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Authors
Lacy, William B
Glenna, Leland L
Biscotti, Dina
et al.

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RESEARCH ARTICLE

The Two Cultures of Science: Implications for University-Industry Relationships in the U.S. Agriculture Biotechnology

William B Lacy[1], Leland L Glenna[2], Dina Biscotti[3], Rick Welsh[4] and Kate Clancy[5]

[1] *University of California, Davis, CA 95616, USA*
[2] *State College, Pennsylvania State University, PA 16801 USA*
[3] *University of California, Davis, CA 95616, USA*
[4] *Syracuse University, Syracuse, NY 13210, USA*
[5] *Johns Hopkins University, Baltimore MD 21218, USA*

Abstract

Partnerships between U.S. universities and industries have existed for several decades and in recent years have become generally more varied, wider in scope, more aggressive and experimental and higher in public visibility. In addition, in the last few decades, public and private interests have advocated for government policies and laws to globally promote the commercialization of university science. This paper examines the persistence or convergence of the two cultures of science and the implications of this commercialization for university-industry relationships in agriculture biotechnology. The perceptions and values of over 200 U.S. university and industry scientists, managers and administrators who participate in or oversee research collaborations in agricultural biotechnology were analyzed. The findings revealed that the participants in these research relationships continue to perceive very distinct cultures of science and identify a wide range of concerns and disadvantages of these partnerships. Several actions were discussed to ensure that the two cultures serve complementary roles and that they maximize the public benefits from these increasing collaborations.

Key words: two cultures of science, agricultural biotechnology, university-industry relationships

INTRODUCTION

Over the last few decades, public and private interests have advocated for government policies to globally promote the commercialization of university science thereby altering the way publicly-funded research universities function. This has been particularly true in the U.S. and in its publicly-funded university system which began during the latter half of the 19th century. To understand the extent of this change, one needs to understand the formation and social basis for the U.S. public research university system.

Federal legislation passed between 1862 and 1914, established public universities in every U.S. state to serve the citizens of each state with applied research and community-based education which provided free access to the research knowledge. Following World War II, these research universities were further augmented by policies which established a social contract between science and society whereby peer-

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Correspondence William B Lacy, E-mail: wblacy@ucdavis.edu

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governed scientific research would provide benefits to society in exchange for substantial public support of university research. A key to implementing this social contract was the 1950 formation of the National Science Foundation which designated the universities as the primary basic research infrastructure for the nation (Slaughter and Rhoades 2004; Glenna *et al*. 2007a).

This social contract, which assumed that both public goods and private goods are needed to enhance the general public good, created a division of labor between the private and public research sectors (Lacy and Busch 1989). Universities received public funding to do basic and other research without direct applications for commercial products. The private sector, on the other land, conducted more applied and proprietary research (Slaughter and Rhoades 2004). The values of these two communities vary significantly (Table 1).

Table 1 Characteristics of public and private science research institutions[1)]

Public research	Private research
Societal responsibility	Proprietary responsibility
Advancement of knowledge and problem solving	Marketable products and profit
Open-ended goals	Specific objectives and tasks
Long term, deliberate	Short term, quick, urgent
Open communication	Secrecy
Egalitarian	Hierarchical
Nonmonetary	Monetary
Individual	Team
Basic and applied research	Applied and development research
Disciplinary	Multidisciplinary

[1)] Source: Lacy 2001.

The primary goal of industry research is to generate trade secrets, patents and exclusive licensing for commercial gain. Research agendas are set through a hierarchical structure with an emphasis on secrecy, intellectual property and proprietary products. In contrast, university research primarily conducted within a more individualistic organizational structure is generally expected to advance knowledge and address broad social problems. Research priority setting and review processes are more transparent, and knowledge is made available to the public through professional journals and university and government publications (Glenna *et al*. 2007b).

