2006b, 2008e, 2008c; DARPA, 2008; National Technology Transfer Center, 2008). The NSF, for example, states that one of its major objectives is to:

> improve the nation's capacity for intellectual and economic growth by increasing the number of industrial partnerships and collaborations. By serving as a catalyst for industry-university partnerships, NSF helps ensure that intellectual capital and emerging technologies are brought together in ways that promote economic growth and an improved quality of life (NSF, 2008g, ¶ 1).

An area where the federal government has established explicit policy on academic-industrial collaboration has been in the area of technology transfer. More specifically, there have been extensive efforts to establish university-based research centers and small business technology transfer programs. The university research centers' goals include the development of "long-term partnerships among industry, academe, and government. The centers are catalyzed by a small investment from the National Science Foundation (NSF) and are primarily supported by industry center members, with NSF taking a supporting role in their development and evolution" (NSF, 2008c, § 3). NSF sees the university research centers as a way in which they can influence "positive change in the performance capacity of the U.S. industrial enterprise" (NSF, 2008b, ¶ 1). They see the centers as catalysts for "high-quality, industrially relevant fundamental research, strong industrial support of and collaboration in research and education, and direct transfer of university developed ideas, research results, and technology to U.S. industry" (National Science Foundation, 2008b, ¶ 1).

The National Technology Transfer Center (NTTC) compliments the university research centers' efforts.  The NTTC works "to link U.S. industry with federal labs and universities that have the technologies, facilities and researchers that industry needs to maximize product development opportunities" (National Technology Transfer Center, 2008, ¶ 1). Blumenthal (2003) found that academic-industrial collaboration is a more effective mode of technology transfer than more traditional modes of technology transfers (Blumenthal, 2003).

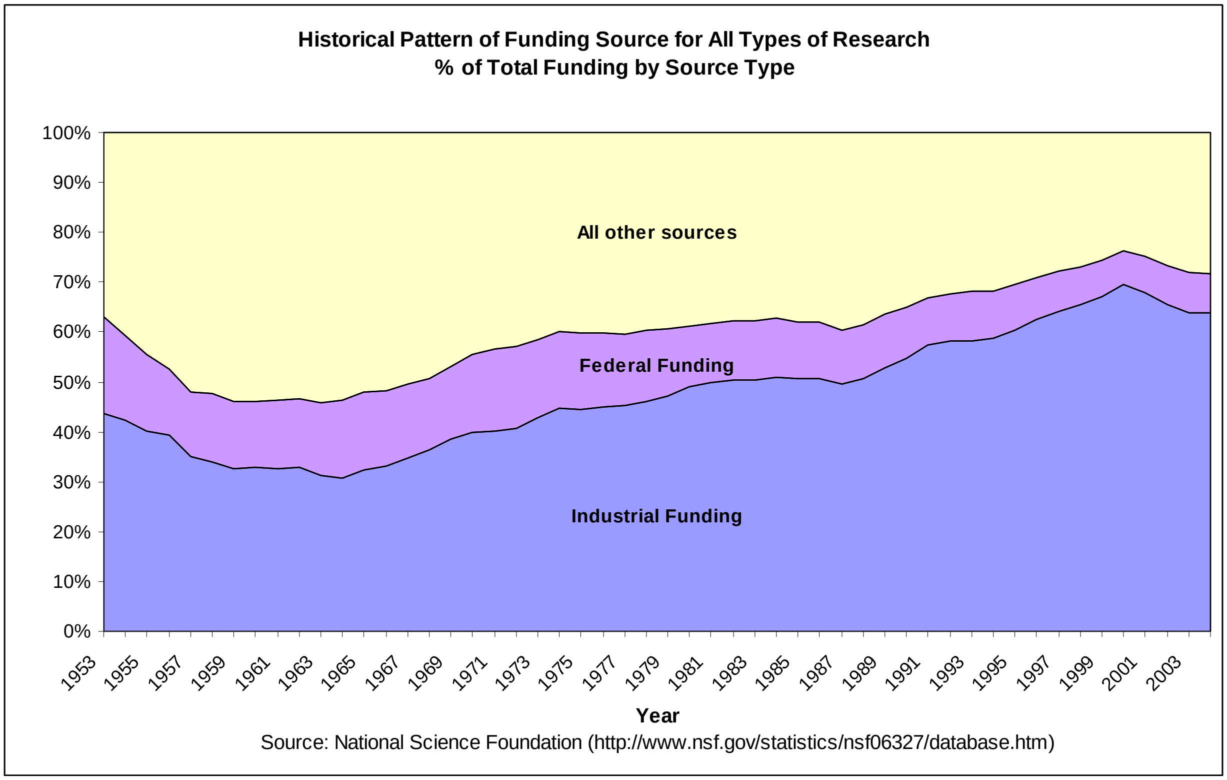
In cooperation with the Small Business Administration (SBA), eight federal executive departments (Agriculture, Commerce, Defense, Education, Energy, Health and Human Services, Homeland Security, Transportation), as well as the Environmental Protection Agency, National Aeronautics and Space Administration (NASA), National Technology Transfer Center (NTTC), and NSF all participate in a program that facilitates collaborations between small businesses, universities, and government researchers (Small Business Administration, 2001).  Each one of these departments sets aside a portion of its annual research and development (R&D) budget to specifically promote these types of collaborations.  The Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) programs brings academic scientists (as well as scientists from other institutions) together with small businesses to "spin-off their commercially promising ideas while they remain primarily employed at the research institution" (National Science Foundation, 2008d, § 2).   Both the SBIR and STTR require one PI from a small businesses and one PI from a research institution (National Science Foundation, 2008a, § 3).  The primary difference between these two small business-oriented programs "is that the STTR requires researchers at universities and other research institutions to play a significant intellectual role in the conduct of each STTR project. These university-based researchers, by joining forces with a small company, can spin-off their commercially promising ideas while they remain primarily employed at the research institution" (NSF, 2008a, § 4).

Direct efforts to increase collaboration between academia and industry are not the only reasons that academic scientists are collaborating more often with industry than they did in the past. The declining level of direct government support of academic research has also led to increased academic-industrial collaboration (Adams, et al, 2005). As scientists see direct support decrease, they are forced to seek other sources of funding for their research. Industry has also become increasingly reliant on other institutions (academic and government labs) for research (Adams, et al, 2005; Antonelli, 2008). Industry sees the link between academia and industry as a way to cultivate their future workforce (Baldwin, 1996; Adams, et al, 2005; Antonelli, 2008).

Looking more broadly at science in the US, it is apparent that scientific discovery in the US has been largely sponsored by industry. The largest sources of funding for scientific and engineering research in the US are private industry and the federal government (Shackelford, 2007). In 2006, academic research received about 64 percent of its funding from the federal government, five percent from industry, 24 percent from universities and colleges themselves, and another seven percent from non-profit institutions (Shackelford, 2007). According to the NSF report on research funding, academic institutions in 2006 carried out about 14 percent of research and development (R&D), 58 percent of basic research, and 13 percent of applied research (measured in terms of expenditures) of all research done in the US (Shackelford, 2007).

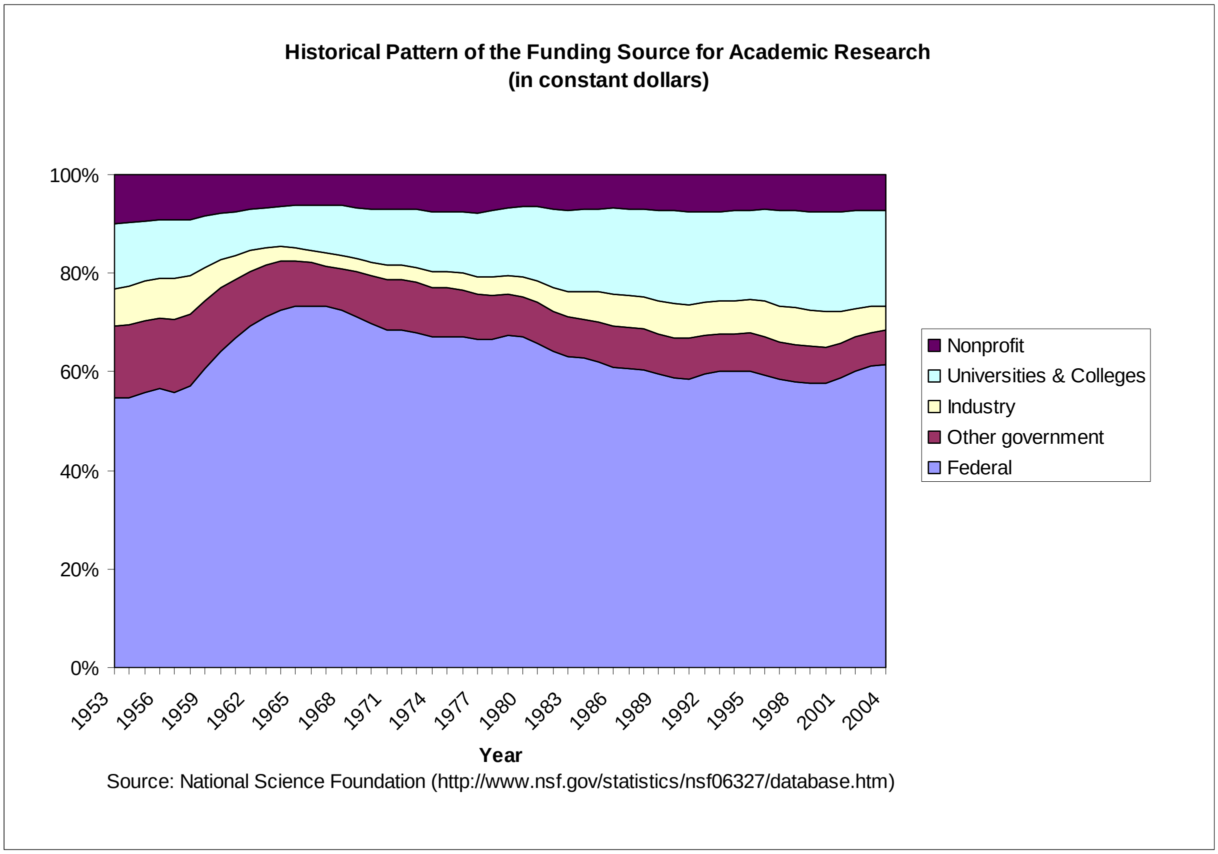
While industrial funding on the whole has taken on a larger proportion of all research funding in the US, it does not appear as thought this shift has occurred in the funding of academic research (see Graph1). The federal government has provided the greatest amount of support for academic research for decades. The decrease in funding by the federal government, since its peak in the 1960s, appears to have shifted financial responsibility in a large part to the universities (see Graph 2).

