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Industry Funded Research Impacts on Engineering Faculty's Research Experiences: A Review and Synthesis of the Literature

Mr. Eric Holloway, Purdue University, West Lafayette (College of Engineering)

Eric Holloway currently serves as the Senior Director of Industry Research in the College of Engineering at Purdue University, where he focuses on industry research in the College of Engineering.

From 2007-2013, Eric served as the Managing Director and the Director of Instructional Laboratories in the School of Engineering Education at Purdue University. As Director, he was in charge of the building and implementation of the Ideas to Innovation (i2i) Laboratory, which opened in August 2008 and houses classrooms and laboratories used by the 2000 students in Purdue's First-Year Engineering Program. He oversaw the daily operation of the i2i lab, and was responsible for the personnel, logistics, and technology used in the classroom and labs. Eric also helped build and directed the College of Engineering sponsored Artisan and Fabrication Lab (AFL), which houses a machine shop, carpentry shop, and a prototyping lab used by all students in the College of Engineering for project work. In 2009, he received a New Employee Staff Award of Excellence from the College of Engineering for his work in launching the i2i lab. Eric has served as the university representative on the Haas Technical Education Council, which is committed to developing manufacturing expertise at the high school, trade school, and university level. He received a BSEE from Purdue University in 1992. He has over 15 years of industrial experience, specializing in manufacturing and electronic controls, for which he holds 3 patents. Eric's industrial experience includes positions at Toyota, Cummins, Woodward, and TRW Automotive. He is currently pursuing his PhD in Engineering Education from Purdue, with an expected graduation date of 2020.

Dr. William "Bill" C. Oakes, Purdue University, West Lafayette (College of Engineering)

William (Bill) Oakes is the Director of the EPICS Program and one of the founding faculty members of the School of Engineering Education at Purdue University. He has held courtesy appointments in Mechanical, Environmental and Ecological Engineering as well as Curriculum and Instruction in the College of Education. He is a registered professional engineer and on the NSPE board for Professional Engineers in Higher Education. He has been active in ASEE serving in the FPD, CIP and ERM. He is the past chair of the IN/IL section. He is a fellow of the Teaching Academy and listed in the Book of Great Teachers at Purdue University. He was the first engineering faculty member to receive the national Campus Compact Thomas Ehrlich Faculty Award for Service-Learning. He was a co-recipient of the National Academy of Engineering's Bernard Gordon Prize for Innovation in Engineering and Technology Education and the recipient of the National Society of Professional Engineers' Educational Excellence Award and the ASEE Chester Carlson Award. He is a fellow of the American Society for Engineering Education and the National Society of Professional Engineers.

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Abstract

Participation in industry funded research can have significant impacts on faculty's research experiences. As industry funded research tends to have different characteristics than government funded research, i.e. industry funded research is relatively short term, deadline driven, more applied, and more focused on commercial outputs than government funded research, these characteristics can lead to measurable impacts on faculty research experiences when participating in industry funded research. This is especially true for Engineering at R1 institutions, where industry funded research is a much higher percentage of R&D expenditures than overall industry funded university R&D expenditures (typically 10 - 25% for Engineering alone, compared to about 6 - 8% of the university overall). This paper examines the existing literature for impacts on Engineering faculty's research experiences when participating in industry funded research, including research productivity as measured by publication output, innovation as measured by patent output, and the likelihood for collaboration with others. Results of the literature review will be synthesized for a better understanding of each of these impacted areas and where there are opportunities for further research on the subject.

Tags: industry, research, faculty, engineering, literature review

Introduction

Industry funded research in academia has always been a part of the engineering education landscape, namely by funding graduates students and equipment to help perform the research. Contrary to government funded research, industry funded research is relatively short term, deadline driven, and more applied than government funded research, which tends to focus on basic science (Geuna, 2001). In recent years, concerns about the sources of funding for academic research have increased due to reductions in US government funding for research. While US government funding was once a plentiful source of research funding, possible decreases have turned attention toward other sources of research funding, including industry funding of academic research (Howard, 2013). While industry funded research has always been a part of academic research, limited studies have been conducted to determine the impacts on the faculty involved in industry funded research, particularly in engineering fields where much of the industry funded research occurs.