By the late 1970s and early 1980s, however, U.S. policy makers began to specify how these benefits would occur by establishing special mechanisms for university-industry relationships (UIR). Key legislation including the 1980 Senate Bayh-Dole Act, the 1980 Stevenson-Wydler Technology Innovation Act, the 1986 Federal Technology Transfer Act, and a series of executive orders and judicial decisions, placed a new emphasis on harnessing university research to foster the emergence of the knowledge economy and promote university-industry collaborations (Welsh *et al*. 2008). The Bayh-Dole Act, in particular, created a uniform patent policy among the many federal agencies that fund research, enabling non-profit organizations, including a provision enabling universities to retain title to inventions made under federal funded research programs. Universities were encouraged to collaborate with commercial organizations, particularly small businesses, to promote the utilization of inventions arising from federal funding. In 2002, an opinion piece in *The Economist* observed that the Bayh-Dole Act is perhaps the most inspired piece of legislation to be enacted in America over the past half-century. At the 30th anniversary of Bayh-Dole Act, the Association of University Technology Managers (AUTM) noted that this legislation changed fundamentally the way America develops technologies from federally funded university research and effectively secured the country's leadership position in innovation (AUTM 2013). Since the passage of the Bayh-Dole legislation, many countries worldwide have adopted similar policies including Brazil, China, Germany, Japan, Russia, South Korea, and the United Kingdom.

Although partnerships between universities and industries had existed for several decades, the new emerging types of university-industry relationships, stimulated in part by these policy changes and particularly in biotechnology and agricultural biotechnology, were generally more varied, wider in scope, more aggressive and experimental, and higher in public visibility than the relationships of the past (Busch *et al*. 1991). The rationale behind these policy reforms and partnerships was that the knowledge economy provided new opportunities for the private sector to utilize research universities' technologies to foster economic growth (Kloppenburg 2004). The assumption was that the UIRs would foster the flow of knowledge and technology from the university to the private sector, while also generating increased basic research funding without changing the activities of working scientists, the university at a structural level, or the process and outcomes of research and educational activities.

However, a number of research analysts and skeptics have countered that commercialization of university science threatens the distinct cultures and their important complementary functions (Lacy 2001; Kenney and Patton 2009; Hong and Walsh 2009; Glenna *et al*. 2011). They claim that the university is losing its distinctive incentive system, which is structured to promote a focus on publicly accessible outputs for which the private sector cannot capture sufficient rewards. Some claim that commercialization of university science is blurring distinctions between the two research cultures. Moreover, these analysts maintain that the research cultures are converging (Kleinman and Vallas 2006; Vallas and Kleinman 2008) and that convergence favors the private sector. Some research institutions and private industry are engaged in basic research and an increasing number of universities are involved in the production of intellectual property and the creation of start-up companies.

In 2011, U.S. universities and their inventors earned more than US$ 1.8 billion from commercializing their academic research, and collecting royalties from a variety of sources such as new breeds of wheat and strawberries, a new drug for treatment of HIV, and longstanding arrangements over products like Gatorade. These universities also completed over 5 000 licenses, filed for over 12 000 new patents and created 617 start-up companies (Blumenstyk 2012). Nevertheless, changes in universities are matters of degree. In recent years universities conducted 53% of the basic research in the U.S. while industry accounted for just 14%. Moreover, although university patenting actually has increased dramatically, universities still account for less than 5% of patents granted in the U.S. (NSF 2008).

However, several reasons for concern regarding an erosion of public interest research at universities still exist. Studies have found a rise in data withholding, secrecy, and impaired communication among university scientists (Blumenthal and Campbell 1986; Blumenthal *et al*. 1986; Curry and Kenney 1990; Vogeli *et al*. 2006; Powers and Campbell 2011). Studies have also explored how academic-industry interactions lead university and industry collaborators to take on characteristics of their counterparts (Cummings and Kiesler 2005) and foster institutional conflicts of interest (Johns *et al*. 2003; Rudy *et al*. 2007); how university research topics over time come to parallel private sector research topics (Krimsky 2003; Welsh and Glenna 2006); and how scientific fraud is associated with commercial ties (Martinson *et al*. 2005, 2009). Industry funding has also been correlated with outcomes favorable to the funder, perhaps due to researcher bias, whether conscious or unconscious, associated with conflicts of interests (for an overview of such studies, see Rose *et al*. 2010).