Graph 1



Source: National Science Foundation (http://www.nsf.gov/statistics/nsf06327/database.htm)

Graph 2



Source: National Science Foundation (http://www.nsf.gov/statistics/nsf06327/database.htm)

Despite the relatively small proportion of the academic funding coming from industry, the influence of industry on the research agenda is substantial. This can be seen in cases where firms have pressured academic scientists to withhold or delay research findings (Rosenberg, 1996; Lexchin, 2005; Blumenthal et al., 1996b), where research is directed toward explicitly commercial products (Lexchin, 2005), when positive aspects of research are overemphasized (Lexchin, 2005), where firms provide incentives to alter results (Blumenthal, 2003), and when communications between scientists are restricted (Blumenthal, 2003). This is all in addition to cases where the simple presence of industrial funding of research can cloud the reliability or authority of that work (Browning, 2008).

Gulbrandsen and Smeby (2005) show potential benefits of academic-industrial collaboration. Their work shows that funding from industrial or private sector sources has been shown to result in academic researchers collaborating more, rather than less, than their peers without industrial support. Looking at evidence from coauthored publications, collaborations have been shown to increase as the amount of external funding (from government or industry) increases (Heffner, 1981; Pao, 1992) and increased funding leads to increased research opportunities.

Information asymmetries may limit the benefits that universities gain when contracting with the private sector. The inability to write a complete contract for the transfer of technology hinders a university's ability to collect associated rents they are due as a result of their scientific and technological breakthroughs (Dasgupta and David, 1994). While technology transfer from academia to industry has been facilitated by the Bayh-Dole Act of 1980[1] (Allen, et al., 2007), the rate of transfer varies considerably by discipline (Shane, 2004). Increased commercialization of the creations of academic scientific discovery–in a large part because of Bayh-Dole–has led to a blurring between "research tools" and "products" (Schachman, 2000, p. 305). This has led to the patenting of products "which historically were exchanged freely and directly among scientists without licenses, material transfer agreements or memoranda of understanding" (Schachman, 2000, pp. 305-306). And while increasing levels of patenting can increase the rents to academic scientists and their institutions, it can also increase barriers to innovation and lead to higher transaction costs.

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[1] "The Bayh–Dole Act of 1980 gave small and universities the right to own inventions resulting from federally funded research (Stevens, 2004, p. 93). Bayh-Dole been credited with propelling scientific and technological discovery by allowed universities to own their inventions. For information on the history of Bayh-Dole see Stevens (2004). For information on Bayh-Dole public policy implications see Mowery et al. (2004) or Link (2006).

What the results of this paper will demonstrate is that academics that engage in industrial collaboration have a greater number of academic and total collaborators. It also demonstrates that while those engaged in industrial collaboration may have more collaborators than those without such support, there remains a downward pressure on how many collaborators they have as the level of industrial support increases. And finally, the intensity of industrial involvement and amount of industrial support to the institution do not appear to have a negative influence on the number of collaborators.

The remainder of this paper is structured as follows: first, the hypotheses will be presented in more detail. Then, a description of the proposed dependent and independent variables will be provided. This is followed by a description of the statistical modeling methods. Next, the results of the statistical tests will be revealed, followed by concluding remarks.

## Hypotheses

The “social contract for science” is the implicit agreement that the US government sponsors basic science, at least those projects deemed worthy from peer reviews, and the scientists, in return, “promise that the research will be performed well and honestly and will provide a steady stream of discoveries that can be translated into new products, medicines, or weapons” (Guston and Keniston, 1994, pp. 1-2). By maintaining this “social contract,” scientists can help to provide economic development and global competitiveness. There is evidence, however, that the US government may not be upholding its side of this “social contract.” Funding levels from the federal government have been shown not to “provide adequate compensation for the basic costs of running a research institution," and the funding is often "so delayed, or so laced with constraints, that responsible financial planning has become increasingly difficult for the research universities" (Guston and Keniston, 1994, p. 3).

The failure to live up to the social contract has implications for economic development. Governments' greatly interest in collaboration by governments can be attributed to collaborations "expected important positive impact on economic performances" (Carayol, 2003, p. 887). The social benefits (Brooks, 1994) and economic benefits (Salter and Martin, 2001; Carayol, 2003; Zucker and Darby, 2001) will, in theory, bring about sustained economic growth and prosperity to a nation, which can play to the advantage of elected and non-elected policy makers.

European governments are pursuing similar policies to those in the US. These efforts can be seen in their investments in academic R&D and a push for greater academic-industrial collaboration. These initiatives are seen as "prerequisites for success in a global knowledge-based global economy" (Norwegian Ministry of Trade and Industry, 2003, p. 8). Innovation and exploration of new scientific and technological knowledge is expensive, risky, and uncertain. Increasing the frequency and intensity of linkages between academia and industry is based on the prospect that the relationship will "ensure the effective transfer and rapid exploitation of new knowledge, from the hopes that 'the second mouse gets the cheese'" (Olsen, 2004, pp. 6-7). The first mouse, presumably, gets caught in the mousetrap, while the second mouse learns (or avoids the risks of the loaded mousetrap) from the first's mistake, and profits from the other's failure. Industry is also able to buy "access to scientific frontiers" that, without the academic-industrial collaborations, they would otherwise not be able to tap into (Bonaccorsi and Piccaluga, 1994).

The benefits of innovation and discovery, while helpful on the more macro level (the US economy, for example), are far more helpful to individual companies at the micro level. They are able to buy into the academics' basic research and development discoveries (generally sponsored by government funding), keeping them on the cutting edge of science and technology, without having to take the risks and expenses associated with that type of research.

The "golden age" of US government R&D support has passed with the end of the Soviet Union and the space race (Guston and Keniston, 1994). Without the common goals and threat that came from the Cold War, the support for maintaining high levels of scientific expenditures is lacking (Guston and Keniston, 1994). The absence of clear goals and support for the spending is coupled with an increasing number of scientists competing for this diminishing pot of money to support an increasingly complex and costly scientific process, making it all the harder to get funding (Guston and Keniston, 1994).

Most sponsorship of basic research and development in academia comes from government grants, contracts, and cooperative agreements; only a "small fraction" of industrial support of basic research is for research outside of the firms own laboratories (Sharp and Kleppner, 1994, p. 149). About 80 percent of the support provided to academic science by industry "is committed to product development and clinical trials" (Sharp and Kleppner, 1994, p. 149). To put this in perspective of scale of involvement by industry, more than 90 percent of US life science companies have some sort of relationship with academia, though most tends to be short-term, targeted, and applied rather than basic science oriented (Blumenthal, et al., 1996a). While the bulk of academic science is supported by government, the investments in R&D made by private firms are quite different than those made by governments because of each sector's different goals. Industrial support becomes more important as government funding decreases for academic scientific R&D; academic scientists are forced to look elsewhere for support of their research.

From the perspective of the individual scientists, a variety of motivations exist as to why they collaborate (whether with other academics, government scientists, or industry). Some motivations more specific to academic science collaboration include: the institutional structures and incentives in place at a university (Landry and Amara, 1998; Schartinger, et al., 2002), research alliances (Pisano, 1991), increasing specialization and complexity in science (Heffner, 1981; Barnett et al., 1988; Guston and Keniston, 1994; Durden and Perri, 1995; Morrison, et al., 2003), sharing of resources and cost sharing (Bonaccorsi and Piccaluga, 1994; Barnett et al., 1988), and the view of science as a social institution—in that scientists would prefer to work with other people rather than by themselves (Katz and Martin, 1997; Smith and Katz, 2000). Factors that tend to motivate all academics (scientific or otherwise) may include: familiarity or history with the collaborator, geographic proximity (Kraut et al., 1988; Katz, 1992; Garg and Padhi, 2001; Turner and Mairesse, 2004), mentoring of students and junior faculty (Morrison, et al., 2003; Fox, 2001; Long, 1990; Murray and Graham, 2007), complementary skills sets (Heffner, 1981), the reputation of the collaborator, work ethic of the collaborator, decreasing the risk of publication/project failure (Barnett et al., 1988; Bonaccorsi and Piccaluga, 1994; Morrison, et al., 2003;), a desire to increase output (i.e. publish or perish) (Barnett et al., 1988; Durden and Perri, 1995; Landry, et al., 1996; Morrison, et al., 2003), and a desire to improve the quality of the output (Medoff 2003).

Landry, et al. (1996) contend that academic-industry collaboration has a bigger influence on research productivity than it does on their collaborative behavior. They find that due to the goal of academic-industrial collaborations—creating marketable products, a scientist's productivity in other areas will diminish. However, Blumenthal, et al. (1996b) find that academic-industrial collaborations enhance commercial productivity without diminishing productivity in more traditional academic activities.  Consequently, there is not consensus on how the academic-industry collaborations influence productivity.

The source of research funding in academia is directly related to each particular study's expectations and outcomes. Federally funded research is mandated to be open and free to the scientific community, and it is expected that results will be communicated broadly within the scientific community (Louis et al., 2001).  The norms and tradition of academic science are intrinsically opposed to those of industry, where results are guarded, withheld, and rents are accumulated in private hands (Louis et al., 2001).   This "entrepreneurial behavior," often associated with privately funded research in universities, "has a positive effect on faculty members' likelihood of denying others' requests for research results" (Louis et al., 2001, p. 239).

In a survey of more than 2000 life scientists, Blumenthal, et al. (1996b) found that scientists with industrial funding published significantly more articles and participated "in significantly more service activities in their institutions or disciplines" than those without industrial funding  (p. 1736). Interestingly, however, the number of publications and service activities was greatest for those academic scientists with "minimal or moderate support from industry (one third or less of the person's total research budget)" (Blumenthal, et al., 1996b, p. 1736).  These variables tended to decline as the proportion of support from industry increased beyond moderate or lower levels (Blumenthal, et al., 1996b). Scientists with more than two thirds of their research support coming from industry had lower publication rates and published less influential articles than those with less support from industry (Blumenthal, et al., 1996b). Greater levels of industrial funding for research also led to an increased likelihood of work having a commercial outcome, which led to greater control of the research agenda by industry (Blumenthal, et al., 1996b). Having a problem solving oriented research agenda, which is commonly the result of industry directed research, can have the consequence of turning academic science away from some the basic science roots. Without those basic science discoveries, solving the problems of the future can be hindered.