This paper looks at the existing literature to determine what insights can be gained with regard to the impacts on engineering faculty involved in industry funded research. The paper will examine several impacts of engineering faculty involvement in industry funded research, including research productivity as measured by publication output, innovation as measured by patent output, and the likelihood for collaboration with others. The paper will also discuss how the findings of the literature apply to US faculty in engineering, limitations and gaps in the literature, potential research topics, and finally a summary and future work.

Trends in Current Academic Research Funding

The report Science and Engineering Indicators 2012 (National Science Board, 2012) highlights the following data about sources of academic research funding:

- *The federal government provided 59% ($32.6 billion) of the $54.9 billion of academic spending on S&E R&D in FY 2009.*
- *Industry's % of funding for academic R&D declined steeply after the 1990s, from above 7% in 1999 down to about 5% by 2004, but has seen a 5-year increase to about 6% in 2009.*

While this indicates that industry funded research is relatively low (6% overall in 2009), some US universities within engineering, especially at large R1 schools, receive a considerably higher percentage of their research funding from industry than the overall 6% reported by the NSB report. Using the National Science Foundation's (NSF) Higher Education Research and Development Survey (HERD) from 2014 (https://ncsesdata.nsf.gov/herd/2014/) to evaluate engineering research expenditure data (from industry and overall), Table 1 below ranks the top 12 universities by engineering industry research expenditures and calculates the percentage of engineering industry research expenditures based on total engineering research expenditures. The data presented in Table 1 clearly indicate that industry research support in engineering is much higher than the 6% overall, as the average is more than double (12.5%).

#	US University	Industry Research Expenditures (*)	Total Research Expenditures (*)	Industry % of Total Expenditures
1	MIT	$63.17 M	$403.21 M	15.7%
2	Texas A&M	$50.47 M	$291.64 M	17.3%
3	Ohio State	$39.68 M	$152.59 M	26.0%
4	Texas, Austin	$37.97 M	$206.53 M	18.4%
5	Georgia Tech	$29.67 M	$505.38 M	5.9%
6	UC Berkeley	$27.86 M	$185.95 M	15.0%
7	NC State	$19.15 M	$150.22 M	12.7%
8	Purdue	$19.07 M	$205.55 M	9.3%
9	Michigan	$18.80 M	$251.30 M	7.5%
10	Virginia Tech	$18.62 M	$228.57 M	8.1%
11	Illinois	$17.76 M	$172.83 M	10.3%
12	Stanford	$17.30 M	$132.94 M	13.0%
	Totals	$359.51 M	$2,886.72 M	12.5%

Table 1: 2014 NSF Engineering Research Expenditure Data for Top 12 US Universities, Ranked by Industry Research Expenditures.

(*) note: all numbers reported are for the engineering schools only, not the university overall.

Figure 1 displays the information from Table 1 in a graphical format.