One major explanation for the effects of commercialization on university science is the shift in institutional cultures that shape scientists' preferences and actions. This focus on institutional cultures and structures, however, tends to mask the internal diversity of university researchers and the co-existence of complex, even contradictory, institutional rationales and scientist perspectives and values. Therefore, it is equally important to focus on the micro-level to better understand scientists as strategic actors in the midst of shifting boundaries between the two cultures. This perspective acknowledges that scientists are self-interested, purposively rational actors motivated to act by personal preferences or tastes within particular institutional contexts. Furthermore, this perspective recognizes the potential for variation among scientists, administrators and managers within and between institutional cultures (Owen-Smith and Powell 2001).

In this paper, we examine the persistence or convergence of the two cultures of science through exploration of the perceptions and values of university and industry scientists, managers and administrators who participate in or oversee university-industry research collaborations in the area of agricultural biotechnology. Focusing on agricultural biotechnology scientists brings with it a number of advantages. Traditionally, agriculture has been the recipient of substantial public investment to support and attract private sector investment (Mowery *et al*. 2004). Further, university research plays a more integral role in the field of biotechnology than for many other areas such as mechanical engineering, computer science or chemistry. More than two decades ago, writers were referring to universities as the lifeblood of biotechnology (Nelsen 1991). In addition, agricultural biotechnology was an early target of efforts to commercialize university research because so much of the research for the emerging agricultural biotechnology sector was conducted in the large public U.S. universities and their colleges of agriculture and life sciences (Busch *et al*. 1991). Statements from university leaders and industry 20 yr ago indicated that agricultural biotechnology would revolutionize farming in the future with tremendous impact on the crops and animals grown for food and affecting agriculture in ways never before dreamed possible (Busch *et al.* 1991). At the time estimates for agricultural markets for the year 2000 ranged from US$ 4 billion to US$ 67 billion. Furthermore, agricultural biotechnology continues to expand in impact on the global agriculture and food system. Biotech crops have been the fastest adopted crop technology in recent years. The first commercial biotech crops (maize, cotton, soybean, and canola) were introduced in 1996. The acreage/hectarage for these crops have increased every year from 1996 to 2012 in both developing and industrial countries, increasing from 1.7 million ha in 1996 to over 170 million ha in 2012. While the U.S. continues to be the lead country with 69.5 million ha followed by Brazil (36.6 million hectares), Argentina (23.9 million ha), Canada (11.8 million ha), and India (10.9 million ha), for the first time, in 2012, developing countries planted more hectares (52%) of the principal biotech crops (maize, cotton and canola) than industrial countries. The number of countries growing these crops also continues to increase, reaching 20 developing countries and 8 industrial countries. Further, stacked rather than single traits are becoming more important, with 13 countries planting biotech crops with two or more traits in 2012. At the same time last year a record number of farmers (17.3 million) grew Bt crops with over 90% being small resource-poor farmers in developing or emerging countries. In China a record 7.2 million small farms elected to plant biotech cotton. The future predictions are cautiously optimistic, with more modest gains in adoption probably due to the already high rates for the principal biotech crops (James 2012). Public and private research cultures and their relationships to each other will continue to play a key role in the future of agriculture biotechnology shaping the priorities and directions of these developments, from measuring and improving efficacy to determining health and environmental impacts.

RESEARCH METHODS AND DATA

To examine the persistence or convergence of the two cultures of science, and the possible implications for agricultural biotechnology, 214 in-depth qualitative interviews were conducted with university scientists and research administrators engaged in agricultural biotechnology research at six U.S. public universities, as well as with their industry partners. The case study sites and the interviewees (key informants) were selected through a two-tiered purposeful sampling technique, one for selecting the universities and a second for selecting the scientists to be interviewed at each institution. During interviews with university scientists and administrators, we asked for names of industry scientists and managers with whom they had collaborated. Purposeful sampling refers to the effort to select subjects for in-depth interviews based on their unique experiences or specialized knowledge (Patton 2002; Glenna *et al*. 2007a).