Restrictions on how data can be used, data embargos, publishing embargos, secrecy agreements, and other pressure from industry on academics are a strong deterrent and impediment to collaboration. Academic scientists that have industrial support have been shown to be more "likely than those without such support to report restrictions on their communication of the results of their research" (Blumenthal, et al., 1996b, p. 1737). These same scientists were also more likely than those without the industrial support to refuse to share their data, results, or other materials with other academics (Blumenthal, et al., 1996b). Scientists "with industrial support are at least twice as likely to engage in trade secrecy or to withhold research results from colleagues as are investigators without such support" (Blumenthal, et al., 1996b, p. 1738). The struggle for academics engaged in collaborations with industry is balancing the benefits of more resources and outputs for products with the restrictions that come with industrial support of research.

The restrictions on academic freedom, data use, and sharing of results can clearly lead to a diminished capacity to communicate with colleagues. Research done for one company can even restrict work done for other companies, and rivalries between companies will keep the academic scientist from sharing similar technologies to competitors (Blumenthal, et al., 1996a). The data and result embargo requirements imposed by industry on academics tend to be two to three times longer than what the NIH says is a “reasonable” amount of time (Blumenthal, et al., 1996a).

In addition to the potential of slowing or inhibiting academic research, academic-industrial collaborations have a history of distorting the selection of the research agenda (Carayol, 2003). Studies that are funded by industry have “demonstrated a statistically greater likelihood to report positive results than studies with other funding sources” (Shah, et al., 2005, p. 1099). These biases may be due to how the studies are designed, bad experimental techniques, poor interpretation of results, or a bias concerning which articles are published (Shah, et al., 2005).

When support is given to an academic scientist, not surprisingly, the industrial donor often wants considerable control over the output resulting from that support. Campbell, et al. (1998) report what industrial donors expect: pre-publication review of articles/reports, acknowledgement in the publications, control over where the support/gift ends up (i.e. not passing equipment to a third party), product testing, and ownership of patentable products; these are seen as restrictive and problematic by both the recipients and their institutions (Campbell et al., 1998). Schachman (2000) contends that the convergence of academic and industrial science “is bound to introduce serious problems since their goals and functions are so disparate” (p. 308).

It has also been suggested that academic scientists' level of industrial "funding increases with their reputation thus reinforcing cumulative advantages" (Carayol, 2003, p 905). Though an increasing level of industrial support does not necessarily equate to being on the cutting edge of science, as "many laboratories, receiving much funding from firms, lag behind the knowledge frontier" (Carayol, 2003, p 905). This may be a result of the type of research that industrial funding supports—applied research. Government funding, on the other hand, tends to focus more on basic research, which may be more likely to push the "knowledge frontier." Blumenthal, et al. (1996b) find that the increasing levels of commercialization in academic science may be reducing the basic or fundamental research that is being done. While it is difficult to forecast the long-term ramifications of declining basic research, many see it as detrimental (Blumenthal, et al., 1996b; Schachman, 2000). The regulation of academic support by industry, fraught with conflicts of interest, has largely been "accomplished by guidance rather than prescription, and has been managed through the mechanism of institutional assurance. However, such light-handed oversight is neither preordained nor guaranteed" (Korn, 2000, p. 2235).

Not all restrictions placed upon academic scientists are externally imposed. Some level of secrecy is self-imposed by the academics themselves or their institution (Schachman, 2000). Consequently, it is not just industry that is the culprit in the increasing levels of secrecy and lack of sharing, as the individual scientists "are aided and abetted in this withholding by the universities in which they work" (Schachman, 2000, p. 308). Retribution may be playing a role in the persistence of data withholding as well. According to Campbell et al. (2000), those most likely to be victims of data/result withholding are those who have done the same to others in the past.

Academic-industrial collaborations not only yield greater secrecy than other types of academic collaborations, but they are also more likely to “encourage investigators to focus on research with a potential for commercial application” (Blumenthal, et al., 1996b, p. 1738). This is not necessarily negative, but it does have big ramifications on what is discovered and the general direction of research. Academic-industrial collaborations are strongly correlated with the number of patents an academic scientist has attained (Carayol and Matt, 2004). Though, like some other studies on academic-industrial collaborations (Heffner, 1981; Pao, 1992), Carayol and Matt (2004) are also finding that academic-industrial collaborations are increasing publishing productivity in addition to increasing the number of patents.

The propensity to collaborate, as measured by co-authorship, has been shown to increase as the amount of external funding (government or industrial) increases (Heffner, 1981; Pao, 1992). The greater level of external support may not cause collaboration, according to Heffner (1981), but what it may do is give “greater access to complicated, expensive equipment, which in turn, may require large numbers of people to operate…[and allow] the researcher [to] be able to pay others to do the tasks that he himself might otherwise have done” (pp. 5-6). In another study, 67 percent of academic scientists saw large benefits associated with industrial funding that allowed them to acquire lab equipment and provide support to graduate students (Carayol, 2003). A similarly substantial majority of scientists revealed that industrial funding enabled insight and the ability to field test their theories into their research (Carayol, 2003). As has been noted, dwindling levels of federal government support has increased academics’ reliance on industrial support for their work. Consequently, academic scientists with a record of industrially funded collaboration have become more and more attractive to universities, and universities with such reputations for working with industry have an easier time attracting and retaining such scientists

(Barnett et al., 1988). Universities that are “successfully engaged” in academic-industrial collaborations tend to be those that are able to balance their funding sources (government and industry) (Debackere and Veugelers, 2005, p. 327). This is the consequence of government funding supporting basic research and industrial funding supporting product development and other applied uses of science (Carayol, 2003).

Not all studies that have looked at the influence of industrial funding have found that they have unduly influenced results or publication statistics. Studies submitted for review with industrial support were just as likely to report positive outcomes and just as likely to be published as the non-funded studies (Lynch, et al., 2007). As an example of how academic-industrial results may not be biasing the results, we can look at a scientific instrument maker; such a manufacturer might collaborate with academic scientists to provide benefits to both the company (higher profits and better, more refined, and accurate instruments) and the researcher (access to more refined and quality equipment) (Brooks, 1994).

The cultivation of skills and knowledge through collaboration, both organizations (academic scientists and industrial firms) can form a mutually beneficial relationship for advancing the knowledge frontier (Santoro and Gopalakrishnan, 2000). These mutually beneficial relationships put both organizations in more vulnerable positions because each is forfeiting some control over their resources, which highlights the need for trust between the parties (Santoro and Gopalakrishnan, 2000). After contracts have been developed, the trust can be built (mutual benefits) or destroyed (shirking) by the actions of the parties. The costs of the collaborations increase or decrease as trust in partners is developed, which, ultimately, is an issue of transaction costs.

An underlying theme in a great deal of the collaboration literature is the influence of transaction costs on the decision to collaborate. Transaction costs are an important factor to consider when thinking about collaboration in general, and particularly when studying academic-industrial collaborations. A firm's decision to collaborate versus internalizing activities will be based on if (or when) costs of contracting (or collaborating) begin to grow too much for the transactions to be done efficiently and effectively (Klein, et al., 1978). Klein, et al. (1978) observe that the expense of contracting will tend to increase at a greater rate than similar costs associated with vertical integration, and thus vertical integration is more commonly seen in the private sector. However, the vast subsidization of academic science by the government makes these scientific discoveries far cheaper for industry to obtain via contract than through the vertical integration of those processes into the companies, which fundamentally alters the decision of the firm. Subsidization by governments allows for the risky, path-breaking scientific discoveries that firms rely upon from their academic partners. The industrial partners are able to reap the rewards of riskier lines of academic research, without having to endure all of the costs (of failure) (Carayol, 2003). Without this subsidization, it is likely, due to the high costs and highly specialized nature of academic scientific discovery, that these tasks would be integrated into the firms rather than contracted. Some have even claimed that the academic-industrial collaborations are fragile and highly dependent upon the federal subsidies of academic science (Feller, et al., 2002). In addition to a potentially fragile relationship, it has been found that "only a limited number of firms draw directly from universities as a source of information or knowledge for their innovative activities," which suggests "that the direct contribution of universities" to industry "is likely to be highly concentrated in a small number of industrial sectors" with "'open' approach to innovative search" (Laursen and Salter, 2004, p. 1212). This implies that the willingness to bear the costs of searching for collaborators and their technology will vary by industry and, potentially, by discipline.

Every contingency of the relationship between collaborating partners (in our case, academic scientists and industry) cannot be easily or cheaply specified in a contract (Klein, et al., 1978). In general, contract partners tend to rely on a long-term implicit contract mechanism that uses a market (as opposed to a legal) enforcement mechanism (Klein, et al., 1978). The threat of future investment loss and potential damage to the scientists' and university's "brand name" will act as the enforcement mechanisms and are key aspects of the contract mechanism winning out over the vertical integration alternative (Klein, et al., 1978).

The number of contractual partners is also controlled, to a degree, by transaction costs. Participation by third parties is discouraged in classical contractual situations because the more participants there are, the more difficult it is to fully specify the contract (Williamson, 1985). The highly specialized nature of the collaboration between academia and industry, produces a situation in which the end product becomes less transferable from one firm to another, which yields an outcome in which contracting becomes more likely and profitable for both parties (Williamson, 1985). However, the complexities of collaborating often lead to increases in transaction costs, which could ultimately lead to decreased productivity (Morrison, et al., 2003). The coordination and bargaining costs of academic-industrial collaborations are higher than collaborations within academia and particularly within the formal structures of the university (Landry and Amara, 1998, p. 910).

In an effort to address the higher coordination, search, and enforcement costs associated with academic-industrial collaborations, universities and the federal government have embarked upon an effort to set up research centers to link academia with industry (Feller, et al., 2002; Ponomariov, 2008). University research centers, typically multi-disciplinary, are supported by various federal efforts (National Technology Transfer Center, 2008; NSF, 2008b, 2008c). They facilitate the transfer of technology from academia to industry (Feller, et al., 2002), and, in theory, lower the transaction costs of these transfers. There is, however, some limited evidence that the coordination costs of academic-industry collaborations done within the confines of the "institutes and teams" are higher than collaborative projects accomplished outside formal structures" (Landry and Amara, 1998, p. 910).