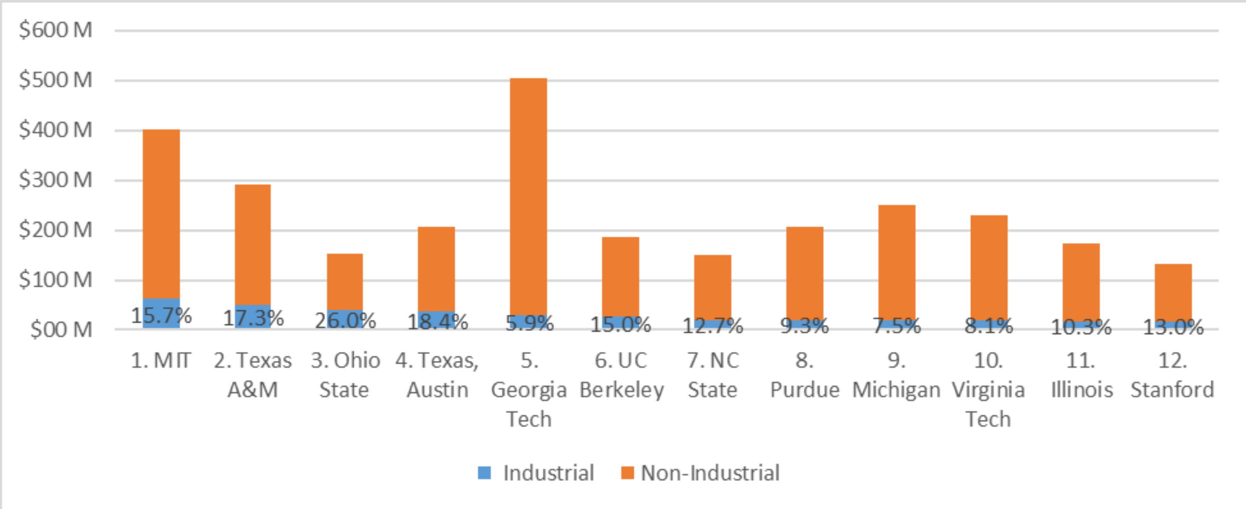

Figure 1: Graph of 2014 NSF Engineering Research Expenditure Data for Top 12 US Universities, Ranked by Industry Research Expenditures.

The fact that industry research support in some areas of engineering is much higher than the national average in other disciplines highlights the need to understand the industry funded research impacts in the engineering even more, especially on faculty, where these impacts are less understood.

Literature Review Approach

The literature reviewed is comprised of the articles listed in Table 2 of the Appendix, with the primary inspiration being the Gulbrandsen and Smeby (2005) article. In this article, Gulbrandsen and Smeby conduct a survey of Norway's four Universities across all disciplines to seek answers to similar issues looked at in this literature review. Among other questions, Gulbrandsen and Smeby look at the following three questions, which inspired the work of this paper; (1) Do professors with industrial funding publish more than professors do without industrial funding? (2) Do professors with industrial funding produce more entrepreneurial output, including patents, than those without industrial funding? (3) Do professors with industrial funding collaborate more frequently than professors do without industrial funding? This motivated the literature review on the following topics of faculty impacts of industry funded research: research productivity as measured by publication output, innovation as measured by patent output, and the likelihood for collaboration with others

The literature review in this paper is organized such that the impacts on faculty publication output will be reviewed first, followed by the impacts on faculty patent output, and finally the impacts on the likelihood of faculty to collaborate with others. A summary of all the literature reviewed is supplied in the Appendix.

Impacts on Faculty Publication Output

From the literature that was reviewed, the impacts of industry funded research on faculty publication output seem to provide mixed results. Some studies find that faculty publication output is impacted positively, some negatively, and some both positively and negatively, depending on funding level.

Godin and Gingras (2000) conducted a metastudy of faculty publications and collaborations compiled from a Canadian bibliometric database from 1980 through 1995 in the areas of science, medicine, and engineering. Among other research questions, they sought to understand the impacts of collaborative research on publication output. They concluded that collaborative research with industry partners has a positive effect on the number of publications produced. Gulbrandsen and Smeby (2005) conducted a survey of all tenured professors in Norway (n=1967) seeking to understand faculty's research profile and behaviors. Based on the results of the survey, they concluded that faculty who have industry funded research report having more scientific publications than faculty who do not. In particular, they find that "industrial funding is strongly correlated with high publication productivities" (2005, p. 947). Van Looy, Ranga, Callaert, Debackere, and Zimmermann (2004) conducted a metastudy from a publication database of the publications of faculty at Catholic University of Leuven, Belgium across the university's 14 divisions, separating those faculty who were involved in industry funded research and those who were not. The researchers found a positive effect on publication output for those faculty who had industry research funding.