We chose five prominent public research universities from the major U.S. regions. All five universities emphasize agricultural biotechnology research (Cornell University, North Carolina State University, Texas A & M University, University of California, Davis, and University of Wisconsin). We also conducted interviews at one smaller public research university (Oregon State University) to explore possible variation among large and small universities. We selected these universities based on size of sponsored research budget, technological ratings, agricultural science citation rankings, and patenting and licensing activities. The five major universities have significant and steadily growing annual research expenditures ranging from a high of US$ 1.1 billion at the University of Wisconsin to US$ 378 million at the North Carolina State in 2011. A large portion of these research funds are provided by the industry partners. For example, at UC Davis, research support from corporations and nonprofit business-related organizations totaled US$ 70 million in 2011 up from US$ 58.5 million the previous year. These institutions also generated significant licensing revenue in 2011 with the University of Wisconsin receiving US$ 57.7 million, followed by UC Davis at US$ 11.1 million, Texas A & M University at US$ 9.3 million, Cornell University at US$ 8.5 million, and North Carolina State University at US$ 5.2 million, putting them all among the top 50 U.S. universities. Other indicators of the active participation of these universities in commercializing their research is the total number of new start-up companies in 2011 (27) and the number of U.S. patents issued (over 400) (Blumenstyk 2012) (Table 2).

Table 2 Selected U.S. public university research and technology transfer activity 2011[1)]

Universities	Research expenditures (US$ million)	License revenue (US$ million)	Startups	U.S. patents issued
Cornell University	795	8.5	10	82
North Carolina State University	378	5.2	4	51
Texas A & M University	706	9.3	4	18
University of California, Davis	738	11.1	5	120
University of Wisconsin	1112	57.7	4	156
Oregon State University	229	3.5	2	9
Total	3958	95.3	29	436

[1)] Source: The Association of University Technology Managers.

We conducted intensive interviews with 84 university scientists, 66 university research administrators, 64 industry scientists and managers representing 30 small and large agricultural biotechnology companies. Those firms included Monsanto, Pioneer (a Dupont Company), Syngenta, Bayer Crop Science, Sagres Discovery, Seminis, Bioworks, Paradigm Genetics, Cropsolution, and AgraQuest. The second-tier sampling was conducted by identifying and contacting active researchers at the selected universities with industry contacts in agricultural biotechnology or other related areas. Following each interview with a university scientist, he or she was asked to identify their industry partners for subsequent interviews. The focus was on university scientists with industry contacts, since they had working knowledge and experiences regarding formal contractual arrangements as well as important informal relations for understanding the nature and impacts of the two cultures of science. While we were doing our analysis, we grouped all industry scientists and managers together into one category. During the course of our research, we discovered that the distinctions between scientist and manager in industry were not as clear as distinctions between scientist and administrator in universities. Furthermore, we interviewed fewer industry scientists than university scientists and administrators, making it difficult to do statistical comparisons after splitting industry respondents into managers and scientists.

All interviews were conducted by experienced research faculty and staff. To improve accuracy, all interviews were recorded and transcribed. The interview guide contained a number of open-ended questions which asked about their background and research interests including opinions of their university's or company's mission and extent and nature of their contacts with the industry and university partners. They were also asked their views of the organizational policies or structures that were most influential in shaping university-industry relations (URIs), general advantages and disadvantages of these relations, and the criteria or factors that were most important in choosing their research agenda. In addition to several open-ended questions, all respondents were presented survey forms to quantitatively measure on a 1-7 Likert scale their views and perceptions of 1) university-industry environmental characteristics, 2) criteria for research problem choice, and 3) advantages/disadvantages of

URI partnerships. We provided scientists and research administrators a list of descriptive statements about university industry collaborations and their research environments and asked to rate the statements from 1 – not characteristic to 7 – highly characteristic. We also gave them a list of criteria that they might use when selecting their research problems or agendas and asked them to rate the criteria from 1 – not important to 7 – highly important. Combining the answers to open-ended questions with the Likert scale quantitative data enabled us to triangulate interpretations of the interviewees' statements with the interviewees' own quantified responses.

We conducted Kruskal-Wallis tests of significance to determine whether responses from university and industry participants were statistically different. The Kruskal-Wallis is non-parametric, which means that there is no assumption of normal distribution. Since our data were drawn from a purposive sample of industry and university scientists, administrators, and managers, the Kruskal-Wallis test is an appropriate procedure (Moore and McCabe 2005).