From the perspective of the individual scientist, affiliation with a research center increases the likelihood of interacting with industry (Corley and Gaughan, 2005). Patenting in academia, which has been increasing due to the research centers (Carayol, 2003; Rahm, 1994), Bayh-Dole, and a host of other reasons, provides signals to industry of the academic scientists' competencies, giving firms insight on ways in which they can explore collaborations and draw upon a university's expertise (Ponomariov, 2008). Additionally, patents can become more "important when viewed not in isolation as a mere source of income from royalties, but as a negotiation chip in sponsored research contracts with industry" (Debackere and Veugelers, 2005, p. 327). Academic scientists who are engaged in technology transfer activities are more likely than their colleagues to be involved in patenting, more likely to be collaborating with industry regarding their research, more likely to have been sought out by industry for their expertise, and more likely to have been paid by industry for some aspect of their research (Rahm, 1994, p. 277). As this demonstrates, there are many ways in which academics and industry can be linked. It is not just the formal agreements between academics and industry that lead to more collaboration; informal interactions also increase the likelihood and intensity of collaborations (Ponomariov and Boardman, 2008). Informal academic-industrial interactions act as “catalysts of collaborative inter-sector research” (Ponomariov and Boardman, 2008, p. 311).

The scope and breadth of recent studies examining industry’s influence on academic scientists could potentially lead one in diverging directions.  It is evident that it is difficult to find a consensus across these studies whether or not academic-industrial collaborations advance or shrink the collaborative profile of academic scientists.  It is apparent that government and industry have strong motivations to pursue these collaborations (Guston and Keniston, 1994; Salter and Martin, 2001; Carayol, 2003; Zucker and Darby, 2001; Norwegian Ministry of Trade and Industry, 2003; Bonaccorsi and Piccaluga, 1994).  And academics, with diminishing access to federal funding, have a strong motivation to create linkages to industry (Guston and Keniston, 1994; Blumenthal, et al., 1996a). While there is clearly a strong impetus for industrial-academic collaboration, the consequences of the popularity of such collaborations are murky, at best.

There have been several studies that have shown that academic scientists collaborating with industry collaborate less with their academic colleagues or have diminished productivity (Rosenberg, 1996; Landry, et al., 1996; Lexchin, 2005; Blumenthal, et al., 1996b). Taking the consequences of increased secrecy and restrictions associated with academic-industrial collaborations (see: Louis et al., 2001; Blumenthal, et al., 1996; Campbell, et al., 1998; Schachman, 2000) into account could result in a diminished collaborative capacity of the academic scientist.  Other study results have shown that collaborating with industry, in some circumstances, increases commercial product output without diminishing other academic outputs (Blumenthal, et al., 1996b). Other lines of research have shown that academic-industrial collaboration leads to an increase in the overall number of collaborations or productivity of the academic scientists (Gulbrandsen and Smeby, 2005; Carayol and Matt, 2004; Heffner, 1981; Pao, 1992). And others have found that industrial funding of research has not led to positive results being reported more frequently than studies without such funding (Lynch, et al., 2007). The nature and scope of the previous studies have not been identical, nor did they all look at scientists in the same countries or the same academic disciplines. As a result, questions remain unanswered regarding the influence that industry has on academic scientists. From a public policy standpoint, it is vital to understand how increasing levels of academic-industrial collaboration could result in a decrease of collaboration overall—which would clearly be an undesirable outcome and contrary to the motivation behind federal government investments in collaboration.

The stance being taken in this paper, and being tested with empirical evidence, is that the demands for secrecy and the restrictions imposed on use of data and sharing of results will build considerable walls around these academics. As the academic scientists become more dependent and more intertwined with the industrial work, it would seem likely that the barriers between themselves and their research colleagues would become greater and greater. Consequently, the assertion being made in this paper is that increasing levels of academic-industrial collaboration will have not only a negative influence on academic-academic collaborations, but also that the net effect on all types of collaborations will be negative.

*H1: Increases in collaboration with industry will decrease levels of collaboration with academics and decrease the overall level of collaboration.*

Not all types of collaborations between academics and industry have the same outcomes or influence on scientists (Behrens and Gray, 2001). Sharing a research paper with an industrial scientist is not the same as accepting research funding or working in an industrial lab. These differences in types of collaboration will likely lead to different types of relationships that may not mean that industrial collaboration would be “clearly associated with decreased communication among academic life-science faculty members” (Blumenthal et al., 1996b, p. 1738). Thune (2007) notes that the closer interactions between academia and industry should lead to better utilization of academic knowledge, quicker adoption of academic discoveries, and the development of more relevant academic research projects. This study also finds that the more complex a relationship between academics and industry, the longer lasting that relationship will be (Thune, 2007). This is due to the nature of these types of relationships; a more intense and complex relationship will take longer to develop.

Open communication can be an important catalyst in advancing scientific research (Rosenberg, 1996). When open communication between scientists is not allowed, the consequences for scientific discovery (and perhaps even public safety) could be significant. Medical and pharmaceutical interests have provided a great deal of support to academic research. It has been demonstrated that these activities have not only decreased communication between scientists, but have also changed the direction of research towards more marketable products (Lexchin, 2005). The effects of this type of influence on the research agenda could be far reaching, influencing the types of scientific discoveries that are made. This type of influence might also result in an inequitable distribution of benefits, though it is not necessarily unethical for a private industry to allocate funding of university research at its own discretion. However, private funding may also indirectly determine how public funds are spent, which may alter the distribution of public benefits from these funds by providing benefits only to those who can pay for them, rather than all citizens (who paid for the research with tax dollars).

It is evident in the restrictions placed upon academics when they enter into industrial collaborations that they are giving up, to an extent, their ability to communicate with other scientists. Consequently, I suspect that the nature of an industrial collaboration taken on by an academic researcher will influence the level of collaboration. By controlling for the intensity of the industrial relationship between the academic and his or her industrial partner, it is conceivable that we will be able to see the extent to which the depth of the relationship matters.

*H2: The more complex the involvement of a researcher with industry the less they will collaborate with other academics.*

A university's ability to write a more beneficial contract may depend on the size of or resources of that university (Ervin, et al., 2003). Ponomariov (2008) looks specifically at the influences on interactions between academia and industry, using the same data employed in this paper. He finds that industrial R&D expenditures at universities have a positive influence on the likelihood of a scientist interacting with the private sector. While Ponomariov (2008) examines the variables affecting the level of interaction among academics, he does not provide direction on how industrial R&D expenditures at a university may change the collaborations among academics.

It has been noted that more prestigious universities have different collaborative profiles, rely more upon the federal government for their research funding, and less on industry, than those with lesser reputations (Lee, 1996; Matt and Wolff, 2004). A researcher’s ability to secure grants has been strongly linked to the reputation and ability of the researcher (Bozeman and Corley, 2004). When people work collaboratively, they tend to make better and smarter decisions and be more innovative (Sawyer, 2007; Surowiecki, 2004). University labs that get more funding from industry are said to be lagging “behind the knowledge frontier” (Carayol, 2003, p. 905). This could suggest that less collaboration is present in industry-supported university labs.

Industrial actors often are the instigators of academic collaboration by bringing projects and funds to a university (or multiple universities) that result in an increase in the number of collaborators. While it is evident that actions by industry will inspire more collaboration in some cases, the proposition in this paper is that the net influence of industry on academic collaborations due to secrecy and confidentiality will eventually produce a decrease in academic collaboration. The effects of the university’s involvement with industry could add an additional layer of restrictions on an academic scientist’s ability to collaborate and communicate. Consequently, I expect to find a negative relationship between the university’s actions (measured via the amount of industrial R&D funded expenditures at the institution) and the number of academic collaborators.

*H3: Increases in the university’s level of industrial R&D funded expenditures will lower the net number of academic collaborators.*

## Description of Data and Variables Used in Analysis

The dataset used in this paper was collected by the Research Value Mapping (RVM) Program, between 2004 and 2005, under the direction of principal investigator Barry Bozeman and housed at the Georgia Institute of Technology. The project received support from the National Science Foundation and the Department of Energy. The survey sample was stratified by academic discipline, academic rank, and gender. The resulting sampling frame included 4,916 individuals.

Implementation of the RVM survey conformed to the tailored design method, as specified by Dillman (2000). The survey was completed over three waves. A wave analysis of responses was done, which correlated survey items with the three survey waves. The wave analysis "indicated no significant differences in response patterns by either wave or date received, indicating that non-respondents, who are theoretically more like late or third wave respondents, are not significantly different than respondents" (Bozeman and Gaughan, 2007).

The survey sampling frame targeted "scientists and engineers in tenure-track academic positions" at Carnegie Doctoral/Research Universities (Research Value Mapping Program, 2005). Once the doctoral/research universities were indentified, further refinement of the sample was done by determining which universities offered science and technology doctorate degrees, using NSF field definitions (resulting number of schools n= 150). The 13 academic disciplines/fields this survey drew upon for respondents include: Biology, Computer Science, Math, Physics, Earth and Atmospheric Science, Chemistry, Agriculture, Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, Materials Engineering, and Sociology.

Two hundred responses were sought from men and 200 women for each field in the RVM survey. The sampling goal was not obtainable for some fields were it was established that fewer than 200 women were employed. Race and R&D rank stratification were not taken on in the survey design.

The lack of weighting may prove problematic because of the oversample of women in the dataset. However, unequal sample done in the survey does not affect the theoretical basis of my models, and consequently I do not believe that this will be an issue. Weighting has been shown to be unnecessary when the weights are functions of the independent variables only, which is the case in this paper (Winship and Radbill, 1994). Consequently, it should not necessary to use weighted models. The oversampling of women in the survey results in half of the respondents being female, where the actual population parameter (in 1995 for tenured and tenure-track women in the Carnegie Research Extensive universities was 17% (National Research Council, 2001). All of this paper’s models control for this sample selection factor, producing unbiased estimates (Winship and Radbill, 1994).

The survey had a response rate of 38 percent. The non-response bias analysis implies that male university scientists had a lower likelihood of responding than females. This analysis also showed that following disciplines were less likely to respond to the survey: computer science, mathematics, biology, and electrical engineering. By including both gender and discipline in all of the models in this paper, omitted variable bias in the results is reduced.