However, some studies showed negative impacts on publication output for faculty involved in industry funded research. Two such studies were conducted in the field of genetics. Blumenthal, Causino, and Campbell (1997) surveyed 2167 life science faculty from 1994 – 1995 at the 50 US universities receiving the most federal support from the National Institutes of Health (NIH). One of their research questions was the impact of industry funded research on faculty publication output. They found that specific to the field of genetics, there was a negative impact of industry funded research on faculty publication output, due to industry restrictions of publications to protect trade secrets. Campbell et al. (2002) also found a negative impact of industry funded research on faculty publication output, specific to the field of genetics. They surveyed 1849 life science faculty in 2000 at the 100 US universities receiving the most federal support from NIH to understand the influences and consequences of withholding data. Industry restrictions on publications to protect trade secrets can sometimes be a consequence of industry funded research. Yet negative impacts of industry funded research on publication output can also be found within the broader fields of science and engineering. Hottenrott and Thorwarth (2011) studied 678 science and engineering faculty at 46 different institutions in Germany. They found that faculty "publish less in subsequent years the higher the share of industry funds relative to their overall total budget" (2011, p. 551). The authors acknowledge this may "depend on the institutional setting in Germany where traditionally research has been predominately financed by public resources and where the increase in industry sponsorship had been most significant" (2011, p. 551). Slaughter, Campbell, Holleman, and Morgan (2002) conducted interviews with 37 faculty in science and engineering at R1 and R2 institutions and found that many faculty found that intellectual property concerns from industry often delayed publishing.

Some studies also find both positive and negative effects of industry funded research on publication output. For example, Banal-Estanol, Jofre-Bonet, and Meissner (2010) tracked a longitudinal dataset of engineering faculty publications at two universities in the UK, from 1985 until 2006. They concluded that industry funding positively affects publication output at lower funding levels, and negatively affects publication output at higher funding levels.

Mendoza (2009), in her analysis and critique of academic capitalism literature, provides a good reason why the literature on the impacts of industry funded research on faculty publication output seem to provide mixed results. She argues that the literature "fails to acknowledge for contextual differences, which results in an oversimplification of the effects of industry-academia collaborations" (2009, p. 301).

Impacts on Faculty Patent Output

The literature indicates that the impacts of industry funded research on faculty patent output are clearly positive. Gulbrandsen and Smeby (2005) and Hottenrott and Thorwarth (2011) both found a positive effect of industry funded research on patent output. Gulbrandsen and Smeby find that "industrial funding and collaboration is strongly correlated with producing patents" (2005, p. 947). Hottenrott and Thorwarth find that "professors whose research is supported by industry may not only be more successful in the granting process, but also more visible and relevant for further applications in industry and hence receive more forward citations" (2011, p. 550). Meissner (2011) uses longitudinal data from 475 tenured engineering faculty from UK universities from 1996-2007 to look at researchers propensity to patent. She finds that "UK researchers receiving funding from industry are more likely to produce patents" (2011, p. 15). However, Mendoza (2012), in a case study of a US engineering department heavily involved in industry research where she interviewed 10 faculty members, found that "faculty are not interested in patenting as much as publishing" (2012, p. 39), although the impact on patent output was not stated. No literature could be found that indicates a neutral or negative impact of industry funded research on patent output.