It is important to clarify here that we did not take a random sample from all universities because we interviewed scientists, managers, and administrators who are directly involved in university-industry research collaborations and therefore, more relevant to the purpose of the study.

RESULTS

To examine the potentially different research cultures we asked each respondent to assess the qualities or characteristics of their institution's research environment along 12 dimensions, as well as their counterpart's institution's research environment. We asked all the respondents to rate the extent to which each of the 12 qualities or dimensions characterized each research environment on a 7 points scale from 1 – not characteristics to 7 – highly characteristic.

We present the results as a side-by-side comparison in Fig. 1. All 214 respondents were asked to characterize the emphasis of each criterion in the industry research environment and the university research environment from proprietary emphasis to the advancement of knowledge. Since there were missing cases, we include the N for the number of responding to each criterion for industry and university research environments.

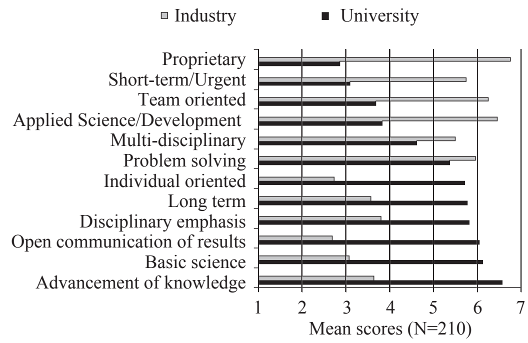

Fig. 1 Characterizing univeristy and industry research environments (N=Indus/Univ). 1, not characteristics; 7, highly characteristic. The same as in Figs. 3 and 4.

The results indicate nearly a perfect mirror image of the institutional research environments (Fig. 1). Respondents indicated that university research environments place a high emphasis on advancing knowledge, on basic science, on open communication, on disciplinary emphasis, long-term in focus, individual orientation of scientists, problem solving, and multidisciplinary emphasis. Universities scored low on applied science, team-orientation, short-term emphasis, and proprietary emphasis. In stark contrast, respondents characterized the industry research environment high on proprietary emphasis, short-term focus, applied science, multidisciplinary emphasis, and problem solving. They gave lower scores on individual orientation of scientists, long-term emphasis, disciplinary emphasis, open communication, basic science, and advancement of knowledge.

The results of our analysis suggest that the university and industry respondents characterize each other's research environments similar to the theoretical characterization of the two research environments we included in Table 1. We found that industry respondents were significantly more likely to rate the university research environment as less team-oriented, less focused on open communication, less multidisciplinary, and more proprietary than their university research partners rated their own environment. By contrast, industry respondents were significantly more likely to rate their own research environment higher on disciplinary emphasis, open communication, individual orientation, multidisciplinary emphasis, basic science, long-term emphasis, and advancement of knowledge. It is important to clarify here that, although there were some significant differences, university and industry agreed on the general characterizations of the distinct research cultures on every item. University and industry partners recognize clear distinctions in research cultures.

In turning attention to the various reasons scientists select research agendas and particular problems to investigate, there are also strong differences between the two university and industry communities as reported by the industry and university respondents. We asked each university and industry scientist to indicate how important each criterion was for his/her research problem choice from 1 – not important to 7 – very important, an approach that has been used in previous research (Busch and Lacy 1983; Glenna *et al*. 2007a). We also asked each industry manager and university administrator to characterize how important each criterion was for the scientists they oversee. The six criteria for university scientists in order of importance were enjoy doing the research, scientific curiosity, the probability of journal publication, advance scientific theory, availability of public funding and contributing to the public good (Fig. 2). Average scores ranged from 6.5 to 5.8 on the 7 points scale. All of these criteria were of less importance for the industry scientists in choosing their research problems or questions except the question on their contributing to the public good. However, even here there was evidence from the open-ended questions that the two cultures of science defined contributing to the public good in different ways. Industry respondents often indicated that providing a marketable final product was their way of contributing to the public good.