Data about the institutions housing the surveyed scientists was added to the original dataset from the 2003 NSF Survey of R&D Expenditures at Universities and Colleges (via the NSF WebCASPAR database).

## Dependent Variables

The primary dependent variable used in this paper is the total number of academic collaborators (faculty and students) that the researcher has had over the last year. This variable is comprised of four separate measures of collaboration: the number of male university faculty, the number of female university faculty, the number of current male graduate students, and the number of current female graduate students.

The second dependent variable is the total number of collaborators. This variable will be the summation of: the number of academic collaborators (graduate students and faculty members) plus the number of current other collaborators.

## Independent Variables

There are several independent variables of interest. For the first hypothesis (H1) the primary independent variable measures the percentage of total research-related work time spent "Working with researchers in U. S. industry."

Hypothesis (H2) investigates the extent to which the intensity of involvement between an academic and industry influences the number of academic or total collaborators. The primary independent variable of interest for H2 is a weighted industrial involvement scale, also used by

Bozeman and Gaughan (2007) and Ponamariov (2008). The weights for this scale are created for this analysis in the same way they were created in those other analyses, which is by “examining the percentages for each industrial interaction items [in the survey of scientists] and then using the inverse as a weight” (Bozeman and Gaughan, 2007, p. 702). The scale is “constructed by summing the weighted variables measuring whether or not the respondents have engaged in one or more of the particular interactions with the private sector” (Ponamariov, 2008). The questions that make up the complexity score are: “Persons from a private company have asked for information about my research and I have provided it;” “I contacted persons in industry asking about their research or research interests;” “I served as a formal paid consultant to an industrial firm;” “I helped place graduate students or post-docs in industry jobs;” “I worked at a company with which I am owner, partner or employee;” “I worked directly with industry personnel in work that resulted in a patent or copyright;” “I worked directly with industry personnel in an effort to transfer or commercialize technology or applied research;” and “I co-authored a paper with industry personnel that has been published in a journal or refereed proceedings.” Individually, all eight variables take on values of either 0 (no work with private sector in this capacity) or 1 (yes they have worked with the private sector in this capacity).

To study the influence of industrial R&D expenditures on academic collaboration (H3), I will use institutional level data, industry-financed R&D expenditures at a university, in millions of dollars for FY2003. These data are part of the 2003 NSF Survey of R&D Expenditures at University & Colleges.

Control variables that are use in all models include: the scientists' participation in a research center, age, marital status, gender, number of children, tenure status, academic discipline, and an institutional control.

It has been demonstrated in a number of previous studies that collaborative behavior is influenced by participation in a university research center (Boardman and Bozeman, 2007; Boardman and Ponomariov, 2007). In center-based research, academic scientists are more likely to be exposed to industrial collaborators, in addition to collaborators from other disciplines within their university. The variable is coded such that being affiliated with a research center is equal to one, not being affiliated with a center is equal to zero.

Age has been shown to change the pattern of collaboration (Liang et al., 2001; Smeby and Try, 2005). The variable for the scientist's age will capture physical age, stature, and experience. This variable takes on a value equal to the respondent's age in 2005. Previous works focusing on gender in academic science has shown females are less likely to collaborate than men (Hagstrom, 1965). A more recent study also found that, in general, productivity in academic science varies according to the gender of the scientist (Long, 1990). This differentiation in productivity might have implications for collaboration. The gender of the survey respondents will be controlled for using a dichotomous variable, where Female=1 and Male=0. This variable will be used to explore the differences between men and women in the study. Long (1990) finds that marriage provides a boost to productivity to researchers, and thus one might conclude that it influences the number of collaborations as well. The marital status variable is coded such that married respondents are equal to 1, while those respondents who are currently unmarried are assigned a value of zero. Further, as one might expect, adding children to marriage has been shown to decrease women’s research productivity (Long, 1990). As a result, the number of children is also used as a control.

Two variables capturing information on the tenure status of the scientists are included because “those with tenure have developed increased levels of S&T human capital which both require and enable additional collaboration” (Bozeman and Corley, 2004, p. 604). Those scientists more advanced in their careers, and perhaps holding supervisory positions, are ideally situated to direct resources and the research agenda (Avkiran, 1997). Assistant professors are the least likely to collaborate and full professors the most likely (Piette and Ross, 1992; Ostrom, 2000). More specific to academic-industry collaborations, it has been shown that more junior faculty tend to devalue commercial ventures (Boardman and Ponomariov 2007), making them less likely to collaborate with industry. The two variables used to control for tenure in this paper are made up of two dichotomous variables: Full Professor and Associate Professor. Those that have not attained tenure are the omitted category. The expectation is that collaboration will increase as rank increases.

A number of studies have shown that collaborative practices and norms differ by academic discipline (Clarke, 1974; Meadows, 1974; Hargens, 1975; Frame and Carpenter, 1979; Stefaniak, 1982; Avkiran, 1997; Beaver, 2001; Garg and Padhi, 2001; Liang et al., 2001; Wagner-Döbler, 2001; Moody, 2004; Gulbrandsen and Smeby, 2005; Toomela, 2007). To control for discipline, NSF definitions of S&T fields are used to classify the academic disciplines in the dataset used in this analysis (Research Value Mapping Program, 2005). The disciplines included in the data are: Biology, Computer Science, Mathematics, Physics, Earth and Atmospheric Science, Chemistry, Agriculture, and all Engineering fields (which include

Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, and Materials Engineering). A dummy variable is used for each discipline, with Physics (often seen as the most collaborative of all of the sciences) as the omitted category.

The scientist's home institution plays an important role in the collaborative behavior (Kraut et al., 1988; Katz, 1992; Smith and Katz, 2000; Garg and Padhi, 2001; Turner and Mairesse, 2004; Ponomariov, 2008). The institutional control variable used in this paper measures the percent of a university's research funds that are federally financed. These data come from the 2003 NSF Survey of R&D Expenditures at Universities and Colleges. This variable is the quotient of Federally Financed Academic R&D Expenditures by Total Academic R&D Expenditure. It is expected to have a positive influence on the number of collaborators.

Table 1 provides the descriptive statistics for all dependent and independent variables used in this paper's models.

| Table 1: Descriptive Statistics | # of Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| Dependent Variables | | | | | |
| Total Number of Academic Collaborators | 1537 | 9.842 | 8.275 | 0 | 113 |
| Total Number of Collaborators | 1537 | 11.633 | 11.488 | 0 | 158 |
| Independent Variables | | | | | |
| Spends Any Amount of Research Time with U.S. Industry | 1537 | 0.340 | 0.474 | 0 | 1 |
| % of time Working with researchers in U. S. industry | 1537 | 3.093 | 6.049 | 0 | 50 |
| Industrial Involvement Scale | 1537 | 1.076 | 1.435 | 0 | 6.586 |
| Industry Financed Academic R&D Expenditures (in Mill. $) | 1537 | 16.461 | 18.214 | 0 | 122.181 |
| Affiliated with a Research Center | 1537 | 0.310 | 0.463 | 0 | 1 |
| Age (in years) | 1537 | 48.397 | 10.457 | 28 | 83 |
| Married | 1537 | 0.859 | 0.348 | 0 | 1 |
| Female | 1537 | 0.519 | 0.500 | 0 | 1 |
| # of Children | 1537 | 0.873 | 1.097 | 0 | 10 |
| Full Professor Status | 1537 | 0.466 | 0.499 | 0 | 1 |
| Associate Professor Status | 1537 | 0.267 | 0.443 | 0 | 1 |
| Physics | 1537 | 0.092 | 0.289 | 0 | 1 |
| Biology | 1537 | 0.080 | 0.271 | 0 | 1 |
| Computer Science | 1537 | 0.084 | 0.277 | 0 | 1 |
| Math | 1537 | 0.066 | 0.248 | 0 | 1 |
| Earth and Atmospheric Science | 1537 | 0.103 | 0.304 | 0 | 1 |
| Chemistry | 1537 | 0.086 | 0.280 | 0 | 1 |
| Agricultural Sciences | 1537 | 0.083 | 0.275 | 0 | 1 |
| Engineering: All Fields | 1537 | 0.407 | 0.491 | 0 | 1 |
| % of Total University R&D Funding that is Federally Sourced | 1537 | 57.769 | 15.956 | 22.781 | 96.168 |

### Method of Analysis

This analysis uses two dependent variables, the total number of collaborators and the number of academic collaborators. As raw counts of collaborations, both dependent variables present themselves as candidates for use with a negative binomial model rather than OLS. The dependent variables are both skewed and thus not ideally suited for OLS. Collaborative authorship, as noted by Beaver (2001), follows “a Poisson distribution, signifying a relatively rare event, gradually tending to a negative binomial distribution as collaboration became more frequent" (p. 367). The models in this analysis do not model collaborative authorship but it could be expected that other measures of collaboration would follow a similar distribution. A negative binomial may be preferable to the Poisson because the dispersion of the data in this case indicate that the sample variance will exceed the sample mean, an indicator that the Poisson will become inefficient (Long, 1997). Initial statistical tests of the dependent variables, total collaborators, and total academic collaborators show a lack of constant variance. Thus heteroskedasticity may be present, and, as a consequence, robust standard errors are used in all models as an attempt to correct this potential problem.

To examine the question posed in H1, whether or not an increase in collaboration with industry decreases the number of collaborators (academic or all types), four models (Models 1-4) are used. The number of academic collaborators is used as the dependent variable in Models 1 and 3, while the total number of collaborators is used as the dependent variable in Models 2 and 4. Models 1 and 2 use the full sample of observations, while Models 3 and 4 use only observations in which the respondents indicated that they were working with researchers in U. S. industry.

The second hypothesis (H2) looks at how the intensity of a researcher's involvement with industry influences how he or she collaborates with other academic scientists. Model 5 assesses the level of involvement using the number of academic collaborators as the dependent variable and only uses the observations of scientists who are actively involved in industrial collaboration.

To investigate H3, which looks at how an increase in industrial R&D funding influences academic collaborations, Model 6 uses the number of academic collaborators in the full sample of all scientists, while Model 7 uses only observations in which the respondents indicated that they were working with researchers in U. S. industry. The full sample (in Model 6) and the smaller sample of just those working with industry (Model 7) are included in the examination of this hypothesis to be able to capture the possibility of a wider influence of funding to the institution, which might influence even those that are not participating in academic-industrial collaborations.