Impacts on the Likelihood of Faculty to Collaborate with Others

From the literature, the impacts of industry funded research on faculty likelihood for collaboration with others provide a clear indication that there is a positive impact. Boardman and Ponomariov (2009) surveyed 1643 engineering and science researchers across US universities from 2003 – 2004 to understand the nature and frequency of academic-industry relationships. They find that "each additional industry grant is shown to increase the likelihood of university scientists co-authoring with industry scientists papers for peer-reviewed journals and conferences" and "industry grants also increase the likelihood of university scientists initiating contact with private companies about research and of their working for companies as paid consultants" (2009, p. 147). As a subset of a larger study, Bozeman and Gaughan (2007) investigated the impacts of research grants on faculty research activities with industry. They used surveys from a representative sample of 1564 US engineering and science faculty. Their findings conclude that faculty who have industry sponsored research collaborate more with industry colleagues than those who do not have industry funded research. Gulbrandsen and Smeby (2005) find that "university professors with funding from companies collaborate a lot more than others with companies and research institutes, but also more with foreign research institutions, the university college sector and with colleagues in their own department" (2005, p. 947). Ponomariov (2009) developed a model from a survey of 1646 faculty in 13 science and engineering disciplines to predict their level of engagement with industry, and found that "that those scientists who have greater involvement with students will be more likely and more able to enter and sustain a variety of interactions with industry" (2009, p. 51). Bozeman, Fay, and Slade (2013) provide a comprehensive literature review of research collaboration in academic entrepreneurship, including industry. They challenge the readers to look beyond co-authorship when looking at collaborations and to look beyond simply outputs when measuring collaborations. While this is interesting advice, it is beyond the scope of this review. No literature could be found that indicates a neutral or negative impact of industry funded research on the likelihood of faculty to collaborate with others.

Discussion of Application to US Engineering Faculty

Applying the findings of this literature to US engineering faculty, which is the population of interest, is challenging. With regard to the impacts of industry funded research on faculty publication output, the results presented in the literature are inconclusive. In addition, most of the results are not from the US, nor specific to engineering. Drawing a conclusion on US engineering faculty is not possible, but lends itself to interesting further research. With regard to the impacts of industry funded research on faculty patent output, it is likely that US engineering faculty, like their European colleagues, would see a positive effect on patent output from industry funded research. However, a research study would need to be done to confirm this result. With regard to the impacts of industry funded research on faculty likelihood to collaborate with others, there is enough evidence from the US that shows this to be the case. A potential research study could be done to confirm this result in engineering.

Limitations and Gaps of the Literature

From the standpoint of focusing on US engineering faculty, there are two significant limitations in the current literature. The first is that most of the studies of industry funded research have not been done in the US. As the US has a very large industry funded research base to study, this provides a significant research opportunity. The second limitation is that most of the studies of industry funded research have not studied engineering in detail. As engineering is one the primary disciplines involved in industry funded research, this again provides a significant research opportunity. These limitations are confirmed by Mendoza's observation that "the vast majority of empirical studies have been conducted with samples of faculty from multiple institutions and disciplines, with almost no consideration given to the unique array of shapes and colors present in each academic tribe and academic unit" (Mendoza, 2009, p. 303).

In addition, several gaps in the literature exist when looking at faculty impacts of industry funded research. Other areas that could (and should) be studied but do not appear much in the literature include the effects of industry funded research on faculty's view of their own research (this was studied by Gulbrandsen and Smeby (2005)), the effects of industry funded research on faculty tenure and promotion, the effects of industry funded research on faculty service work, and the effects of industry funded research on faculty teaching.

Potential Research Topics

Several potential topics for additional research have been identified in this paper, and are summarized here:

- Topic: the US engineering faculty population has not been deeply studied for industry funded research impacts on publication output, patent output, and likelihood of collaboration
- Topic: industry funded research effects on faculty's view of their research
- Topic: industry funded research effects on faculty tenure and promotion
- Topic: industry funded research effects on effects on faculty service work
- Topic: industry funded research effects on effects on faculty teaching

It may be interesting to replicate the survey and analysis done by Gulbrandsen and Smeby (2005) in Norway on a US engineering faculty population. The research questions addressed in their study, as applied to US engineering faculty, would shed interesting light on the effects of industry funded research on faculty careers, and create an interesting comparison between the US and Norway.

Other studies may be done as well. For example, to better understand the effects of industry funded research on faculty in the tenure and promotion process, records of faculty who are considered for tenure and/or promotion could be studied to understand if there is a relationship between the presence or amount of industry funded research and the success of the tenure/promotion case, and the time to tenure and/or promotion. In addition, interviews with members of tenure and promotion committees could be conducted to understand their views and perceptions of the relative value of having industry funded research in a faculty's research portfolio.