In contrast, the industry respondents identified the following six criteria for their research problem choice in order of importance, market a final product, priorities of the research organization, the potential to patent and license the research findings, client demands, new methods and materials, and the public good. Average scores ranged from

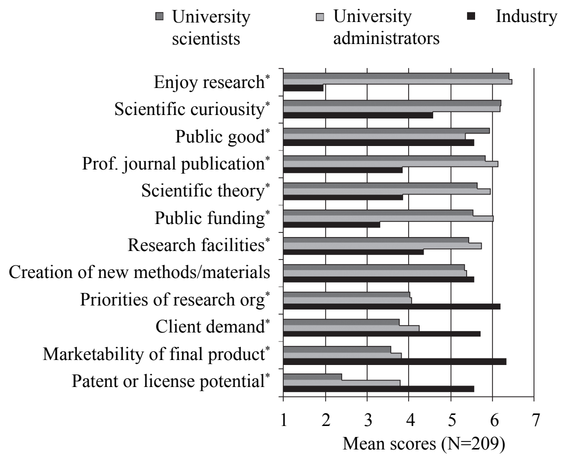

Fig. 2 Comparing primary criteria for research problem choice for all respondents by affiliation. 1, not important; 7, very important. *, Kruskal-Wallis Test significant at $P<0.05$, the same as below.

6.7 to 5.5 on the 7 points scale. The university scientist gave a moderate to less important score to four of these criteria, market of a final product, the research organization priorities, patent or license possibilities, and client demands (Fig. 2). With these highly significant differences in the ways scientists characterize the two cultures of science and the widely divergent criteria they indicate they employ to select research problems, there appear to be potential challenges in working together. However, some quirks in the findings stand out. A Kruskal-Wallis test of significance indicated that university administrators and scientists, and their industry counterparts, offered significantly different rankings on all criteria, except for the variable measuring the creation of new methods/materials. This suggests that university and industry partners may be finding common ground on this practical goal. And although there is a significant difference among participants on the criterion of the public good, the differences are minimal. All participants ranked that goal highly. One finding that may raise concerns is the disparity between university scientists and administrators on the question of patenting and licensing potential of research potential. University administrators are significantly and substantially more likely to think that patenting and licensing research outputs are more important than their scientists think is the case.

The final analysis examines the advantages of university-industry collaborations, as well as the disadvantages. Generally both communities share similar views of the major advantages of university-industry research collaborations (Fig. 3). Both groups see the collaborations providing new research funds and tools, support for students and post-doctoral fellows, expanding their network of scientists and enhancing product development. Scores for all five of these perceived advantages were between 5.4 and 6.0 on the 7 points scale where 7=highly characteristic. Both groups also agreed, albeit less strongly, that access to industry intellectual property was an advantage of the collaborations. Two possible advantages of collaborations for which there were significant differences of opinion between the two groups were on the issues of access to new knowledge and whether these collaborations elevated university prestige. Access to new knowledge was seen as the most important advantage by the industry respondents (6.1) and to a slightly less degree by university administrators (5.6), but was viewed as only moderately characteristic of these collaborations by university scientists (5.0). Similarly industry respondents (5.4) and university administrators (5.0) believed that university-industry research collaborations elevated university prestige while university scientists rated this characteristic in the neutral range (4.4).

When examining the two communities perceived disadvantages of university-industry research collaborations there is a much greater disparity. In general both groups perceived substantial advantages. However, the research partners held significantly different perspectives on 8 of 10 of the disadvantages. Scores for all the items were low when compared to scores on the advantage items, but the disparity between the groups is substantial. The greatest perceived disadvantage is the potential for conflicts of interest, followed by restriction of communication, inhibiting material transfer, and a de-emphasis of non-proprietary research. Other disadvantages such as potential lawsuits over intellectual property, limiting of student and faculty publishing, a de-emphasis of basic science and undermining of university scientists' credibility were seen as only moderately characteristic of UIRs (Fig. 4).