## Results

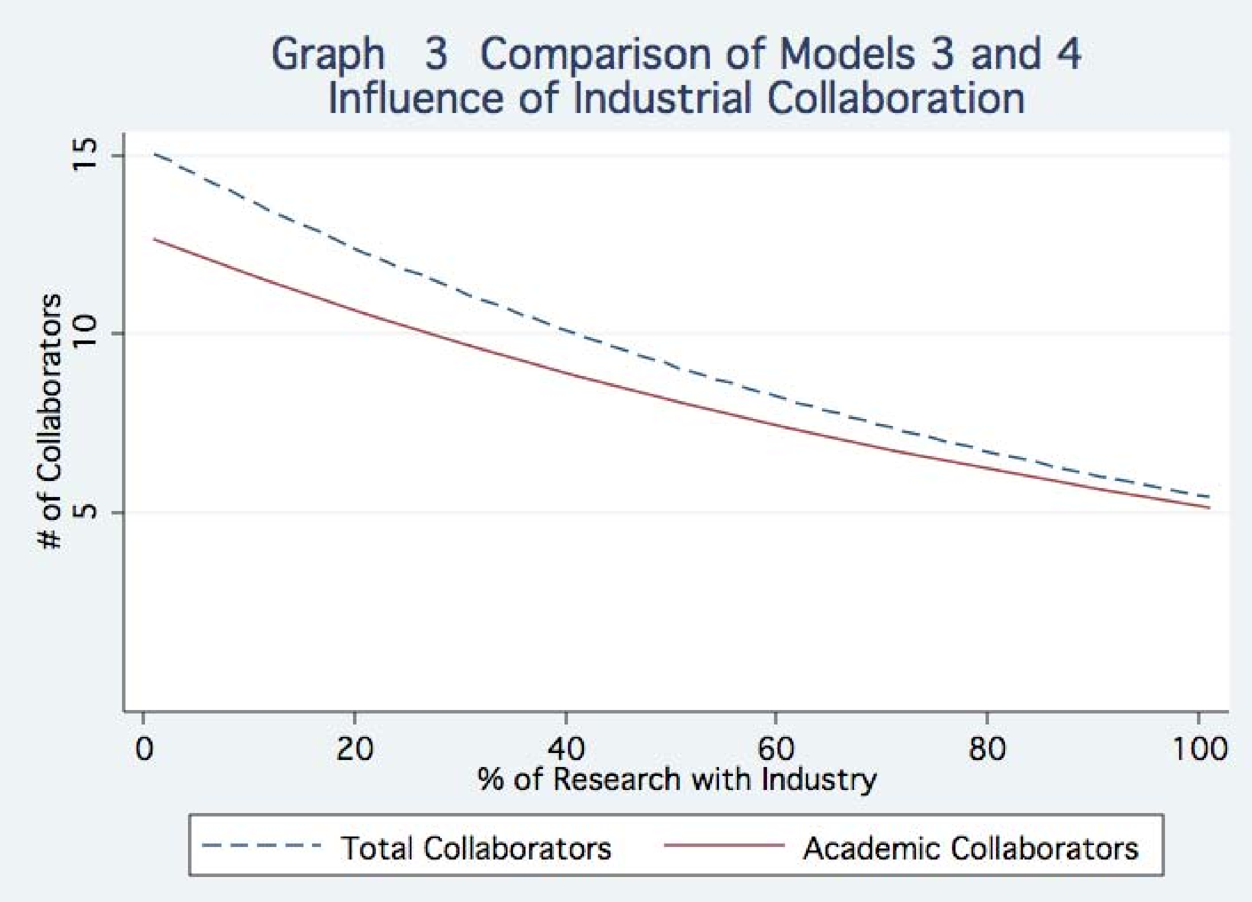
*H1: Increases in collaboration with industry will decrease levels of collaboration with academics and decrease the overall level of collaboration.*

The results in Table 2 indicate that any amount of academic-industrial collaboration can lead to an increase in the expected number of academic and total collaborators. Models 1 and 2 show that working with industry increases the expected number of collaborators 26 and 33 percent respectively. This, however, does not fully answer the question of whether an increasing amount of industrial collaboration leads to an increasing or decreasing amount of collaboration. The results in Table 3 provide more substantive answers to this question. Since it has been established that those working with industry (about 1/3 of the total sample) and those who do not work with industry (about 2/3 of the sample) have significantly different patterns of collaboration, it is appropriate to look at the sub-sample that includes only those who are actively engaged in academic-industrial collaboration. Models 3 and 4 show that increases in the amount of research time spent with industrial partners leads to decreases in both academic and total collaborators.  For each percent increase in the amount of time working with industry, a 0.9 percent decrease in the expected count of academic collaborators is seen, and a 1 percent decrease in the number of total collaborators can be observed. This finding is consistent with the proposed hypothesis. Graph 3 provides a graphic representation of the differences between Models 3 and 4. It shows the expected number of academic collaborators (Model 3) and total collaborators (Model 4).

| Table 2 | (1) | | (2) | |
|---|---|---|---|---|
| All Models Use Negative Binomial | DV-# Academic Collaborators | % change in expected count for unit increase in X | DV-# Total Collaborators | % change in expected count for unit increase in X |
| Spends Any Amount of Research | 0.2 | 26.3 | 0.3 | 32.9 |
| Time with U.S. Industry | [0.0402]*** | | [0.0431]*** | |
| Affiliated with a Research Center | 0.3 | 28.7 | 0.3 | 30.7 |
| | [0.0397]*** | | [0.0459]*** | |
| Age (in years) | 0.0 | -2 | 0.0 | -1.8 |
| | [0.0030]*** | | [0.0032]*** | |
| Married | 0.1 | 9.2 | 0.1 | 12.1 |
| | [0.0657] | | [0.0646]* | |
| Female | 0.1 | 7.3 | 0.1 | 11.2 |
| | [0.0388]* | | [0.0436]** | |
| # of Children | 0.0 | -4.2 | -0.1 | -5.7 |
| | [0.0186]** | | [0.0182]*** | |
| Full Professor Status | 0.4 | 55.3 | 0.4 | 54.5 |
| | [0.0699]*** | | [0.0718]*** | |
| Associate Professor Status | 0.2 | 20.2 | 0.2 | 17.5 |
| | [0.0499]*** | | [0.0514]*** | |
| Biology | -0.4 | -33.6 | -0.7 | -48.6 |
| | [0.1323]*** | | [0.1532]*** | |
| Computer Science | -0.1 | -13.1 | -0.4 | -35.7 |
| | [0.1152] | | [0.1358]*** | |
| Math | -0.7 | -51.3 | -0.9 | -61 |
| | [0.1354]*** | | [0.1834]*** | |
| Earth and Atmospheric Science | -0.1 | -12.1 | -0.4 | -33.4 |
| | [0.1179] | | [0.1395]*** | |
| Chemistry | -0.3 | -25.4 | -0.6 | -43.8 |
| | [0.1198]** | | [0.1406]*** | |
| Agricultural Sciences | -0.2 | -15.1 | -0.5 | -37.4 |
| | [0.1163] | | [0.1379]*** | |
| Engineering: All Fields | -0.1628 | -15 | -0.4763 | -37.9 |
| | [0.1064] | | [0.1285]*** | |
| % of Total University R&D Fundi | -0.0017 | -0.2 | -0.0008 | -0.1 |
| that is Federally Sourced | [0.0011] | | [0.0013] | |
| Constant | 3.0572 | | 3.2859 | |
| | [0.1951]*** | | [0.1995]*** | |
| Observations | 1538 | | 1538 | |
| Robust standard errors in brackets | | | | |
| * significant at 10%; ** significant at 5%; *** significant at 1% | | | | |

| Table 3: Test of H1 | (3) | | (4) | |
|---|---|---|---|---|
| All Models Use Negative Binomial | DV-# Academic Collaborators | % change in expected count for unit increase in X | DV-# Total Collaborators | % change in expected count for unit increase in X |
| % of time Working with researchers in U. S. industry | -0.0090 | -0.9 | -0.0102 | -1.0 |
| | [0.0033]*** | | [0.0033]*** | |
| Affiliated with a Research Center | 0.2197 | 24.6 | 0.2240 | 25.1 |
| | [0.0517]*** | | [0.0553]*** | |
| Age (in years) | -0.0212 | -2.1 | -0.0181 | -1.8 |
| | [0.0041]*** | | [0.0043]*** | |
| Married | 0.0673 | 7.0 | 0.0095 | 1.0 |
| | [0.0802] | | [0.0896] | |
| Female | 0.0523 | 5.4 | 0.0746 | 7.7 |
| | [0.0515] | | [0.0554] | |
| # of Children | -0.0160 | -1.6 | -0.0173 | -1.7 |
| | [0.0198] | | [0.0200] | |
| Full Professor Status | 0.4797 | 61.6 | 0.4009 | 49.3 |
| | [0.0771]*** | | [0.0916]*** | |
| Associate Professor Status | 0.2499 | 28.4 | 0.2009 | 22.2 |
| | [0.0676]*** | | [0.0733]*** | |
| Biology | 0.2477 | 28.1 | -0.2660 | -23.4 |
| | [0.3527] | | [0.4473] | |
| Computer Science | 0.1790 | 19.6 | -0.3921 | -32.4 |
| | [0.1587] | | [0.3250] | |
| Math | -0.2531 | -22.4 | -0.8105 | -55.5 |
| | [0.2040] | | [0.3421]** | |
| Earth and Atmospheric Science | 0.1089 | 11.5 | -0.4308 | -35.0 |
| | [0.1743] | | [0.3302] | |
| Chemistry | -0.0227 | -2.2 | -0.6040 | -45.3 |
| | [0.1692] | | [0.3286]* | |
| Agricultural Sciences | 0.0263 | 2.7 | -0.5658 | -43.2 |
| | [0.1556] | | [0.3186]* | |
| Engineering: All Fields | 0.0984 | 10.3 | -0.4885 | -38.6 |
| | [0.1433] | | [0.3170] | |
| % of Total University R&D Funding that is Federally Sourced | -0.0045 | -0.4 | -0.0028 | -0.3 |
| | [0.0015]*** | | [0.0017]* | |
| Constant | 3.2631 | | 3.8495 | |
| | [0.2777]*** | | [0.3914]*** | |
| Observations | 523 | | 523 | |
| Robust standard errors in brackets | | | | |
| * significant at 10%; ** significant at 5%; *** significant at 1% | | | | |