Other interesting engineering education research topics related to industry funded research include graduate student topics (several topics similar to as faculty could be studied), as well as comparing engineering faculty against non-engineering faculty.

Summary

Industry funded research is a large part of the US engineering education landscape. At many US universities, in engineering, industry funded research is well above the 6% average of the industry funded research for the university overall. Yet the impacts on research funding on faculty, the intellectual workforce of the university, is not well understood. Areas that are important to understand about faculty, such as publication output, patent output, and likelihood to collaborate with others, and the impacts from industry funded research on those areas, have been studied somewhat by others, mostly in Europe, and not usually in engineering specifically. While the studies that have been done tend to show that industry funded research is inconclusive on publication output at this point, and has a positive impact on patent output and likelihood for collaboration with others, no studies exist that look at specifically at US engineering, so making any conclusions about US engineering faculty is difficult at this time. This, however, lends itself to several interesting potential research topics, including studying the US engineering faculty population, the faculty's view of their research, the effects on faculty tenure and promotion, and effects on faculty service work and teaching.

Future Work

In the future, looking at this from the aspect of expanding the literature review, this literature review can be expanded to look at additional impacts on engineering faculty involved in industry funded research by including items such as interactions with graduate students (mentoring, advising, etc.), interactions with undergraduate students, and a review of what other factors are present in the literature.

Next Steps – Research Results

As this paper is a literature review and is focused on providing a summary and synthesis of the current literature, research results and new findings are not presented in this paper. The main conclusion of this paper, presented earlier, is that there is a gap in the current literature on the impacts of industry funded research on engineering faculty's research experiences from the standpoint that the population of US engineering faculty is under-studied. The next step would be to perform research studies that evaluated this population in detail, which is left to others.

Appendix – Literature Review Summary

The literature used in this paper is summarized in alphabetical order by the author in Table 2 below. Highlighted in the table is the country of the study, the disciplines that were studied, and the key findings related the paper.

Authors (Yr)	Country	Disciplines	Key Findings Related to Paper
Banal-Estanol et al. (2010)	UK	Engineering	<u>Publication output</u>: industry funding positively affects output at lower funding levels, and negatively affects output at higher funding levels.
Blumenthal et al. (1997)	US	Genetics	<u>Publication output</u>: industry funding negatively affects publication output (industry sometimes restricts publications).
Boardman and Ponomariov (2009)	US	Science	<u>Collaboration</u>: industry funding positively affects co-authorship of papers with industry scientists.
Bozeman et al. (2013)	All	All	<u>Collaboration</u>: look beyond co-authorship when looking at collaborations, and look beyond outputs when measuring collaborations.

Authors (Yr)	Country	Disciplines	Key Findings Related to Paper
Bozeman and Gaughan (2007)	US	Science & Engineering	Collaboration: industry funding positively affects industry collaboration.
Campbell et al. (2002)	US	Genetics	Publication output: industry funding negatively affects publication output (industry sometimes restricts publications).
Godin and Gingras (2000)	Canada	Science, Medicine, & Engineering	Publication output: industry funding positively affects publication output.
Gulbrandsen and Smeby (2005)	Norway	All	Publication output: industry funding positively affects publication output. Patent output: industry funding positively affects patent output. Collaboration: industry funding positively affects collaboration with others.
Hottenrott and Thorwarth (2011)	Germany	Science & Engineering	Publication output: industry funding negatively affects publication output. Patent output: industry funding positively affects patent output.
Meissner (2011)	UK	Engineering	Patent output: industry funding positively affects patent output.
Mendoza (2012)	US	Engineering	Patent output: faculty were more interested in publishing that patenting.
Ponomariov (2009)	US	Science & Engineering	Collaboration: greater interaction with graduate students leads to better collaborations with industry.
Slaughter et al. (2002)	US	Science & Engineering	Publication output: intellectual property concerns from industry often delayed publishing.
Van Looy et al. (2004)	Belgium	All	Publication output: industry funding positively affects publication output.

Table 2: Primary Literature Summary.

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