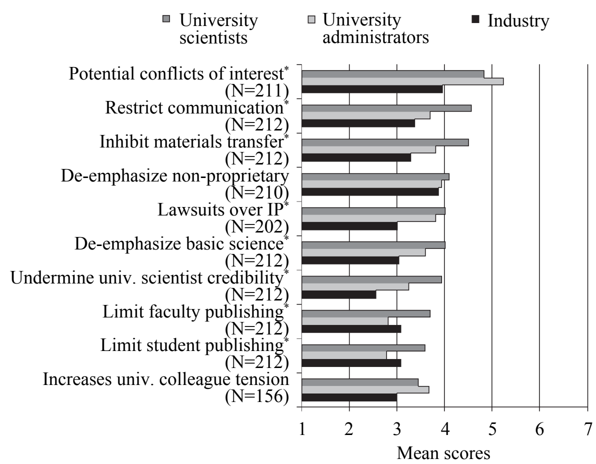

Fig. 4 Disadvantages of university-industry research collaborations.

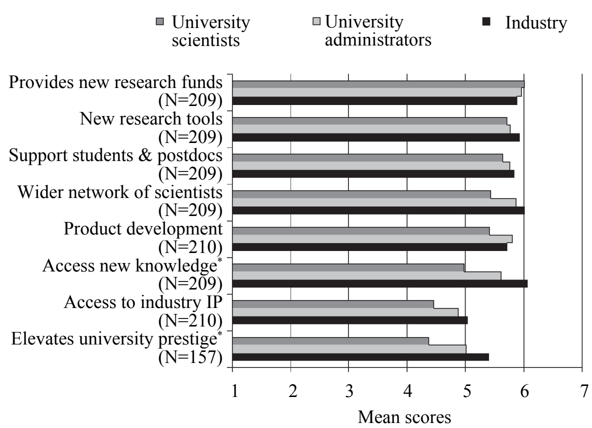

Fig. 3 Advantages of university-industry research collaborations.

The open-ended questions provided more details and specific information to complement the Likert scale instruments and confirmed the perception of the continuing existence of the two cultures despite increased collaborations. Most notable was the different reasons the two communities gave for working with each other. University scientists indicated they collaborated with industry for funding, equipment, materials, expertise, access to proprietary information and databases, technology and opportunities to place graduate students. In contrast, industry scientists and managers reported they sought university collaborations for access to university scientists and graduates students who could be future employees, to increase the credibility and legitimacy of their work, to enhance receiving regulatory approval for their new products, and strengthening then marketing possibilities, and to leverage resources, increase research efficiency and lower infrastructure costs.

While the perceived advantages are viewed as more strongly characteristic of UIRs than the disadvantages, particularly among the industry respondents, there are numerous concerns and perceived disadvantages that are viewed by several respondents. For example, university scientists noted, "there may be more constraints (when working with industry partners) than what a university scientist is used to; we're used to open access, discussing your research results at meetings, publishing, talking with others about it [depending on the research]…." A company can tell you, "no, you can't go to this meeting, you can't disclosed any of this information…." Another university respondent said, "in some instances, you run the risk of faculty becoming too jaded by the money that industry might throw at them, by the prestige they might get by working in the industry." One university administrator observed, "the university wants to patent, big time. It has almost become more important than publications…. It's status for the university…. I think more and more universities are being judged on how many patents they (produce)."

At the same time, many industry scientists also expressed concern that the complementary roles of the two cultures may be eroding and contributing to negative consequences of the UIRs. Some of the most insightful observations of the appropriate division of labor between the two cultures surfaced in the debate about the effect of the Bayle-Dole Act. One industry scientist observed that what we typically find is that less and less of the basic research is being done and we find we're competing against university labs for the same technologies, so it's like funding your own competition. And Bayh-Doyle has caused some changes in the way that universities protect intellectual property and some of them are very, very aggressive, so you've got to be careful. Another industry respondent noted that, "I think if universities want to get into the intellectual property and commercialization game, then they need to get in with both feet and follow all the rules. If they don't want to do that, which I think they should because it's going to inhibit the academic freedom…. Then I think they should get out of it. I think it puts faculty in…a position where you are supposed to be an entrepreneur but you're not…, if you really want to be an entrepreneur then you really should get out of the university and start your own company. "