| Table 4: Test of H2 and H3 | (5) | | (6) | | (7) | |
|---|---|---|---|---|---|---|
| All Models Use Negative Binomial | DV-# Academic Collaborators | % change in expected count for unit increase in X | DV-# Academic Collaborators | % change in expected count for unit increase in X | DV-# Academic Collaborators | % change in expected count for unit increase in X |
| Industrial Involvement Scale | 0.0956 | 10.0 | | | | |
| | [0.0150]*** | | | | | |
| Industry Financed Academic | | | 0.0502 | 5.2 | 0.0596 | 6.1 |
| R&D Expenditures (in Million $) - Logged | | | [0.0186]*** | | [0.0263]** | |
| Affiliated with a Research Center | 0.1911 | 21.1 | 0.2667 | 30.6 | 0.2209 | 24.7 |
| | [0.0504]*** | | [0.0393]*** | | [0.0530]*** | |
| Age (in years) | -0.0207 | -2.0 | -0.0213 | -2.1 | -0.0213 | -2.1 |
| | [0.0040]*** | | [0.0031]*** | | [0.0041]*** | |
| Married | 0.0722 | 7.5 | 0.0926 | 9.7 | 0.0766 | 8.0 |
| | [0.0784] | | [0.0622] | | [0.0796] | |
| Female | 0.0950 | 10.0 | 0.0618 | 6.4 | 0.0623 | 6.4 |
| | [0.0508]* | | [0.0393] | | [0.0513] | |
| # of Children | -0.0163 | -1.6 | -0.0346 | -3.4 | -0.0093 | -0.9 |
| | [0.0193] | | [0.0183]* | | [0.0199] | |
| Full Professor Status | 0.4124 | 51.0 | 0.4648 | 59.2 | 0.4620 | 58.7 |
| | [0.0757]*** | | [0.0700]*** | | [0.0782]*** | |
| Associate Professor Status | 0.1985 | 22.0 | 0.1984 | 21.9 | 0.2498 | 28.4 |
| | [0.0639]*** | | [0.0503]*** | | [0.0680]*** | |
| Biology | 0.2608 | 29.8 | -0.3942 | -32.6 | 0.2303 | 25.9 |
| | [0.3471] | | [0.1347]*** | | [0.3492] | |
| Computer Science | 0.1521 | 16.4 | -0.0586 | -5.7 | 0.1550 | 16.8 |
| | [0.1621] | | [0.1147] | | [0.1608] | |
| Math | -0.1969 | -17.9 | -0.7105 | -50.9 | -0.2756 | -24.1 |
| | [0.2071] | | [0.1333]*** | | [0.2211] | |
| Earth and Atmospheric Science | 0.1310 | 14.0 | -0.1141 | -10.8 | 0.1172 | 12.4 |
| | [0.1755] | | [0.1166] | | [0.1724] | |
| Chemistry | -0.0170 | -1.7 | -0.2429 | -21.6 | -0.0175 | -1.7 |
| | [0.1733] | | [0.1182]** | | [0.1698] | |
| Agricultural Sciences | -0.0261 | -2.6 | -0.0674 | -6.5 | -0.0027 | -0.3 |
| | [0.1603] | | [0.1143] | | [0.1583] | |
| Engineering: All Fields | 0.0539 | 5.5 | -0.0741 | -7.1 | 0.0706 | 7.3 |
| | [0.1486] | | [0.1041] | | [0.1468] | |
| % of Total University R&D Funding | -0.0043 | -0.4 | -0.0015 | -0.2 | -0.0039 | -0.4 |
| that is Federally Sourced | [0.0015]*** | | [0.0011] | | [0.0016]** | |
| Constant | 2.9924 | | 2.9532 | | 3.0194 | |
| | [0.2787]*** | | [0.2045]*** | | [0.2880]*** | |
| Observations | 523 | | 1537 | | 523 | |
| Robust standard errors in brackets | | | | | | |
| * significant at 10%; ** significant at 5%; *** significant at 1% | | | | | | |



Looking to the influence of the control variables on the number of academic and total collaborators, Models 3 and 4, the affiliation with a research center is consistently a significant influence on increasing the number of collaborators, leading to approximately a 25 percent increase in the expected count of collaborators in both models. This finding was predicted and expected. The age variable shows a consistent negative influence on the number of collaborators in both Model 3 and 4. This is the expected result, as we tend to collaborate less the older we get. Being married does not seem to influence the number of collaborators, as it is not a significant variable in any of these models[2]. The results show that being female does not have a

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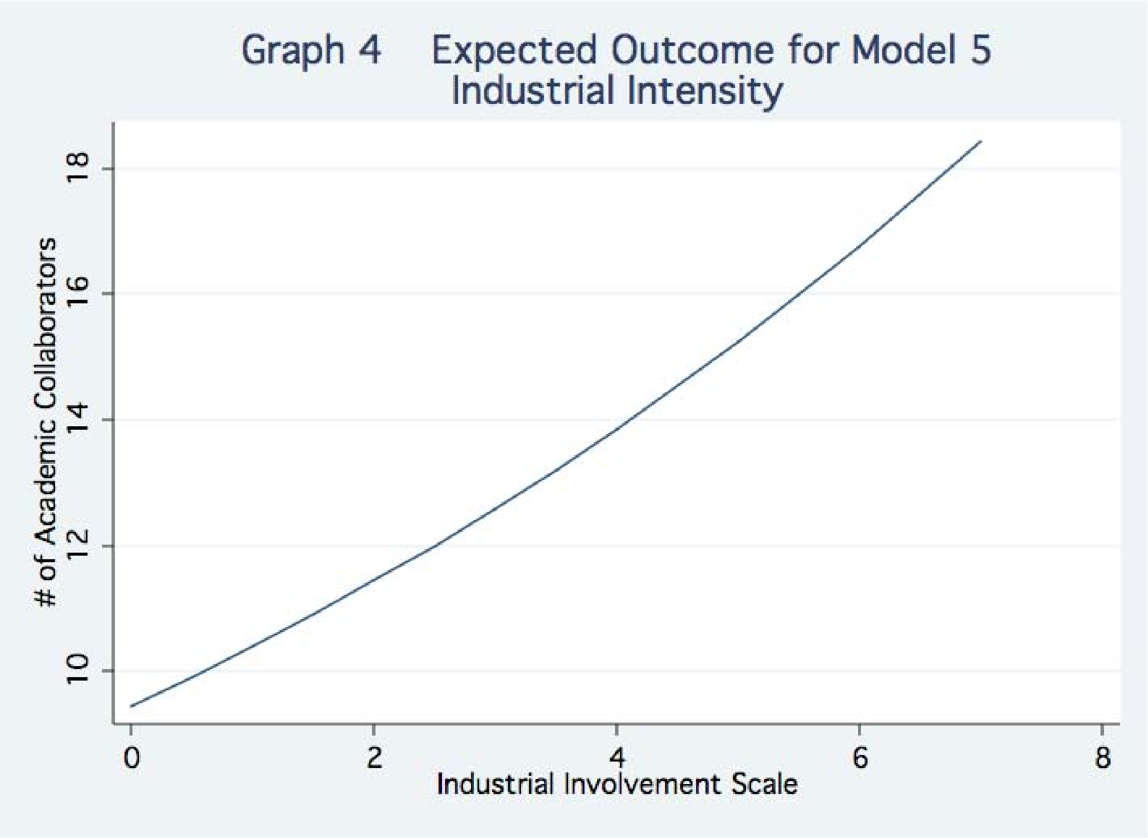
[2] Running Model 3 with an interaction term between female and married also shows no significant results (full results of that model have been omitted). Long (1990) had previously shown the influence of marriage was greater on females than males.

significant influence on the number of collaborators. The number of children does not seem to influence the number of collaborators either. The two tenure variables provide further evidence that more senior faculty members (full professors and associate professors) do have more collaborators than their non-tenured colleagues. The discipline variables demonstrate that there is variation between the number of collaborators and the disciplines. All significant individual discipline variables show the trend of physicists collaborating more than academics in other disciplines. And finally, the proportion of R&D funding that is federally sourced does have a significant influence, indicating that an increase in the percent of federally sourced R&D expenditures decreases the number of collaborators (Models 3 and 4).

*H2: The more complex the involvement of a researcher with industry the less they will collaborate with other academics.*

Model 5, seen in Table 4, examines the question posed in H2. The results in this model indicate that an increase in the industrial involvement scale leads to an increase in the expected number of academic collaborators. The results show that a one-unit increase in the industrial involvement scale leads to a 10 percent increase in the expected number of academic collaborators. Graph 4 provides a graphical representation of the expected number of academic collaborators across the spectrum of values of the industrial involvement scale. It shows a slightly exponentially shaped curve increase as the values of the involvement scale increase. From the graph it is possible to see that the expected number of academic collaborators is equal to a value slightly more than 9 when there is no involvement with industry. The expected number of academic collaborators increases to about 17 when the involvement is at 6 (highly involved).