There are, however, a number of diverse opinions about the Bayh-Dole Act and its effects on university research. Because some companies have been so successful in leveraging university research, one industry manager stated that "The Bayh-Dole act was the greatest encouragement for university-industry collaborations that I've ever seen". Another industry respondent recognized the mixed results with the insightful comment, "Bayh-Dole has a lot of impacts. The positive impacts are that there's generally now more emphasis placed on protecting intellectual property as opposed to publication…, where it has caused issues is in conflicts with the mission of the university, especially land-grant (public) universities…. Their goal is to ensure that these technologies are protected, but commercialized for the public good. Nowhere in the mission does it say for as much revenue as we can possibly generate…. There are all kinds of ways [to transfer technology]; it's not purely for revenue. But they're focused now on revenue." Finally, one industry interviewee was particularly negative about the Bayh-Dole impacts. He stated, "My industrialist view? Bayh-Dole screwed us. It was easier to do business before Bayh-Dole. That's probably too extreme a statement, but still, it conflicts with the mission of the university. It moves (the university) away from education and the public good." These comments from industry participants indicate that even though they generally see research collaborations to have many advantages, they also recognize shortcomings.

CONCLUSION

This paper has examined the question of the persistence of two distinct university and industry cultures of science in the face of increasing university-industry research collaborations and the shift in universities towards efforts to commercialize scientific outputs. Several analysts observe that the two research cultures are converging, and that the university research culture is becoming more like industry culture than vice versa. Our study of university scientists, university administrators, and industry scientists and managers who collaborate on agricultural biotechnology research does not support the convergence thesis.

Since these two groups of scientists are working together and collaborating on research, one might expect a great deal of convergence among them on the perceived characteristic of their research environment, their criteria for their research agenda and problem choice, and their views of the advantages and disadvantages of this collaboration. The findings, however, revealed that the participants in these university-industry research relationships continue to perceive very distinct cultures of science. The two cultures hold very different values and goals, characterize their research environments in distinctively different ways, and select their research agenda utilizing different criteria. While both communities view similar advantages to engaging in university-industry collaborations, they identify a wide range of concerns and disadvantages of these partnerships. There is a recognition that these disadvantages could negatively derail the advantages of the collaborations between the two cultures and undermine the complementary roles the two groups serve in commercializing knowledge.

These findings are paradoxical in terms of the long-term sustainability of the two cultures. The perceived disadvantages indirectly confirm the persistence of the two cultures, but they also indicate that there are shared concerns. After all, industry scientists indicate substantial concern regarding conflicts of interests, restricted communication, inhibited material transfer, a de-emphasis on non-proprietary research, lawsuits over intellectual property, the de-emphasis of basic science, and the undermining of the university's credibility.

Many researchers have noted that university science is only valuable as a generator of economic development if it maintains a degree of autonomy from industrial interests. Consequently the increasing number and intensity of university-industry collaborations and the potential blurring of the distinct differences between the two cultures of science result in both real opportunities and challenges. Maximizing the public benefits from these increasing collaborations will require several actions. First, monitoring the nature, goals, and outcomes of these relationships will be important. As Derek Bok (2003), former president of Harvard University noted, "It will take very strong leadership to keep the profit motive from gradually eroding the values on which the welfare and reputation of universities ultimately depend". Second, it will require strong intelligent, creative and appropriate policies, practices and organizational arrangements to enhance university interactions with the private sector while protecting the autonomy and freedom of operation of university scientists. These policies should be both transparent and be directed at realizing the goals of both cultures of science. Several industry respondents acknowledged that the UIRs create a paradox for the university. They realize that the very independence and publicness of universities are what make university expertise valuable and publications legitimate. At the same time, it is the rise of UIRs that can erode the very thing that makes them valuable and turns university scientists into subcontractors. Third there needs to be adequate public agricultural research funding and support to ensure that public research institutions and the culture of science they promote are strong and complementary partners with industry. Only then can there be an appropriate balance between the goals and mission of the broad, long-term public interest emphases of the university and its scientific culture, and the narrower, short term, proprietary and profit interests of the private sector and the industry scientists culture.

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