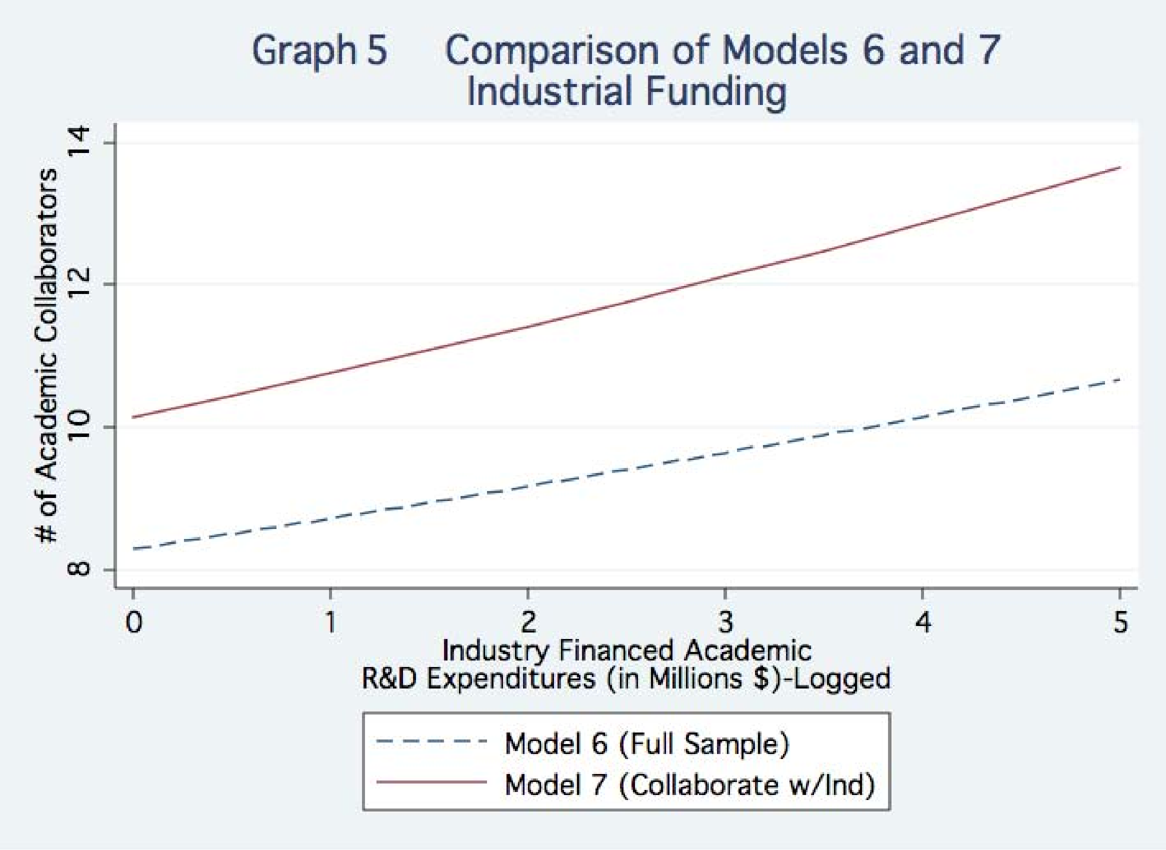


The influences of the control variables in Model 5 are similar to those found in the other models. They show that an affiliation with a research center has a positive influence on the number of academic collaborators. Age also is shown to have a significant negative influence on the number of academic collaborators. Marriage, as was the case in Models 3 and 4, does not have a significant influence on the number of academic collaborators in Model 5. The female variable is again marginally significant, at a 10 percent significance level. This result is likely due to the women in the sample being significantly younger than the men. Age has consistently shown to hinder collaboration; the men in this sample have an older mean age than the women, and, as one might expect, we see them collaborate less than the women. Again, the number of children does not have a significant influence on the number of collaborators. Tenure status is showing, again, to have a significant influence on the number of academic collaborators. Full professors and associate professors both have more collaborators than the non-tenured faculty members. The discipline effects are again showing what is expected: physicists collaborate more than the other disciplines. And, finally, the proportion of R&D funding at a university that is federally sourced is significant, and again shows that increases in the federally sourced funding lead to a decrease in the expected number of academic collaborators.

*H3: Increases in the university's level of industrial R&D funded expenditures will lower the net number of academic collaborators.*

In both Models 6 and 7 (found in Table 4), the results indicate that as the amount of industrial R&D funded expenditures at a university increase, the number of academic collaborators increases. The results in both models are contrary to what was hypothesized. In Model 6, the full sample model, a one percent increase in industry funded R&D, results in a 5.2 percent increase in the expected number of academic collaborators. Looking at only those involved in industrial collaboration (Model 7), we see similar results, where a one percent increase produces a 6.1 percent increase in the expected number of academic collaborators. Looking at only those involved in industrial collaboration (Model 7), we see similar results, where a $1 million increase produces a 0.3 percent increase in the expected number of academic collaborators. Graph 5 compares the expected outcomes from Models 6 and 7. In that graph it is possible to see that the expected number collaborators are higher for all values of R&D

expenditures in Model 7, as would be expected since Model 6 is weighed down by people who do not collaborate at all with industry, and thus could not be influenced by them.



The influence of the control variables in Models 6 and 7 are consistent with those seen in all of the previous models. Affiliation with a research center has a significant positive influence on the number of academic collaborators. Age, again, has a negative influence on the number of academic collaborators. Marriage, once again, does not prove to have a significant influence on the number of academic collaborators. The variable tracking the gender of the respondent is not significant in either Model 6 or 7. The number of children is significant in Model 6, showing that for each additional child there is a 3.4 percent decrease in the expected number of collaborators; the variable is not significant in Model 7. Full professors and associate professors again have more academic collaborators than their untenured colleagues.  The discipline controls show academics in physics collaborating more than in the other disciplines, along with showing variations in the number of academic collaborators between the disciplines. Finally, the percent of an institution's R&D expenditures that are federally sourced is not a significant variable in Model 6, but it is significant in Model 7, in which increases in the percent of R&D funding that is federally sourced decreases the expected number of academic collaborators.

## Conclusion

Generally speaking, collaborating with industry has a positive influence on the expected number of academic and total collaborators, as was shown in Models 1 and 2. The efforts to enhance collaboration by linking up academics and industry do appear to be having the intended effect. By providing these academics with greater access and greater diversity in their funding sources, as Heffner (1981) noted, we are giving them greater access to the complex and expensive equipment that often requires more collaborators.

Another story that seems to emerge from the findings in Models 1 and 2 is that by collaborating with industry, would increase the likelihood of diverting an academic's attention from more traditional academic outputs (Landry, et al., 1996).  As a consequence, scholars are seeking out more collaborators to maintain their level of productivity in outputs that are more highly valued in academia. It has been noted that the reality of science today, and in fact other areas of the economy as well, is that collaboration with industry is the foundation for success (Norwegian Ministry of Trade and Industry, 2003).  The findings in this paper could also be viewed as a demonstration of the pragmatism of academic science; recognition of the importance of getting their ideas to the market is vital to the survival of scientists.

A secure future for academic science is going to be linked to scientists' ability to maintain constant streams of funding. Debackere and Veugelers (2005) have noted that those universities that are successful in their relationships with industry are those with a balance of funding from differing sources. The federal support of basic science is become less and less adequate, and often excessively burdensome, such that it is hard for many labs to operate (Guston and Keniston, 1994). Accordingly, it is no surprise that academic scientists would be motivated to collaborate with other sectors. The desire to work with other sectors is met by an industrial sector that has become increasingly reliant on academia for their research (Adams, et al, 2005; Antonelli, 2008). Thus, by searching for other sources of funding, the academic scientists expand their network of collaborators. This demonstrates the catalytic effect, identified by Ponomariov and Boardman (2008), which is the result of academic-industrial interactions, creating more opportunities for within and outside of academia.

However, when we dissect the larger group (scientists that were surveyed), and conduct a more detailed look at the influence that academic-industrial collaboration is having on those actively involved in collaboration, the picture changes. The picture that emerges from Models 3 and 4 shows that increasing the time devoted to industrial collaboration decreases the expected number of academic and total collaborators. This finding is consistent with others (see Blumenthal, et al., 1996b) that have seen higher levels of collaborations with industry leading to fewer collaborators.

The narrative that seems to be arising from the findings in this paper is that that the layers of mandates that are extensions of the academic-industrial collaboration—secrecy, data embargos, and restrictions on communication (Louis et al., 2001; Blumenthal, et al., 1996; Campbell, et al., 1998; Schachman, 2000)—can all lead a scientist to have fewer collaborations. These limitations, Schachman (2000) notes, may not be the consequence of an explicit request from industry, but, rather, self imposed by the academic or his or her university.

Looking to the question of intensity of involvement between academia and industry, not only are we not seeing a decrease in the expected number of collaborators as the intensity of the relationship increases, but it would appear the relationship may be quite the opposite. More persistent collaborations are the result of more complex and intense collaborations (Thune, 2007). I would speculate that the more intense involvement by academic faculty is resulting in better collaborations. Having better and stronger collaborations could be leading to an improved reputation, which would draw more people to work with these individuals. There may also be an element of resources. If these individuals have stronger, more intense involvement with industry, perhaps they are also getting more equipment and resources. As their resource pool increases they will demand an increasing number of collaborators, and attract those without resources to conduct research. While it is not possible to determine if the academics with increasing levels of industry support are in falling behind in the knowledge frontier (as has been proposed by Carayol, 2003), what can be seen is that they are not falling behind in terms of collaborators.

The concern at the onset of this paper was that as the government pursued a policy to increase both academic-academic and academic-industrial collaborations, one type of collaborative relationship might fall victim to the other. But the results of this paper indicate that the government can promote both policies, to some extent, without the fear of diminishing the effectiveness of either type of collaboration. The expecting full disclosure of findings under conditions of intense academic-industrial collaboration may not be realistic. Yet with minimal to moderate interaction a scientist's involvement with industry appears to benefit the collaborative profile of the scientist.

Looking finally to the results from H3, it was expected that pressure from a university on its scientists might influence how the scientists are able to communicate and share their work. However, the findings in Models 7 and 8 do not show this to be the case. Instead, what is seen is that increases in support from industry to a scientist's university leads to increases in collaboration. This, like the findings in Models 1 and 2, may be demonstrating that these funds are allowing scientists to buy the expensive and complex equipment that draws in more collaborators, despite any strings that might be attached to their use. This may also be evidence of the freedoms that are at the core of academic science. It could also be evidence, when comparing the results from Models 3 and 4, that the ability to influence collaboration negatively is going to come at the individual level, rather than by fiat from university administrators.

The consequences of this paper's results are that, in part, they seem to unify some seemingly contradictory results from previous studies. On the one hand, academic-industrial collaboration increases collaboration; on the other hand, the results indicate that scientific collaboration with industry results in fewer total collaborations. While these two results may be contrary, they are based on two different levels of collaboration; this enhances our understanding of how industrial support of academic science influences the collaborative behavior of academic scientists. Ultimately, it seems as though a small dose of academic-industrial interaction will not lead to a dampening of the openness of the scientific disciplines. The policy implication that arises from these findings may be that pushing for academic-industrial collaboration is good for science, but that pushing scientists to high levels of collaboration with industry, at the expense of other types of collaborations, will be counterproductive. High levels of collaboration with industry may not be counterproductive for product development and technology transfer; in fact, it is possible that they are good, but such collaboration certainly will influence how those academic scientists interact with other scientists.

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